DECLARATION

This Research project is my original work and has not been presented for a degree in any other university for examination.

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The research work has been submitted for examination with our approval as university supervisors

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DEDICATION

I retract this work to my mother and Grandmother Mrs. THOUPOPNOU born PEUMEGNE Elisabeth for all her sacrifices and efforts to my success.

ABSTRACT

SoilsfromofManguand Igeganiaandare widely locally usedin construction.These materialsare vastlyused bylocal peoplein their natural statein order for makingcompressed earth blockswhicharedevelopedover timecracks andcracksin the walls.The termsof our workfocusedon the effects ofstabilizers onthe physical and mechanicalproperties ofcompressedearthblockswith thecase studyusing Mangu soilinthesub-county Manguthika (Kenya). Geotechnical studiesconducted both in the fieldand laboratorywere used to characterizeand classifynatural materialswhich enabled us to determine the need of improvethese materialsfor the production of good blocks.Compression tests, abrasion, and capillary absorptionwere carried out ontheproductblocks to confirm their suitability for using according to the standard. From the obtained results, particle size analysis of these naturalmaterials givescurves that are partiallyfit in the granular spindle of soilusedforcompressed earth blocks. Clay contentare85% and 45% respectively both sitesIgeganiaandMangu, andsandcontentsrespective12%and 5%attestingthe dominant presence offiner particles. Thelaboratory testshelped to confirm that soils are notsuitablefor the productionofcompressed earthblocksof good quality.However, adequate formulationimprovedthe particle size ofthematerialby adding 50% sandin orderto incorporatethe grain size ofthese materialswithin thegranularspindlerecommendedby the standardsfor the production ofblocks. The addition ofbinders such ascementclass35 andhydratedlime withrespective contentsof at least 6% and 7% are required to stabilized and improve the properties of compressed earth blocksmade,hey offer better compressive strength, abrasion resistance and improve the qualities of blocks to withstand in wet area. Moreover contribution insandon materialsthese siteswouldfavoran economy inbinders (cement and lime). However, the study enabled also to confirm that the using of plastic fibers highly improved the compressive strength to the same values of strength obtained using lime and cement. Plastic fibers helped by increasing the bound between the particles against crushing of blocks in compression of blocks then they are highly useful and recommended only for dry environmentin terms of economy mostly when the matter of cost reduction come that is helpful for people from the study areas.

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LIST OF ABREVIATIONS

CSB:	Compressed Soil Blocks
CEB	Compressed Earth Blocks
CSSB	Compressed Stabilized Soil Blocks
CSEB	Compressed Stabilized Earth Blocks
CSEBM	Compressed Stabilized Earth Blocks Masonry
CEB O	Compressed Earth Blocks for Ordinary
CEB F	Compressed Earth Blocks for Normal facing
CEB NF	Compressed Earth Blocks for Normal Facing
CEB FF	Compressed Earth Blocks for Fine facing
CSSBM	Compressed Stabilized Soil Blocks Masonry
UTM	Universal Testing Machine
JKUAT	Jomo Kenyatta University of Technology and Agriculture
PAUISTI	Pan Afican University-Institute of Basic Sciences Technology and Innovation
ARS:	African Regulation Standard
N/A	Not applicable
ASTM	American Standard
OMC	Optimum Moisture Content
MDD	Maximum Dry Density
BS	British Standard
Specimen 1	CSB= Clay (soil)+ Water; also called Clay Block (CB)
Specimen 2	CSSB = Clay (soil) + Sand + Water; also called Clay Sand Block (CSB)
Specimen 3	CSSB = Clay (soil) + Sand + Cement + Water; also called Clay Sand Cement Block (CSCB)
Specimen 4	CSSB = Clay (soil) + Sand +Lime + Water; also called Clay Sand Lime Block (CSLB)
Specimen 5	CSSB= Clay (soil)+ plastic fibers + Water; Also called Clay Fiber Block (CFB)

NOMENCLATURE

f_b:	Compressive strength at failure
W:	Water Absorption
ACP:	AfricCaraib and Pacific
W_L :	Liquid Limit
W_P :	Plastic Limit
P_i :	Plasticity Index
Dmax	Maximal diameter
m	meter
cm	centimeter
mm	millimeter
%	percentage
°C:	degree Celsius
Kg:	kilogram
g	gram
m^3	cubic meter
MPa:	mega pascal
N:	newton
kN:	kilo newton
D_{60}	effectif sieve diameter through which 60% of sand pass on the grain size distribution curve
D_{30}	effectif sieve diameter through which 30% of sand pass on the grain size distribution curve
D_{10}	effectif sieve diameter through which 10% of sand pass on the grain size distribution curve
C_u	coefficient of uniformity
C_z	Coefficient of curvature or coefficient of Hazen

CHAPTER 1: GENERAL INTRODUCTION

1.1: BACKGROUND INFORMATION

Earth block also called Adobe is one of the oldest and most widespread building materials. In the past, it was very common building material used many years for almost all types of construction instead of timber, sand and concrete (Silveira et al., 2012). This material isthe main compoundfor clay product such as clay brick, tiles andterra cottaclay tile by its good properties to weather conditions,the geochemicalpurityand easy accessandat a low price (Gonzalez-murillo, n.d.).

Earth (Clay) is a great heritage of sustainable clay buildings around the world. It follows the heritage of the traditional architecture and cultural to the communities (Abdulrahman, 2009) said that the using unburned bricks in wet area require an insulation of the wall from rain infiltration because the biggest problem in the unburned blocks is water effects on the brick strength.

The clay brick is one of the oldest building materials and in fact the first to be manufactured and used by man after wood (bamboo). Clay brick still widely used as building material mainly because of its structural properties, easy availability, relatively low cost, and architectural workability reasons. Traditionally, clay brick is considered a solid and sustainable material under normal weather conditions. Where clay is available, bricks can be manufactured locally, which makes it easily available at relatively low cost(Chan, 2011). These bricks have certain advantages which are aesthetics, thermal and acoustic insulation, low cost of maintenance, fire resistance, flexibility in its application and can be made with different surface textures, making it a more acceptable architecture. It is widely used for the building envelope and commonly forms part of the wall adopted for facing brick facade buildings since it ensures the preservation of the cultural heritage in Africa.

Clays are widely used worldwide (Monteiro et al., 2008). While 30% of people in the world live in earthen structure, more than 50% of population in developing countries still live in earth building (Silveira et al., 2012) with a majority in the rural area. Clay has been used extensively for wall worldwide, particularly in developing countries. Mbumbia et al.,(2000), revealed that in Cameroon, approximately 70% of houses, both in rural and urban areas are made in lateritic clay bricks. Lateritic soils are used both for building and roadconstruction. For buildings, many houses in urban and rural zones are one storey buildings.

Compressed soil block is defined as construction elements used in masonry works made by static or dynamic compression in a mold from the soil mixed with water. The soil used can be improved by using stabilizers such as cement, lime for wall or asphalt for roads (Meukam, 2004).

1.2: HISTORY ON CLAY STUDY

In recent decades, the importance of historic buildings for cultural, social and economic reasons caused a high increase in studies on soil as building materials (Kadir & Sarani, 2012), revealed that as early as 14,000 BC in Egypt, blocks were manually, produced; hand-molded and sun-dried. Clay was the most important raw material for building construction in the ancient Mesopotamia. The first use of bricks recorded was the ancient city of modern Iraq that was built with mud bricks around 4,000 BC and the early walls of Jericho around 8,000 BC. Starting from 5,000 BC, the knowledge of preserving clay bricks by firing has been documented in the stories' archives (Adorni et al., 2013), fired bricks were developed as archaeological traces discovered in early civilizations, such as Euphrates had used both fired and unfired bricks. Most of the countries have continued to develop bricks and till today, clay brick remains a highly competitive material, technically and economically. Besides clay bricks are more sustainable than other materials in terms of durability, fire resistant, and require very little maintenance. The main raw material for bricks is clay besides clayey soils, soft slate and shale, which is abundantly available from open pits (Kadir & Sarani, 2012).

This study will examine Compressed Stabilized Earth Blocks (CSEB) and determine the relationship between soil properties as are influenced by the various types of stabilizers, quantity of stabilizers used and quality of stabilized earth with the goal to come out with new composite Earth blocks for sustainable construction. A better understanding of the interrelationship between the different properties will help in the selection of materials and improve the future design blends to produce composite bricks with desirable qualities. It is on this basis that this study will be conducted to examine the main physical and mechanical properties of soil used and blocks made of a mixture of Portland cement, lime, sand, plastic fiber and soil, and determine the interaction of these key parameters.

1.3: STUDY SCOPE

This study focuseson the physical and mechanical characterization of the red clay soil fromIgegania and Mangu in Kenya, the mechanical properties of the CSB made including Abrasion resistance, compressive strength, water absorption by capillarity of compressed stabilized soil blocks (stabilizedwith Portlandcement, hydraulic lime and plastic fiber)as abuilding material forwalls of buildings.For the study, the soilsamples have been collectedin the Kiambu County particularly on sites in Igegania and Mangu. The casting andtesting and analyses will be carried out in the Engineering Laboratories of the Civil, Construction and Environmental Engineering Department of Jomo Kenyatta University of Agriculture and Technology (JKUAT).

Samplesof the red clay soil have been collected in Igegania and Manguvillages, Portlandcement, lime and plastic fiberwill be used to make the blocksspecimensin the laboratoryby mixing cement and lime with both soiland sandandtesting of the specimens in laboratories. The results of thesetestswill be usedfor the interpretation.The different specimenswill be comparedby the propertiesobtained from abrasion resistance, compressive strength, water absorption by capillarity andcompare those results with relevant standards.

1.4: LIMITATION

Thisstudy is limited on the physical characterization of the red clay soil of Igegania and Manguin the Kiambu County in Kenya. The effects of stabilizers materials (cement, lime and plastic fibers) on the properties of blocks made with the soil from the above mentioned sites on the physicaland the mechanical properties ofsoil blocks made with varying proportions of sand cement, lime and plastic fiber, of reinforcements of sand, cement and lime in the properties of soil blocks.

1.5: PROBLEM STATEMENT

In past years, adobe blocks have contributed to the development of the construction industry building. The use of these blocks has provided structural integrity to the masonry works by integrating the three aspects of sustainable development (i.e. social, economic and environmental). Those blocks have certain advantages which are esthetics, thermal and acoustic insulation, low cost of maintenance, fire resistance, and flexibility in its application.

Uponues, these blocks may start developing stress failures (due to shrinkage, absorption of water) leading to some negative phenomena which may discourage manufacturers from choosing soil blocks as a sustainable solution. Blocks are subjected to permanent crushing resulting in cracking once in service in the building. These cracks which develop over time affecting the structural stability of the walls. Some problems observed during the use of bricks on site are shown (see Figure 1.1) below.

(a) **(b)** **(c)**

Figure 1-1: Illustration of the observed phenomena on site

1.5.1: Problems observed on the blocks on site

Some of the problems observed on bricks in service are:

- The dimensions of blocks used are not standardized;
- Excessive shrinkage observed which is the result of the excess water during the mixing which results in cracking during drying;
- A sudden shrinkage of blocks during drying in the sun causing a faster evaporation of water causing excessive shrinkage;
- Excess water in the mortar coating of a bricks causes drying shrinkage;
- No spraying of water on the bricks before laying the bedding mortar of the bricks that involve suddenly the absorption of large amount of water of bedding mortar by the blocks. This action combined with the sun effects develop shrinkage and cracking during drying.
- It is also observed that the coating mortar is very fine clay and the fact of lack of non-active particles in water (sand) that the retractive the mass is very large. So to combat the phenomenon of shrinkage non-active particles to the water must such as sand be added to the coating mortar and brick.

Alternative materials such as Natural rocks available in some parts of Kiambu County offers some advantages in terms of resistance to cracking and resistance (compression and bending) and water absorption that are the main causes that discourage the using of adobe blocks in the Mangu and Igegania but it is a threat cause of the changing of the natural environment.

To address the above mentioned problemsobserved onsite, the solution is not to force people to abandon their blocks and their practice use, but to:

- **For the blocks,** propose methods as formula for the improvement of the quality of the soil to make good blocks;

- **For coating mortar,** As a solution for cracking plastering mortar, people should mix the mortar with sand particles.

We should be scientifically proved the above mentioned problems by tests by mixing the coating clay used with sand at different percentage and measure and shrinkage rule (width of openings), until reaching this micro cracks (inconspicuous to the naked eye) and the results expressed as graphs.

There is a real need to improve on the physical and mechanical performance of blocks to enhance its using in the studied sites in order to attain the objectives of the Millennium Development goals, which encourages the use of local materials (Earth), which is easily accessible less expensive and has low environmental impact.

1.6: RESEARCH QUESTIONS

The main issuesto be achieved in theobjectives of this researchare:

1. What are the physical characteristics of soils from Mangu and Igegania?
2. In which class belong the soils from studied sites?
3. What is the required moisturecontent to prepare the studied materials for a maximum compaction result in making compressed blocks?
4. Do the soils of these regions satisfy to the criteria of a good earth for the production of good CSB? If not how to correct these materials so that they satisfy to these conditions? Or is it possible to make Compressed Earth Blocks with the studied soils? If not how to correct (modify) their granular textures?
5. What percentages of stabilizers are required to use?
6. What is the compressive strength of the blocks specimens made?
7. What is the water absorption coefficient of blocks specimens made?
8. What is the abrasion resistance of blocks specimens made?
9. Do the mechanical and hydrological featuresof the blocks made satisfy to the criteria imposed by the standards?

1.7: JUSTIFICATION

Faced with thehighcostsofbuildingconstructionmasonrycement,thenew challenges ofthe environment in construction industryis the need toproducelow-costsustainablebuildingsaccessible to allstrataof the populationby developingthe use of materials that are sustainable, locallyavailable, and of lowenvironmentalimpactsuch assoil blocks.

In Kenya like everywhere in the world, natural soil is abundantly available.Most of peoples are limited to precarious revenue then unable to afford the high costs of construction with imported materials. Earth blocks offer cultural and traditional heritage to the people.

In the sites covered by this research the blocks made are subjected to cracks, shrinkage and lack of standard applicable on site due to the lack of appropriate classification of the existing soil which is necessary to determine the amount of stabilizers required to make good blocks. While the cement and lime have better cohesive and binding properties of materials by hydration, the sand has properties that reduce plastic shrinkage which justify the using of those stabilizers to improve the blocks make on site.

While people have no access to the laboratories for costly mechanical tests, abrasion resistance test is one of the cheapest tests on the mechanical properties of blocks rarely carried out which do not need a laboratory to be carried out. There is a need to carry out this research and to spread the results as a solution to the problems that people have been facing on the studied sites to clay as sustainable construction material. This justifies the reason to focus our research on the physical and mechanical properties of those soils in order to improve the properties of strength and durability of compressed soil blocks.

Study the effect of stabilizers on Earth blocks in order to upgrade the using of clay blocks in buildings as sustainable solution will be benefit for all social strata of localities of Igegania and Mangu in the Kiambu County.

1.8: RESEARCH GAP

1.8.1: Work done before:

Do the soils from the studied zone have been done before, if not what were the limits of their study?

In most of the previous studies done elsewhere dealt with the stabilization of soils with the addition of asphalt, cement, lime(Mbumbia et al., 2000). Sand is currently used with Cement and lime and gravel to obtain concrete. Little work has been done on sand mixed with cement in making blocks but have not mixed sand with lime to make CSB. That is why this research will be focused on the effects of sand on clay bricks mixed with cement, lime and plastic fiber as stabilizers on the physical and strength characteristics of soil blocks.Most of the previous studies done elsewhere(not on the sites of this study) on CSSB dealt with compressive, tensile strength and water absorption by complete immersion, some who have done about the abrasion of the soil and concrete in road construction but not on soil blocks combined with sand and both Cement/lime In making blocks for building walls.

1.8.2: My contribution the Engineering Research:

Did the soils from Igegania and Mangu have been studied, characterized, classify? If yes,

Does the study or characterization of those soils have been extended to the production of Compressed stabilized earth blocks?

Do these zones are used for the production of CSSB? If yes is these blocks are they made according to the standard?

Then, my contribution in this research shall be toidentifyareasin needin Kenya (Mangu and Igegania) wherepeoplestill build very poorly using soil as wall materials, determine thephysical characteristics of the soils in thesezones, classify those soils, offer to that region a design mixing to make good compressedstabilizedearthblocks with sand, cementand limeadded as stabilizers at varying proportions, find theoptimummixing ratiofor each type ofstabilizer used forthese sites. Provide those communities leaving in the studied sites CSSBforbuilding with the requirements of thestandards and the mechanical (compression, abrasion) and hydrological (water absorption coefficient) performances of the blocks made.

This is an originalscientific work that goes in the frame of the characterization of soils in order to know them better for a better using in the production of CSSB. Especially assoil characteristicsvary from one regionorarea to anotherandthe use ofgeneral mixture suitable for a specific region may not be the optimumfor all the regionsor areas.

1.9: RESEARCH OBJECTIVES

1.9.1.1: Main objective:

Themainobjective of thisresearch are: (a) to characterize and classify the soil in order to produce sustainable blocks, (b) to investigate the effects ofadding sand, cement/lime and plastic fiber as stabilizers on the physical and mechanical properties such as Abrasion resistance, capillarity absorption and durability.

1.9.1.2: Specific objectives:

a) Determine the properties to characterize and classify the soil sample for manufacturing of Earth blocks i.e. moisture content, thebulk density, liquid limit, plastic limits, plasticity Index, linear shrinkage, porosity, void ratio, the saturationratio; particle size distribution, particle density to find which and the amount stabilizers are required to make good blocks this in order to design the a good mixing ratio required of each ingredients materials make good blocks with soils from Igegania and Mangu;

b) Determine the moisture content required to prepare the studied materials for a maximum compaction result in making compressed blocks: Optimum Moisture Content (OMC).

c) Determine the Abrasion coefficient (resistance) of the specimens made;
d) Determine the dry compressive strength of the specimens made;
e) Determine the Water Absorption by capillarity of the specimens made;
f) Compare and investigate the effects of stabilizers on the CSSB made with relevant standard ARS and BS to check if the results obtained are acceptable or not.

1.10: ORGANIZATION OF THE THESIS

Chapter 1 has presented the general introduction and background information. Chapter 2An extensive literature review and approach the different aspects on the materials used, the stabilization; and the results of the durability tests on the previous works has been carried out for this research. The summary results are shown in literature review. The third Chapter describes the standardsexperimental methods and test procedures to meet the objectives.The results and the analysis of soils classification, physical and mechanical tests on the blocks made are discussed in Chapter 4. The fifth chapter is focus on discussion of the results gotten both on the raw materials and the made blocks. Finally, this research work end with a general conclusion and recommendations in the sixth chapter.

CHAPTER 2: LITERATURE REVIEW

2.1: INTRODUCTION

In the third world countries such as Kenya, the majority of houses in rural areas are built with laterites (Mbumbia et al., 2000). Despite the obvious limitations of sustainability, acceptability and strength, the use of lateritic earth has continued to increase (Abdulrahman, 2009). Because of these limitations in the use of lateritic earth in construction activities, recent research efforts are directed toward improving the mechanical properties of stabilized earth bricks for the construction of buildings which are low cost and durable(Isik & Tulbentci, 2008). These efforts aim at improving the traditional technology of lateritic earth in the construction industry with increased strength, durability and other performance characteristics with lower water absorption. Notably, Chinese cooperation through the Ministry of Scientific Research and Innovation of Cameroon is committed to the research for the re-evaluation of soil blocks in Cameroon to revive and develop the use of earth materials for the construction of low cost housing. The researchers have focused on the need for stabilization and compression of the earth in machines that are manufactured locally for the bricks.

Mbumbia and al. (2000) revealed in their study that stabilization of lateritic soil with cement; lime, bitumen etc are efficient means of improving engineering properties of lateritic soils. In their study Oladayo Azeez et al. (2011)focused on evaluating the characteristics of hybrid bricks, it was revealed that compressive strength is a mechanical property used in brick specificationswhich has the greatest importance for two reasons. With a higher compressive strength, the other properties also improve; while other properties are relatively difficult to evaluate, the compressive strength is easy to determine.

2.2: SOIL

2.2.1: Definition

Soil is defined as the result of the transformation of the underlying parent rock into smaller components and aggregates by weather, water, biological processes and by animal and plant life. Soil is also defined as a set of organic or inorganic materials covering the most of the Earth's land surface, consisting of the unconsolidated products of rock erosion and organic decay.

2.2.2: Soil strata

The soils stratum on site is divided in three zones which are: Zone 1, Zone 2 and Zone 3. The soil strata is not the same in all its depth (see Figure 2.1) such as:

a) **Zone1**

The top Soil from 100 to 300mm depth: The top soil content vegetables matters, humus, and organic matter which is normally loose and unstable soil and not suitable for construction works. It is not sustainable to use the top soil to make soil stabilized blocks.

b) **Zone 2**

Sub-soil located below 300mm, to depth of 5 meters and beyond. This soil contents: silt, clay and sand particles which are reasonably stable for construction works. The soil used to make soil blocks should always come from this section.

c) **Zone 3**

Under the sub-soil which is soil is located from 5 meters depth in the underground; it may be soft rock, dead rock and sometime sandy soils; it may be also sometime hard rocks. This soil is not suitable for soil stabilized blocks making.

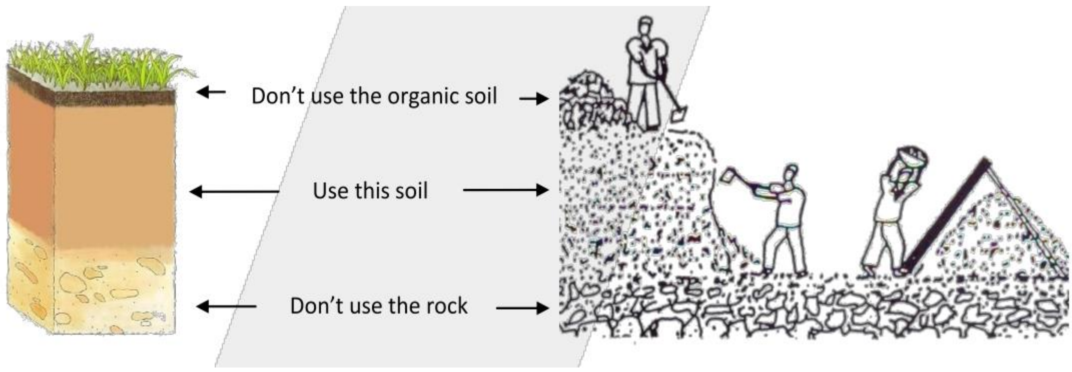

Figure 2-1: Illustration of varying soil stratum (AnyWay Solid Environmental Solutions Ltd, n.d.)

2.2.3: Composition and classification of soil

Soil can be classified in four typical categories which depend from the main components (gravel sand silt, clay). The properties and behavior of the soil are different from one category to another. Also the soil can be either classified as gravely (if more gravel), sandy (if more sand), silty (if more silt) or clayey (if more clay). The soil can be classified also according to its plasticity (lower, medium and high) plasticity by combining the liquid limit and plasticity index.

According to the proportion of the different components (gravel, sand, silt, clay), the soil will have different properties and behavior. It will be named either as gravely (if it contains more gravel), sandy (if it contains more sand), silty (if it contains more silt) or clayey (if it contains more clay). These classifications may be obtained after carrying out particle size distribution test. The soil classification can be illustrated as shown in Figure 2-2 below:

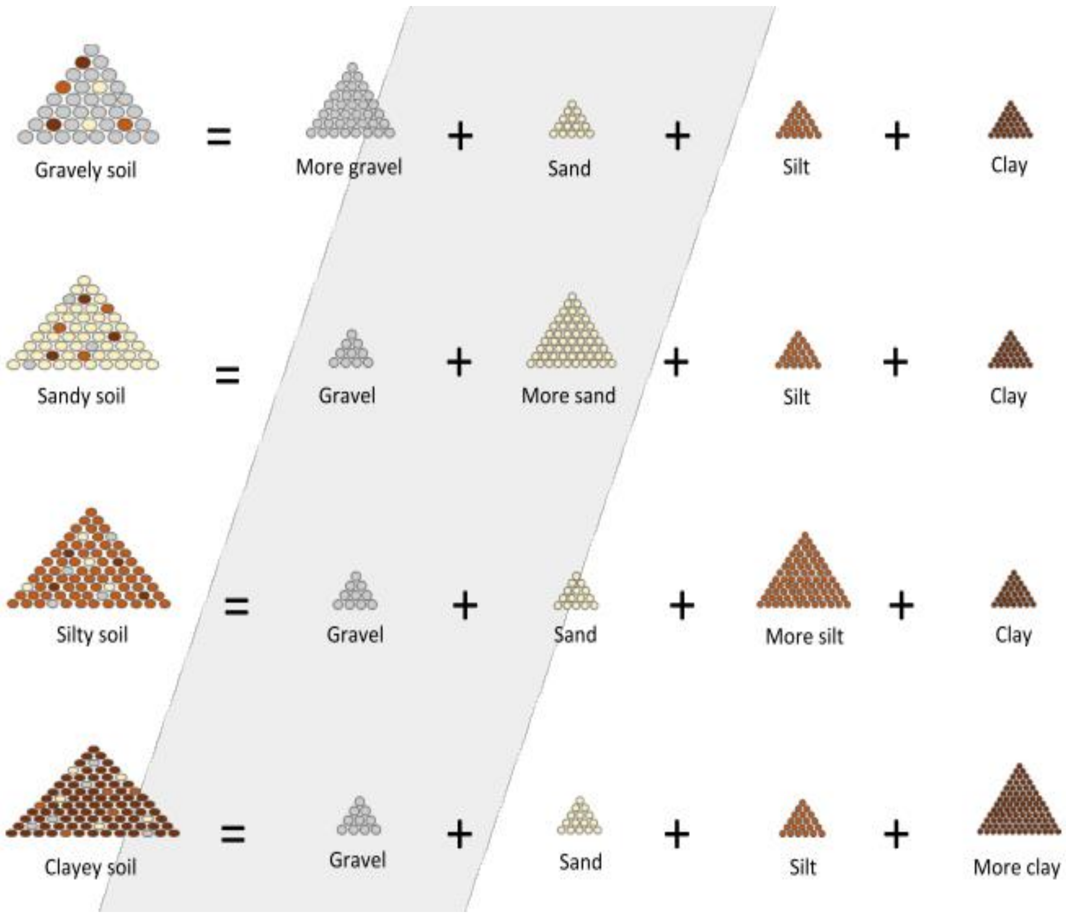

Figure 2-2 : Illustration of soil classification (AnyWay Solid Environmental Solutions Ltd, n.d.)

2.2.4: Identification of right soil for making stabilized soil blocks

It has been found by (USAID; 2012) in a manual guide of the Production of Stabilized Soil Blocks that the best soils for making stabilized blocks are the sandy soils which contain 30-40% clay and 60-70%sand.Murram and laterite type of soils are the best for making Stabilized Soil Blocks.

2.3: COMPRESSED SOIL BLOCKS

Abdulrahman, (2009) found that the compressed earth blocks are widely used through the world in developed countries as in developing countries. Machines were first used to compress earth as early as the 18th century. In France, the use of compressed earth blocks for architectural purposes came into effect only in 1952 by Engineer Raul Ramirez of the CINVA centre in Bogota, Columbia, designed the ClNVA-Ram press machine. This was used in the world and is still used especially in developing countries in Africa, South America and Asia. Compressed earth blocks are made by using a variety of machines. Some, like the CINVA-Ram were invented for compressing earth blocks. The Compressed earth block technology with the CINVA-RAM machine (see Figure 2-3) offers an alternative kind of building construction which is more accessible and of high quality.

Figure 2-3: CINVA-Ram Hydraulic Compressed Machine;

2.4: SOIL BLOCKS AND SUSTAINABILITY

According to the World Commission on the Environment and Development, to preserve the environment for the future generation, sustainability requires resources to be saved in the right way to be environmentally friend. To do so, sustainable development has defined as the development that responds to the needs of the present, without threat the ability of future generations to supply their own needs (Isik and Tulbentci, 2008). The environment's harms due to human activities can be reduced by recycling of the industrial wastes and re-integrate in construction materials like clay bricks. Sustainability is one of the main requirements to be considered in the design of all types of construction. All components and materials of construction are designed and manufactured to perform certain functions of sustainability for the life cycle of the materials or the projects. Sustainability refers to the ability to perform successfully the duties for a specified period called the life of the building. Innovative technologies enable the use and recycling of local available materials while creating strong and easy to use earth blocks. The attributes of soil blocks are environment friendly because they include all the required factors for the environmental sustainability which benefit everyone such as:

a. Cost and Energy Efficient in production;
b. Durability;
c. Fire and Pest Resistant;
d. Cost and Energy efficient through the lifespan of the building;
e. Aesthetically pleasing;
f. Virtually Soundproof with acoustic insulation integrated(AnyWay Solid Environmental Solutions Ltd, n.d.)

Various factors may adversely affect the performance during this period. Those factors include:

a. Material properties;
b. Water absorption;
c. Cracks;
d. Strength;
e. Durability and design considerations;
f. Construction techniques ;

g. Environmental conditions (humidity, moisture) ;

h. Maintenance.

Although beyond these factors may act together, some of them may be more common (e.g. moisture) than others. Of all these factors water absorption is the key factor of deterioration of bricks.

The journals on clay bricks manufactured in developing countries are generally different from those modern used in developed countries. Blocks made have weak features develop cracks on the walls once used, such as high porosity and absorption, low compressive strength and modulus of elasticity. The construction industry is booming around the world in response to population growth. To build sustainable homes there is need to study different technologies and building materials to improve the using and durability of CSB in developing countries.

2.5: MANUFACTURING OF COMPRESSED SOIL BLOCKS

Clay blocks are generally produced by fully mechanized process in developed countries but are still largely produced by traditional methods of hand molding in less developed countries such as Hoffman kiln, The CINVA -Ram hydraulic compressed machine and AURAM Press. Whereas mechanized processes enable the production of bricks with the best qualities in term of strength and durability they require high energy and cost inputs, the hand molding process generally produces poor quality bricks depending on the level of skilled labour used (Gonzalez-murillo, n.d.). Figure 2-4 below shows production of stabilized earth blocks using manually operated compressing machine.

Figure 2-4 : Production of compressed stabilized blocks in Sudan (AnyWay Solid Environmental Solutions Ltd, n.d.)

2.5.1: Stabilizers and adding materials in clays blocks

Soil stabilization is the modification of the properties of soil to obtain a new material with needed qualities. Laterite and lateritic soils are, however, sustainable materials. most lateritic soils contain essential minerals such as quartz, kaolinite, iron oxides and hydroxides which suggest that it is possible to produce strong bricks using these soils without the need for additives (Mbumbia et al., 2000). Climatic conditions cause damage to blocks which are dried and non stabilized in open air, this justify the use of adding materials to improve the qualities requirements of bricks. Various materials are used as stabilizer of soils for many reasons. Stabilization with binding materials (also called stabilizers) such as cement, lime, bitumen, are used to improve the strength and reduce the water absorption, natural fibers are added to control cracking (Silveira et al., 2012) and for thermal insulation while others recycled waste are used to improve the quality of natural environment, all with the main goals to improve the properties of bricks. Bricks can be also improved by cooking process called stabilization by cooking.

With regard to the durability of bricks all the factors that affect it must be taken in consideration such as water absorption, strength, abrasion, shrinkage, thermal insulation and acoustic insulation. The shaping, drying and firing of lateritic soil bricks should be conducted carefully to avoid and reduce cracks and deformation blocks. The increased consumption of materials and resources together with the associated creation of solid and toxic wastes underscore the need for the construction industry to develop, use and dispose building products in a sustainable manner. Sustainable construction is using our natural resources in such a way that they meet our economic, social and cultural needs, but not depleting or degrading these resources to the point that they cannot meet these needs for future generations (El-Mahllawy, 2008).

Bricks are stabilized with some cement, lime or bitumen to improve their properties. Straw is also known to have been employed in stabilizing bricks/mud meant for construction purposes. The inclusion of these bending materials is meant to improve the properties of bricks by having control actions' on contraction, water absorption, expansion and cracking.

Azeez et al., (2011) showed in his study that better products can be achieved if lateritic soils are stabilized with cement, lime and bitumen. He showed that adequate strength is obtained based on the amount of additive used.Focusing on the improvement of properties of clay bricks, differentreinforcing materialsor additivescan be usedto enhance their strength, thermal insulation properties, stiffness, lightness and strength.

2.5.2: Properties of clays blocks

Mechanical characterization is fundamental for structural work and safety assessment. The compressive strength and water absorption are the key parameters in the case of masonry structures. The compressive strength of masonry in the direction normal to the bed joints has been traditionally considered as the exclusive property of structural materials most affected by the water absorption.

The compressive strength is a mechanical property most used in the specification of bricks for two reasons. First, with a higher resistance to compression, other properties are also improved. Second, the compressive strength is easy to determine (Azeez et al., 2011). The compression strength decreases with increasing porosity (water content).Compression testing is a method for evaluating the ability of a material to withstand compressive loads. The machine used for this test is called the Universal Test Machine (UTM). Compressive strength of blocks and bricks is a critical parameter for the determination of the quality of these materials. Loads and forces acting on these materials in walls during their service life are compressive in nature and ability to withstand such loads and forces without failure is a measure of reliability.

2.6: STABILIZATION OFSOIL

2.6.1: Generalities

Stabilization isa set ofmethods for modifyingthe properties of thesoil tobeimprovedso that it canmeet the requirements ofthe use in which it was intended.Beforestabilization ofsoil, it is important to know thecharacteristics and propertiesof the soilto be stabilized anditisgood to knowthe expected improvementsthatwill determinethe effectiveness ofstabilizationin terms of qualityandcosts.The type ofstabilizerused depends on thetype of soilstabilized. Stabilizationis necessary to improve structure of the soil to use it as a construction material.The properties ofsoil determinethe appropriate method ofstabilization to use. Make bricks; it may be usefuland necessaryto stabilize the soil to be used. Because of high rainfalls involving high moisture inthe bricks which leads developing cracks leading theirfragmentation it is then necessary tostabilizethecompressedearthblocks to avoid that phenomenon.Stabilization isa set of physicalor chemical processesthat improvethe characteristics of amud brick, especially its bearingstrength,water sensitivityand durability.

2.6.2: Objectives of soil stabilization

The key objectives of stabilization are:

- Improvement of physical and mechanical characteristics
- Increase the strengths (compressive, tensile);
- Improvement of the resistance against weathering;
- Reduction of porosity, shrinkage and variation of volume;
- Improve the binding between the particles in order to reduce the void ratio and void index.

2.6.3: Types of stabilization

Generally, there are many stabilizers used in order to stabilize soil blocks. Each stabilizer is used for specific purposes and their choice depends on the characteristics and the properties of the soil to stabilize. Among those stabilizers used, there are

a. Cement and lime used to increase binding force,

b. Fibers used in order to reinforce the soil to increase the elasticity of the soil used with fibers and reduce the cracking;

c. Bitumen used to reduce the permeability of the soil mostly in road construction;

d. Chemical products used for chemical stabilization;

e. Sand and gravels mostly used when the soil contain a high amount of clay.

2.6.3.2: Mechanical stabilization

Mechanical stabilization is the improvement of the quality of bricks by compacting which changeenhancing its density,compressibility and reducing the water absorption, permeabilityand porosity because these materials are very sensitive to water.Mechanical stabilization can be efficient only if it is done in good condition (Abdulrahman, 2009).

2.6.3.3: Chemical stabilization

The addition of chemicals products or other chemicals additives in soil to change the properties is called chemical stabilization. The most common chemicals products used for chemical stabilizations are defined as admixtures such as retarders, plasticizers, accelerators. Air-Entrainments are added in order to reduce the sensitivity to water. is often used to increase hydraulic binders make the treated soil less hydrophilic (Meukam 2004). The addition of cement as a hydraulic binder is used to bind the sand while stabilizing clay soil. To improve mechanical properties and water sensitivity, It is required to ensure that the mixing water does not contain organic matter (salt, sulfates).

2.6.3.4: Physical stabilization

Physicalstabilization is the changing of the characteristics of the material by correcting its granularity and texture. It is mostly done by controllingthe mix of differentgrain fractions, drying orfreezing, heat treatment and electricaltreatment (Abdulrahman, 2009). Physicalstabilizationmodifiessoil propertiesby improvingthe characteristics of thematerialby correcting thegranularity.

2.6.3.5: Cement stabilization

Cement is a binding material. Ordinary Portland Cement (OPC) is an extremely fine ground product obtained by burning together at high temperatures specifically proportioned amount of calcareous and argillaceous raw materials (clayey) and adding gypsum in small quantities.

In the manufacture of Stabilized Earth Bricks, we must consider the fact that cement needs water to start setting (hydraulic material). Cement is probably the best stabilizers for Compressed stabilized blocks. Uploading cement, prior to compaction, improves the characteristics of the material. Cement acts with aggregates such as sand, gravel. The compressive strength will depends on the cement content for stabilized earth bricks. To obtain satisfactory results, usually a dosage of 5-6% cement gives better results for the stabilization of compressed earth bricks(Ndanga Moimo Adonis Rory, 2011)

Previous works found that the optimum service performance under compressive loading is at 6% cement (Azeez et al., 2011) otherwise it will not be enough of a binder. This minimum is for good quality cement and depending on the qualities of cement used; this percentage can rise to over 10%. More soil content fine particles, high will the amount of cement to bind the particles together. (Abalo P'KLA, 2002) Said that the required amount of cement in making blocks should be between (4% - 12%) of cement of dry mixing which shall give after 7 drying days a compressive strength of 2MPaaccording the ASTM C-109 Standard.

2.6.4: Lime stabilization

Lime is a cementing material coming from a rock called limestone (CaO) with the capacity of holding structural units (e.g. bricks, stones, aggregates) together with sufficient strength and is mostly used where cement is either expensive or not readily available. With its binding properties, lime can be used for soil stabilization. There are three types of lime among which quick lime also called fat lime or pure lime (CaO>93%) is highly caustic and has to be hydrated or slaked before use in the construction. The second is the hydrated lime (Ca $(OH)_2$)on which sufficient water should be added for complete hydration. Thirdly hydraulic lime with content clay (10-20) % in addition to CaO also has the capacity to set and harden under water and in the absence of air (hydraulicity). Among all those limes the one mostly used in construction is hydraulic lime. Lime stabilization is an economic solution for the stabilization of soil through improved sub-grade stability and reduction in pavement structure. Lime is mostly used to stabilize the soils with high clay content like black cotton soil. That solution has been used to improve very poor sub-grade soils, avoid wasting of bad soil and increase the soil support value. Lime stabilization is recommended for the soils having the following properties: Plasticity Index > 15-18; Volume Change > 20-30%; Clay Content > 25-30%. Hydraulic Lime is a right solution for soil stabilization because it is recognized to have some potential health and safety after mixing carefully. The amount of lime requires for stabilization is based on soil types, for the poorest soils, the higher percentage of lime should be used. The minimum stabilization are 6% deep for marginal soils, (8 - 9)% for poorer soils and (10-12)% for the very worst soils ("Guidelines for Lime Stabilization," 2011).

Soil stabilization with is more used in road works mainly for temporary roads. The advantage is that it acts positively with clay soils with high moisture content mostly for provisory access road to the construction site. Lime normally acts with clay soil not with sands. This stabilizer is not recommended for use in compressed earth blocks which requires low moisture content and Lime is used when the stabilization with cement is not possible. But lime stabilization gives better results than bitumen or resins. For ordinary stabilization generally the mixing ratio require 6-12% lime to give the same results with cement (Ndanga Moimo Adonis Rory, 2011) with 20 to 40% of clay particles in the soil used. Natural binder (limestone) is more environmental friendly and cheaper than hydraulic binder (cement) who significantly improve the strength and water resistance but it contributes to negative environmental impact. For lateritic soil, (Riza et al., 2011) revealed that lime stabilization of soil depend on the quantity of lime, environmental condition curing time, and testing method. They also observed that use lime together pozzolanic material to form a binder that can acts as a stabilizer. The combination of lime with Lateritic soil will give better performance compared to the use of cement as the stabilizer.

2.6.5: Stabilizationcooking

Bricks arederived from amixture of earthand water,with certain materials;grainfuelssuch assawdust are added for insulation like to make the block to be water proof.Whencookinginnatural gas furnaces, sawdust burnssaving energydisappearsfrom the oven andcreatingsmall air bubblesthat improvethe thermal insulation.Theclay brickisa material thatcan effectivelyremove moistureto the outside by cooking.This essentialcontrol ofhumidityand ventilationis an advantage thathasterracotta.A brick houseofclayis abioclimatichabitatthat protectsoccupantsfrom noise,climatic variations, moisture, and fire(Meukam, 2004).

2.7: PROPERTIES AND PERFORMANCES OF COMPRESSED STABILIZED EARTH BLOCKS

2.7.1: Compressive strength

Compressive test is a test carried out to assess the ability and capability of blocks withstand to the compressive loads it is the most important mechanical test which stimulate the condition of the material in service(Azeez et al., 2011). Compressive strength of a materialis the ability toresista compressive force. It shows thestressthat the materialcan withstand. In other wordsthe effectivestrengthof a material isequal tothe stress failure of the material. The test for the compressive strength can be done according to the ASTM C 126: E 4, ARS 1996, and BS. Those standard methods required the test to be carry out 14 days after cooling and cooling (Mbumbia et al., 2000). Generally, compressive strength decreases with increasing porosity but strength is also influenced by clay composition and firing. The compressive strength of clay bricks depend on other parameters such as the percentage of each ingredients, firing temperature, porosity and, which are key parameters for durability of blocks. Thecompressive strengthof the soil canbe improved by usinga good method ofstabilization which will alsoimproveits durabilityby increasingits resistance. The main categories ofbinders that can be used to enhance the mechanical properties of Earth are Portlandcement, lime, bitumen, natural fibers and chemicalsolutionssuch as silicates(Elert, et al., 2003). Previous studies found that the compressive strength is the most significant property determining the quality of masonry brick. It depends of the properties of soil and the binder used. Under wet condition the compressive strength is weaker because of the moisture content and water absorbed. Riza et al., (2011)revealed that the compressive strength is highly influenced by many factors such as the type of soil, compacting procedure and the binding materials used. They also revealed that the iron present in the soil is responsible for low compressive strength in the soil stabilization process, the compaction and the ratio of each ingredients material. Additions of natural fibers improve the compressive strength by reducing cracking due to shrinkage, cementing materials by increasing cohesion forces. Azeez et al., (2011) in his study his study focus on the compressive strength of bricks in mixing clay with cement revealed that the he optimum ratios of cement (5 - 10)% give the highest compressive strength; his results shown that with 0% of cement, the compressive strength is 727.91 N; With 4% cement mixed with the clay sample, the compressive load is 481.03 N. and that when 6% cement is mixed with the clay sample, the highest compressive load at break is 2,537 N; it means that cement is an important material to improve the compressive strength of Clay bricks.

2.7.2: Density

The apparent dry density of fired lateritic soil bricks greatly depend to the temperature of firing. Which means that the dry density increases or decrease with the temperature. Mbumbia et al., (2000) revealed that from 27°C to 350°C the density decreases slightly to reach the lowest value of 1.51g/cm^3 at 750°C. From 750°C, the dry density is increasing. They also say that the stabilization of lateritic soil bricks with lime decrease the dry density when the lime is in a range of 2 to 4% and they conclude that the additional lime increase the density of bricks. Riza et al., (2011) found that the density of bricks vary from 1500 to 2000 kg/m3 the dry density depend to the characteristics of the materials, moisture content, the compacting procedure and the load of compacting; (Heath et al., 2009) found that the addition of wood fibers up to 12% reduce the density but without affecting the strength. This means that some light materials can be used to reduce the density of the bricks. International standard can be used to determine the density of brick such as ASTM C 140 and BS 1924-2 (1990).

2.7.3: Water absorption and moisture content

Water absorption is the main cause of the deterioration of Earth bricks and the main factor for the durability of bricks. The high absorption of water contributes to a rapid deterioration of this type of brick (Türkel and Aksin, 2012). The amount of absorption of water depends to the type of soil used. Water absorption is related with the compressive strength and durability of the materials. The increase of the moisture content reduces the strength which is more related to the porosity of the material. Heath et al., (2009) revealed in their study that the decrease of the compressive strength with the increase of the water content is the same for almost all the bricks and also that with the moisture content in a range from 1 to 6% the strength decreased approximately up to 50%. Mbumbia et al., (2002) revealed that water absorption is an indication of the porosity of bricks and that water absorptionand porositygreatly depend onthe ambient temperature. Kadir & Sarani, (2012)in his study focused on physical and mechanical properties of wastes Recycling in Fired Clay Bricks, indicated that the using of fly slag in high amount increase the density and the strength but decrease the water absorption index which has been defend by (Eliche et al., 2012)Showing in his study that good bricks can be produced with an addition of organic–inorganic wastes or marble residue mixed with clay soils. They investigated the change occurred in the water absorption and porosity with waste addition at each temperature. Their results shown that porosity and the water absorption increased with the addition of residues. They observed decrease in open porosity and water absorption when the temperature increased from 950 to 1050°C. This increased the compressive strength by reducing the porosity content.

According (Riza et al., 2011), moisture contents affect the strength development and durability of the material. The stabilization of clay bricks with cement, lime, cement-lime and cement-resin, show the lowest water absorption. When the brick is dry, water is rapidly sucked out of the mortar preventing good adhesion and proper hydration of the cement. Water absorption can be reduced by adding hydrophobic materials. When siloxanepolymethylhydrohen- siloxane is mixed with slag + fly ash the results show that the water uptake with the addition of

0.5% siloxane is less than a quarter of the water uptake of fly ash-slag without addition.

Water content is also affected by the type of compaction. The dynamic compaction can reduce water content from 12% to 10% with increasing of the compressing strength up to 50%. In a range of 10 to 13% of water content, compaction by vibration slightly increase the compressive strength. The international standard to determine water content can be presented such as ASTM D 558, Australian Standards 1289, BS 1924-2 (1990), BS EN 1745, ASTM C 140 BS EN 771-2 and Australian Standards 2733.

2.7.4: Linear shrinkage

Clay alone is not suitable for making sustainable blocks. According to (Abdulrahman, 2009), earth construction suffers from shrinkage cracking and should be reduced with good stabilizer. They also said that stabilizing decrease the blocks shrinkage due to the cohesive property of clay which is required as natural binder for composite block. Bhavsar et al, (2014) Sustain by saying that by increasing stabilizing content linear shrinkage reduces, in their study, the Maximum decrement in shrinkage were noted in 50% replacement of soil by stabilizer. Chan, (2011), found that Romans added sand, natural fibers (straws and dried grass) in clay-water mixture to improve the workability property and to reduce excessive shrinkage and cracking. Türkel & Aksin, (2012) revealed in their study that the drying shrinkage depends primarily on clay mineralogical composition and texture, shaping conditions of the paste and used water quantities, and rate of the degreasing material. For fired blocks, the shrinkage during firing called shrinkage occurs which is related to the elimination of the organics components and to the structural reactions and transformation. The linear shrinkage is expressed as the difference between the initial and the final length after drying. (Karaman, et al., 2006), studied influence of the Firing temperature and firing time on the mechanical and physical properties of clay bricks they found that the firing shrinkage firing process varying in firing temperature and firing time has important effects on quality of bricks. Firing shrinkage increases with higher temperature. They demonstrated that firing temperature is a key factor affecting shrinkage in the firing process. High shrinkage causes destruction of bricks both in firing and drying stage of production. Shrinkage in bricks occurschemically and mechanically bound water is lost because there is a highly significant relationship between firing temperature and shrinkage.

Riza et al., (2010), found that drying shrinkage of bricks mainly dependson plasticity index and cement content. They said that water-loss also contributes to the shrink of the clay fraction. For low clay mineral content the index plasticity below is 20%, drying shrinkage showed steady increase with the increase of clay content while for plasticity index beyond 25% – 30% drying shrinkage increased rapidly as the clay content also increased moreover soil with plasticity index below 20% is good for cement stabilization with cement content 10%. They also said that sand seems has significance influence in shrinkage although sand content does not affect significantly that has been sustained by (Adam, 2001) sand is required to reduce the linear shrinkage. Sand particles are inactive in water. Although sand content does not affect significantly the compressive strength it can decrease plasticity, linear shrinkage and warping.(Riza et al., 2011) also revealed that when cement is used as stabilizer in Earth brick, generally, shrinkage set up quickly during the first four days therefore addition of sand would reduce shrinkage because sand particles are inactive particles to water. They found also that the addition of sand can reduce up to 44% for 10% of cement content in the mixture. The international standards that can be used to measure drying shrinkage are such as: BSI 6073 and Australian Standards 1733.

Bhavsar et al., (2014), said that Shrinkage limit is an important parameter in which soils tend to shrink when they lose moisture. In India, when black cotton soils imbibe water during monsoon, they expand and on evaporation thereof in summer, they shrink. Because of this alternate swelling and shrinkage, structures founded on them are severally damaged. The test results indicate that the progressive decrease in liquid limit, decrease in plastic limit and increase in shrinkage limit with curing time. And they concluded thatBlack cotton soils have high swelling and shrinkage characteristics and extremely low CBR value and shear strength. Hence, there is need for improvement of these properties.Agbede & Joel, (2011),shown that addition of carbide waste to Makurdi shale greatly improved its engineering properties and the plasticity index and linear shrinkage attained their minimum values of 10% and 7% respectively at 4% carbide waste. From which suggested that 4% carbide waste can be recommended to stabilize

Makurdi shale. The utilization of carbide waste to improve Makurdi shale has the advantage of preventing the pollution of air and ground water.

For making good compressed stabilized earth blocks, the suitability of the soil for stabilization may require to add sand if the soil has an excessively high linear shrinkage (Adam, 2001). Others stabilizers such as Chopped straw, grasses and natural organic fibers, although not active stabilizers, are used as reinforcement materials to reduce linear shrinkage problems which occur with soil that has a high clay content. They also said that in Methodological Costing Techniques sand is added only if there is a need to modify the linear shrinkage(Adam, 2001).

The linear shrinkage test helps to determine the amount of cement or stabilizer required to make blocks. The test is currently carried out on different moulds which different from their shape and sizes. The standard molds used according BS 1377:1990-2 (British Standard, 2003), (Adam, 2001) are metal box measuring (600mm x 40mm x 40mm) from which once you get the shrinkage. Linear shrinkage test is used to determine the amount of cement or lime to use for soil stabilization the results can be interpreted according the manual to guide the production of Stabilized Soil Blocks written by USAID in June 2012. We can use the obtained value of the linear shrinkage to determine the quantity of cement required to make good blocks as shown on table 2-1 below.

Table 2-1 -Interpretation of the Linear Shrinkage Values

Soil shrinkage	Less than 12mm	12-24mm	24-39mm	39-50mm	Over 50mm
Cement / soil ratio by volume	1/18	1/16	1/14	1/12	Require additional sand to make good blocks and use less cement.
% of cement	5.5%	6.25%	7.15%	8.3%	

Sarkar et al.. (2012), investigated the determination of the optimum materials required for adobe blocks, Lime was used for giving adhesive strength and sand was used to reduce the linear shrinkage of adobe. The properties of clay depend on the amount of water in clay. In their study, sand was used as a retarder of linear shrinkage of adobe. They said that the properties of clay depend on the amount of water in clay and the amount of water divided by the conditions of clay is called the Atterberg's Limits which includes the Liquid Limit (L.L), the Plastic Limit (P.L.) and the Shrinkage Limit (S.L.). The consistency of the matrix mainly depends on the lime content because more water is required for the hydration of lime. The effects of shrinkage of fine grained soils are of considerable significance to cause serious damage of small building and highway pavements , the Linear shrinkage of the samples were determined. And that the linear shrinkage of a soil for the moisture content equivalent to the liquid limit is the decrease in one dimension, expressed as a percentage of the original dimension of the soil mass and that when the moisture content is reduced from the liquid limit to an oven-dry state. To determine the value of linear shrinkage cylindrical specimen of 2'' diameter and 4" depth were prepared through cylindrical mould and kept it 3 days, 7 days and 28 days for drying. After that, the change in length and diameter were determined and from that change 3 days, 7 days and 28 days volumetric shrinkage of all the samples were determined. From all the graphs and the regression equations they conclude that the value of linear shrinkage shows a positive trend with the addition of sand content as it decreases with the increase of sand content.

Mehedi et al., (2012), in their study focused on characterization of brick making soil, they investigated the basic geo-engineering, elemental and thermal properties of brick making soil using British Standard (BS) 1377. In the results, the average moisture content, specific gravity, liquid limit, plastic limit, plasticity index, liquidity index and linear shrinkage of the soil were 43.4%, 2.7, 45.9%, 21.3%, 24.4%, 0.89 and 7.7%, respectively. Linear shrinkage of the studied soil sample ranged from 7.28 to 8.5% while average was 7.7%. They said that shrinkage on soil caused by loss of pore water and has enormous damage to structures built on or with clays. They mentioned that the greater the plasticity, the greater the shrinkage on drying. Clay with linear shrinkage less than 5% are "non-critical", 5% to 8% are "marginal" and values more than 8% are "critical". Higher shrinkage limit is not desirable in brick making as this may create cracks on final products**.** They concluded thatSample soil was grouped as intermediate plasticity clay that exists naturally in fine-grained plastic state holding marginal linear shrinkage was thermally stable. The overall results support the soil was suitable for brick production.

2.7.5: Abrasion resistance

Kumar & Sharma, (2014) their study presents a classification and a detailed discussion of different ASTM methods tests being currently used to measure abrasion resistance of concrete such as Test method for abrasion resistance of concrete by sand blasting (ASTM C 418); Test method for abrasion resistance of horizontal concrete surfaces (ASTM C 779); Test method for abrasion resistance of concrete – Underwater method (ASTM C 1138). they conclude in his study that it ASTM C 799 test procedure is suitable for simulating most of the traffic related abrasive actions, while the abrasion resistance of concrete in hydraulic structures like dams and spillways etc., can be better studies using underwater abrasion test of ASTM C 1138.He shows also a tabular guide illustrating the suitability of each method in different abrasive loadings which is useful in deciding the type of test required to best simulate the field of abrasion conditions. For common use in Africa as African Regulation Standard for Compressed Soil Blocks have been developed by (Boubekeur 1998) who said that according to the environmental constraints in the fields of use, compressed Soil blocks for facing CEBs belonging to the category A are for structural elements capable of withstanding mechanical abrasion (impact, rubbing or wind damage) such as corners or wall subjected to impact, areas subject to rubbing by animal or areas subject to sand storms. They also gave the acceptable value for the abrasion resistance which must be always between 0 to 10% either for dry environment, effect of water by lateral spraying and vertical penetration.

Adam, (2001), said that one of the limits of CEB is the low resistance to abrasion andimpact - if not sufficientlyreinforced (stabilizer) or protected and thatthe abrasion coefficient can then be calculated; this expresses the ratio of thesurface to the quantity of the material removed by brushing and is proportional tothe abrasive strength.Adam, (2001) confirmed that (Boubekeur 1998) gave the principle of the test for abrasion strength, in which a CEB is subjected to mechanical erosion applied by brushing with a metal brushat a constant pressure over a given number of cycles.The brushing is applied to the sides of the block which are actually used as facing, the abrasion coefficient can then be calculated; this expresses the ratio of thesurface to the quantity of the material removed by brushing and is proportional tothe abrasive strength.Standards ARS 674, 675, 676, 677 give the abrasive strength values in percentagemass (mass of lost matter/mass of the block before abrasion), this value being oneof the standardized classifications for CEBs to be taken into account. However, theabrasion coefficient gives a more significant value which is also easier to compare,regardless of the configuration of the CEBs.

Iyambo,(2012), in his thesis focused on durability of CSEBs, said that compressive strength and other CSEB durability measures such as resistance to abrasion, resistance to water uptake and water sorptivity testing are used to compare blocks produced without chemicals to blocks produced with chemicals additives. In addition, it has been found that increase of cement concentrations in blocks is the most effective measure in resisting abrasion or wind and rain driven erosion. Moreover, the addition of 4% OPC15FA reduces rain induced erosion of bricks, where this amount is also sufficient to prevent abrasion damage. The porosity of soil cement blocks is reduced by increasing the concentration of OPC15FA used in mix design. Blights study concludes that a 4%OPC15FA blend produces durable blocks suitable for one storey load bearing masonry construction.

Iyambo, (2012) in his thesis basis on durability of CSEBs, said that Resistance to abrasion is improved with increasing cement content and reduced by clay content. Cement acts to bond soil particles together whereas clay minerals disrupt cement bonding. At 10% cement content, at maximum clay content, 11% mass is lost whilst at minimum clay content 1% mass is lost. His results show In general the increasing of wet strength, resistance to abrasion and resistance to water uptake increase. This show the connection between strength and durability of blocks is that the increase in strength of CSEB’s leads to increased durability of blocks. He concludes in his study that increased dosage of the various chemicals would lead to increased saturated strengths. Additionally higher chemical dosages’ might lead to the betterment of other durability parameters such as abrasion resistance and resistance to water uptake. Altogether, different specific conclusion, the results from Control blocks A and Bin his study show that an increase in cement content is accompanied by increases; in strength, in reduction to water uptake by capillary action, to reduction in permeation of water through blocks and to reduction in losses through abrasion/erosion. In most cases Control block B having uneconomically high cement content shows to be more durable (assessed using durability measures) than blocks produced with chemical.

2.8: USING OF RECYCLED WASTE MATERIALS IN IMPROVING PROPERTIES OF CLAY BRICKS.

The disposal of waste materials has become a vital requirement to keep the environment as clean as possible. Waste treatment and reuse of components in the construction industry will be useful for a long-term trend and the economy. One of the major worldwide environmental problems is the disposal of industrial wastes. For the environmental protection, (El-Mahllawy, 2008)revealed that with the growing of wastes from many factories, there is a real need to integrate those wastes for re-using or recycling. The using of industrial waste like blast-furnace slag, basalt - granite and kaolin fine residue as additive in construction materials may contribute to save the environmental and ecosystem which could be the contribution of civil engineers for a sustainable environment.

2.9: RECYCLING OF NATURAL FIBERS AND SAND ONTHE PROPERTIES OFCLAYBRICKS

Human activitygenerates wastepollutingthe environment. To safeguarda sustainable environment, it is imperative for construction industryto use recycled or recyclable materials with low environment impact.Thosewastes andincorporated intobuilding materials toimprove the materialsproperties by making it sustainable (Eliche-Quesada et al., 2012). Due to the significance of bricks as building materials in civil engineering, many researchers have focused their works on the potential wastes that can be recycled and incorporated into fired clay bricks. Various types of wastes have successfully been recycled and incorporated into fired clay bricks by previous researchers in their works. Previous studies revealed that the most common wastes used are wastes paper, polystyrene, fly ash and sludge, sawdust, Kraft pulp residues, processed waste tea, tobacco, grass, spent grains, glass windshields, PVB-foils, label papers, boron concentrator and cigarette butts. Kadir & Sarani, (2012)in their study focus on the effects of different waste into fired clay bricks shown that a wide range of recycled waste like rubber, limestone dust, wood sawdust, processed waste tea, fly ash, polystyrene and sludge have positive effects on mechanical properties of clay bricks by producing lightweight fired clay bricks with increased porosity, improved thermal conductivity. Chan, (2011)his study, Baked and unbaked bricks were made with the mixture of clay, cement and fibers (pineapple leaf and oil palm fruit bunch), different were examined, with focus on the water absorption, compressive strength, density and efflorescence. He observed that specimens with higher density had corresponding higher strength and water absorption index with cement acting as the binder of the composite material. He concluded that the benefits of fiber inclusion is observed in a range of 15% of cement added and the strength is improved with inclusion of fibers on non-baked bricks

2.10: WASHED COAL WASTE ON MECHANICAL PROPERTIES OFCLAY BLOCKS

(Ramadan et al., 2001)investigated the effects of waste coal washing plant on clay bricks in their study improved the mechanical properties of bricks by mixing clay with sand that was the main goal of their work. The effects of different factors such as the weight percentage of sand and particle size on the mechanical properties of brick patterns were studied. The residual clay tailings were found to have about 78% ash content. This means that a considerable amount of coal fines are still unrecovered. They mixed clay with sand to improve physical and mechanical properties as well as avoid the burst of briquette during the ignition; the goal of this was to increase the porosity of clay. And they found that 20% and 60% of sand are respectively sufficient to reach a large extent on improving the mechanical properties of the clay brick produced.

2.11: STANDARD REQUIRED FOR COMPRESSED SOIL BLOCKS

2.11.1: Goal of the standard

The goal of the standard is to define, classify according the aspects and the using condition of Compressed Soil Blocks (CSB).

2.11.2: Classification of CSB

According (Boubekeur, 1998), the using; the CSB can be classify in two groups such as:

2.11.2.1: Classification according to use

- Ordinary CSB used in masonry walls intended to be covered by some form of protection (e.g. cement mortar).
- Facing CSB used in walls intended to remain visible, exposed without protection required.

The normative classification of the BTCS foresees several levels of performance, which are defined according to the types of use. The using area of Compressed Soil Blocks in building construction can be presented according two types of solicitation: mechanical and environmental solicitation.

2.11.2.2: Classification according to the field of use

According to the field of use, CEB are classified in two types of constraints which are:

- Mechanical Constraints
- Environmental Constraints

2.11.2.2.A: Mechanicalconstraints

According the mechanicalconstraints, there are three class of resistance:

Class 1: structural elements for unload walls which can withstand to limited external loads (e.g. boundary wall, fill in a load bearing structure, single story building made of load- bearing structural elements).

Class 2: Structural Units capable to withstand to important externals (live) loads. Loaded structures (wall) which can withstand to important loads with external actions (e.g. a two storey building with accessible terrace made of thin load-bearing structural elements).

Class 3: Structural Units for structure walls which can withstand high externals (live) loads (e.g. a three storey building made of thin load-bearing elements.).

2.11.2.2.B: Environnementalconstraints

According the environmental stress, the blocks can be classify in four categories of environment that should take in consideration in order to choose the appropriate block that is suitable with:

- Category D: Structural units for Dry environment without any risk of moisture of being wet (e.g. blocks for internal partition which are not exposed or which are protected from water damage).

- Category R: Masonries units capable to withstand in wet environment and water damage that can withstand to the stress of water (e.g. blocks make for lateral walls exposed to rain like for bathroom walls being splashed).

- Category C: Masonries Units for walls capable to withstand to water damage vertical absorption of water by capillarity, gravity and internal condensation (e.g. external wall unprotected from capillary rise, internal wall unprotected from water leaking through the roof).

- Category A: Blocks that can withstand to mechanical Abrasion (e.g. impact, rubbing or wind damage) for example (corners or walls subjected to impact, area subjected to rubbing by animals and area subjected to sand storms.

2.11.3: Designation of forms of CSB

According (Boubekeur, 1998), CSSBM can be designated according the following indication:

Designation according to use: O for Ordinary,

F for Facing;

NF for Normal Facing;

FF for Fine Facing.

Designation according to Mechanical Constraints:

1 for category 1;

2 for category 2;

3 for Category 3.

Designation according to the Constraints of the Hygrometric environment

D for category C

R for category R

C for category C

Designation according Mechanical abrasion environment Constraints:

A for category A

The designation of CSSBM may also include the following indications:

Color;

Decorative effect;

Load bearing or non load bearing.

2.11.4: Mechanical, hygrometric and physical characteristics required for facing CSB

Although standards of CSEB are less developed and less spread than other masonry used (cement mortar, concrete) for example, however, there are specific standards for ADOBE blocks worldwide varying from one region to another and that depending on the use of the brick. These standards are based on durability tests are less known by the fact that they are mostly locally made for local use and do not be published.

(Abalo P'KLA, 2002), said in his study that the African Organization for Standard has developed a common standard across Africa since 1998 standard; he also said that the required (Minimum-Maximum) amount of cement in making blocks should be between (4% - 12%) of cement of dry mixing which shall give after 7 drying days a compressive strength at the failure (f_b) of 2MPaaccording the

ASTM C-109 Standard. In the United State; the standard used for blocks is the ASTM C-109.

Table 2-2 : ASTM C-109.[(Abalo P'KLA, 2002)]

The compressive strength at the failure load is ensure when f_b> 2MPa	f_b> 2MPa
The tensile strength at the failure	Tensile strength > 0.34MPa
Water Absorption by capillarity after 7 days.	4% after 7 days.

Table 2-3 : Mechanical, Hygrometric and physical Characteristics Required for facing CSBs (Boubekeur, 1998) in the ARS 678: 1996.

Type of Block	**Type of environment**	**Class of mechanical stress**	**Dry compressive strength (f_b dry) (MPa)**	**Wet compressive strength ($f_b$wet) (MPa)**	**Water absorption by capillarity (%)**	**Abrasion coefficient (%)**
CEB (NF 1D or FF 1D)	Dry environment (D)	1	≥ 2	N/A	N/A	≤ 10
CEB (NF 2D or FF 2D)		2	≥ 4	N/A	N/A	≤ 5
CEB (NF 3D or FF 3D)		3	≥ 6	N/A	N/A	≤ 2
CEB (NF 1R or FF 1R)	Effect of water by lateral spraying (R)	1	≥ 2	≥ 1	N/A	≤ 10
CEB (NF 2R or FF 2R)		2	≥ 4	≥ 2	N/A	≤ 5
CEB (NF 3R or FF 3R)		3	≥ 6	≥ 3	N/A	≤ 2
CEB (NF 1C or FF 1C)	Effect of water by vertical penetration (C)	1	≥ 2	≥ 1	≤ 15	≤ 10
CEB (NF 2C or FF 2C)		2	≥ 4	≥ 2	≤ 10	≤ 5
CEB for (NF 3C or FF 3C)		3	≥ 6	≥ 3	≤ 5	≤ 2

Boubekeur, (1998) in the ARS 1996 said that the use of CEBs IN R and C category requires using a stabilizer if the protection provided is not guaranteed. And said also that it the protection provided against water damage is guaranteed, the environment is regarded as category D. all the tests on mechanical characteristics should be carry out after blocks are 21 days old. If stabilizers are used, then the tests should be performed on the blocks after they are 28 days old if the stabilizer is Cement and 90 days old if the Stabilizer used is lime. In their work gave the specifications regarding the appearance dimensional characteristics gave the tolerable values of dimensions, cracks, crazing and fissure in which they said that:

For cracks, crazing and fissures, the tolerable values are following:

- Only micro-cracks are tolerated on all surfaces,
- For macro cracks, conditions of acceptability for all faces are:
  - They must not exceed 1mm in the width;
  - They must not exceed 40mm in the length;
  - They must not exceed 10mm in de depth;
  - They must not exceed 3in number on any one surface.
- For dimensional characteristics, the tolerance dimensional of blocks as follows:
  - Length: +2 to -3mm;
  - Width: +2 to -3mm;
  - Height: 3 to -3mm.

(Mahamat, 2009), In his study explained the existing of standards in ACP countries on the production and using of CSB by presenting some previous standards such as ORAN of 1996(ARS 670-683, 1996) and for the standard in Burkina-Faso the values of the standards for CSBformasonrybearing wallswithoutplaster(classB40) are as follows:

Table 2-4: Current Performance of CSB in Burkina (Mahamat, 2009)

Designation	CSB B40
Compressive strength (Wet)	2 MPa
Compressive strength (Dry)	4 MPa
Density	1800kg/m3
Water Absorption	15%
Thermal Insulation	0.8 to 1w/m°C

2.12: CRITICAL LITERATUREREVIEW

The previous studies related to pure soilblocks deal withphysical, chemicaland mechanical properties (Lourenço et al, 2010), the stabilization of lateritic soils with the addition of asphalt, cement and lime (Cicek & Tanrıverdi, 2007)and durability (Elert et al., 2003). Most of previous study on clay blocks always dealt with durability, compressive, tensile strength and water absorption by full immersion very few deal with plastic fiber. But only few on them dealt with capillarity absorption of water by capillarity by partial immersion. For those who used stabilizers used cement, lime, sand and sugar fiber separately but they have neither combined soil together with both sand and cement/lime to make blocks or neither used/comment the effects of plastic fibers in making blocks. Only few like (Kumar &Sharma, 2014) did their research on the abrasion resistance of concrete in abrasion resistance focused on road traffic, in hydraulic structures like dams and spillways of concrete subjected to abrasive actions but they have not done about the abrasion of the Compressed Soil Blocks. That is why in this research our contribution to the engineering knowledge in this research is: to evaluate the physical and mechanical properties of compressed stabilized soil blocks with the soils the studied sites, to evaluate the abrasion resistance water absorption and Compressive Strength for poor people who doesn't have facility to carry out the tests for durability in laboratories.

CHAPTER 3: MATERIAL AND EXPERIMENTAL METHOD

3.1: INTRODUCTION

This chapter presents the studied materials as well as the apparatus and experimental technical used to determine the parameters of state of the materials used, to characterize the physical, mechanical properties of the blocks descended of these materials following the different stabilizations to the lime and to the cement. The materials will be presented according to their characteristic geotechnical, chemical in the goal to study their influences in relation to the two stabilizers used. It will be also presented the process of making blocks. And, in end, it will be described the experimental processes applied to test the mechanical and physical properties: compression, abrasion, capillary absorption of the blocks.

3.2: SAMPLING SITE, JUSTIFICATION AND SAMPLING COLLECTION

3.2.1: Location of the research site

The soil samples used for this study came from the Kimabu County more precisely from the localities of Igegania and Mangu. The geographical coordinates of the site are of 27°00'0 ‘’ of the north altitude and 98°92'20 ‘’ from South the altitude.

3.2.2: Justification of the site

Many localities have been visited after which the localities of Igegania and Mangu have been selected for this research works by the fact that the two localities presented a big interest for this research firstly because people are very poor and continuous to construct with the Earth blocks traditionally made, red coffee soil is abundantly available. In that sense that we foresee bound this research with the problem of development issues. For the improvement the practices and techniques of construction in the Soil blocks of those locality in order to make the more durable and sustainable.

3.2.3: Sampling operations on site

All the sampling operations on site have been leaded according the following process:

- all the vegetation, grass, herbs has been removed and discarded out from the site of collection
- all the top soil (Zone 1) were excavated and removed in a depth of 30cm on a wide surface larger than the collection area because it content vegetable matters, humus, vegetable soil, organic matters. and roots in order to reach the sub-soil(Zone 2) from which the collection will started;
- Collection of soil sample from 300mm depth by excavating, Put the soil collected soil sample into the plastic bags in order to save the moisture content.
- take that sample from site to the laboratories to carry out the tests for identification, classification and to make the blocks specimen;

3.3: MATERIAL AND EXPERIMENTAL METHOD IN LABORATORY WORKS

3.3.1: RAW MATERIALS USED

a. Soil is a sustainable construction material abundantly available in the worldwide. It is the cheapest. Its properties can be determined by geotechnical tests, grains sizes and the limits of consistency. The soils samples came from Igegania and Mangu.

b. Stabilizers are binding materials used to increase the binding properties of a material. The stabilizers used were :

–Plastic fibers

–Sand

–Hydrated lime

–Ordinary Portland cement

3.3.2: OXIDE COMPOSITION OF THE SOIL

The oxide composition of the soil sample from Mangu have been determined using -ray fluorescence technique of the Institute of Nuclear Science & Technology of the University of Nairobi. The soil spectrum is shown in appendix 4.

3.3.3: STATE PARAMETERS OF NATURAL MATERIALS (SOIL)

The works of laboratory were carried out in the laboratories of soil and foundation of Jomo Kenyatta University. Works carried on the determination of the geotechnical studies and state parameters which will enable to characterize and classify materials used, the amount of additive material required for making good Compressed Soil Blocks, the mechanical tests on the produced blocks.

3.3.3.1: MOISTURE CONTENT

The goal of the moisture content test is to determine the amount of water present the soil sample as percentage of the mass of dry soil. The moisture content is the amount of soil present within the pore space between the soil grains which is removable by drying in a drying oven at a temperature between 105°C to 110°C.

a. Requirements

Drying oven from 105°C to 110°C, balance readable to 0.1g, three metal containers; a desiccators, a fresh soil sample coming immediately from the site.

b. Operating method

The test was carried out according to the BS1377: Part 2: 1990. Performed as below:

Weight the dry clean the metal container(moisture content tins) asM1;Place about 100g of crumbled soil sample in the container and weight the mass as M2;Place the container with its content (soil sample) in the drying oven for 24hours drying at 105°C;Take out the container and the soil from the drying oven, leave them cool for while (30 minutes);Weight the dry soil with the container and record the values as:M3;Compute the moisture content by equation 3.1:

$$W(\%) = \frac{(M2-M3)}{(M3-M1)} x100 \qquad (3.1)$$

Where: M1 = mass of the container (g) M2=mass of the container and wet soil (g) M3= mass of the container and dry soil (g).

3.3.3.2: BULK DENSITY, DRY DENSITY, POROSITY, VOID RATIO, SATURATION RATIO

The bulk density is the density of the soil sample INSITU on site. From the bulk density of a soil sample, the unit weight of the soil may easily be determined. The unit weight of a soil is an essential parameter in most geotechnical engineering analysis, e.g. stability of slope, consolidation settlement, earth pressure and bearing capacity analyses. The bulk density of a soil is the ratio of the total mass to the total volume. The unit weight of the soil is the ratio of the total weight to the total volume. There are several other parameters required when the determining the bulk density of a sample, i.e. the dry density, the void ratio, the degree of saturation and the unit weight.

For the test, the soil samples were collected in lump in order to get them inside the cylindrical ring by readjusting their shaping and dimension

i. Requirements

Plate Knife(trimmer), knife, rings cutter, trimmer, Vanier caliper, a balance readable to0.1g, plastic stallion on the bench, rubber hammer; Lump of soil sample(coming immediately from the field with all the moisture content) ; distilled water in small quantity.

ii. Operating method

The test was carried out according to the BS1377: Part 2: 1990.as following:

- Collection of coarse lumps of soil samples from the site immediately to the laboratory for the test in order to save all the moisture during the test.
- record the internal dimensions of the cylindrical ring: diameter($ø_C$), the length of the cylinder(L_C) and the volume of the cylinder(V_C) ;Weight the clean dry cylindrical ring, record the masse as: M1

- Take the lump of soil sample on the flat plate carefully, the cylindrical ring is pushed by rolling into the soil to get the soil lump within the ring;
- Fill the existing void with fine soil particles by hammering, Trim and level the end of the sample on both the top and bottom faces, then Weight the cylindrical ring with the soil sample inside and record the mass at the nearest 1g as: M2.

3.3.3.3: PARTICLE DENSITY OF THE SOIL SAMPLES

Particle density is also called specific gravity of particles, it is essential for determination to others test such as: porosity, void index, and for the computation of particle size analysis from a sedimentation procedure (hydrometer analysis).

a. **Requirements**

03 density bottles of 50ml each with stoppers (pyknometer), soil sample sieved at 2mm, drying oven at 105°C, balance readable to 0.01g, distilled water in a wash bottle, sieve of 2mm, container/glass beaker, and thermometer.

b. **Preparation of the sample**

An open-air dried soil sample of about 100gwas prepared and sieved on 2mm sieve.

c. **Quartering method:**

The test was carried according to the BS1377: Part 2: 1990 and performed as outlined below:

- Dry the three density bottles and stoppers in the drying oven for 30 minutes, weight them and record the values as: **M1;**

- Weight about 50 g of soil sample and transfer them to the density bottle, replace the stoppers and weigh them, record the values as: **M2;**

- Transfer distilled water to the density bottle containing the soil, shake the bottle with its content to expel (release) any air trapped in the soil sample, continue the process of shaking and adding more water until the water fills the bottle;

- Place the bottle containing soil and water without the stopper on a bench for at least an hour to expel all the air out from the bottle. Shake the bottles till no more air is released; replace the stopper so that the water overflows from the top of the stopper. Wiped dry carefully the external surface, weight (bottle, soil, water and stopper): **M3.**

- Empty the content and clean the bottle, fill it with distilled water, replace the stopper, wiped dry the external surface, then weight the stoppered bottle full of water,: **M4**

- Calculate the particle density **(ρs)** in (kg/m3) from equation 3.2

$$\rho s = \frac{M2-M1}{(M4-M1)-(M3-M2)} \text{ x}100 \qquad (3.2)$$

Where: M1 = mass of density bottle (g), M2=mass bottle and dry soil (g), M3= mass of bottle, soil and water (g), M4=mass of bottle full of water only (g)

- Particle density is reported as the value at 20°C therefore, measure the temperature (T) of the distilled water using the thermometer. Determine the correction coefficient (C1) by using the temperature on the table below.

Table 3-1 : Temperature correction factor for 20°C

T°C	0	1	2	3	4	5	6	7	8	9
10	1.0015	1.0014	1.0013	1.0012	1.0011	1.0010	1.0009	1.0007	1.0004	1.0002
20	1.0000	0.9998	0.9996	0.9993	0.9991	0.9988	0.9986	0.9983	0.9980	0.9977

- Determine the corrected particle density equation 3.3:

$$\text{Cfd} = \rho_S \text{x} C1 \qquad (3.3)$$

3.3.3.4: PARTICLE DENSITY OF SAND SAMPLE

The requirements for the test are Pycnometer bottle with stoppers, washed sand sample, drying oven at 105°C, balance readable to 0.01g, distilled water in a wash bottle, sieve of 2mm, Trowel, Mutton clothes for wiping, cone, two stirring rod (biggest for Roding each layer with 25 blows and the smallest for leveling the sand surface in the cone after Roding), sample container (bucket), glass beaker, two sieve: one of75µm size and one of 5mm size.

Take a sample of sand about 2kg from which 500g shall be used for each after washing. Wash the sample trough 5mm sieve and get the retained of 2kg, wash that sand in a bucket and pour the water by using 0.075mm sieve and back the retain in the sand.

The test was carried out according to the BS1377: Part 2: 1990. As following:

- Place the sand sample in a bucket, add enough water, agitate vigorously and immediately pour the wash water over the sieve of 0.075mm size to remove the particles finer than 0.075mm. The operation was repeated until wash water became clear. Then transfer the washed sand in a tray and add enough water up to complete immersion,

- Keep the sample immersed in water for 24hours to saturate the sand sample with water by keeping the temperature constant at 25°C.

- Carefully, drain the water from the sample by decantation, repeat the washing process to remove the remaining clay particles by decantation through 0.075mm sieve, return any sand retained on the sand sample in the tray;

- Dry the surface of saturated sand by removing the moisture content on the sand surface by drying in using mutton cloth sample to become saturated with dry surface.

- Divide the sand sample in three sub-samples of 500g respectively in three different trays. Weight 500g of saturated surface dry sample and record the value as: M1.

- Place the 500g of sand in the pycnometer and fill it with water. Remove all the trapped air by rotating the metal rod in the mixture (sand+ water) into the pycnometer; dry the external surface with a cloth and weight it and record the obtained value as: M2

- Empty the sample in a tray, refill the pycnometer with water to the same level as before, weight it and record the obtained values as:M3.

- Carefully drain the water from the sample by decantation through 0.075mm sieve, return any material retained to the sample. Place the sample in a tray and take in an oven for oven drying at a constant temperature of 105°C for 24hours. Take the sample out from the oven, and weight it then record the obtained value as M4.
- Get the specific gravity on a saturated and surface dried, and the dry specific gravity, the Apparent Specific gravity and Water absorption in the bellow formulas:

Specific gravity on an oven dried basis from equation 3.4:

$$Sp.d = \frac{\text{M4}}{\text{M1}-(\text{M2}-\text{M3})} \quad (3.4)$$

Specific gravity on a saturated and surface dried basis from equation 3.5:

$$Sp.w = \frac{\text{M1}}{\text{M1}-(\text{M2}-\text{M3})} \quad (3.5)$$

Apparent Specific gravity from equation 3.6:

$$A.Sp = \frac{\text{M4}}{\text{M4}-(\text{M2}-\text{M3})} \quad (3.6)$$

Water Absorption (percentage of dry mass) from equation 3.7:

$$W.A = \frac{100\,(\text{M1}-\text{M4})}{\text{M4}} \quad (3.7)$$

Where: M1 = mass of Saturated sample with dry surface (in g), M2= mass of pycnometer + sample + water (in g), M3= mass of Pycnometer + Water (in g), M4= mass of the sample after d Oven drying (in g).

3.3.4: GRANULARITY PARAMETERS OF NATURAL MATERIALS (SOILS) USED

3.3.4.1.A: PARTICLE SIZE DISTRIBUTION OF SOIL USED:WET SIEVING

The goal of this test is to determine the percentage in mass of soil sample particles with sizes greater than 0.074mm according to the BS 1377. The wet sieving method covers the quantitative determination of particle size distribution of essentially cohesion less soil, down to fine sand size. The combined silt clay can be obtained by difference the initial weight minus the passing though 0.074mm after drying.

This method is used because firstly because after several field tests (touching test) it has been found that the soil sample used is a cohesive soil. By taking the assumed sandy particles obtain from the dry sieving method, in pressing those particles with hands it crush in smallest particles and secondly after put the lump soil particles in water sandy from the dry sieving method crushed itself and became finer particles (clay and silts) which means that the sample of soil used is a cohesive soil. So the cohesive soil can be defined like a soil that the sizes of the particles change in presence of water and small pressure. For those soils, the method use for particle size distribution is Wet Sieving method.

a. **Requirements:** Soils sample; Sieves test: 20mm, 9.50mm, 4.76mm, 2.00mm, 0.84mm, 0.42mm, 0.25mm, 0.105mm, 0.074mm; lid and receiver a balance readable and accurate to 0.5g; plastic trays, sieve brushes, automatic sieve shaker; metal scoop, riffle box and two metal trays of 20mm size according the biggest particle sizes, metal scoop

b. **Main principle:** The test consists in splitting up by a set of sieve a material in several granular classes of decreasing size. The mass retained or those of the passing are returned to the total mass of the material, thus the gotten percentages are exploited to plot the graph of particle sizes distribution curve. The procedure involves two phases such as: Wet sieving for the preparation the soil sample through 0.074mm sieve. In order to remove silts and clays sized particles are saved for sedimentation test. The dry sieving of the remaining coarse particles retain on 0.074mm sieve. The benefit of this procedure is that it allows measuring mass of fine particles that will be added to the mass of coarse particles used retain on 0.074mm sieve in order to get the total mass from the beginning.

c. **Preparation of the sample:** Dry the test sample by air drying during 24hours, from which a representative of 3000g of sample for three runs has been obtained by quartering.

d. **Operating method:** The test was carried out according to the BS1377: Part 2: 1990.

- Weight M1: 1000g of the air dried test sample, soak it in immerse water for 24hours, then wash the sample carefully by sieving through a 0.074mm sieve, allow the passing through 0.074mm sieve to release clayed and silt particles.
- Transfer all the retained soil on the sieve in a metal tray and dry it in an oven at 105°C for 24hours, let it cool for while and weight M2;
- Sieve the dried fraction with appropriate colon of sieves rank in decreasing order from the top to the bottom using dry sieving method using the automatic sieve shaker switch on for 10 minutes.
- Weight each sieve separately with its retained soil and record. Compute the data and plot the particle distribution curve. Add the discarded sample during washing with the passing through 0.074mm sieve or on the retained on the pan.

3.3.4.1.B: SEDIMENTATION TEST

The equipments required for the test are Hydrometer, Glass measuring cylinder (jar), 1000ml, Rubber bung for the cylinder (jar), Mechanical stirrer, Weighing balance, accuracy 0.01g, Oven, Desicator, Evaporating dish, Conical flask or beaker, 1000ml, Stop watch, Wash bottle, Thermometer, Glass rod, Water bath, 75µm sieve, Scale, Deflocculating agent.

a. **Calibration of hydrometer**

i. Take about 800ml of water in one measuring cylinder. Place the cylinder on a table and observe the initial reading.

ii. Immerse the hydrometer in the cylinder. Take the reading after the immersion.

iii. Determine the volume of the hydrometer (V_H) which is equal to the difference between the final and initial readings. Alternatively weigh the hydrometer to the nearest 0.1g. The volume of the hydrometer in ml is approximately equal to its mass in grams.

iv. Determine the area of cross section (A) of the cylinder. It is equal to the volume indicated between any two graduations divided by the distance between them. The distance is measured with an accurate scale.

v. Measure the distance (H) between the neck and the bottom of the bulb. Record it as the height of the bulb (h).

vi. Measure the distance (H) between the neck to each marks on the hydrometer (R_h).

vii. Determine the effective depth (H_e), corresponding to each of the mark (R_H) as

a. $$H_e = H + \frac{1}{2}\left(h - \frac{V_H}{A}\right) \quad (3.9)$$

viii. Draw a calibration curve between H_e and R_h. Alternatively; prepare a table between H_e and R_h. The curve may be used for finding the effective depth H_e corresponding to reading R_h.

b. **Pre-treatment and dispersion**

i. Weigh accurately, to the nearest 0.01g about 50g air-dried soil sample passing 2mm IS sieve, obtained by riffling from the air-dried sample passing 4.75mm IS sieve. Place the sample in a wide mouthed conical flask.

ii. Add about 150ml of hydrogen peroxide to the soil sample in the flask. Stir it gently with a glass rod for a few minutes. Cover the flask with a glass plate and leave it to stand overnight.

iii. Heat the mixture in the conical flask gently after keeping it in an evaporating dish. Stir the contents periodically. When vigorous frothing subsides, the reaction is complete. Reduce the volume to 50ml by boiling. Stop heating and cool the contents.

iv. Filter the mixture and wash it with warm water until the filtrate shows no acid reaction. Transfer the damp soil on the filter and funnel to an evaporating dish using a jet of distilled water. Use the minimum quantity of distilled water.

v. Place the evaporating dish and its contents in an oven and dry it at 105 to 110 °C. Transfer the dish to a desicator and allow it to cool.

vi. Take the mass of the oven dried soil after pre-treatment and find the loss of mass due to pre-treatment. Add 100ml of sodium hexa-metaphosphate solution to the oven – dried soil in the evaporating dish after pre-treatment. Warm the mixture gently for about 10minutes.

vii. Transfer the mixture to the cup of a mechanical mixture. Use a jet of distilled water to wash all traces of the soil out of the evaporating dish. Use about 150ml of water. Stir the mixture for about 15minutes.

viii. Transfer the soil suspension to a 75 µ IS sieve placed on a receiver (pan). Wash the soil on this sieve using a jet of distilled water. Use about 500ml of water.

ix. Transfer the soil suspension passing 75µmsieve to a 1000ml measuring cylinder. Add more water to make the volume exactly equal to 1000ml.

x. Collect the material retained on 75 µm sieve. Dry it in an oven. Determine its mass. If required, do the sieve analysis of this fraction.

c. **Sedimentation test (execution of sedimentation test)**

i. Place the rubber bung on the open end of the measuring cylinder containing the soil suspension. Shake it vigorously to mix the suspension thoroughly. Remove the bung after the shaking is complete. Place the measuring cylinder on the table and start the stop watch.

ii. Immerse the hydrometer gently to a depth slightly below the floating depth, and then allow it to float freely. Take hydrometer reading (R_h') after 1/2, 1, 2 and 4 minutes without removing the hydrometer from the cylinder.

iii. Take out the hydrometer from the cylinder, rinse it with distilled water. Float the hydrometer in another cylinder containing only distilled water at the same temperature as that of the test cylinder.

iv. Take out the hydrometer from the distilled water cylinder and clean its stem. Insert it in the cylinder containing suspension to take the reading at the total elapsed time interval of 8minutes. About 10 seconds should be taken while taking the reading. Remove the hydrometer, rinse it and place it in the distilled water after reading.

v. Repeat the step (7) to take readings at 15, 30, 60, 120 and 240minutes elapsed time interval. After 240 minutes (4 hours) reading, take the readings twice within 24 hours. Exact time of reading should be noted.

vi. Record the temperature of the suspension once during the first 15minutes and thereafter at the time of every subsequent reading. After the final reading, pour the suspension in an evaporating dish, dry it in an oven and find its dry mass.

vii. Determine the composite correction before the start of the test and also at 30minutes, 1, 2 and 4 hours. Thereafter just after each reading, composite correction is determined.

viii. For the determination of composite correction (C), insert the hydrometer in the comparison cylinder containing 100ml of dispersing agent solution in 1000 ml of distilled water at the same temperature. Take the reading corresponding to the top of meniscus. The negative of the reading is the composite correction.

3.3.4.1.C: PARTICLE SIZE DISTRIBUTION OF SAND

Particle size distribution of sand is a test carries out to classify the sand according the sizes through dry sieving analysis. The test has been carried out both on the unwashed sand and the washed sand separately using dry sieving method.

a. **Requirements:** Sand sample; Sieves test: 9.58mm, 4.76mm, 2.00mm, 0.84mm, 0.42mm, 0.25mm, 0.105mm; lid and receiver a balance readable and accurate to 0.5g; plastic trays, sieve brushes, automatic sieve shaker; metal scoop, riffle box and two metal trays of 20mm size according the biggest particle sizes, metal scoop

b. **Preparation of the sample:** For the washed sand, about 2kg of sand has been washed to remove the impurities. For the unwashed sand, about 2kg of sand has been used. For both the two, sand has been dried in an oven at a constant temperature of 105°C for 24hours and cool.

The test was carried out according to the BS1377: Part 2: 1990. As following

- Take about 1kg of the sand coming from the quarry;
- Take 1kg of dried; weight each sieve separately. Rank the sieves in a colon in decreasing other from the top to the bottom with a pan at the bottom; Fix the ranked sieves on the machine called sieve shaker;
- Place the sand initially weight into the sieves from the top; cover it with the lid to avoid spreading of dust during sieving. Block the sieves content the sand sample with the sieve shaker. Switch on the power for 3minutes (fine aggregates) sieving. After sieving, take each sieve separately with its content and weight it and record the value.
- Tabulate the results in the table provided and calculate the cumulative weight passing on each sieve as a percentage of the total sample to the nearest whole number. Plot the grain size distribution curve (particle size distribution curve) in the granular chart.

c. **Determination of the coefficient of uniformity (C_u) and Hazen coefficient (C_z).**

The coefficient of uniformity is obtained by equation 3.11:

$$C_u = \frac{D_{60}}{D_{10}} \qquad (3.11)$$

The coefficient of Hazen is obtained by equation 3.12:

$$C_z = \frac{D_{30}^{2}}{D_{10} x D_{60}} \qquad (3.12)$$

Where:

D_{60} Effectif sieve diameter through which 60% of sand pass on the grain size distribution curve

D_{30} Effectif sieve diameter through which 30% of sand pass on the grain size distribution curve

D_{10} Effectif sieve diameter through which 10% of sand pass on the grain size distribution curve

C_u Coefficient of uniformity

C_z Coefficient of curvature or Hazen coefficient.

3.3.5: LIMIT OF CONSISTENCY

Limits of consistencies also called Atterberg limits are state limits of a soil. It may change in a large limit with the amount of water content in its voids between the particles.

Plastic Limit is the water content at which it still possible to make rolls of 3mm diameter without cracking. Liquid limit is the water content at which if more water is added the soil will flow in the liquid state. The Atterberg limits are the conventional physical constants that mark the doorsteps between the passage of a soil from the liquid state to the plastic state (Liquid Limit: W_L), the passage of soil from the plastic state to the solid state is the plastic Limit W_P.

The values of those limits are the water content of soil in the state of transition considered, expressed in percentage of the mass of the dry material. The difference $I_P = W_L - W_P$ that defined the extended of the plastic domain, is especially important, it is the indication of malleability.

Sample preparation: Dry in open air the soil sample coming from site for 48 hours Take a sample of soil of sufficient size to give a test specimen weighing about 400g which passes through 425µm sieve. That quantity is enough for both Plastic Limit and Linear Shrinkage tests in addition to the Liquid Limit test.

Transfer the soil sample to a glass plate. Add water and mix thoroughly with two palette knives until the mass becomes a thick homogeneous paste.

3.3.5.1: Execution of consistency limits tests

3.3.5.1.A: Liquid limit test

The liquid limit is established as the moisture content at which a soil passes from the liquid state to the plastic state. In the liquid state, the soil behaves like mud and the paste flow like water. It provides a means of identifying and classifying fine grained cohesive soils especially when the plastic state is known. The paste from which the liquid limit is reached (that gives 20mm of cone penetration) is used for the linear shrinkage test.

Method: Cone penetrometer method has been used for this research in order to determine the liquid limit. The principle of this method cover the determination of the liquid limit of a sample in its natural state for which the sample used is the retained on 0.42mm sieve test. The method is based on the measurement of penetration of standardized cone into the soil paste.

a. Requirements

Spatula spoon, sieve of 42µ (0.42mm), plate knife(trimmer), cup in aluminum, two tray in plastic(container for mixing), 14 moisture content tins, Penetrometer, cone of 30° to fix on the penetrometer, oven for drying at 105°C, Wash bottle, distilled water, vernier caliper (ruler), a balance readable at 0,1grm.

b. Operating method

The test was carried out according to the BS1377: Part 2: 1990.

- Take by weighing about 400g of passing of that soil through a sieve of 425µ (0.425mm) and place it in a plastic tray; Mix into the second tray about 200g of that passing by adding distilled water gradually in order to obtain a homogeneous paste after 10 minutes of mixing using spatula (plate knife);

- Numbering the water content tins, weight (by using moisture content balance) each of the tins and record: **M1**

- Fix the cone of 30° on the penetrometer. Reading of the penetrometer: (1°=0.1mm). Fill the cup with the paste with spatula (knife), gently taping the cup against floor surface. Strike off excess soil with the spatula to give a smooth level surface.

- Take it to the penetrometer with penetration cone locked in the raised position lower the cone so that it just touches the surface of the soil such that a slight movement of cup will just mark the soil surface.

- Press the button to release the cone inside the paste for a period of 10 seconds after locking in position, lower the dial gauge to contact the cone shaft and record the reading of the dial gauge to the nearest 0.1mm; and measure the penetration Depth (H) of the cone inside the paste; 1°=1mm of penetration

- Lift out the cone and clean it carefully; From the sample used on the penetrometer, take a bit of that paste(mud) from the cup to the Water content tins, weigh each of them and record: **M2**

- Add more water on the paste remaining into the tray, get it into the cup cleaned and repeat the same process for seven(7) runs and two tins was used for each run,

- Penetration test has been repeated for six more times y using the soil sample to which further increments of water has been added. The amount of water added was in a way that the range of penetration values will fall between (15mm to 25mm).

- Dry the initial soil and tins weigh in a drying oven at a constant weather of 105°C during 48hours; weight the tin and dry soil and tins and recorded the values: **M3**

- simulate the moisture content values of each runs by computing in equation 3.13:

$$W(\%) = 100 * \frac{(M2-M1)}{(M3-M1)} \qquad (3.13)$$

Where:

M1 = the mass of the tins (in g), M2=mass of the tins and wet soil (in g), M3= mass of the tins and dry soil (in g)

- Draw the graph (Figure 1-aand 1-b of Appendix 5) of Moisture content (Ox) against the penetration (Oy) with all the values in the below table. The liquid limit is the water content value on which the penetration value on the graph is 20 mm.

3.3.5.1.B: Plastic limit test

The test is commonly performed as a continuance of the Liquid Limit test, and the material used for the test has been conveniently prepared as a part of the Liquid Limit.

Requirements: Soil sample about 400grms; Spatula for mixing; two tray in plastic(one for mixing the soil and one containing dry sieved soil); Metallic sieve of 425µ (0.425mm), one flat porcelain plates for rolling threads; three (03) moisture content tins, drying oven at 105°C, Wash bottle; distilled water; a balance readable at 0.1g.

The test has been carried out according to the BS 1377: Part 2: 1990. As following:

- Take by weighing about 400g of passing of that soil through a sieve of 425µ (0.425mm) and place it into one of the plastic tray; Take about 100g of that sieved soil into a second plastic tray, make a plastic paste with it by adding distilled water gradually to get a homogeneous mixing until it become plastic enough to be shaped into a ball;

- Mould the ball of soil between the fingers and roll it between the palms of the hands until the heat of the hands has dried the soil for slight cracks to appear on its surface; Divide the previous sample into 2 sub-samples and carry out separate determination on each portion, divide each portion into 4 sub-sample again into 4 more or less equal parts; Mould the soil in the fingers to equalize the distribution of moisture, then form the soil into a thread of about 6mm diameter between the fingers and thumb of each hand;

- Continuous roll the thread between the fingers, from finger-tip to the second joint, of the hand and the surface of the porcelain plate. During the rolling, produce enough pressure in order to reduce the diameter of the thread to about 3mm, forward and back, movements of the hand; Pick up the soil, mould it between the fingers to dry it further, form it into a thread and roll it out again as specified above;

- Repeated the same procedure of rolling between one hand and the porcelain plate until the diameter of the rolled thread become 3mm both longitudinally and transversally. Use the metal rod to gauge the diameter, the first crumbling point is the plastic limit when, then stop the rolling because the plastic limit is reached when the first crumbling point appear;

- Get the moisture content tins (container) numbering them and weigh them empty, then record the values as: M1. Gather together the pieces of crumbled soil thread and transfer them into the water content tins(container) For determination of the moisture content;

- Repeat the rolling procedure on the others three(03) portion of the sub-sample remaining, placing them in the same container for determination of the moisture content;

- Mix the paste remaining in the container, make a ball and repeat the rolling procedure as described above and get them in two different moisture content tins (container) for the two moisture content tins remaining. Weight the crumbled soil thread with the container together and recorded the values as **M2;**

- Take the tins with their contained (pieces of crumbled soil thread) in an drying oven in a content temperature of 105°C during 24 hours drying. take them out of the oven, leave them cold in an open air for while, weight the dry pieces of crumbled soil thread and the container, then recorded the values as: **M3;**

- Calculate the moisture content for each of the three samples into the containers separately; get the average of the three samples and express it at the nearest whole number in equation 3.14:

$$W(\%) = 100 * \frac{(M2-M3)}{(M3-M1)} \quad (3.14)$$

Where:

M1 = the mass of the tins empty (grams), M2=mass of the tins and wet crumble soil thread (grams), M3= mass of the tins and dry crumbled soil thread (grams).

3.3.5.1.C: Plasticity index (i_p)

Note that the plasticity index is defined as the difference between the Liquid Limit **(W_L)** and the Plastic Limit **(W_P)**,and is calculated from the equation:

$$I_P=W_L-W_P \quad (3.15)$$

3.3.6: LINEAR SHRINKAGE

Linear shrinkage is a way to quantify the amount of shrinkage likely to be expressed by clayey material. Such value is also relevant to the converse condition of expansion due to the wetting. Linear shrinkage due to drying is significant in clays, but less so in silts and sands. The linear shrinkage is use to determine the amount of stabilizer (cement) required to make blocks. For the test two different moulds have been used: linear shrinkage mould with small size (L=140mm, ø=25mm) and the mould with big size (600x40x40) mm.

a. **Principe of the Linear Shrinkage**

The method of linear shrinkage covers the determination of the total linear shrinkage from linear measurements on a bar of soil of a fraction of a soil sample passing a 425µm (0.42mm) test sieve, originally having the moisture content of the Liquid Limit.

b. **Requirements**

Three brass mould for linear shrinkage test(L=140mm, ø=25mm) and the metal box(600x40x40)mm; a spatula, tray in plastic for mixing; water container;

distilled water; a balance readable at 0.1g; a brush; petroleum grease(SAE 40) for oiling the mould; a drying oven at 105°C; mutton cloth.

c. **Preparation of the sample**

The test is was performed as a continuance of the Liquid Limit and Plastic Limit tests, and the material was therefore prepared from a part of the Liquid Limit test (where the penetration of the cone from the penetrometer is likely 20mm depth).

d. **Operating Method**

Two moulds with different sizes have been used as following:

i. For the small linear shrinkage mould (L=140mm, ø=25mm)

- Clean the mould thoroughly and oiling the mould with petroleum grease. Measure the internal length of the brass mould: **Lo**. Take about 200g soil paste sample at approximately the Liquid Limit using spatula.

- Place the soil/water mixture in the mould such that it is slightly proud of the sides of the mould to remove any air pockets in the mixture. Level the soil along the top surface of the mould with the palette knife and remove all soil adhering to the rim of the mould by wiping with a damp cloth.

- Level the soil along the top of the mould by trimming the excess of mud with a spatula and remove all the soil adhering to the rim of the mould by wiping with a cloth;

- Place the mouldfor air drying for between 24-48 hours until the soil has shrunk away from the walls of the mould. Then, Place it in an oven for complete drying at 105°C.

- Cool the mould and measure the length L_D of the soil bar by pressing it against the end of the mould where there is a better fit. And calculate the linear shrinkage of the soil as a percentage of the original length of the specimen, in equation 3.16:

  Percentage of linear shrinkage (%) = $(1-\frac{Ld}{L0})x100$ (3.16)

Where:

L_0= Original length of the specimen, (mm), L_D = the length of the specimen after drying in the drying oven (mm).

ii. For the Metal box(block press) of size(600x40x40)mm

- Clean the mould, oiling the mould with petroleum grease, Mix the soil with water at the Liquid Limit.
- Fill the metal box with the mixture and let it dry in a dry cool place for at least 3 days; after drying, the soil has been shrink and crack. Pushed the shrink soil to one side of the metal box (mould) and the gap left on the other end measured.

3.3.7: MECHANICAL PARAMETERS: COMPACTION TEST: DRY DENSITY-MOISTURE CONTENT RELATIONSHIP

The tests were carried out for two specimens: soil; soil + sand.

The goal of the compaction test is to obtain the relationship between compacted dry density and the moisture content of soil, using two magnitudes of compaction effort which are: light compaction test and heavy compaction. The difference between the two compaction tests is the weight of the compaction rammer: The light compaction test which implies the using of 2.5kg rammer (standard proctor), with a greater drop on thinner layer of soil was used.

Requirements: Compaction apparatus(operator machine); compaction rammer of 2.5kg for light compaction test(standard proctor); compaction mould of 100mmø and 127.5mm height; extension collar of the mould of 100mmø; spanner; brush; trimmer; sieved soil samples; sieve of 20mmø(19.1mmø used in this case); distilled water; moisture content tins; trays(water content); jack extruder; insulating tape to bond the mould and the extension collar; balance accurate readable to 0.1g; scoops in metal; scoop in plastic; petroleum oil; trays;

Preparation of the sample: Dry a quantity of soil sample in open air for 72hours; take about 21kg of sieved soil sample passing through 19.1mm sieve; each run will take about 3kg; clean the mould and its plate base and fix them together.

Oil the mould and its components with petroleum oil using brush;

3.3.7.1: Case of soil and water

Operating method

- Attach the mould and its plate base together. Attach the extension collar on the mould. Weight the mould and its plate base**: M1** andplace them on the operator apparatus.

- Fix the 2.5kg rammer on the operator machine, ensure that the lever arm is adjusted on 100mmø corresponding to the light compaction test and diameter of the mould;

- Mix the 21kg of sieved soil by adding gradually in mixing with hand 10% of water (21 x10%=2.1L) mix them with fingers until get an homogeneous mixture; Cover the homogeneous mixture with polyethylene paper for curing during 24hours;

- Place a quantity of moist soil in the mould such that when compacted it occupies a little over1/3 of the height of the mould. Place the rammer with guide on the soil in the mould, lift the rammer handle unit it reach the top of the guide, then release handle to drop freely on the sample;

- Change the position of guide and again drop rammer, repeat the process systematically covering entire surface of the soil sample; a total of 27 blows shall be applied. Parameter the keyboard of the operator machine in the way that 27 blows shall be applied on each layer (on the screen we can fix at 27 it would start decreasing one by one after each blows rammer on the sample.

- Scarify the top surface of compacted soil before add the next layer of soil. Scarification is done to bond two consecutives layers. Scarify the top surface of the first and second layers of compacted soil to bond two consecutive layers;

- Remove the rammer the compaction rammer, fill the next layer of moist soil in the mould and repeated the above process twice more by applying 27 blows to both the second and third layers.

- After compacted the three layers, take out of the operator machine the mould with its content by dismantling from the operator machine to the table. Remove the extension collar carefully, trim the excess of soil and level the surface of compacted soil to the top face of the mould using metal trimmer, replace any coarse particles removed in the leveling process. Weight the compacted mould with the compacted soil together: **M2.**

- Remove the compacted soil sample from the mould using the jack extruder. Take a representative of about 100g at the mid part of the compacted specimen to the moisture content tins. Discard the remainder of the compacted soil sample;

Determination of moisture content

- Numbered the moisture content tins. Weight the moisture content tins: **M3**. Take a representative of about 100g at the mid part of the compacted specimen the moisture content tins and weight: **M4;**

- Place the moisture content tins with the soil content in the oven for drying. After 24hours of oven drying at 105°C, take out from the oven. Weight the moisture content tins and the dry soil: **M5.**

- the whole process have been repeated for at least six runs of specimens by adding about 5% water gradually on the remaining paste from the initial mixture.

- Plot the compaction curve by drawing the moisture content against the dry density.

3.3.7.2: Case of soil, OMC and sand at different ratios

The same above process has been repeated. In order to get the Maximum Dry Density of soil and water (OMC) mixed with sand added gradually. The results of this test shall be used to make the blocks specimens with the highest strength.

3.4: MAKING OF BLOCKS SPECIMENS

A total of 369 straight non interlocking blocks were produced for four different specimens by static compaction using the non interlocking Block press machine available in the Laboratory of Civil Engineering of JKUAT, with a internal dimension of (L x l x h) = (290x140x120)mm to make straight non interlocking blocks. The specimens are described as below:

- Specimen 1: Clay+ Water = (CSB= Compressed Soil Blocks) also called Clay Block (CB).
- Specimen 2: Clay + Water + Sand= (CSSB= Compressed Stabilized Soil Blocks, stabilized with sand) also called Clay Sand Block (CSB).
- Specimen 3: Clay + Sand + Cement + Water = (CSSB= Compressed Stabilized Soil Blocks) stabilized with cement also called Clay Sand Cement Block (CSCB)
- Specimen4: Clay + Sand + Lime + Water= (CSSB= Compressed Stabilized Soil Blocks) stabilized with Lime. Also called Clay Sand Lime Block (CSLB)
- Specimen5: Clay + Plastic Fiber + Water= (CSSB= Compressed Stabilized Soil Blocks) stabilized with Lime. Also called Clay Fiber Block (CFB).

The manufacturing process is the following:

3.4.1: Basic preparation

3.4.1.1: Drying of soil:

Dry the soil and sand samples. It is impossible to work with wet soil and sand; break up big soil lumps soil particles. Remove the vegetables matters.

3.4.1.2: Sieving

Eliminate all components with a diameter greater than 5mm required by sieving is done manually by sieving the soil and sand through 5mm sieve inclined at 45° with the horizontal. All the passing through 5mm sieve are used and the retained discarded.

3.4.1.3: Dry mixing

Buckets were used to weight and to batch out the raw materials according the ratio that gave the OMC and MDD from the Light compaction Test: 55% soil (containing 15% Sand) + 45% Sand. Note that that ration gave the minimum required from the BS which is 30% Clay soil and 60% Sand. Start with sand, soil and stabilizer (Cement, Lime) on top; add the stabilizers last on top of soil and sand. The dry mixing was performed until achieve a uniform color.

3.4.1.3.A: Ratio of stabilizers used

Stabilizers were added during dry mixing to improve the properties and quality of materials used to enhance the durability of blocks by increasing the binding within the particles. The amounts of stabilizers used were determined based on the dry weight of soil + sand.

Table d-2: **Amount of Stabilizers**

Cement in (%)	3	4	5	6	7	8	9	10	11	12	14
Lime in (%)	3	4	5	6	7	8	9	10	11	12	14
Sand (%)	45										
Plastic Fibers	½ rolls or 0.11%				2 rolls or 0.5%				4 rolls or 1.20%		

The choice these ratios has been guided by the code of practice for the production of CEB of the standard ARS 680(Boubekeur , 1998).

Wet mixing

After mix the dry materials, Add water at the nearest value of the OMC get from the light compaction test avoiding making the mix too wet it is very important for the quality of CEB and CSEB. The wet mixes were used within 1 hour.

Making the blocks

After oiling, the block making machine was fill with the wet mixture; Compress the blocks using the handle of the machine while maintaining the pressure for at least one second at the end of compression, then eject the block.

3.4.2: Wet Curing

The blocks were stored in a flat surface protected from wind, rain and direct sun; allow the blocks to dry and set for the next 24 hours before start watering and Watering the blocks after they are 24 hours old for the next 7 days.

3.4.3: Final Drying and storing of blocks

The blocks have been stock on top of each other to a height of 1meter after they are three days old; and the blocks have been cover with a block polythene paper for the next 7 days. The blocks were stored in a dry cool place ready to be used.

Figure 3-1 disposal and curing of blocks

Requirements: Sieve with 5mm size; Spades, non-interlocking block making machine with internal sizes of (Lxlxh = 290x140x120) mm, polythene paper, plastic, A balance of range scale 50kg with an accurate at 1gram.

3.5: TESTSOFBLOCKS

It is break the blocks specimens to determine the dry compressive strength of the blocks; subject to mechanical erosion by friction applied by a metal brush at constant pressure to determine the abrasion resistance; immersing the blocks in partial immersion in water for the absorption of water by capillarity and dimensional physical characteristics.

3.5.1: Dry compressive strength

After certain periods of drying in wet curing of 7, 14, 21 and 28 days, blocks were subjected to direct compressions up to direct crushing.

The dry compressive strength was determined according to the ARS683: 1996 on the rectangular plates of the compressive test machine. After drying, the blocks were cleaned with a soft brush in order to detach and to remove the dusts and elements glued to the block.

The block specimen was centered between the two horizontal plates of the UTM, in a way that the geometric center of the structural surface is situated on the axis of the plates. Ensure the centering while verifying on the four sides the distances between the sides of the block.

The pressing load was applied in a continuous way, with a regular speed of load corresponding to a rise in pressure of 0.2 MPa/sec until complete crushing of the block. The maximum load and compressive strength were obtained by direct reading on the machine screen and recorded.

Atotalof231specimensofblockshave been tested in compression at 7, 14, 21 and 28 days.; the blocks were initially weight before subjected to the compressive strength in order to determine their Real density at the testing period.

The main equipment used was An Universal Testing Machine (UTM) with maximal compression strength of 1500kN. The frame for compression strength was used with the machine set up or calibrates to stop the load at 4% with a rate of loading at 0.2MPafor the power to be compatible with strength of the blocks. A balance of range scale 11kg.

Figure 3-2: Illustration of the Universal Testing Machine and compressive strength test

Table 3-3: Periods and number of dry blocks crushed by the UTM in compression

I	**PURE SOIL BLOCKS**											
	Tests Period											
	7 days	3										
	14 days	3										
	21 days	3										
	28 days	3										
	Total	12										
II	**Clay + Sand**											
	Tests Period											
	7 days	3										
	14 days	3										
	21 days	3										
	28 days	3										
	Total	12										
III	**Clay + Sand + Cement**											
	Cement Ratio (%)	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**
	Tests Period											
	7 days	3	3	3	3	3	3	3	3	3	3	3
	14 days	3	3	3	3	3	3	3	3	3	3	3
	28 days	3	3	3	3	3	3	3	3	3	3	3
	Total	99										
IV	**Clay + Sand + Lime**											
	Lime Ratio (%)	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**
	Tests Period											
	7 days	3	3	3	3	3	3	3	3	3	3	3
	14 days	3	3	3	3	3	3	3	3	3	3	3
	28 days	3	3	3	3	3	3	3	3	3	3	3
	Total	99										
V	**Clay+Plastic Fibers**											
	Tests Period											
	28 days	3	3	3								
	Total	9										
GENERAL TOTAL		231										

3.5.2: Test of water absorption Test by capillarity

In the test the material is partially immersed on a height of 5mm. And the all the precautions are taken to keep the 5mm of immersion constant during the test. The absorption coefficient of water corresponds to the absorption speed. That value is representative to the behavior of the block subjected to a violent storm. It corresponds to the absorption capacity at saturation of a block position in capillary absorption after several days.

The test was carried out according to the ARS 683: 1996. The specimens of blocks were preventively dried at in open air at 40±2°C for 28 days. In this test, the blocks were partially immersed on 5mm height in a metal tray of size (190x100x20) cm; the 5mm was kept constant during the test.

Their dry mass was measured and recorded as M_0. The bottom face of each block were put on the level guides in wood placed into the metal tray in their position of normal using, distilled water at 20°C was put in the tray to immerse the blocks on 5mm depth for the blocks to absorb that water by capillarity absorption. The water level was kept constant during the test up to the saturation of the blocks.

The mass of wet blocks M_i was recorded after 10, 20, 30 minutes and 1, 4, 24, 48, 72 and 96 hours. The mass of water absorbed was calculated.

3.5.3: Test of the abrasion resistance: Loss of material

The goal of this test was to subject the blocks to mechanical erosion applied by brushing with a constant pressure over a number of cycles. The frictions were applied on the faces of such facings indeed exposed to the stress, usually the header or the stretcher. The test was done according to the ARS 683: 1996. The abrasion coefficient is proportional to the abrasion resistance. It is deducted which represents the ratio of the surface by the amount of material detached during brushing.

Requirements: A meter, a balance with a scale rangeof11 kg and accurate of 1g, a wire brush in steel loaded with a mass of 3 kg.

Operating method: each block was numbered and Weight (M_1), take the block to a horizontal bench for brushing with a wire brush loaded at 3kg on the face to brush, which has been correctly set in its center a mass of3 kg. The Brushing was done in a rate of 60 roundtrip (go and back)per second for a minute.

At the end of brushing, blocks specimens are cleaned from soil items displaced and weighed (M_2). The mass of displaced material is then obtained by M_1 - M_2; and the area of brushing is obtained by A=Lxl in (mm); Where, L: length of the face brushed of the block and l: Width of the wire brush.

3.5.4: Sizes, mass and densities of the blocks

Normally, the dimension of a block is not exactly the nominal size of the mold of the press. By removing the block from the machine a relaxation phenomenon is observed then shrinkage due to drying. The mold can twist and the trays of compressions of the press can topple. So the length, the width and the height of the block cannot be constant. It is then necessary to take some measures therefore on every face of the block.

A block always contains water that is in balance with the ambient environment because the material is hygroscopic. It is necessary to weigh it therefore after drying when it reached a constant mass.

The density relates will give an indication of the degree of compaction of the block. For it the correct measures of the volume and the mass.

The blocks used were minimum 3 weeks old for the specimens 1, 2 and of 4 weeks old for the specimens 3 and 4 because of the stabilizers used. The block was cleaned with a brush in order to detach and to remove the dusts and elements glued to the block.

Execution of the test

After identification of the block by numbering, the blocks were set on the bench corresponding to the sense of compression of the blocks.

The measurements (length, width, height) are defined like follows: Length (L): bigger dimension of the block; width (l): dimension of the corresponding block to the width of the pose face; height (h): dimension of the block measured in the sense of the compression also corresponding to the smallest dimension of the block.

After drying, every dimension of the block is measured near to the millimeter with a Vanier caliper at the middle of each face; their averages and volume of the block are calculated:

CHAPTER 4: RESULTS AND ANALYSIS

4.1: INTRODUTION

This chapter presents the tests results obtained from the methods applied in the third chapter.

Building materials are subjected to different stress and react to those stresses of which they are by their physical and mechanical and hydrological properties. They are also subjected to the effects link to the environment as the abrasion and the presence of waters. They undergo the effects of their own weight in the first place then of the loads of the work that they bear. The weight has the tendency to crush the materials, to press them. The first quality of a block is therefore to withstand that pressure without distorting itself and secondary to resist the effects related to the environment as the erosion and water to which they are exposed.

To ensure that the CSB produced are well adapted well to the construction of the buildings, some tests were developed in order to determine the state parameters as well as the compression strength, the abrasion, and the water absorption by capillarity.

4.1.1: OXIDE OR CHEMICAL COMPOSITION

The oxide composition has been determined for the natural material from Mangu only because its components has a lower amount of sediments (45% clay, 37%silt), than the natural material from Igegania (85% clay and 10% silt). With 85% clay, the use of the soil from Igegania would not be sustainable than the soil from Mangu (45% clay). The oxide composition test of the soil sample from Mangu was determined using x-ray fluorescence technique at the Institute of Nuclear Science and Technology of the University of Nairobi. The values of the oxide composition obtained are presented in Table 4-1.

Table 4-1 : Oxide Concentrations in µg/g(mg/kg) or ppm

Elements	Oxydecomposition		Elements	Oxyde Composition	
	mg/kg	**%**		**mg/kg**	**%**
Potassium (K)	2646 ± 54	4	Zinc (Zn)	75.2 ± 2.0	0
Calcium (Ca)	436 ± 18	1	Arsenic (As)	<0.01	0
Titanium (Ti)	4342 ± 65	7	Bromine (Br)	<0.01	0
Vanadium (V)	<0.10	0	Rubidium (Rb)	52.9 ± 1.4	0
Chromium (Cr)	<0.10	0	Strontium (Sr)	12.9 ± 0.8	0
Manganese (Mn)	1354 ± 22	2	Yttrium (Y)	60.7 ± 1.7	0
Iron (Fe)	50058 ± 600	85	Lead (Pb)	63.4 ± 1.8	0
Copper (Cu)	15.8 ± 1.1	0			

The highest oxide component is iron (85%) followed by Titanium (7%). The lowest oxide item was arsenic and bromine (0%).

4.2: GEOTECHNICAL PARAMETERS

4.2.1: State parameters

Those parameters are required before think about the improvement of the soil materials used. They are useful to make the decision of which soil among the samples required less additive materials to be improved. To decide among the soil samples used the best to make good blocks. Geotechnical parameters of soils from Mangu, Igegania and sand are detailed in Tables 1and 2 of the Appendix 2 and a summary of the results are presented in Table 4-2 below.

Table 4-2: Geotechnical Parameters of Soil Used:

Samples source	Moisture content W (%)	Particle density g/m^3	Bulk density g/m^3	Dry density g/m^3	Porosity n (%)	Void ratio: e	Degree of saturation
Igegania	24	2.38	1.37	1.10	43	1.16	50.01
Mangu	18	2.28	1.33	1.14	42	1.10	38.80
Sand		2.9					

The data on the Table 4.2, show that the soil from Igegania has a natural mointure content of 24% and a saturation ratio of 50,01%. Its specific gravity and its bulk density are respectively 2.38 and 1.33 while its dry density is 1.10. The void ratio and porosity are respectively 1.16 and 43%. The soil sample from Mangu has natural moisture content 18% and a saturation ratio of 38.80%. The specific gravity and bulk density are respectively 2.28 and 1.33. The dry density, the void ratio and the porosity are respectively 1.14, 1.10 and 42%.

4.2.2: GRANULARITY PARAMETERS

In order to characterize the grain size distribution used, the particle size distribution and Atterberg limits were determined.

4.2.2.1: Particle size distribution

The results of the particle sizes distribution analysis of soil materials from studied sites are detailed in Tables 1 and 2, Figures 1and 2 and Appendix 3. The results are summarized in the Figure 4-1 and Table 4-3below. The particles size distribution curves are represented on the Figure 4-3 below.

The particles size distribution curves are represented on the Figure 4-3 below.

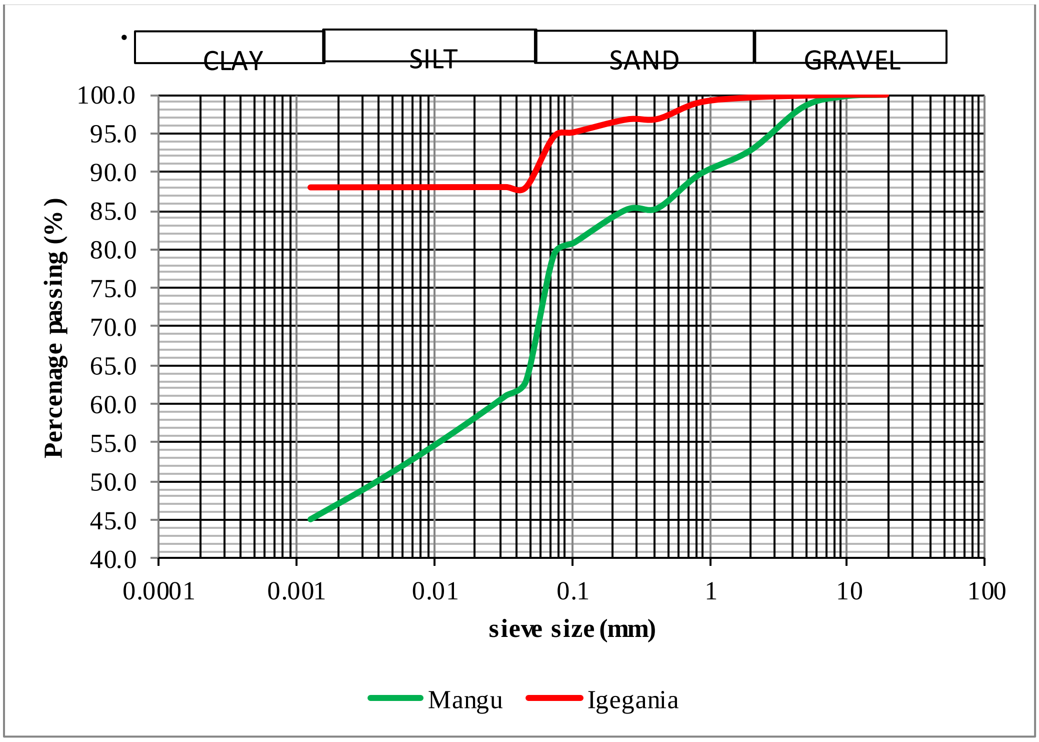

Figure 4-1: Particle sizes distribution curves of soils materials.

Particles size distributions from Figure 4-1 are summarized in Table 4-3 below.

Table 4-3: Grain size distribution of soils samples used

Samples sources	Dmax	%passing through sieve			
		Clay (0.0001-0.002) mm	Silt (0.002-0.075) mm	Sand (0.075–2) mm	Gravel (2 – 60) mm
Igegania	20mm	85%	10%	5%	0%
Mangu	20mm	45%	37%	12%	6%

Data in Table 4-3and Figure 4-1 show that the highest diameter of the material used is of 20 mm. For the material from Igegania, the particles passing through sieves of 0.002, 0.075 mm, 2mm and 20 mm were respectively of 85%, 10%, 5% and 0%. For the soil samples from Mangu, the particles passing through sieves of 0.002, 0.075 mm, 2mm and 20 mm were respectively of 45%, 16%, 12% and 6%.

It may be concluded that the particle size distribution was:

- 85% clay, 10% silt, 5% sand and 0%gravel for the soil sample from Igegania.
- 45% clay, 37% silt, 12% sand and 6% gravel for the soil sample from Mangu.

Figure 4-2 below show that a soil to be qualified for making good soil blocks, its contents should have 30 to 40% clay and 60 to 70% sand.

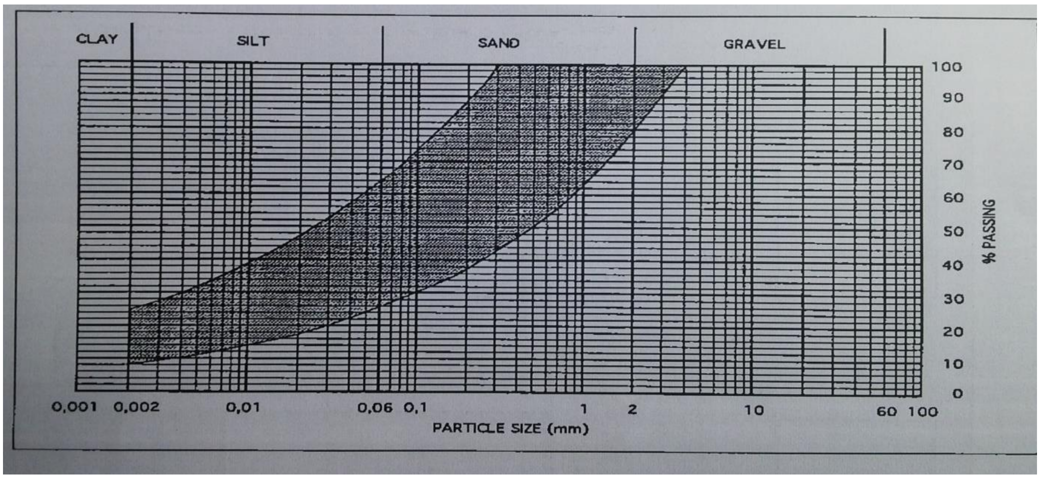

Figure 4-2: Recommended granular texture soils for making soil blocks according to the ARS 681: 1996

The particle sizes distribution of sand sample used to improve the granularity of the studied soils is presented in Figure 4-3.

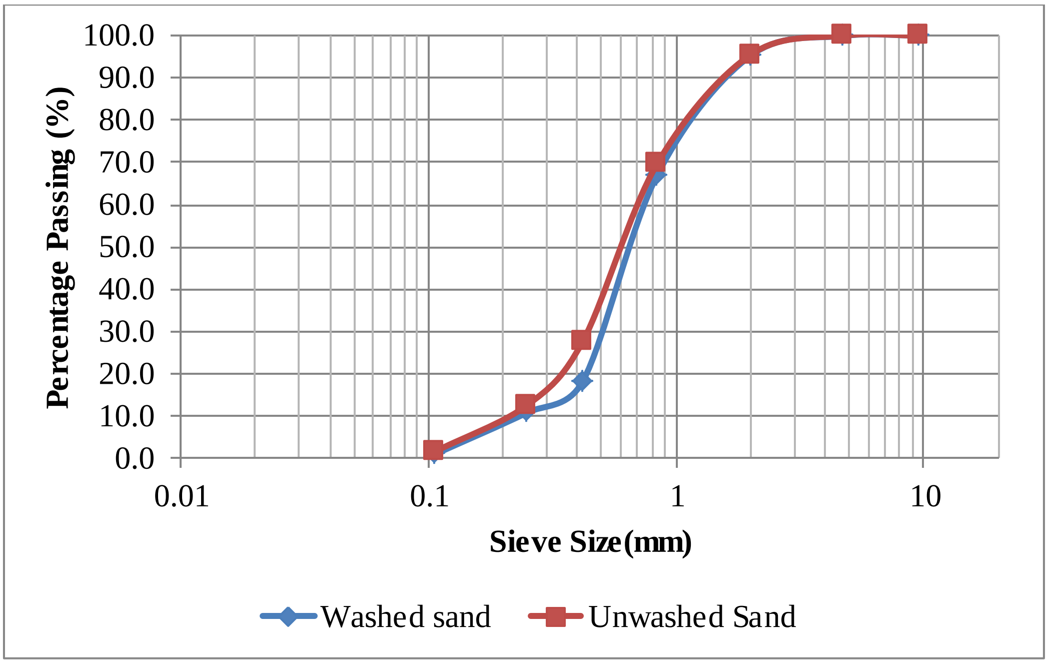

Figure 4-3: Particle size distribution curves of sand used.

The particle size distribution of sand used is summarized in table 4-4 below.

Table 4-4: Grain size distribution particles of sand

Sample	Dmax	%passing through sieve		
		Fine (0.075-0.2) mm	Medium (0.2–0.55) mm	Coarse (0.55–10)mm
Sand	10mm	10%	30%	60%

Data of Table 4.4 show that the diameter of the thickest particle of sand used was 10mm.The percentage of sand passing through 0.2mm, 0.55mm and 20mm were respectively 10%; 30% and 60%.From figure 4-3, D_{60}=0.8, D_{30}=0.40, D_{10}=0.25 then C_u=3.20; C_z=0.80.

4.2.2.2: Consistency limits

The values of the liquid limit, plastic limit are presented in the tables (1, 2, and 3) of the Appendix 4. The average values of those limits are summarized in Table 4-5 below.

Table 4-5: Consistency limits and plasticity index

Samples sources	W_L in %	W_P in %	I_P in %
Igegania	62.0	20.60	41.4
Mangu	50.0	26.0	24

Table 4.5 shows that the values of W_L and W_P of the soil from Igegania are respectively 62% and 20.6% and its plasticity index is 41.4%. For the soil from Mangu, those values are respectively 50% and 26% with a plasticity index of 24%.The figure 4-4 shows the plasticity texture recommend by the African Regulation Standard (ARS: 1996) for a soil to be qualified good for making soil blocks.

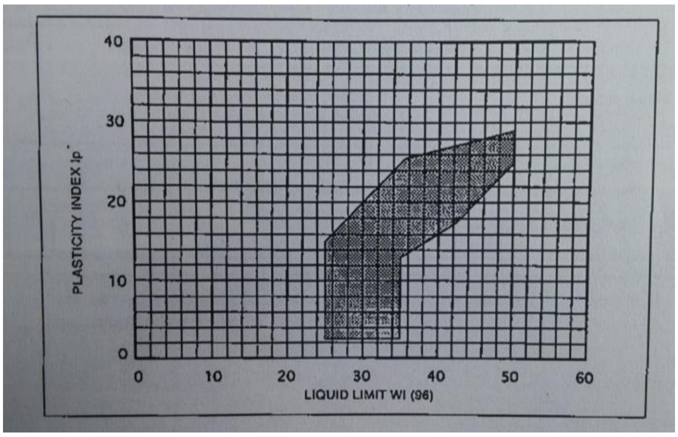

Figure 4-4: Plasticity texture for a good soil for making blocks recommended by the ARS: 1996

Figure 4-5 below shows the plasticity of natural materials used in the recommend plasticity of soil for making good blocks required plasticity recommended by the ARS for making good blocks.

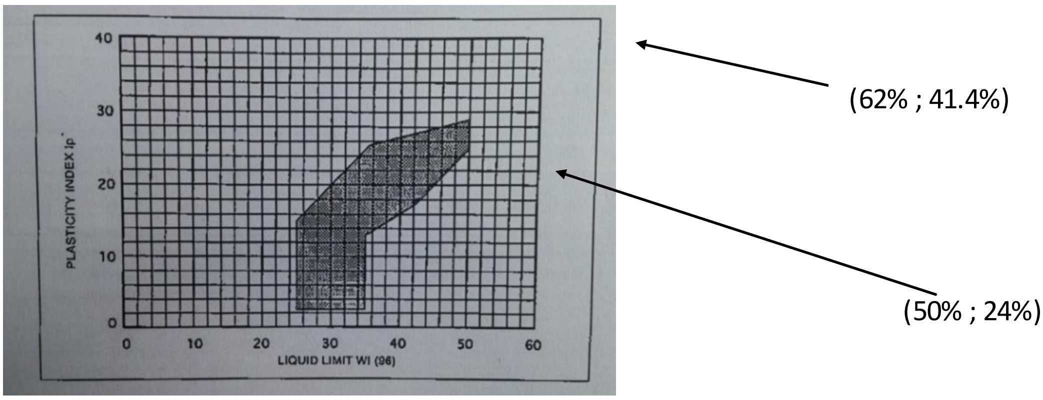

Figure 4-5: Presentation of plasticity of soils used in the Plasticity Texture (spindle) required for a soil to be quality for making good soil blocks according to the ARS: 1996.

4.2.2.3: LINEAR SHRINKAGE

The obtained results for linear shrinkage of natural materials are detailed in Tables 4(a, b, c and d) of Appendix 4. The results are summarized in Tables 4-6 and 4-7 and Figures 4-6 and 4-7.

a. For the mixture soil-sand, the obtained results are summarized in Table 4-6 below.

Table 4-6: Linear shrinkage of clay mixed with different ratios of sand

Material Used	**clay + sand**					
Reference to test method	ref, BS 1377: Part 2: 1990					
Source of sample	**Mangu**					
Water added: Liquid Limit (%)	50	29.50				
Sand added (%)	0	3	5	8	10	50
Total Sand content (%)	12	15	17	20	23	62
Average of linear shrinkage (%)	10.87	8.67				1.67

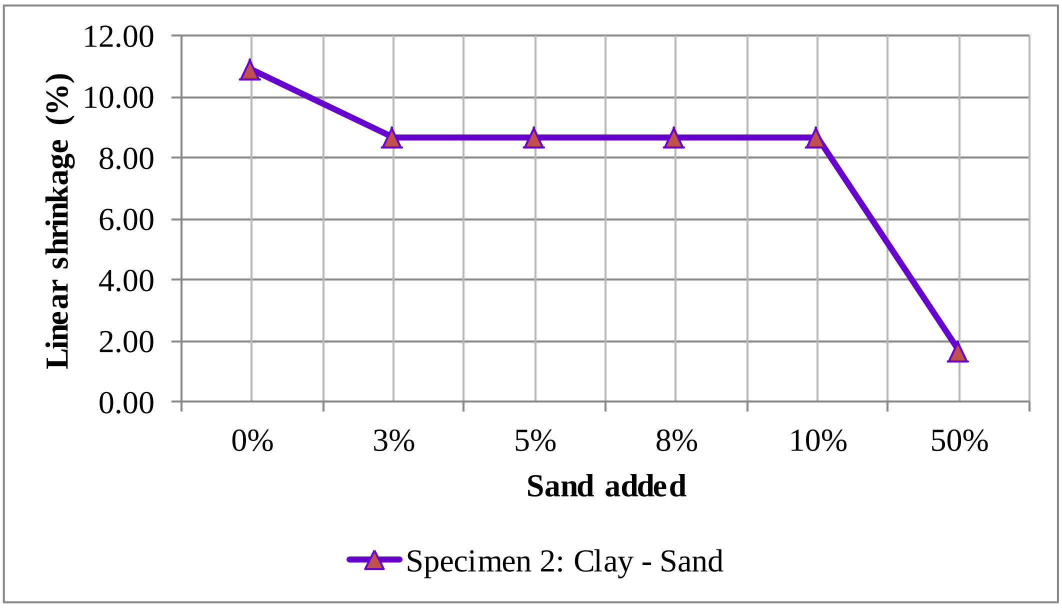

Figure 4-6: Graph of showing the variation of the shrinkage at varied ratio of sand

In table 4-6 and figure 4-6, clay was mixed with various ratios of sand from 0 to 50% and the shrinkage obtained varies from 10.87% to1.67 %. It is observed that the addition of 50% shrink less than others.

b. For the mixtures soil-sand-binders (cement or lime), the obtained results are summarized in Table 4-7 and Figure 4-7 below. Note that the amount of sand used is 50% because it gave the lowest linear shrinkage in table 4.6.

Table 4-7: Linear shrinkage of clay-sand mixed with various ration of binders

MATERIALS USED	Clay + SAND (50%) + Binders						
% of binders added	0	4	6	8	10	12	14
Water added: LquidLimit	50	29.5					
Soil+sand(50%)	1.67						
Soil+Sand+cement in (mm)	10	8	2	0.5	0	0	0
Soil+Sand+Lime in (mm)	10	9	8	9	9	9	9
Soil+Sand+cement in (%)	1.67	1.33	0.33	0.08	0.00	0.00	0.00
Soil+Sand+Lime in (%)	1.67	1.50	1.33	1.50	1.50	1.50	1.50

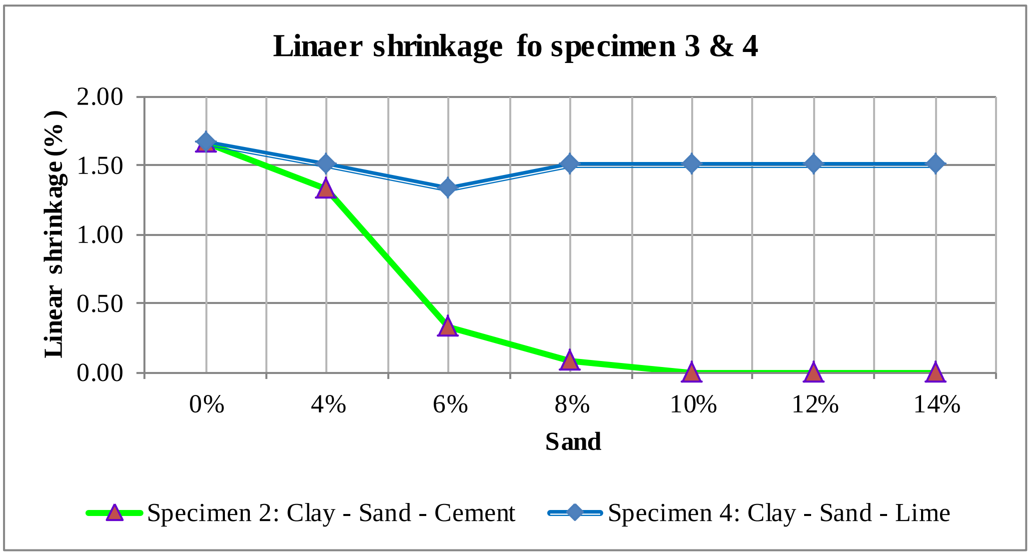

Figure 4-7: Graph of showing the variation of the shrinkage at varied ratio of lime and cement

In Table 4.7 and Figure 4-7, the mixing of clay-sand plus various ratios of binders gave different values of shrinkage. With cement from 4 to 14% the shrinkage is between 1.67 to 0% while with lime the shrinkage is the same 1.50%. The mixing of sand-cement to that soil has reduced the linear shrinkage up to zero value while the mixing sand-lime with that soil has not significantly improved. It means the mixture of soil-sand-cement has more positive effects than the soil-sand-lime.

4.3: MECHANICAL PROPERTIES OF COMPRESSED SOIL BLOCKS MADE

The blocks specimens make were subjected to mechanicals tests in order to get the dry compressive strength, the abrasion resistance and the absorption by capillarity. The detailed results are consigned in Tables 1, 2, 3and 4 of the Appendix 6 for compressive strength, in Tables 1, 2 and 3 of Appendix 7 for abrasion coefficient and in Tables 1, 2 and 3 of Appendix 8 for water absorptions.

4.3.1: Compressive strength of blocks specimens

The averages of the results for compressive strength obtained have been consigned in Tables 4-8, 4-9, 4-10, and 4-11 and in Figures 4-8, 4-9and 4-10 for compressive strengths.

Table 4-8: Compressive strength at 7 days of various clay block compositions with varying percentages of stabilizers

COMPRESSIVE STRENGTH (MPa) at 7 days												
Clay block composition	**% Stabilizers**											
	0	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**
Soil (MPa)	0.6	--	- -	- -	--	--	--	- -	--	--	--	--
Soil + sand (MPa)	0.7	--	--	- -	--	--	--	--	--	--	- -	- -
Soil+Sand+cement (MPa)	--	0.7	1.1	1.0	2.1	2.8	2.6	3.3	3.8	3.7	3.7	4.7
Soil+Sand+Lime (MPa)	- -	0.7	0.7	0.8	0.9	1.9	1.5	2.0	1.8	2.3	1.4	2.3

Table 4-9 : Compressive strength at 14 days of various clay block compositions with varying percentages of stabilizers

COMPRESSIVE STRENGTH (MPa) at 14 days												
Clay block composition	**% Stabilizers**											
	0	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**
Clay (MPa)	1.9	-	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
Clay+ sand (MPa)	0.9	-	- -	- -	- -	- -	- -	-	- -	- -	- -	- -
Clay+Sand+cement (MPa)	- -	1.6	1.6	1.6	2.2	2.6	3.6	4.2	4.6	5.0	5.4	4.2
Clay+Sand+Lime (MPa)	--	0.9	1.0	1.3	1.6	2.9	2.5	2.9	3.4	3.3	2.7	3.3

Table 4-10 : Compressive strength at 28 days of various clay block compositions with varying percentages of stabilizers

COMPRESSIVE STRENGTH (MPa) at 28 days												
Clay block composition	**% Stabilizers**											
	0	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**
Clay (MPa)	2.0	-	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
Clay+ sand (MPa)	2.3	-	- -	- -	- -	- -	- -	-	- -	- -	- -	- -
Clay+Sand+cement (MPa)	- -	2.4	2.4	2.4	3.1	3.9	4.4	4.6	5.3	5.5	5.7	5.4
Clay+Sand+Lime (MPa)	--	2.2	2.1	2.4	2.8	3.1	3.3	4.3	3.5	3.7	2.6	4.4

The bar chart of compressive strengths of blocks for specimen 2(clay-sand) specimens 3(clay-sand-cement) and for specimen 4 (soil-sand-lime) are presented in Tables 4-6 and 4-6 below.

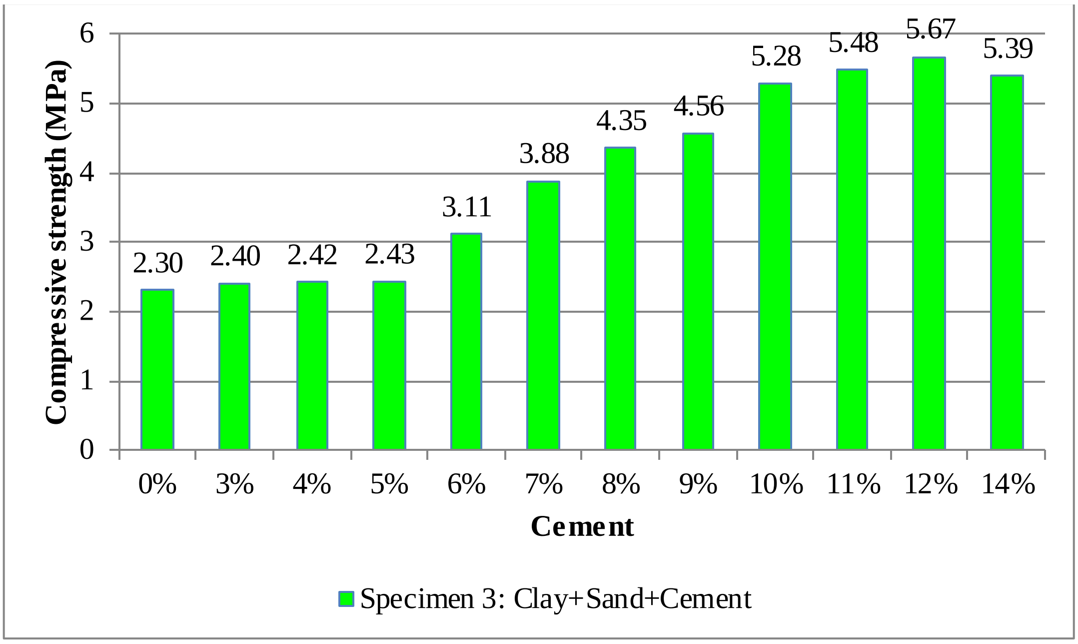

Figure 4-8: Bar chart of compressive strength of blocks specimen 3(clay+ sand+ cement)

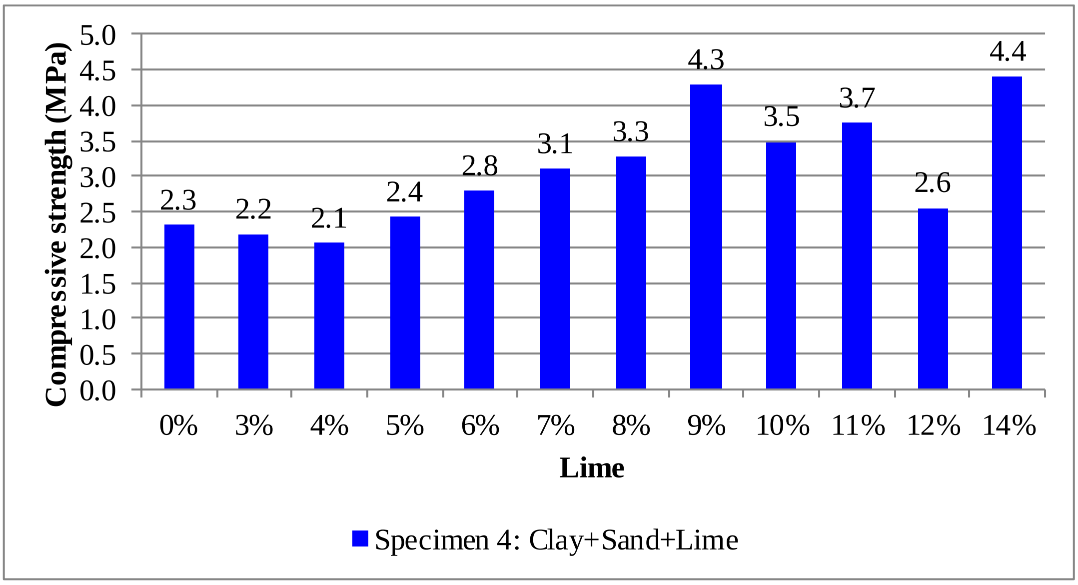

Figure 4-9: Bar chart of compressive strength of blocks specimen 4 (clay+ sand+ lime)

Table 4.10 and Figures 4-8 and 4-9 allow observing that the dry compressive strengths of blocks made are: 2MPa for pure soil blocks without stabilizer, 2.3MPa for CSB stabilized with the sand strength fall in a range of 2.4 to 5.7MPa for the CSSB stabilized with sand-Cement and a range of compressive strength of 2.2 to 4.40MPa for CSSB stabilized with sand-lime.

The compressive strength of natural material from Mangu mixed with plastic fiber is summarized in Table 4-11 and Figure 4-10 below.

Table 4-11 : Compressive strength at 28 days of clay blocks with varying ratio of plastic fiber

SPECIMEN 5: Clay + Plastic Fibers				
Amount of fibers used	0	½ roll or 0.11%	2 Rolls or 0.11%	4 Rolls or 1.20%
Average of Compressive strength (MPa)	2.00	3.30	4.70	3.89

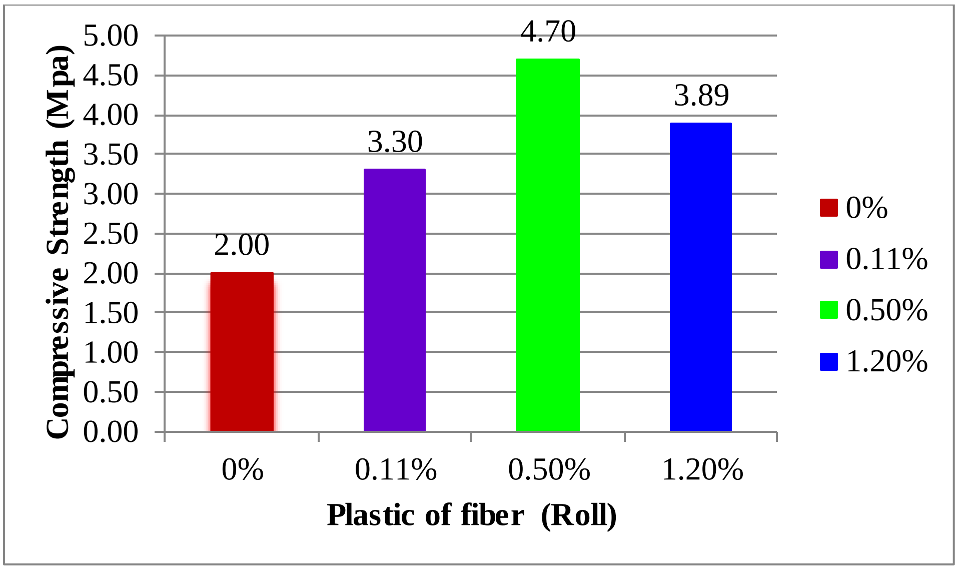

Figure 4-10 : Bar chart of Compressive strength of blocks specimen 5 (Clay+ fiber)

According to the Table 4-11 and Figure 4-10, the dry compressive strength at 28 days varies from 3.30 to 4.70MPa for the blocks stabilized with plastic fibers.

4.3.2: Water absorption of blocks specimens

The averages of obtained results of water absorption by capillarity are summarized below in tables 4-12 and in figures (4-11and 4-12).

Table 4-12: Absorption coefficient by capillarity at 28 days of various clay block compositions with varying percentages of stabilizers

WATER ABSORPTION (%) at 28 days												
Clay block composition	**% Stabilizers**											
	0	3	4	5	6	7	8	9	10	11	12	14
Clay (%)	11.3	-	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
Clay+ sand (%)	17.8	-	- -	- -	- -	- -	- -	-	- -	- -	- -	- -
Clay+Sand+cement (%)		5.99	10.58	7.48	3.52	4.04	5.63	3.99	3.99	5.35	0.07	0.05
Clay+Sand+Lime (%)		2.87	2.36	2.69	3.01	17.12	7.89	6.05	8.20	10.53	0.59	12.91

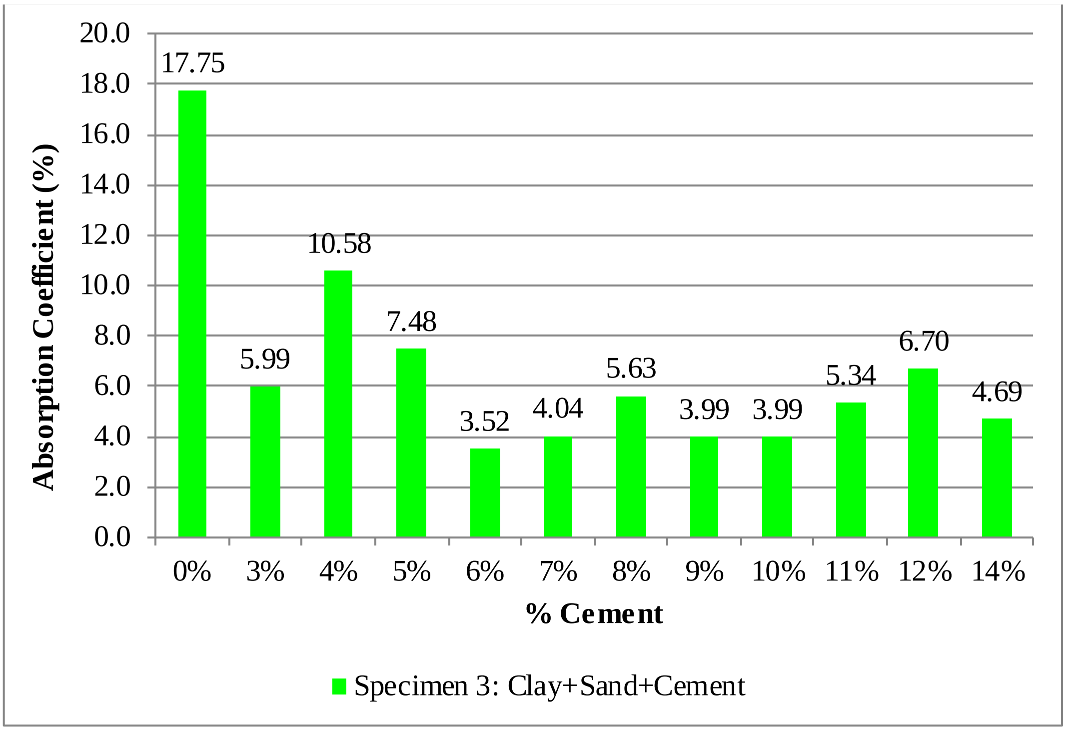

Figure 4-11: Bar chart of capillarity absorption for specimen 3: Clay +sand +cement)

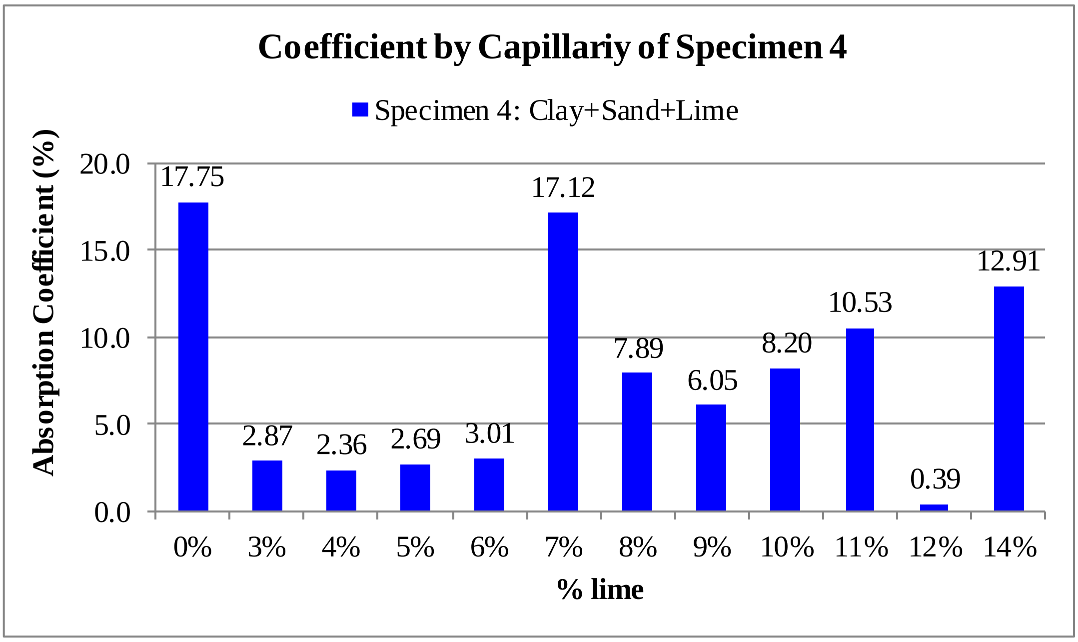

Figure 4-12: Bar chart of capillarity absorption for specimen 4 (Clay +Sand +Lime)

According to the Table 4.12 and Figures 4-11 and 4-12, it is observed that the values of capillarity absorption of blocks specimens are respectively: 6.81% for pure soil blocks, 8.44% for CSB stabilized with the sand strength fall in a range of 5.99 to 0.05% for the CSSB stabilized with sand-Cement and a range of compressive strength of 2.87 to 12.91% for CSSB stabilized with sand-lime.

4.3.3: Abrasion resistance

The values of the abrasion resistance (coefficient) of blocks specimens are summarized in Table 4-13 and Figures 4-13 and 4-14below.

Table 4-13: Abrasion coefficient at 28 days of various clay block compositions with varying percentages of stabilizers

ABRASION COEFFICIENT (cm^2/g) at 28 days												
Clay block composition	**% Stabilizers**											
	0	3	4	5	6	7	8	9	10	11	12	14
Clay (%)	1.12	-	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
Clay+ sand (%)	3.32	-	- -	- -	- -	- -	- -	-	- -	- -	- -	- -
Clay+Sand+cement (%)		2.96	3.66	1.93	1.26	0.60	0.83	0.54	0.64	0.50	0.32	0.25
Clay+Sand+Lime (%)		2.60	1.89	1.10	0.31	0.84	1.10	0.86	0.85	0.34	0.38	1.24

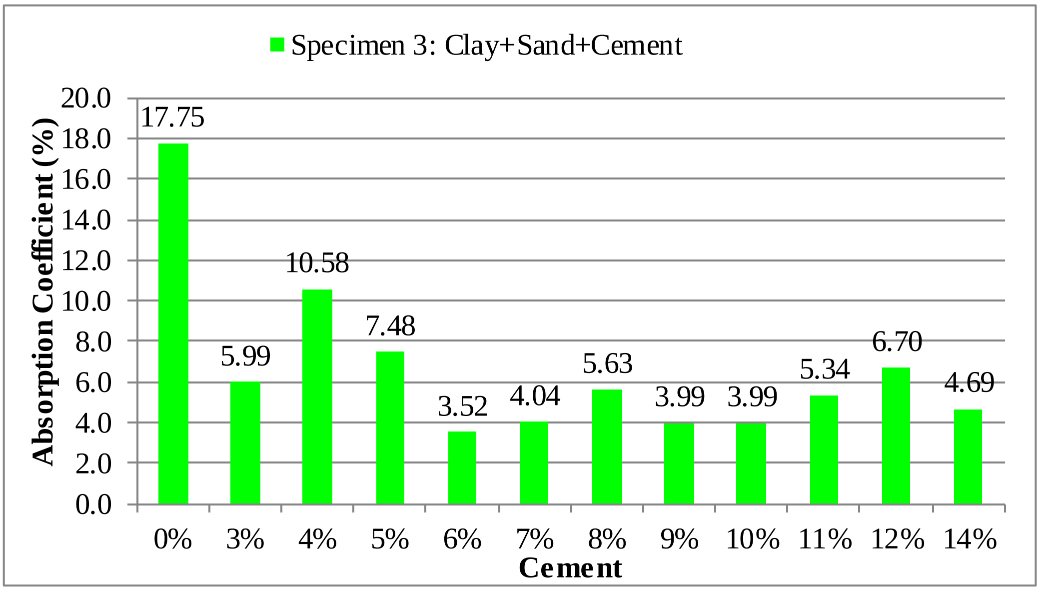

Figure 4-13: Bar chart of the abrasion coefficient for specimen 3 (clay +sand +cement)

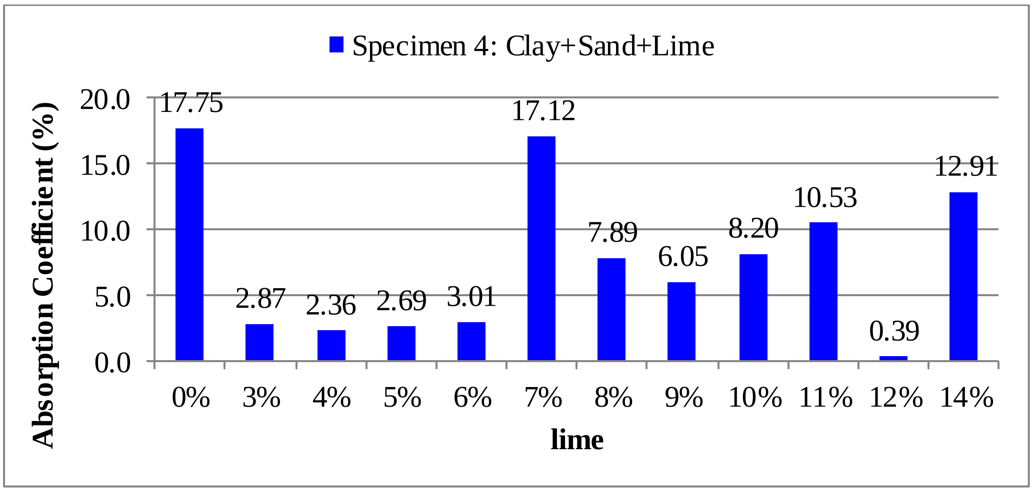

Figure 4-14: Bar Chart of the Abrasion Coefficient for Specimen 3 (Clay +Sand +Lime)

According to table 4.13 and figures (4-13, 4-14), it is observed that the values of the abrasion resistance of blocks made are respectively: 1.12% for pure soil blocks, 3.32% for CSB stabilized with the sand strength fall in a range of 2.96 to 0.25% for the CSSB stabilized with sand-Cement and a range of compressive strength of 2.60 to 0.34% for CSSB with sand-lime.

4.4: SIZES, MASSES AND DENSITIES OF BLOCKS

The sizes, masses and densities have been for the specimens 3 and 4 correspond to the mixing ratio with 8% binder (cement or lime) which are taken as the optimum. For the specimen 5 it with plastic fibers is the average of all the blocks. The results detailed in on the table of the Appendix 9 are summarized in Table 4-14.

Table 4-14: Sizes, Masses and Densities of blocks.

SAMPLE	**Specimen 1**	**Specimen 2**	**Specimen 3**	**Specimen 4**	**Specimen 5**
AGE OF BLOCKS	28 days				
Length (L) in mm	28.30	28.80	28.90	28.90	28.8
Larger (l) in mm	13.50	13.70	14.00	14.10	13.8
Height (h) in mm	11.20	11.50	11.90	12.00	11.70
Area (A) in mm^2	382.05	394.56	404.60	407.49	397.44
Volume of Blocks in cm3	4278.96	4537.44	4814.74	4889.88	4650.05
Mass of blocks (g)	7186.00	8442.30	9068.00	8591.00	8506.9
Density of blocks (g/cm3)	1.68	1.86	1.88	1.76	1.83

The densities of blocks of specimens (1, 2, 3, 4 and 5) are respectively 1.68, 1.86, 1.88, 1.76 and 1.83g/cm3.

CHAPTER 5: DISCUSSION OF RESULTS

Works done the soils of Igegania and Mangu in Kenya were essentilly carried on the physical characterization of the soil used in view of the production of the earth blocks for buildings. It is question in this chapter to analysis the determined parameters in order to make propositions in order to improve the natural material (soil) used. The first shutter of the present chapter concerns the interpretation and the discussion of natural material features and those of the earth blocks manufactured with their use. The second shutter concerns the propositions and recommendations in view of the improvement of the soils used for the production of the earth blocks compressed.

5.1: NATURAL SOIL

5.1.1: Oxide composition

Data in Table 4-1 show that the highest oxide component obtained is iron oxide with 85% of all the oxide components. That 85% of iron is responsible of red color of the soil used. That obtained value is too far above the desirable value (4 to 6) % oxide content of soil for making blocks.

5.1.2: State parameters of natural soils

The soils samples used were red in color. That red color came from the high amount of the mineral Iron-magnesium rich in iron oxides and layers of manganese oxides, which came respectively from the oxidization of iron and the manganese during the change of the natural rock.

Table 4-2 shows that water content obtained in soil got from Igegania of 24% while the soil from Mangu has 18%. Water content recorded in the soil from Igeganiawas higher than the soil from Mangu. This shows that material from Igegania has higher sensibility to water than the soil got from Mangu. This can be explained by the fact that the material from Igegania is richer in clayey particles than the one from Mangu.

Specific gravity of the soil from Igegania is 2.38 against 2.28 for the soil from Mangu. Those values of specific gravities are not high sometime they can reach 2.90, this due to the presence of iron oxide and minerals clayey. Those values of specific gravities vary according to the collection site depending on climatic conditions which act on the formation of the material.

Dry density obtained of soils from Igegania and Mangu were respectively 1.10 and 1.14; with porosities of 43% and 42% and void ratio of 1.16% and 42% explain the stabilization require for soils studied.

5.1.3: Granularity characteristics

The granularities of soils used were characterized by their particles size distribution, their content in fine particles and their consistency parameters.

5.1.3.1: Particles sizes distribution

The particles sizes composition showed in Table 4-3shows that the studied soils are too rich in finer elements, what reveals the high amount of finer particles. This can be explained by the fact that these soils come from the same environment. However, the slopes of grain size distribution curves show that these materials are mostly finer particles (sediments). On the other hand the strong slope observed with these particles sizes distributions curves indicate high content of clayey-silty particles. On the whole, these materials are very poor in medium and coarse particles, rich in fine grains, and contain some sands.

5.1.3.2: Limit of consistency

Tables 4-5, shows that liquid limits obtained of soils from Igegania and Manguare respectively 62% and 50%. Plastic Limits are 20.60% and 26.00%. Plasticity Index is 41.4% and 24%.

According to the diagram shart of Casagrande (Figure 1 in Appendix 10), the values of plasticity index show that the soil coming from Igegania is constituted of inorganic clays with high plasticity while the soil from Mangu is constituted of inorganic clays with medium plasticity. The absence of organic matters in those clays shows that the natural materials used were not vegetable contaminated and that they came from sub soil(from 30cm depth). According to their plasticity index, soils used can be classified as:

- High plasticity (I_p is 41.4 that is higher than 40) for the soil from Igegania
- Medium Plasticity ($I_p$is 24 that is more than 15%and less than 15%) for the soil from Mangu

5.1.3.3: HBR classification of soils used

From HRB classification Table (Table 1 in Appendix 10),the natural materials studied belong to the class A-6 called Clayey Soils. So depending on their plasticity index and on HBR it can be concluded that the natural soils used are:

- Clayey soils for the soil with high plasticity sample coming from Igegania;
- Clayey soils with medium plasticity for the soil sample coming from Mangu.

The values of group index corresponding are less than 16, which means that materials used have the lowest geotechnical performances according to the HRB classification, higher the group index is, lower is the performance of the material in geotechnical road.

5.1.3.4: Linear shrinkage

Tables 4-6, and Figure 4-6 show that the addition of sand has highly improved the granular properties of the clay used by reducing the shrinkage. Moreover Table 4-7 and Figure 4-7 show that addition of sand-cement has completely canceled the shrinkage and the shrinkage is no longer appearing while additions of sand-lime give the same shrinkage than the mixing clay-sand, it means lime almost neutral. From the above results it can be conclude that stabilization with 50% sand plus cement(6-14)% improve the material to the best quality for making blocks.

5.1.3.5: Classification according to the nature of soil used

According to the ARS: 1996 (Boubekeur S., 1998), from the percentage passing through 80µm sieve and the plasticity index on Table 2 and figure 2 in Appendix 10,

- The soil from Mangu belongs to the class A1: is an acceptable material for making blocks but with too many fines;

- The soil from Igegania belongs to the class A4, which is classified as a material which is very difficult to use, as it is very active. By conclusion it is not an acceptable material for making CSB even from its granular composition.

From these classifications, the natural materials from Mangu will be used for block production in a condition to change the **grains size distribution** with sandy particles.

5.1.4: Classification of sand used

5.1.4.1: Classification according the Coefficient of Uniformity

For the sand both washed and unwashed sand, C_U=3.2 which is higher than 2 the grains size are tight.

5.1.4.2: Classification according the Coefficient of Curvature

According to the Curvature coefficient, the coefficient of curvature of the sand studied C_Z is 0.8, which is less than 1. Therefore, the grain sizes distribution in Table 4-4 is not well graduated. Concerning to the shape of the particle distribution curve (see Figure 4-3), the sand use is very poor in fines sand particles.

5.2: USING OF SOILS STUDIED FOR MAKING GOOD COMPRESSED SOIL BLOCKS

The grain size distribution curve of red soils used show that all those curves are partially included in the granular spindle usable for CSB (see Figure 4-2). The results obtained from soil identification and particle size distribution curves enable to affirm that red natural materials used contain a high amount of finer particles sediments (silt-clay) particles and very poor in coarse (sandy) particles required to make CSB. The high amount of sediments (finer particles) is responsible of cracking during drying of blocks and makes the blocks unsuitable to the water absorption and strength. In regard to the grains sizes, these soils studied are not suitable to make good CSB unless they are consolidated with stabilizers. For using the studied soils in block production, they need to be improved by adding sand before binders (cement and lime).

The Figure 4-1shows that the particles distribution curves of soils both from studied sites do not follow the general trend of the granular texture of good soils for making soil blocks. according to the ARS 681: 1996 in Figure 4-2, the studied soils are not qualify for making blocks. To use those soils for making blocks, we have changed by improving their granular texture by adding 50% sand in order to reach the recommended values of the ARS standard.

Figure 4-5 shows that the plasticity of the soil from Mangu is near the plasticity texture while the sample from Igegania is far out from the required plasticity recommended by the ARS for making good blocks.

5.2.1: Conclusion

From the particle size distribution curves figures (4-1, 4-2) and Atterberglimits (figure 4-5), we conclude that the studied soils are not qualified to be used in their natural state for making good blocks. The soil from Igegania is poorer than the one from Mangu. Then to be more sustainable, the natural material from Mangu will be used to continue this study and making the blocks.

Figure 4-2 shows that a soil to be qualified for making good soil blocks has to been within the recommended granular texture and then must content 30 to 40% clay and 60 to 70% sand. From Table 4-3, the sand content of studied soils is respectively 5% for Igegania and 12% for Mangu which are lower than the requirements for block production. Then to use those soils for making blocks, we have changed by improving their granular texture by adding 50% sand to reach 62% which is the recommended values of the ARS 1996.

5.3: COMPARISON OF MECHANICAL AND PHYSICAL AND HYGROMETRIC PROPERTIES OF BLOCKS MADE

The mechanical characterization of earth blocks products basis on soil from Mangu permitted to determine the dry compressive strength, determine the behavior of the blocks in abrasive and capillary environment. This study were carried out on compressed soil blocks on one hand, and on compressed stabilized soil blocks on the other hand. The mechanical and physical features of these blocks vary depending to the ratio of stabilizers used such as cement, hydrated lime or fibers plastic. The results of hygrometric and mechanical performances of the specimens are compared below in Figures 5-1, 5-2, 5-3, 5-4, and 5-5.

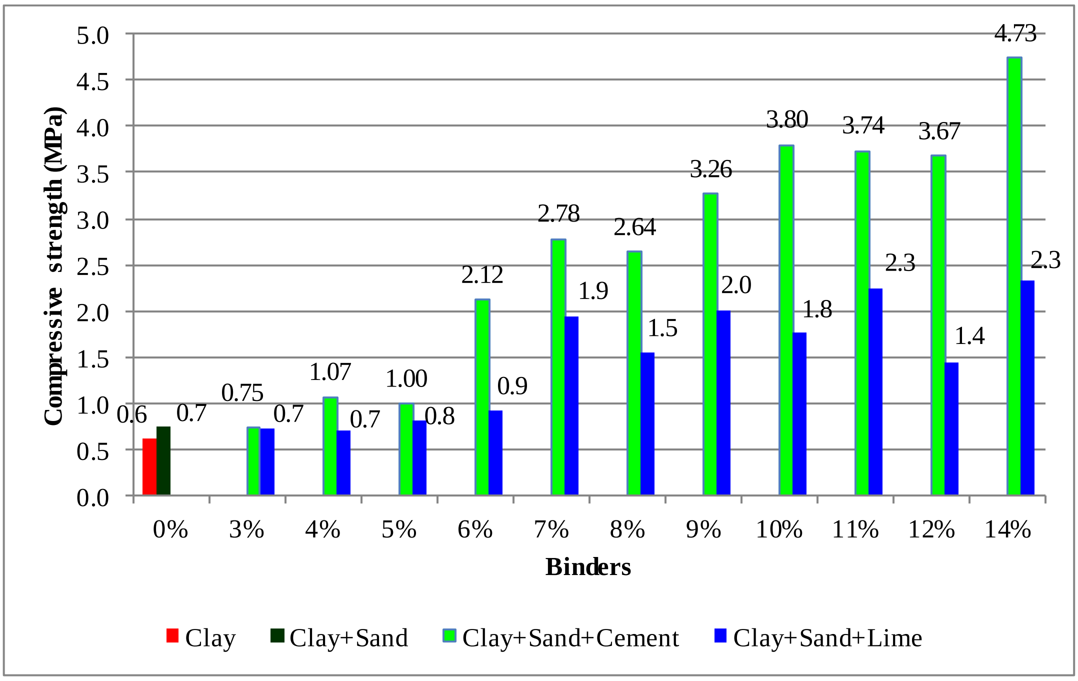

Figure 5-1: Comparison of compressive strength of CSB and CSSB at 7 days old

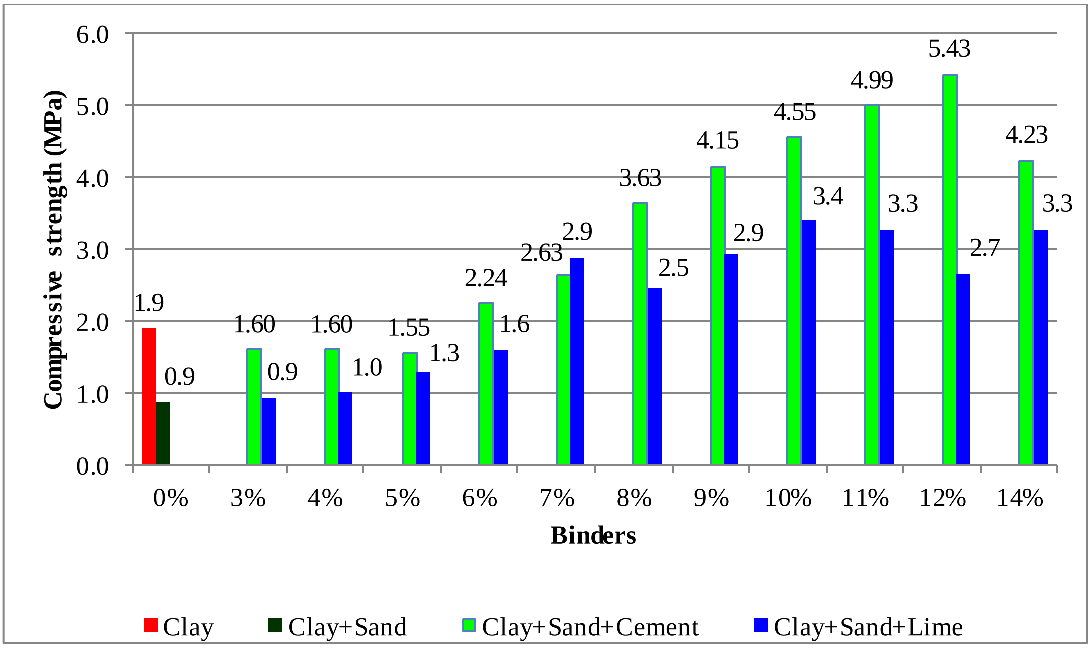

Figure 5-2: Comparison of compressive strength of CSB and CSSB at 14 days old

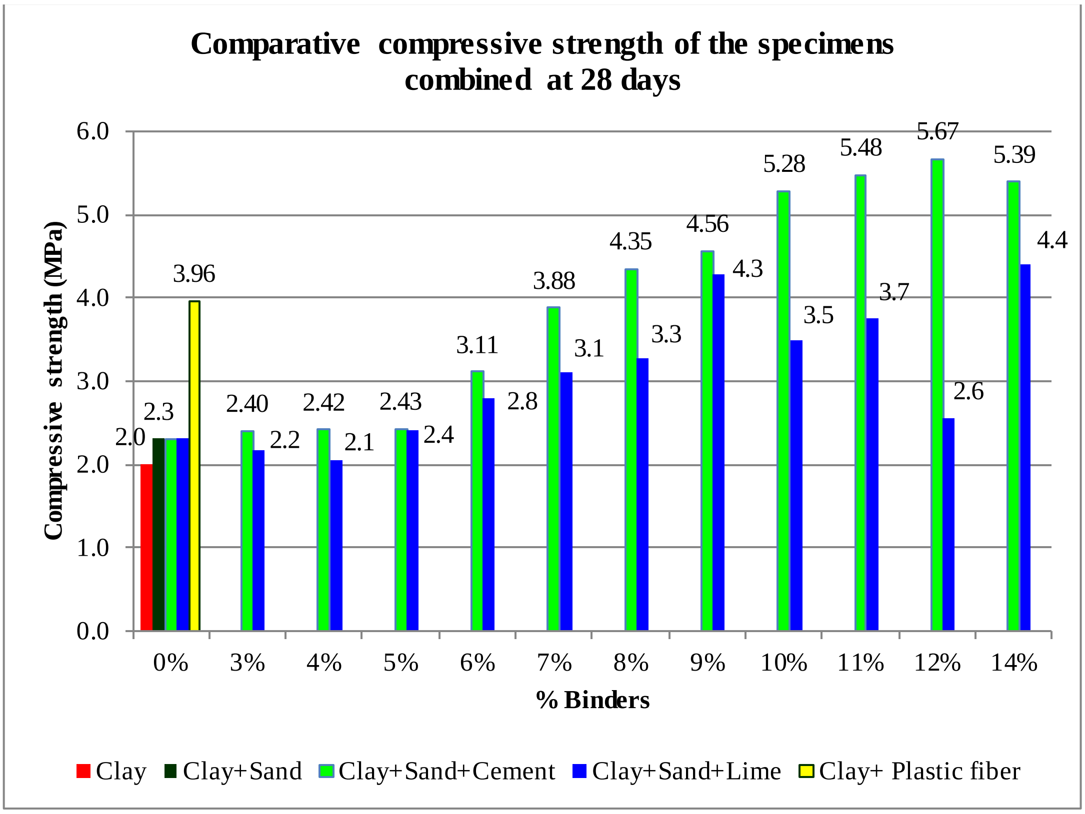

Figure 5-3 : Comparison of compressive strength of CSB and CSSB at 28 days old

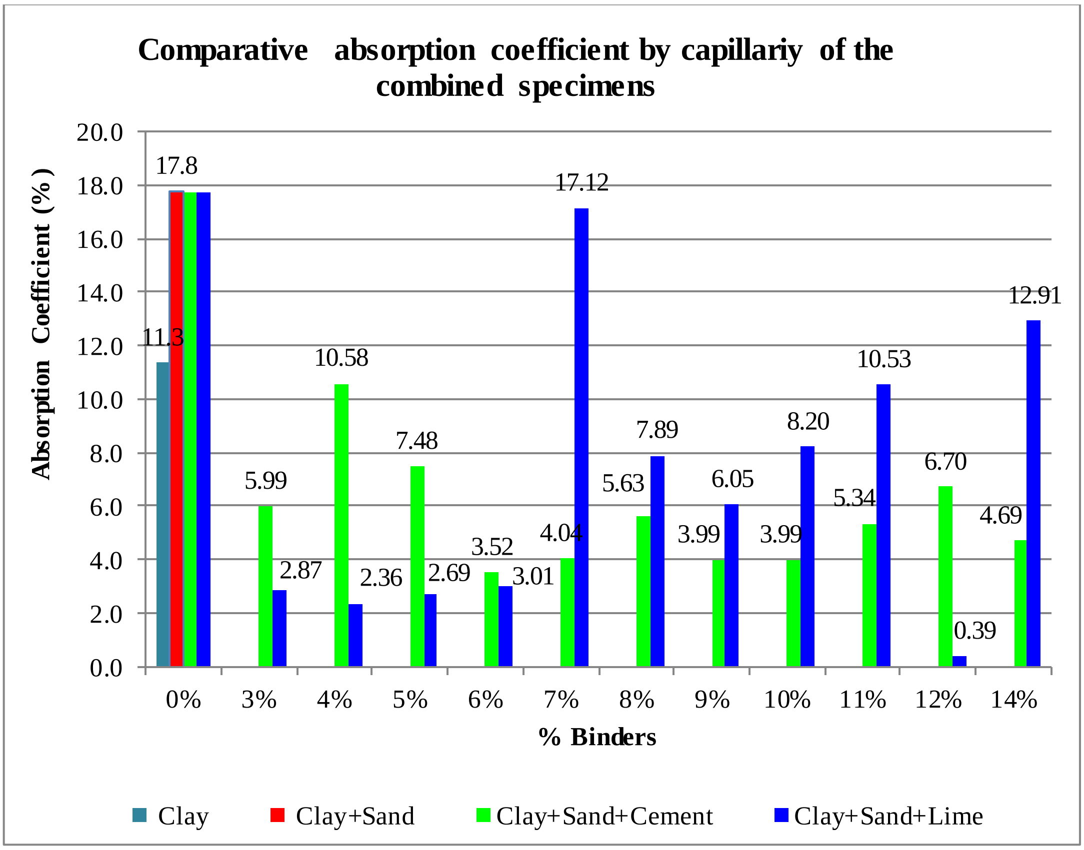

Figure 5-4: Comparison of water absorption by capillarity of CSB and CSSB

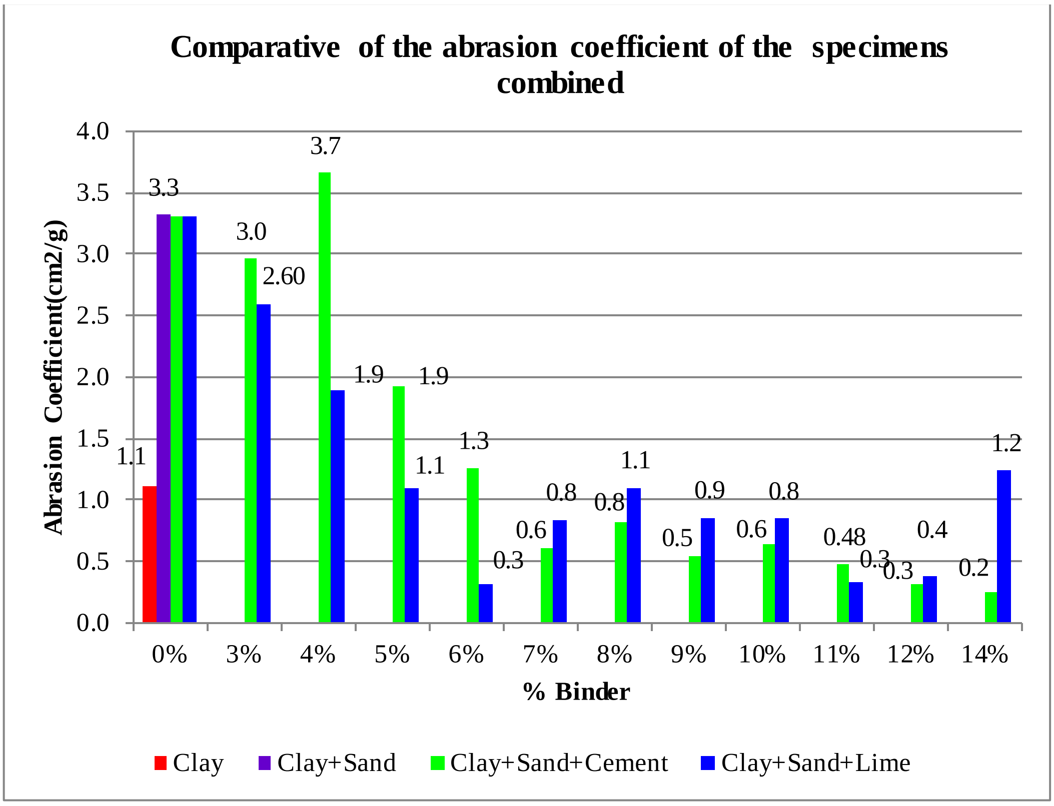

Figure 5-5: Comparison of the abrasion coefficient of CSB and CSSB

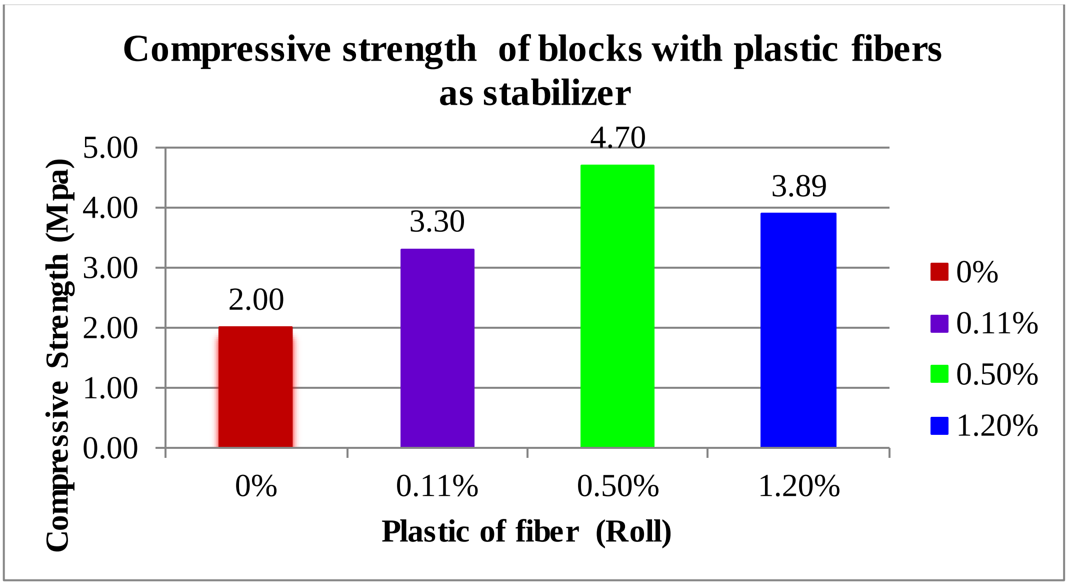

Figure 5-6: Comparison of compressive strength of CSB and specimen 5(soil-Plastic fiber)

From Figures 5-1, 5-2, 5-3, 5-4, 5-5 and 5-6, it is observed that the specimen 3 stabilized with sand-cement that gave the best performances in service either in mechanical and physical and hydrological in term of the highest values obtained. However for compressive strength, Figure 5-3 shows that specimen 5(soil - plastic fibers)(bar with yellow color) gave the high mechanical performances close to specimen 3(soil-sand-lime) and Figure 5-6 shows that specimen 5(soil-plastic fiber) has higher strength that the control (specimen1: Soil). This can be explained by the fact that plastic fiber has increase the bound within the particles that plays against crushing of blocks when subjected to compression.

5.4: USING OF BLOCKSMADE ACCORDING TO THE STANDARD

CSBs made were mechanically characterized by the results of the tests to the abrasion, dry compressive strength, as well as of the tests for the absorption by capillarity. It was the same for the CSSB consolidated with 50 % sand and different percentages of binders (3-14)% of cement and (3-14%) of lime and plastic fibers (0.11, 0.50 and 1.20)% as stabilizers..

5.4.1: Dry compressive strength

Results of tests performed and the mechanical feature values fixed by the standard (Table 2-3 in chapter 2) for Earth construction for the structures units subjected to the environmental stress of R and C categories and CS and capable to withstand to important stress are reported in Table 5.1 below

Table 5-1: Comparison of dry compressive strength at 28 days of various clay block compositions with varying percentages of stabilizers with the standard (ARS: 1996)

Compressive strength recommended by ARS:1996 according to the using for CEB NF (1,2,3)D and FF (1,2,3)D	≥ 2MPa for CEB NF 1(D, R, C) and CEB FF 1(D, R,C) ≥4MPa for CEB NF 2(D, R, C) and CEB FF 2(D, R,C) ≥6MPa for CEB NF 3(D, R, C) and CEB FF 3(D, R,C)											
Clay block composition	**% Stabilizers**											
	0	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**
Clay (MPa)	2.0	-	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
Clay + sand (MPa)	2.3	-	- -	- -	- -	- -	- -	-	- -	- -	- -	- -
Clay+Sand+cement(MPa)	- -	2.4	2.4	2.4	3.1	3.9	4.4	4.6	5.3	5.5	5.7	5.4
Clay+Sand+Lime (MPa)	- -	2.2	2.1	2.4	2.8	3.1	3.3	4.3	3.5	3.7	2.6	4.4
Clay + Plastic fibers (MPa)	3.96	--	- -	- -	- -	- -	- -	-	- -	- -	- -	- -

From Table 5.1, the dry compression strengths vary from a specimen to another depending to the types and percentages of the stabilizers used. Therefore the gotten values are:

1- The spécimen1 (CSB with soil only) gave a dry compressive strength of 2 MPa. This value corresponds to the lower limit of strength acceptable.
2- The specimen 2(Soil+ sand) gave a dry compressive strength 2.3MPa. It shows that the stabilization with sand improved the resistance slightly in compression from 2 to 2.3MPa but the compressive strength value still low.

From Table 5-1, it is deducted that specimen 1(clay) and specimen 2 (clay-sand) made with soil from the studied site cannot withstand to the different stress actions and therefore can only be used for the unloaded bearing wall. (E.g. boundary walls, fill in has load-bearing structures, single storey building made of load - bearing structural elements) walls referring to the CEB NF 1(D, R, C) CEB or FF 1(D, R, C) of the ARS: 1996.

Stabilization with the binders (cement and lime) gives acceptable and high strength such as :

3- For the specimens 3 (CSSB stabilized with both sand + cement) the compressive strength for (3-7)% cement gave (2.4 -3.9) MPa that is acceptable. For (8-14) % cement, the compressive strength obtained was between 4.4 to 5.7MPa that is high.

These values permit to deduct immediately that with the addition of the sand and (3-7)% cement, the strength has been improved from 2.4 to 3.9MPa and blocks can be used for unloaded walls e.g. boundary walls, fill in a load bearing structure, single story building made of load-bearing structural elements) to fairly loaded walls. While addition of sand and (8-14) % cement gave (4.4-5.7) MPa that is high. Blocks can withstand important external (live) actions (e.g. a two storey building with accessible terrace made of thin load-bearing structural elements) referring to CEB NF 2(D, R, C) and CEB FF 2(D, R, C) of the ARS: 1996.

4- For the specimens 4 (CSSB stabilized with both sand + lime) the compressive strength for (3-8 and 10-12) % lime gave (2.1 to 3.7) MPa that is acceptable. For (9 and 14) % lime, the strength obtained was (4.3 - 4.4) MPa that is a bit high.

These values permit to deduct immediately that with the addition of the sand and (3-8 and 10-12) % lime, the strength has been improved from 2 to 3.7MPa and blocks can be used for unloaded walls (e.g. boundary wall, fill in a load bearing structure, single story building made of load- bearing structural elements) to fairly loaded walls. While addition of sand and (9 and 14) % lime gave (4.3-4.4) MPa that is high. Blocks made can withstand important external (live) actions (e.g. a two storey building with accessible terrace made of thin load-bearing structural elements) referring to CEB NF 2(D, R, C) and CEB FF 2(D, R, C) of the ARS: 1996.

5- The specimen 5 (soil stabilized with plastic fiber) gave an average of dry compressive strength of 3.96 MPa which shows that the addition of plastic fibers as stabilizer has improved the strength from a prohibited (2MPa) to an acceptable and recommendable value (3.96 MPa) and the blocks of this specimen is highly recommended that specimen 1 and specimen 2 because it can withstand to the loads heavy than specimen 1 and 2. The blocks this specimen can be use in building for non bearing load walls (e.g. boundary wall, fill in a load bearing structure, single story building made of load- bearing structural elements) to fairly loaded walls.

5.4.2: Water absorption by capillarity

The values of water absorption coefficient obtained are presented in Table 5-2.

Table 5-2: Comparison of water absorption at 28 days of various clay block compositions with varying percentages of stabilizers with the standard (ARS: 1996)

Water Absorption coefficient of the standard for CEB NF (1,2,3)D and FF (1,2,3)D	≤ 15% for CEB NF 1C and CEB FF 1C ≤ 10% for CEB NF 2C and CEB FF 2C ≤ 5% for CEB NF 3C and CEB FF 3C											
Clay block composition	**% Stabilizers**											
	0	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**
Clay (%)	11.3	-	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
Clay + sand (%)	17.8	-	- -	- -	- -	- -	- -	-	- -	- -	- -	- -
Clay+Sand+cement (%)	- -	5.99	10.58	7.48	3.52	4.04	5.63	3.99	3.99	5.35	0.07	0.05
Clay+Sand+Lime (%)	- -	2.87	2.36	2.69	3.01	17.1	7.89	6.05	8.20	10.5	0.59	12.9

1- For the specimen 1, pure soil without stabilizer, capillary absorption coefficient is 11.3% which is within of the recommended values (0-15) % by the standard (ARS: 1996). CSB basis on the soils from studied site can be in a capillary environment provide with protection against water damage like used for unload-bearing structure for walls covered or protected with cement mortar against water damage.

2- The percentage of capillary absorption coefficient for the specimen 2 is 17.8% very far above the recommended values by the standard because of sandy particles effects. CSSBs for this specimen are not suitable for a capillary environment therefore can be used only in a dry environment with no risk of being wet (e.g. blocks for internal partition which are not exposed or which are protected from water damage).

3- For specimen 3, soil mixed with both sand and various ratio of cement, at (3, 5, 8, and 11) % cement, the capillary absorption coefficient varies between 5.35% and 10% due to the reaction effect between sand and cement with clayey soil. These values are acceptable for a capillary environment in relation values recommended by the standard in Table 5-2 and recommended in capillary environment for structural elements capable to withstand to important loads (e.g. blocks make for lateral walls exposed to rain like for bathroom walls being splashed).

   For CSSBs with sand and (6-14) % cement, the absorption coefficient varies between 0.05 and 3.99% due to the high amount of cement which act with sandy particles. These values are highly recommended for a capillary environment for blocks capable of withstanding to high external (live) loads like external exposed loaded and uncovered walls (e.g. external wall unprotected from capillary rise, internal wall unprotected from water leaking through the roof).

4- For specimen 4, soil consolidated with sand and different ratio of lime, at 7% lime gives 17.12%, value far above the recommended value by the standard. Blocks made with that mixing ratio are not suitable for capillary environments therefore are only recommended for a dry environment with no risk of being wet.

With (8-11, and 14) % lime, the capillary absorption coefficient of water are between 6.05% and 12.91% due to the effect high amount of lime and sand in presence of clay soil used. These values are acceptable for a capillary environment in relation values recommended by the standard in table 5-2 and recommended for works (e.g. blocks make for lateral walls exposed to rain like for bathroom walls being splashed).

With (3-6 and 12) % limes the capillary absorption coefficients vary 0.59 and 3.01% due to the presence of lime. These values highly are recommended for a capillary environment according to the standard values indicated in table 5-2.those values are recommended for exposed and uncovered walls (e.g. external wall unprotected from capillary rise, internal wall unprotected from water leaking through the roof).

5- Without test the absorption coefficient, this specimen is classified the same as specimen 1 and 2 because the stabilizer use(plastic fiber) cannot play against penetration of water then blocks of specimen 5 are highly recommended only for dry area with no risk of being wet such as blocks or internal partition protected with a covered coating such as cement mortar.

5.4.3: Abrasion coefficient: loss of material

The values of the abrasion coefficient are indicated in Table 5-3.

Table 5-3: Comparison of abrasion coefficient (loss in matter) at 28 days of various clay block compositions with varying percentages of stabilizers with the standard (ARS: 1996)

Abrasion (loss of matter) of the Standard for CEB NF (1,2,3)D and FF (1,2,3)D	≤ 10% for CEB NF 1(C, R, C) and CEB FF 1(D, R,C) ≤ 5% for CEB NF 2(C, R, C) and CEB FF 2(D, R,C) ≤ 2% for CEB NF 3(C, R, C) and CEB FF 3(D, R,C)											
Clay block composition	**% Stabilizers**											
	0	3	4	5	6	7	8	9	10	11	12	14
Clay (%)	1.12	-	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
Clay + Sand (%)	3.32	-	- -	- -	- -	- -	- -	-	- -	- -	- -	- -
Clay+Sand+ Cement (%)	- -	2.96	3.66	1.93	1.26	0.60	0.83	0.54	0.64	0.50	0.32	0.25
Clay+Sand+Lime (%)	- -	2.60	1.89	1.10	0.31	0.84	1.10	0.86	0.85	0.34	0.38	1.24

From Table 5-3, the values of abrasion coefficient being proportional to the loss of mass blocks subjected to mechanical erosion.

1- The specimen 1 (soil without stabilizer) has an abrasion coefficient of 1.12%, which is good in term of abrasion resistance. This is due to the fact that soil is essentially clayey and to this content a high cohesive force even without addition of stabilizer but once use it to make blocks it develop cracks.

2- The specimen 2 (soil with sand as stabilizer) has an abrasion coefficient of 3.32%that is recommendable by the standard but the amount loss of materials is higher than for the specimen 1. This is due to the fact that the addition of sand (sandy particles) has reduced the cohesion force (binding properties) of clay but in same time helped to reduce cracking by consolidating the sandy and clayey particles together for that the grain size distribution curve be within the granular texture recommended.

With the addition of binders (cement and lime) as stabilizer, the percentages in loss of materials decrease with the increase of the stabilizing binders. It is due to the addition of both sand and binders as stabilizer, to that effect CSSBs become therefore hard, strong with best values of resistance to the abrasion.

3- For specimen 3(CSSB with cement and sand as stabilizer) the percentage in loss of materials varies in decreasing manner (increasing of the abrasion resistance) by adding more cement. With the increasing of the percentage of cement (3-14) % cement, the losses of materials reduce from 3.66 to 0.25% which is highly recommended by the standard in table 5-3.

4- For the specimen 4 (CSSB with sand and lime as stabilizer), the percentage in loss of materials varies in decreasing way (increasing of the abrasion resistance) by adding more lime. With the increase of the percentage of lime (3-14) % lime, the losses of materials reduce from 2.6 to 0.31% which is highly recommended by the standard shown in table 5-3.

5- For specimen 5, in term of abrasion this specimen is identified to be the same as specimen 1 because the soil used is essentially clayey and addition of plastic fibers in considered to have increased the bound which means these blocks can withstand in abrasive area subjected to impact, rubbing by animals or block for corners in walls.

5.5: EVOLUTION OF PHYSICAL AND MECHANICAL PROPERTIES OF BLOCKS MADE

A total of 231 Blocks were tested in dry compressive strength, 39 in capillary absorption and 42 in abrasion with equal ratios. Stabilization with cement gives the best results than lime and others specimens made.

From the obtained results, it may be concluded that for making good CSSB, stabilization with cement give the best results than lime and sand. Their grains sizes distribution curves are out from the granular spindle recommended by the ARS.

5.5.1: Evolution of compressive strength during curing period

Blocks non consolidated reaches 90% of their compressive strength from the 14th day whereas those consolidated with the sand reach only 40% of its strength. While consolidated with cement reaches an average of 80% of their resistance in compression, those consolidated with lime are only 65%. From Tables 4-8, 4-9, 4-10 and 4-11;Figures 4-8, 4-9, 4-10, compressive strength of blocks stabilized with cement and lime are increasing depending to the % of cement/lime used. For both the maximum strength is reached at the final day of curing. Finally it is observed that characteristics of cement and lime are different and reaction of lime take time to react whereas cement reaction is quick.

Blocks stabilized with Sand-Cement are enough dry from the 14th Day more than those stabilized with sand-lime. This can be explained by the fact that the lime required more of time to react compare to cement. With cement as stabilizer, of 28 days of curing are sufficient enough whereas lime requires between two at three months (90 days) to complete its reaction.

5.5.2: Abrasion coefficient

For non stabilized blocks, the loss of matter is low because of the high cohesion between the soil particles due to the fact that the soil used is clayey. For the specimens stabilized with sand from Table 4-13,Figure 4-13 and 4-14 the abrasion coefficient is high due to the action of sand add. Sand is not a cohesive material. The blocks being stabilized with cement/lime, the general trend of the abrasion coefficient is decreasing with the increasing of % cement/lime. This justifies the bond effect of binders used.

In general manner, the stabilization permitted to reduce the losses of mass in the blocks by reinforcing the cohesion of the soil particles and grains of sands between them with the cement and lime as stabilizers. To the scene of the results, the stabilization with the cement produces the best abrasion resistance than the one with the lime. All the specimens made are indicated for abrasive environment but stabilization with the cement is more indicated for an abrasive environment subject to impact, sand storms, rubbing by animal.

5.5.3: Physical appearance and observation on the blocks during curing

During drying, blocks developed different phenomena from a specimen to another that justify by the variation of the mixing ration of the materials used. The physical aspects and behavior of blocks varied from a specimen to another below:

5.5.3.1: Specimen 1: soil + water (CSB)

- **Cracking**: The cracks were observed with opening larger than 2mm on length side after 7 drying days in all the directions (edge and faces); which result from the highest amount of sediments: 85% (silt and clay content) in the soil used from wet sieving which is too far above the requirements (30-40)% of clay and (60-70)% sand to make good blocks. That is justified also by the fact that to make good blocks with that soil, its properties (grain size) has to be improved by adding inactive particle to water such as sand. The speed of drying was very low because after 7 days drying the blocks were still wetter than the other specimens (2, 3 and 4) because of the high amount of sediments content.

- **Weight**: The blocks of this specimen were also very lightest with a weight of 7186g/block which were very close to the dry density of the soil used.
- **Shrinkage:** The blocks shrunk and reduced the sizes of the blocks from 290 to 283mm in the length direction and from 140 to 135mm.
- **Abrasion coefficient:** after brushing the blocks for the abrasion test, the penetration of the brush was 5mm depth. The CSB without stabilizer can withstand to abrasion even in an aggressive environment (Area).
- **Water absorption by capillarity:** After 01 hour of partial immersion in water, blocks were not able to withstand to their owns load and crushed (collapsed) themselves which means even if the absorption coefficient was in within the acceptable recommended values by the standard, from the physical behavior this specimen can be recommended in dry environment.

5.5.3.2: Specimen 2: soil+water+sand (CSSB stabilized with sand)

- **Cracking:** By adding 45% sand on the specimen 1 to reach the minimum required amount of 60% sand, the cracking has been reduced and only micro cracking were observed with opening cracks less than 1mm, which show that the addition of sand as improved the properties(grain size) of the material used. And the drying was faster than the specimen 1.
- **Weigh:** the addition of sand has increased the density of blocks to 8440 g/block. The blocks of this specimen were also heavier than the specimen 1. With a weight of 8440g.
- **Shrinkage:** The blocks shrunk and reduced the size of the blocks from 290 to 288mm in the length direction and from 140 to 137mm from which it is observed that by adding sand to the 60% required, the shrinkage is reduce compare to the specimen 1. The reduction of the shrinkage observed is 3mm in the length direction and 2mm in the width direction.
- **Abrasion coefficient:** after brushing the blocks for the abrasion test, the penetration of the brush was 20mm depth. The CSB + Sand cannot

withstand to abrasion stress and there by cannot be used in an aggressive environment (area).

- **Water absorption by capillarity:** After 30 minutes, of partial immersion in water, blocks were not able to withstand to their owns load and crush themselves, and the absorption coefficient in table 5-2, if not in the recommendable values by the standard then from the physical behavior observed, these specimens can be recommended in dry environment.

5.5.3.3: Specimen 3: soil+sand+cement+water (CSSB stabilized with sand +lime)

- **Cracking:** at (3% - 4%) cement, some micro-cracks were appearing but decreasing from 3% to 4% cement. From (5%-14%) cement, none cracks were observed.

- **Weigh:** the addition of both sand and cement increased the density of blocks to 9068g/block. The blocks of this specimen are the heaviest.

- **Shrinkage:** after 28 days drying the shrinkage observed on the block was too negligible and insignificant, the size of the blocks goes from 290 to 289.5mm in the length direction and from 140 to 139.5mm this for only specimens with (3-6)% cement from which it was observed that by adding cement has widely shrinkage is reduce compare to the specimen 1 and 2. The reduction of the shrinkage observed is 0.5mm both in the length and the width direction.

- **Abrasion coefficient:** after brushing the blocks for the abrasion test, the penetration of the brush was decreasing by adding cement from 15mm depth at 3% Cement to 1mm at 10% Cement. This means that the cement has significantly improved the abrasion resistance by reducing the abrasion stress of the blocks.

- **Water absorption by capillarity:** Even after 4jours (96 hours) of partial immersion, blocks with (3-5) %cement/lime reached the saturated point from 48 hours and with (6-10) % cement/lime reached the saturation point after 96 hours of immersion from 10% cement/lime, the saturation was not reached after 96hours. This means from the physical behavior of partial immersion and from the absorption coefficient, these specimens can be highly recommended for wet environment.

5.5.3.4: Specimen4: soil+sand+lime+water: (CSSB stabilized with sand +lime)

- **Cracking:** no cracks were observed from the 7^{th} to 28^{th} days of curing.
- **Weigh:** the addition of both sand and lime has increased the density of blocks to 8591g/block. The blocks of this specimen are the heaviest.
- **Shrinkage:** after 28 days drying were very low and too negligible
- **Abrasion coefficient:** after brush the blocks for the abrasion test, the penetration of the brush is decreasing by adding cement from 15mm depth at 3% Cement to 1mm at 10% Cement. This means that the cement has significantly improved the abrasion resistance by reducing the abrasion stress of the blocks.
- **Water absorption by capillarity:** The phenomenon observed was the same with specimen 3 above.

5.5.3.5: Specimen 5: soil + sand + lime + water: (CSSB Stabilized Plastic Fiber)

- **Cracking:** no cracks were observed from the 7^{th} to 28^{th} days of curing. That was already foreseeable because fibers increased the bound between the particles and play against cracking.
- **Weigh:** the addition of both sand and lime has increased the density of blocks to 8509g/block.
- **Shrinkage:** after 28 days drying were very low and too negligible
- **Abrasion coefficient:** same as the specimen 1:after brushing the blocks for the abrasion test, the penetration of the brush was 5mm depth. The CSB without stabilizer can withstand to abrasion even in an aggressive environment (Area).

- **Water absorption by capillarity:** N/A

5.5.3.6: Conclusion

- **Specimen 1: Soil + Water:** cracking are appearing in high amount and in all the directions with larger opening cracks.
- **Specimen 2: Soil + Water + Sand:** Only micro cracks appeared on the blocks showing that the addition of sand helps to reduce the shrinkage and cracking.
- **Specimen 3: Soil + Sand + Cement + Water**: At (3% 4%)cement some fine cracks almost invisible appear, (5%-15%) cement no crack appearing, the blocks are drying very fast and the compressive strength (table 4-8) is higher than the specimen(1&2) and the blocks are well polished due to the binding properties of the cement.
- **Specimen 4: Soil + Sand + Lime + Water**: No cracks were observed, the blocks are drying slowly than specimen 3 and the compressive strength (Table 4-8) is higher than the specimen(1&2) but lower than specimen 3 and the blocks are well polished due to the binding properties of the lime but still very fragile.
- **Specimen 5**: Soil + plastic Fiber: No crack was observed.

5.6: RECOMMENDATIONS FOR THE USINGOF SOILS FROM IGEGANIAAND MANGUIN MAKING STANDARDIZEDBLOCKS

On the basis of the results obtained in this work, it is clear that Mangu and Igegania soils can be used for making good CSSB under condition to modify their grain size distribution. Indeed, according to the conditions of acceptability for facing CSB related to the general appearance and macro-cracks appearing on the blocks (Boubekeur S., 1998), these soils should not be used in natural state in making CSB due to the higher amount of clay content involving macro-cracks on blocks with wide opening exceeding the requirements of the standard (20 mm length side, 0.5 mm width, 5mm in depth and more than 10 mm in all the surfaces). Also the shrinkage of blocks is higher than the dimensional tolerances (+1 to -3mm in the length, + 1 to -2mm in the width and +2 to -2mm in the height). To use Mangu and Igegania soils for making CSB, the grain size distribution has to be improved by adding sand to be well distributed with good gradation in order to increase the Maximum Dry Density (MDD) in compacting according to the standard with the aim to reduce cracks.

The natural materials from Mangu and Igegania should not be used in their natural state. Their grain size distribution has to be improved by adding 50% sand to reach the requirements of a good soil for making soil blocks in order to reduce the shrinkage and cracking.

The soil from Mangu and Igegania can be used to make CSB with optimal features by adding sand or add 50% up to the required proportions (62% sand) to get a good earth for making blocks. Indeed, this proportion of sand elements will allow the grain size distribution curves to enroll in the preferential area according to the standard. This improvement will also allow reducing the percentage of the binders to be used for earth stabilization.

Once improve their properties, those soils from Mangu can be used to make good CSSB regarding the standard for building. To do so, the grain sizes distribution of the soils must be improved by adding 50% sand to reach the optimum values of 62% sand with binders in a range of 6 to 8% for cement or 7 to 9% for lime.

Plastics fiber can also be used as stabilizer because they improve the compressive strength close to those obtain with binders (cement and lime). The use of plastic fibers allowed the increasing of the bound between the particles against crushing of blocks in compression. Plastic fibers are highly useful and recommended to address the issues of people living in the studied sites in terms of economy mainly when the matter of cost reduction comes, *that* is helpful because in Mangu and Igegania people are facing money issues.
Sand and plastic fibers reduce cracks and binders increase the bond by making the CSB or CSSB strong and hard as required by the standard.

These soils should not be used in natural state in making blocks for destined to remain appearing like external unprotected wall from capillary rise, internal wall unprotected from water leaking through the roof. However, raw soils from studied sites can be used in making non stabilized CSB but only for unload walls protected with a coating mortar only in dry environment without any risks of being wet (e.g. blocks for internal partition which are not exposed or which are protected from water damage). These blocks can also be used for structural elements for unload walls which can withstand to limited external loads (e.g. boundary walls, fill in a load bearing structures, single story buildings made of load- bearing structural elements).

All values of the abrasion coefficient for all the CSB and CSSB varying from 3.32 to 0.25% are within the recommended values (less than 5%) by the ARS (1996) from which it is therefore deducted that all blocks specimens made are recommended for an abrasive environment subjected to violent storm or impacts.

In general recommendation, for areas where the soil present the physical characteristics near to the studied soil from Mangu and Igegania, the results of this research can be extended to those places.

CHAPTER 6: GENERAL CONCLUSION AND RECOMMENDATIONS FOR FUTUR SCOPE OF STUDY

6.1: GENERAL CONCLUSION

The aim of this study was to study the effects of stabilizers on the physical and mechanical properties of clays blocks for the soil samples from Igegania and Mangu. To reach that aim, firstly there was a need to determine the geotechnical properties of the soil studied in order to improve their properties for the production of good blocks responding to the standard. All the necessary tests have been carried out to classify these soils. The results obtained show that, in their natural state these soils are no good not good for making blocks. Therefore they need to be improved. Secondly we determined the percentages of each stabilizer required (sand, lime, cement and plastic fibers) to improve the natural materials for the production of good compressed stabilized soil blocks and we finished with the comparison of the mechanical and hygrometric features of blocks specimens produced with the standard. From this study we may conclude that:

Soils from the studied sites belong to the class A-6 called clayey soils according to the American classification of Soils (HBR). According to casagrande classification chart, Igegania and Mangu soils are respectively clayey soil with high plasticity and clayey soil with medium plasticity.

The soil from Igegania is not suitable for making cheap blocks it content 95% clay content against 85% from Mangu. To use the soils for the production of compressed earth blocks focusing in help people with low income to be settled at low cost and decently, soil from Mangu is better because it requires less sand to be improved for the production of good blocks.

The grain sizes distribution of these soils are not well graduated, the particles sizes distribution curves show that these soils content only very weak proportions of sand and the particle size distribution curves do not enrolling completely the granular spindle, that means that those natural soils are not good for making CSB of good quality. However, Compressed Soil Block made with these non stabilized soils can be used in building with reinforced concrete structures under condition to protect or cover the surfaces of the walls with sealers in earth stabilized with both sand and cement/lime.

The obtained results from the physical characterization of the studied soils from Igegania and Mangu have enabled to bring out corrections to their grain size by adding up to 50% sand if not 0.50% (plastic fibers with each fiber cut in length of 5mm) to bring the sand content at 62% which has improved their physical quality and granular properties for the production of good CSSB stabilized with cement/lime.

Stabilization with both sand and from 8 to14% cement or with both sand and from 9-14% lime enable to make good blocks with acceptable characteristics of load-bearing unprotected walls for buildings capable to withstand in wet and capillary environment. Whereas stabilization with both sand and 3-7% cement or 3-8% lime enable to make good CSSB with acceptable characteristics for the construction of structures elements for unload-bearing walls capable to withstand in dry environment with no damage of being wet.

Stabilization with plastic fiber has also highly improved the compressive strength and can be used in building for both unload-bearing and load-bearing structure but in dry environment with no damage of being wet.

With the obtained characteristics of the CSSB made in this study, for the economic reason, people of studied sites would choose the optimum values for using according to the fields of use, stress and the environment in which the building will be subjected related to.

Beside, the using of CSSB in good condition require the integration of technical criteria (mixing time, watering, curing) and good knowledge of the rules of earth constructions.

The present study permitted to reach significant results with the mechanical behaviors of compressed stabilized soil blocks stabilized with both sand mixed with cement or lime. Stabilization with sand-cement mixed gave the best performances. This result was already foreseeable seen the improvement of the grain size distribution of soils used with sand. From the literature review cement is known as the best stabilizer of soil for mechanical purpose (compressive strength and abrasion resistance) but with clay content not exceeding 30 to 40 %. Contrary to the cement, lime reacts with the clay and gives good results with a rate of about 45%. The lime can block the effect of the organic matter until a rate of 20% (Mahamat, 2009).

The results from Control blocks show that the increasing in stabilizers content (cement, lime) content is accompanied by increases of compressive strength the reduction of capillary absorption and the reduction in losses of matters through abrasion/erosion. The results showed that increase in cement or lime (from 6% to 14%) leads to the increase in strength and durability properties. In most cases having uneconomically high cement or lime content shows to be more durable (assessed using durability measures) than blocks produced with chemicals.

6.2: RECOMMENDATION FOR FUTURE SCOPE OF STUDY

In the next study it will be interesting to spread the scope of this work by using at different ratio of plastic fibers to see up to which value the mechanical and hygrometric properties of blocks can be improved. It will be also very interesting to work on lateritic or sandy soils to take into account the using of the two stabilizers. It could be also good to examine the stabilization of soil with sand mixed with both cement-limes, plastic fiber together. The use of several types of lime and others stabilizers such as plastic waste will be also interesting and useful. It is highly recommended that further similar research work be carried out:

- using different soils from different localities;
- using clays from different locations to ascertain the optimum contents of cement and lime stabilizers;
- using other different types of potential stabilizers e.g. sugarcane bagasse ash, fly ash, rice husks ash, etc;
- on the durability and water absorption of prototype masonry units (e.g. walls) built using stabilized compressed soil blocks and exposed to varying external weather conditions.

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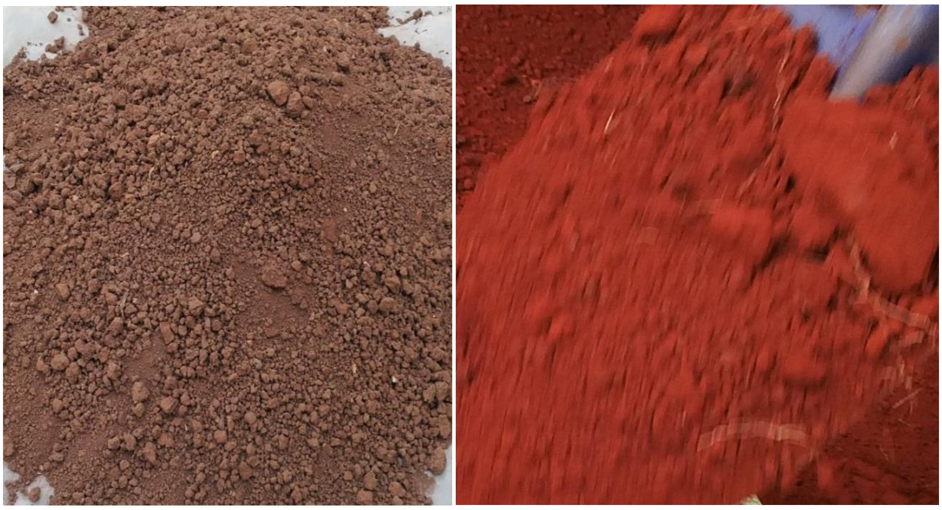
APPENDIX

APPENDIX 1: PICTURES



(a) Soil sample from IGEGANIA (b) Soil sample from MANGU

PLate 1 : VariousSoils samples studied

(b) Linear Shrinkage of soil + sand, (a) Linear Shrinkage of soil without any stabilizer

(c) Linear Shrinkage of soil + sand + Cement +Lime

(d) linear shrinkage of Soil + Sand

Plate 2 : Linear shrinkage of different specimens

...(a)

(b)

Plate3 (a-b): Illustration of abrasion of blocks

(a): Specimen 1 (b): Specimen 2 (c): Specimen 3-4

Plate4 (a-b-c): Illustration of the physical appearance of blocks after drying

(a) (b)

Plate4 (a-b): Illustration of water absorption test by capillarity of specimen 3 &4

APPENDIX 2: GEOTECHNICAL PARAMETERS

Table 1-a: Water content, bulk density, dry density, porosity, saturation ratio, bulk unit weight of soil from Igegania

BULK DENSITY, DRY DENSITY, VOID RATION, DEGRE OF SATURATION & BULK UNIT WEIGHT					
Reference to test method	ref, BS 1377: Part 2: 1990				
Source of sample	**Igegania**				
Samplereference			1		
Run: Specimenreference			1	2	3
Container N°			2	4	12
Mass of container	M1	g	9.34	9.52	9.37
Mass of container+ Wet soil	M2	g	115.47	119.57	110.34
Mass of Container +dry soil	M3	g	94.78	98.05	90.4
Mass of moisture	M2-M3	g	20.69	21.52	19.94
Mass of dry soil	M3-M1	g	85.44	88.53	81.03
Moisture content	w	%	24.2158	24.3081	24.6082
AverageMoisture Content	w	%	24.37737931		
Particle Density (obtained from particle density test)	ρs	%	2380.75		
DETERMINATION OF THE BULK DENSITY					
Lendth of cylinder	L	cm	2		
Internaldiameter	D	cm	6		
Area of sample	A=πD2/4	cm2	28.26		
Volume of sample	V=LxA	cm3	56.52		
Run of the specimen			1	2	3
Mass of cylindrical ring	mc	g	61.4	61.4	61.4
Mass of cylindrical ring +sample	mt	g	133.9	141.7	141
Mass of sample	M=mt-mc	g	72.5	80.3	79.6
BULK DENSITY	ρ=(M/V)x1000	kg/m3	1282.7	1420.74	1408.35
Averageof BULK DENSITY	ρ	kg/m3	1370.606275		
	100ρ		137060.6275		
	100+W		124.3773793		
DRY DENSITY	ρd=100ρ/(100+W)	kg/m3	1101.973914		
POROSITY		%	42%		
VOID RATIO	e=(ρs/ρd)-1		1.16044134		
DEGRE OF SATURATION	S=(wρs/e)xExp(-3)	%	50.01239078		
Bulk Unit Weight	ρx9,81 x exp(-3)	kg/m3	13.44564756		

Table 1-b: Water content, bulk density, dry density, porosity, Saturation ratio, bulk unit weight of soil from Mangu

BULK DENSITY, DRY DENSITY, VOID RATION, DEGRE OF SATURATION & BULK UNIT WEIGHT								
Reference to test method	ref, BS 1377: Part 2: 1990							
Source of sample	**Mangu**							
Samplereference			1.00			2.00		
Run: Specimenreference			1.00	2.00	3.00	4.00	5.00	6.00
Container N°			3.00	8.00	9.00	10.00	13.00	24.00
Mass of container	M1	g	9.29	9.49	9.38	9.38	9.56	9.43
Mass of container+ Wet soil	M2	g	85.27	90.71	97.91	90.09	88.63	90.12
Mass of tin +dry soil	M3	g	73.93	78.41	84.40	77.93	76.73	78.05
Mass of moisture	M2-M3	g	11.34	12.30	13.51	12.16	11.90	12.07
Mass of dry soil	M3-M1	g	64.64	68.92	75.02	68.55	67.17	68.62
Moisture content	w	%	17.54	17.85	18.01	17.74	17.72	17.59
AverageMoisture Content	w	%	17.80			17.68		
Particle Density	ρs	%	2283.17			2380.75		
DETERMINATION OF THE BULK DENSITY								
Lendth of cylinder	L	cm	2.0			2.0		
Internaldiameter	D	cm	6.0			6.0		
Area of sample	A=πD2/4	cm2	28.3			28.3		
Volume of sample	V=LxA	cm3	56.5			56.5		
Run of the specimen			1.0	2.0	3.0			
Mass of cylindrical ring	mc	g	61.4	61.4	61.4	61.4	61.4	61.4
Mass of cylindrical ring +sample	mt	g	137.7	136.1	135.7	133.0	137.7	136.6
Mass of sample	M=mt-mc	g	76.3	74.7	74.3	71.6	76.3	75.2
BULK DENSITY	ρ=(M/V)x1000	kg/m3	1350.0	1321.7	1314.6	1350.0	1350.0	1330.5
Average of BULK DENSITY	ρ	kg/m3	1328.7			1343.5		
	100ρ		132873.3192			134347.7235		
	100+W		117.7995423			117.681581		
DRY DENSITY	ρd=100ρ/(100+W)	kg/m3	1128.0			1141.6		
POROSITY		%	42%			44%		
VOID RATIO	e=(ρs/ρd)-1		1.0			1.1		
DEGRE OF SATURATION	S=(wρs/e)xExp(-3)	%	39.7			38.8		
Bulk Unit Weight	ρx9,81 x exp(-3)	kg/m3	13.0			13.2		

Table 2-a: Specific gravity of soil from Mangu

SPECIFIC GRAVITY OF SOIL SAMPLE					
Reference to test method	ref, BS 1377: Part 2: 1990				
Souce of sample	Mangu				
Specimenreference			1	2	3
Densitybottlenumber			20	31	38
Mass of bottle	M1	g	51.47	53.28	47.24
Mass of bottle +dry doil	M2	g	104.64	105.15	98.99
Mass of bottle+soil +water	M3	g	182.53	182.6	176.04
Mass of bottle full of water	M4	g	152.83	152.51	147.72
Mass of soil	(M2-M1)	g	53.17	51.87	51.75
Mass of water full in bottle	(M4-M1)	g	101.36	99.23	100.48
mass of water used	(M3-M2)	g	77.89	77.45	77.05
volum of soilparticles	(M4-M1)-(M3-M2)	g	23.47	21.78	23.43
ParticleDensity	$\rho s = \frac{M2 - M1}{(M4 - M1) - (M3 - M2)} x1000$	kg/m3	2265.4	2381.5	2208.7
Average			2285.231578		
Teemperature of distilled water	T°C	°C	24		
Correction Coefficient	C1		0.9991		
CorrectedParticleDensity	(C1xρs)		2263.4	2379.4	2206.7
Corrected average of particle density		kg/m3	2283.17487		

Table 2-b: Specific gravity of soil from Igegania

Reference to test method	ref, BS 1377: Part 2: 1990				
Souce of sample	Igegania				
Specimenreference			1	2	3
Densitybottlenumber			38	31	20
Mass of bottle	M1	g	47.24	53.28	51.47
Mass of bottle +dry doil	M2	g	97.22	103.22	101.5
Mass of bottle+soil +water	M3	g	177.04	181.25	181.13
Mass of bottle full of water	M4	g	147.72	152.67	152.02
Mass of soil	(M2-M1)	g	49.98	49.94	50.03
Mass of water full in bottle	(M4-M1)	g	100.48	99.39	100.55
mass of water used	(M3-M2)	g	79.82	78.03	79.63
volum of soilparticles	(M4-M1)-(M3-M2)	g	20.66	21.36	20.92
ParticleDensity	$\rho s = \frac{M2 - M1}{(M4 - M1) - (M3 - M2)} x1000$	kg/m3	2419.2	2338	2391.5
Average			2382.891283		
Teemperature	T°C	°C	24		
Correction Coefficient	C1		0.9991		
CorrectedParticleDensity	(C1xρs)		2417	2335.9	2389.3
Corrected average of particle density		kg/m3	2380.746681		

Table 2-c: Specific gravity of sand from the quarry JUJA

Reference to test method	ref, BS 1377: Part 2: 1990				
Souce of sample	JUJA QUARRY				
Run			1	2	3
Weight of Saturated sample with dry surface	M1	g	500	500	500
Weight of pycnometer+sample+water	M2	g	1723	1722	1723.5
Weight of Pycnometer+Water	M3	g	1420		
Weight of Oven dry sample	M4	g	453.7	454.6	455.7
Sp. Gravity on dried oven sample basis	$Sp.d = \frac{M4}{M1-(M2-M3)}$		2.303	2.296	2.3191
Average of Sp. Gravity on dried oven sample basis			2.30		
Sp. Gravity on saturated & dried surface basis	$Sp.w = \frac{M1}{M1-(M2-M3)}$		2.5381	2.5253	2.5445
Average of Sp. Gravity on saturated with dried surface basis			2.53		
Apparent Specificgravity	$A.Sp = \frac{M4}{M4-(M2-M3)}$		3.0106	2.979	2.9941
Average of the Apparent Specific gravity			2.99		
Water Absorption	$W.A = \frac{100(M1-M4)}{M4}$		10.205	9.9868	9.7213
Average of Water Absorption			9.97		

APPENDIX 3: GRAIN SIZE DISTRIBUTION

Table 1-a: Grain size Distributionof the soil from Igegania, Run 1

		RUN 1				
Source of sample		Igegania				
Sieves sizes (mm)	WtSieve (g)	Wt sive + Soil (g)	Wt Retained (g)	Weigth of CumuledRetain	% Cum Retained	% passing
19.1	526.8	526.8	0	0	0.0	100.0
9.52	475.6	475.6	0	0	0.0	100.0
4.76	434.1	435.4	1.3	1.3	0.1	99.9
2	423.4	425.6	2.2	3.5	0.4	99.6
0.84	378.8	385.4	6.6	10.1	1.0	99.0
0.42	355.7	376.8	21.1	31.2	3.1	96.9
0.25	350.8	351.5	0.7	31.9	3.2	96.8
0.105	329.5	345.7	16.2	48.1	4.8	95.2
0.074	327.9	334.1	6.2	54.3	5.5	94.5
Pan	322.5	1263.2	940.7	995.0	100.0	0.0

Table 1-b: Grain size distribution of the soil from Igegania, Run 2

		RUN 2				
Source of sample		Igegania				
Sieves sizes (mm)	WtSieve (g)	Wtsive + Soil (g)	WtRetained (g)	Cum Retain	% Cum Retained	% passing
19.1	526.8	526.8	0.0	0.0	0.0	100.0
9.52	475.6	475.6	0.0	0.0	0.0	100.0
4.76	433.9	436.6	2.5	2.5	0.3	99.7
2	422.8	426.8	3.4	5.9	0.6	99.4
0.84	378.7	386.0	7.2	13.1	1.3	98.7
0.42	351.4	375.9	20.2	33.3	3.3	96.7
0.25	350.6	351.8	1.0	34.3	3.4	96.6
0.105	328.8	344.4	14.9	49.2	4.9	95.1
0.074	327.8	329.5	1.6	50.8	5.1	94.9
Pan	325.7	1266	943.5	994.3	100.0	0.0

Table 1-c: Grain size distribution of the soil from Igegania, Run 3

		RUN 3				
Source of sample		Igegania				
Sieves sizes (mm)	Wt Sieve (g)	Wtsive + Soil (g)	Wt Retained (g)	Wt Cum Retained	% Cum Retained	% passing
19.1	526.8	526.8	0.0	0.0	0.0	100.0
9.52	475.6	476.8	1.2	1.2	0.1	99.9
4.76	433.9	435.7	1.6	2.8	0.3	99.7
2	422.8	426.0	2.6	5.4	0.5	99.5
0.84	378.7	385.6	6.8	12.2	1.2	98.8
0.42	351.4	376.7	21.0	33.2	3.3	96.7
0.25	350.6	352.0	1.2	34.4	3.5	96.5
0.105	328.8	346.6	17.1	51.5	5.2	94.8
0.074	327.8	331.1	3.2	54.7	5.5	94.5
Pan	325.7	1261.6	939.1	993.8	100.0	0.0

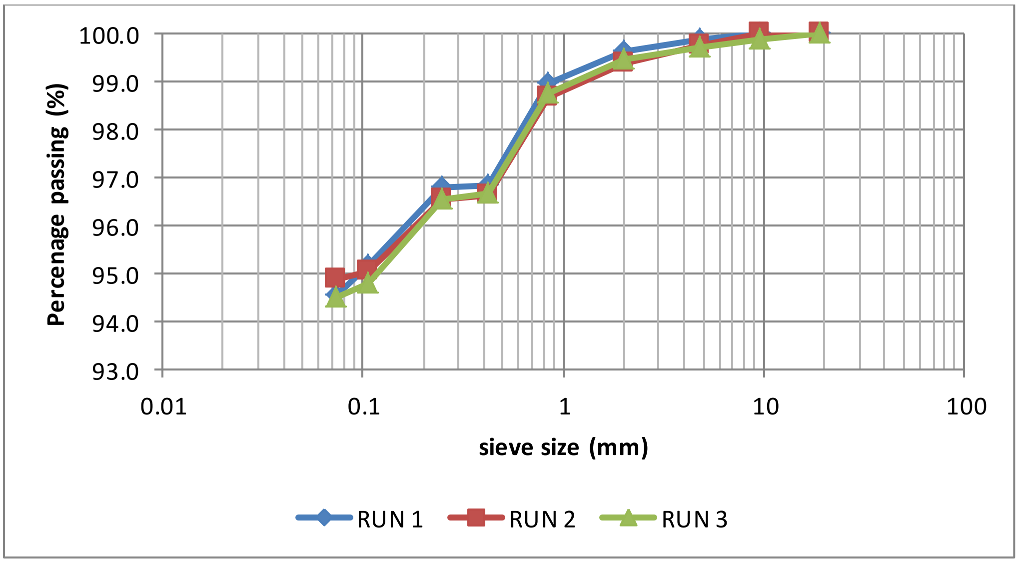


Figure 1-a: Grain Sizes Distribution Curve of Soil from Igegania

Table 2-a: Grain size distribution of the soil from Mangu, Run 1

		RUN 1				
Source of sample		Mangu				
Sieves sizes (mm)	Wt Sieve (g)	Wtsive + Soil (g)	Wt Retained (g)	Wt Cum Retain	% Cum Retained	% passing
19.1	526.8	526.8	0	0	0.0	100.0
9.52	475.6	477.8	2.2	2.2	0.2	99.8
4.76	434.1	447.9	13.8	16	1.6	98.4
2	423.4	478.7	55.3	71.3	7.1	92.9
0.84	378.8	410.7	31.9	103.2	10.3	89.7
0.42	355.7	398.9	43.2	146.4	14.7	85.3
0.25	350.8	352.6	1.8	148.2	14.9	85.1
0.105	329.5	371.8	42.3	190.5	19.1	80.9
0.074	327.9	344.5	16.6	207.1	20.8	79.2
Pan	322.5	1112.7	790.2	997.3	100.0	0.0

Table 2-b: Grain size distribution of the soil from Mangu, Run 2

		RUN 2				
Source of sample		Mangu				
Sieves sizes (mm)	WtSieve (g)	Wtsive + Soil (g)	WtRetained (g)	Wt Cum Retain	% Cum Retained	% passing
19.1	526.8	526.8	0.0	0.0	0.0	100.0
9.52	475.6	478.0	2.4	2.4	0.2	99.8
4.76	434.1	450.3	16.2	18.6	1.9	98.1
2	423.4	468.4	45.0	63.6	6.4	93.6
0.84	378.8	407.5	28.7	92.3	9.2	90.8
0.42	355.7	396.4	40.7	133.0	13.3	86.7
0.25	350.8	353.0	2.2	135.2	13.5	86.5
0.105	329.5	370.7	41.2	176.4	17.6	82.4
0.074	327.9	335.7	7.8	184.2	18.4	81.6
Pan	322.5	1138.2	815.7	999.9	100.0	0.0

Table 2-c: Grain size distribution of the soil from Mangu, Run 3

		RUN 3				
Source of sample		Mangu				
Sieves sizes (mm)	Wt Sieve (g)	Wt sive + Soil (g)	Wt Retained (g)	Wt Cum Retain	% Cum Retained	% passing
19.1	526.8	526.8	0.0	0.0	0.0	100.0
9.52	475.6	476.6	1.0	1.0	0.1	99.9
4.76	434.1	450.3	16.2	17.2	1.7	98.3
2	423.4	467.0	43.6	60.8	6.1	93.9
0.84	378.8	407.3	28.5	89.3	8.9	91.1
0.42	355.7	397.9	42.2	131.5	13.1	86.9
0.25	350.8	353.6	2.8	134.3	13.4	86.6
0.105	329.5	369.5	40.0	174.3	17.4	82.6
0.074	327.9	336.9	9.0	183.3	18.3	81.7
Pan	322.5	1140.0	817.5	1000.8	100.0	0.0

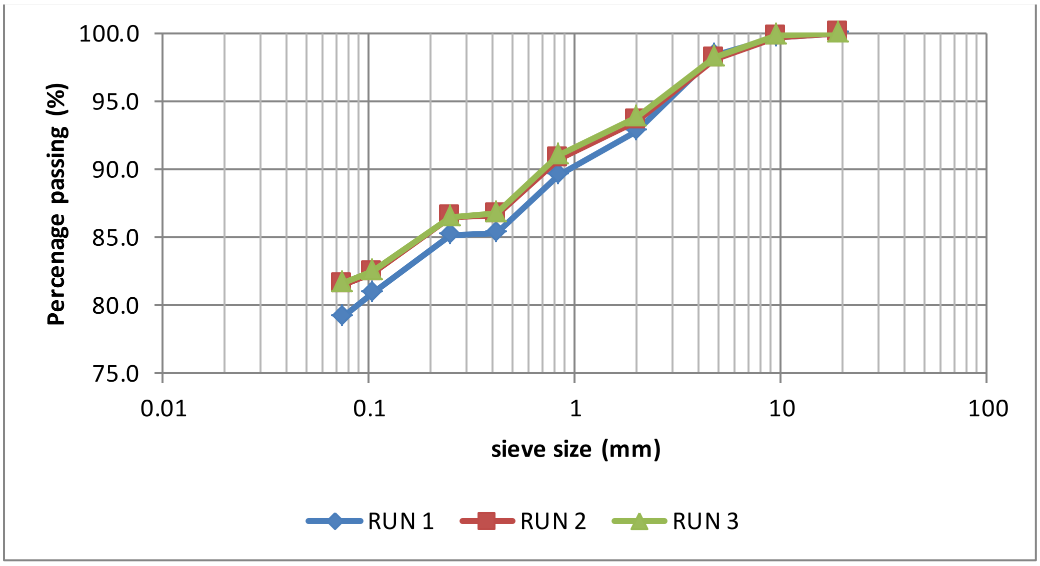


Figure 2-a: Grain Sizes Distribution Curve of Soil from Mangu

Table 3-a: Grain size distribution of the washed sand

		WASHED SAND				
Source of sample		JUJA QUARRY				
Sieves sizes (mm)	Wt Sieve (g)	W tsive + Soil (g)	Wt Retained (g)	Wt Cum Retain	% Cum Retained	% passing
9.58	476	476	0	0	0.0	100.0
4.76	433.8	434.5	0.7	0.7	0.1	99.9
2	423.1	470	46.9	47.6	4.8	95.2
0.84	378.8	660.9	282.1	329.7	33.0	67.0
0.42	351.4	839.5	488.1	817.8	81.8	18.2
0.25	351	425.3	74.3	892.1	89.2	10.8
0.105	329.7	429.3	99.6	991.7	99.2	0.8
Pan	322.3	330.8	8.5	1000.2	100.0	0.0

Table 3-b: Grain size distribution of the unwashed sand

		UNWASHED SAND				
Source of sample		JUJA QUARRY				
Sieves sizes (mm)	Wt Sieve (g)	Wt sive + Soil (g)	Wt Retained (g)	Wt Cum Retain	% Cum Retained	% passing
9.58	476	476.0	0.0	0.0	0.0	100.0
4.76	433.8	433.8	0.0	0.0	0.0	100.0
2	423.1	468.6	45.5	45.5	4.6	95.4
0.84	378.8	635.7	256.9	302.4	30.3	69.7
0.42	351.4	771.7	420.3	722.7	72.3	27.7
0.25	351	502.1	151.1	873.8	87.4	12.6
0.105	329.7	440.3	110.6	984.4	98.5	1.5
Pan	322.3	337.1	14.8	999.2	100.0	0.0

Appendix 4: RESULTS OF CONSISTENCY LIMITS TESTS OF SOILS

Table 1-a: Liquid limit of soil from Mangu

Reference to test method	**BS 1377 : Part 2: 1990**														
Source of sample	**Mangu**														
Test N°		1.0		2.0		3.0		4.0		5.0		6.0		7.0	
Container N°		10.0	11.0	3.0	5.0	9.0	13p	18.0	29LC	36.0	38.0	34tp	1.0	2.0	8b
AveragePenetration	mm	15.8		16.0		17.3		19.0		20.0		21.3		23.5	
Mass of the container (M1)	g	6.4	6.4	6.5	6.5	6.4	6.5	6.4	6.5	16.2	22.9	16.2	6.4	6.4	6.5
Mass of centainer +Wet soil (M2)	g	37.8	29.9	29.3	28.8	29.1	27.6	28.3	27.6	41.8	45.6	37.9	26.8	28.5	31.9
Mass of container +dry soil (M3)	g	27.8	22.4	22.0	21.6	21.7	20.7	21.0	20.6	33.3	38.0	30.6	19.9	20.8	23.0
Mass of moisture (M2-M3)	g	10.0	7.4	7.3	7.1	7.4	6.9	7.2	7.0	8.5	7.6	7.3	6.9	7.7	8.9
Mass of Dry soil (M3-M1)	g	21.4	16.0	15.5	15.2	15.3	14.3	14.7	14.2	17.1	15.2	14.3	13.5	14.4	16.5
Moisture content (W%)	%	46.7	46.6	46.8	47.0	48.5	48.0	49.3	49.1	50.1	49.9	51.1	51.2	53.7	53.8
AverageMoisture		46.6		46.9		48.3		49.2		50.0		51.1		53.7	
from the liquid limit curve the Liquid limit which fail on 20mm penetration is 50%															

Table 1-b: Liquid limitof soil from Igegania

Reference to test method	**BS 1377 : Part 2: 1990**														
Source of Sample	**Igegania**														
Test N°		2.0		3.0		7.0		4.0		5.0		6.0		1.0	
Container N°		12.0	13.0	9.0	10.0	2.0	8.0	14.0	15.0	29.0	30.0	20.0	24.0	3.0	4.0
AveragePenetration	mm	16.0		17.0		17.1		17.7		17.8		19.4		22.2	
Mass of the container (M1)	g	9.4	9.6	9.4	9.6	9.3	9.5	9.5	9.3	9.5	9.4	9.3	9.4	9.3	9.5
Mass of centainer +Wet soil (M2)	g	22.4	20.1	23.3	24.4	24.6	24.0	23.7	23.8	25.5	25.5	25.1	25.5	21.0	21.5
Mass of container +dry soil (M3)	g	18.0	16.6	18.6	19.4	19.4	19.0	18.8	18.8	20.0	19.9	19.6	18.9	16.0	16.7
Mass of moisture (M2-M3)	g	4.4	3.5	4.7	5.0	5.3	5.0	4.9	5.0	5.6	5.6	5.5	6.6	5.0	4.8
Mass of Dry soil (M3-M1)	g	8.6	7.0	9.2	9.8	10.0	9.5	9.4	9.5	10.5	10.5	10.2	9.4	6.7	7.2
Moisture content (W%)	%	50.6	50.2	51.4	51.5	52.6	52.5	52.4	52.3	53.2	53.1	53.4	70.0	75.3	66.4
AverageMoisture		50.4		51.4		52.6		52.4		53.1		61.7		70.8	
from the liquid limit curve the Liquid limit which faill on 20mm penetration is 62%															

Table 1-c: Liquid limit of soil from Mangu + sand

Reference to test method	**BS 1377 : Part 2: 1990**																
Source of Sample	**SOIL(Mangu) +SAND(JUJA)**																
Test N°		5.0		4.0		3.0		7.0		6.0		2.0		8.0		1.0	
Container N°		8A	9A	5A	7A	11.0	8B	29LC	5.0	10A	11A	9.0	10.0	36.0	1.0	2.0	3
AveragePenetration	mm	15.0		16.0		17.7		18.1		19.0		19.7		20.0		21.3	
Mass of the container (M1)	g	5.4	5.4	4.0	3.9	6.3	6.5	6.4	6.4	5.2	5.4	6.3	6.3	16.0	6.2	6.3	6.4
Mass of centainer +Wet soil (M2)	g	40.0	40.3	35.5	39.1	39.7	39.4	31.8	34.9	42.0	43.5	39.0	43.9	49.0	38.1	37.0	34
Mass of container +dry soil (M3)	g	32.4	32.6	28.5	31.3	32.2	32.0	25.8	28.2	33.4	34.6	31.5	35.3	41.1	30.5	29.9	27
Mass of moisture (M2-M3)	g	7.6	7.7	7.0	7.8	7.5	7.4	6.0	6.7	8.6	8.9	7.5	8.6	7.9	7.6	7.1	6.3
Mass of Dry soil (M3-M1)	g	27.0	27.2	24.5	27.4	25.9	25.5	19.4	21.8	28.2	29.2	25.2	29.0	25.1	24.3	23.6	21.0
Moisture content (W%)	%	28.1	28.3	28.6	28.5	29.0	29.0	30.9	30.7	30.5	30.5	29.8	29.7	31.5	31.3	30.1	30.0
AverageMoisture Content		28.2		28.5		29.0		30.8		30.5		29.7		31.4		30.0	
from the liquid limit curve the Liquid limit which faill on 20mm penetration is 30%																	

Table 2-a: Plastic limitof soil from Igegania

PLASTICITY LIMIT					
Reference to test method	**BS 1377 : Part 2: 1990**				
Source of sample	**Igegania**				
Test N°			1	2	3
Container N°			18	25	28
Mass of the container	(M1)	g	9.36	9.41	9.42
Mass of centainer +Wet soil	(M2)	g	17.1	21.35	25.9
Mass of container +dry soil	(M3)	g	15.57	19.25	23.65
Mass of moisture	(M2-M3)	g	1.53	2.1	2.25
Mass of Dry soil	(M3-M1)	g	6.21	9.84	14.23
Moisture content (W%)	$W(\%) = \frac{(M2-M3)}{(M3-M1)} x100$	%	24.638	21.341	15.812
Average of Plasticity Limit Wp=(Wp1+Wp2+Wp3)/3		%	20.60		

Table 2-b: Plastic limit of soil from Mangu

PLASTICITY LIMIT							
Reference to test method	**BS 1377 : Part 2: 1990**						
Source of sample	**Mangu**						
Test N°			1.0	2.0	3.0	4.0	5.0
Container N°			3.0	8.0	9.0	13.0	24.0
Mass of the container	(M1)	g	9.3	9.5	9.4	9.6	9.4
Mass of centainer +Wet soil	(M2)	g	25.2	28.4	25.4	25.3	25.2
Mass of container +dry soil	(M3)	g	21.9	24.4	22.0	22.1	22.1
Mass of moisture	(M2-M3)	g	3.3	4.0	3.4	3.2	3.1
Mass of Dry soil	(M3-M1)	g	12.7	15.0	12.7	12.6	12.7
Moisture content (W%)	$W(\%) = \frac{(M2-M3)}{(M3-M1)} x100$	%	26.1	26.6	26.8	25.7	24.8
Average of Plasticity Limit Wp=(Wp1+Wp2+Wp3)/3		%	26.0				

Table 3-a: Plasticity index of soil from Mangu

PLASTICITY INDEX			
Reference to test method	**BS 1377 : Part 2: 1990**		
Source of Samp;e	**Mangu**		
LiquidLimit	WL	%	50
PlasticityLimit	Wp	%	26.0
Plasticity Index	WL-Wp	%	24.0

Table 3-b: Plasticity index of soil from Igegania

PLASTICITY INDEX			
Reference to test method	**BS 1377 : Part 2: 1990**		
Source of Samp;e	**Igegania**		
Liquid Limit	WL	%	62
Plasticity Limit	Wp	%	20.6
Plasticity Index	WL-Wp	%	41.4

Table 4-a: Linear shrinkage of soil from Mangu

LINEAR SHRINKAGE				
MTARIEL USED: SOIL ONLY				
Reference to test method	**ref, BS 1377: Part 2: 1990**			
Source of sample	**Mangu**			
Specimenreference		1	2	3
Initial length (Lo)	mm	140	140	140
Oven-DriedLength (LD)	mm	122.6	121.1	121.1
Lenght Variation (Lo-LD)		17.4	18.9	18.9
Linear Shrinkage LS=100(1-LD/Lo)	%	12.4285714	13.5	13.5
Average of linearshrinkage	%	13.14285714		

Table 4-b: Linear shrinkage of soil from Igegania

LINEAR SHRINKAGE				
Reference to test method	**ref, BS 1377: Part 2: 1990**			
Source of sample	**Igegania**			
Specimenreference		1	2	3
Initial length (Lo)	mm	140	140	140
Oven-DriedLength (LD)	mm	122.2	123.95	123.1
Lenght Variation (Lo-LD)		17.8	16.05	16.9
Linear Shrinkage LS=100(1-LD/Lo)	%	12.7142857	11.4642857	12.0714286
Average of linearshrinkage	%	12.08333333		

Table 4-c: Linear shrinkage of soil +sand

LINEAR SHRINKAGE							
MTARIALS	**SOIL + SAND**						
Reference to test method	**ref, BS 1377: Part 2: 1990**						
Source of sample	**Mangu**						
Sand added	%	0	3	5	8	10	45
Total Sand content	%	15	18	20	23	25	60
Specimen reference		1	2	3	4	5	6
Initial length (Lo)	mm	600	600	600	600	600	600
Final Length after 5 days of air drying (LD)	mm	534.8	548	548	548	548	590
Lenght Variation (Lo-LD)	mm	65.2	52	52	52	52	10
Linear Shrinkage LS=100(1-LD/Lo)	%	10.87	8.67	8.67	8.67	8.67	1.67
Average of linear shrinkage	%	10.87	8.67				1.67

Table 4-d: Linear shrinkage of soil +sand+ cement

LINEAR SHRINKAGE								
MTARIEL USED : 55%SOIL + 45%SAND +CEMENT								
Reference to test method	**ref, BS 1377: Part 2: 1990**							
Source of sample	**Mangu**							
% Cement added	%	0	4	6	8	10	12	14
Specimen reference		1	2	3	4	5	6	7
Initial length (Lo)	mm	600	600	600	600	600	600	600
Final Length after 5 days of air drying (LD)	mm	590	592	598	599.5	600	600	600
Lenght Variation (Lo-LD)		10	8	2	0.5	0	0	0
Linear Shrinkage LS=100(1-LD/Lo)	%	1.6667	1.33	0.33	0.08	0.00	0.00	0.00

Table 4-e: Linear Shrinkage of soil +sand+ lime

LINEAR SHRINKAGE								
MTARIEL USED : 65%SOIL + 45%SAND +LIME								
Reference to test method	ref, BS 1377: Part 2: 1990							
Source of sample	MANGU							
% Lime added	%	0	4	6	8	10	12	14
Specimenreference		1	2	3	4	5	6	7
Initial length (Lo)	mm	600	600	600	600	600	600	600
Final Length after 5 days of air drying (LD)	mm	590	591	592	591	591	591	591
Lenght Variation (Lo-LD)		10	9	8	9	9	9	9
Linear Shrinkage LS=100(1-LD/Lo)	%	1.6667	1.50	1.33	1.50	1.50	1.50	1.50

APPENDIX 5: RESULTS OF STANDARD PROCTOR (LIGTH COMPACTION) TESTS ON SOILS

Table1-a: Results of light compaction test of soil from Mangu

COMPACTION TEST FOR SOIL SAMPLE FROM MANGU							
Reference to test method	ref, BS 1377: Part 4: 1990						
Run		1	2	3	4	5	6
Weight of the soil sample	Kg	18	the remaining of the initial 18 kg for the previous run used for each next run up to the last				
Water Added	L	2	0.5	0.5	0.5	0.5	0.5
Weight of the mould + its plate base: W1	g	4169.6					
Weight of the mould + compacted soil: W2	g	5469.3	5631.7	5748.1	5870.4	5839.1	5755.9
Weight of Soil sample (W2-W1)	g	1299.7	1462.1	1578.5	1700.8	1669.5	1586.3
Volume of the mould: V	mm3	1000875					
Bulk Density: ρ=(W2-W1)/V	mg/mm3	1.299	1.46	1.58	1.7	1.668	1.585
Bulk Density: ρ=(W2-W1)/V	kg/m3	1298.564	1460.82	1577.12	1699.31	1668.04	1584.913
Moisture content determination							
N° of moisture content tins		8	9	13	14	15	18
Weight of container (tin)	g	9.47	9.37	9.55	9.47	9.31	9.36
Weight of moisture content tins+wet soil	g	91.4	97.35	104.54	110.94	109.94	109.1
Weight of moisutre content tins+dry soil	g	80.28	83.6	87.84	90.38	87.22	83.8
Moisture content (w)	g	11.12	13.75	16.7	20.56	22.72	25.3
100ρ		129856.4	146082	157712	169931	166804	158491.3
100+W		111.12	113.75	116.7	120.56	122.72	125.3
Dry density: ρd=100ρ/(100+w)	kg/m3	1168.614	1284.24	1351.43	1409.52	1359.225	1264.895
on the Graph we can read the: Optimum Moisture Content(OMC)=20%; the Maximum Dry Density (MDD)=1400kg/m3							

Table1-b: Results of light compaction test of soil from Igegania

COMPACTION TEST FOR SOIL SAMPLE FROM Igegania							
Reference to test method	ref, BS 1377: Part 4: 1990						
Run		1	2	3	4	5	6
Weight of the mould + its plate base: W1	g	4170.4					
Weight of the mould + compacted soil: W2	g	5398.6	5442.6	5479.5	5653.5	5771.1	5732.3
Weight of Soil sample (W2-W1)	g	1228.2	1272.2	1309.1	1483.1	1600.7	1561.9
Volume of the mould: V	mm3	1000875					
Bulk Density: ρ=(W2-W1)/V	g/mm3	0.001227	0.00127	0.00131	0.00148	0.001599	0.001561
Bulk Density: ρ=(W2-W1)/V	kg/m3	1227.126	1271.09	1307.96	1481.8	1599.301	1560.535
Moisture content determination							
N° of moisture content tins		3	10	9	29	24	30
Weight of moisture content tins	g	9.27	9.56	9.37	9.48	9.43	9.37
Weight of moisture content tins+wet soil	g	106.99	110.86	110.72	112.1	108.04	111.77
Weight of moisutre content tins+dry soil	g	93.21	94.57	92.76	90	82.87	82.48
Moisture content (w)	g	13.78	16.29	17.96	22.1	25.17	29.29
100ρ		122712.6	127109	130796	148180	159930.1	156053.5
100+W		113.78	116.29	117.96	122.1	125.17	129.29
Dry density: ρd=100ρ/(100+w)	kg/m3	1078.508	1093.03	1108.81	1213.6	1277.703	1207.003
on the Graph we can read the: Optimum Moisture Content(OMC)=26%; the Maximum Dry Density (MDD)=1285kg/m3							

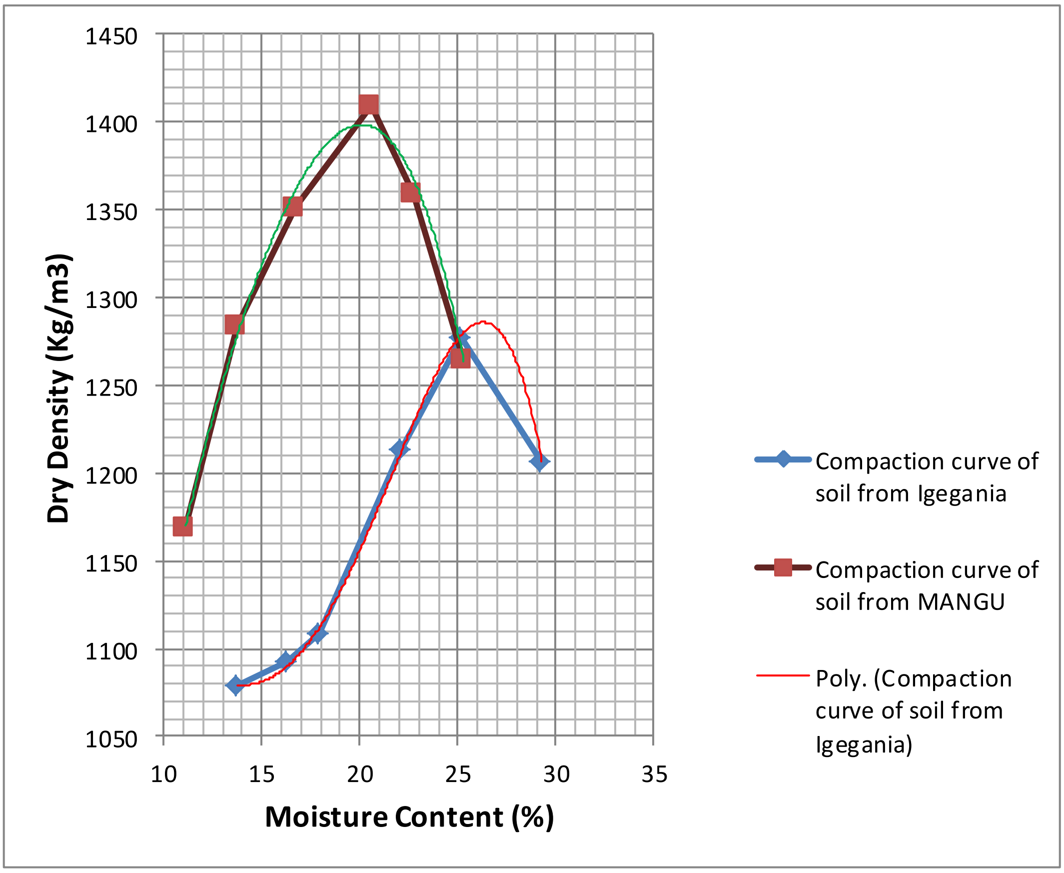


Figure 1-a: Light compaction curve of soil from Mangu and Igegania

Table1-c: Results of light compaction test of soil (Mangu)+sand

SOIL(CONTENING 15% SAND) + 45% SAND ADDED= 40% SOIL + 60% SAND						
Reference to test method	ref, BS 1377: Part 4: 1990					
Run		1	2	3	4	5
Weight of the mould + its plate base: W1	g	4169.2				
Weight of the mould + compacted soil: W2	g	5531.5	5875	5996.8	5971.4	5910
Weight of Soil sample (W2-W1)	g	1362.3	1705.8	1827.6	1802.2	1740.8
Volume of the mould: V	mm3	1000875				
Bulk Density: ρ=(W2-W1)/V	g/mm3	0.001361	0.0017	0.00183	0.0018	0.001739
Bulk Density: ρ=(W2-W1)/V	kg/m3	1361.109	1704.31	1826	1800.62	1739.278
Moisture content determination						
N° of moisture content tins		35	38	13	3	7A
Weight of moisture content tins	g	16.5	22.7	9.5	9.2	5.2
Weight of moisture content tins+wet soil	g	119.3	122.1	129.8	115.4	103.5
Weight of moisutre content tins+dry soil	g	111.6	111.2	113.6	98.3	85.4
Moisture content (w)	g	7.7	10.9	16.2	17.1	18.1
100ρ		136110.9	170431	182600	180062	173927.8
100+W		107.7	110.9	116.2	117.1	118.1
Dry density: ρd=100ρ/(100+w)	kg/m3	1263.79	1536.8	1571.4	1537.6	1472.71
on the Graph we can read the: Optimum Moisture Content(OMC)=14%; the Maximum Dry Density (MDD)=1590kg/m3						

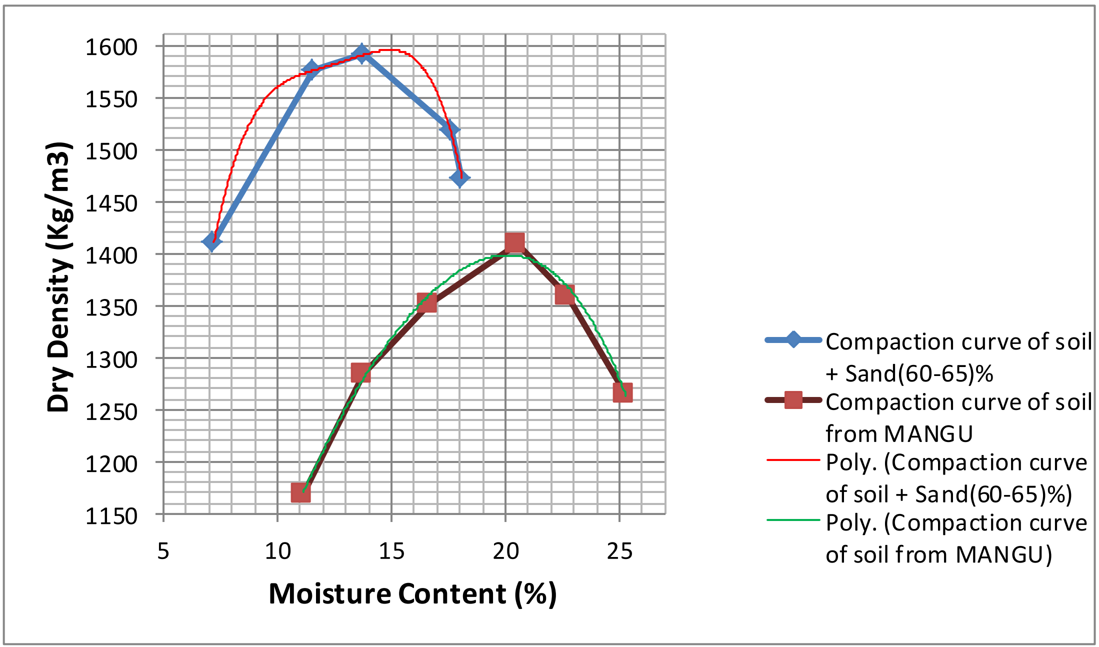


Figure 1-b: Results of light compaction test of soil (Mangu)+ sand

APPENDIX 6: MECHANICAL TESTS ON BLOCKS

Table1: Dry compressive strength of blocks specimens 1 and 2

SAMPLE	SPECIMEN 1				SPECIMEN 2			
	CSB				CSSB withsand			
AGE OF BLOCKS	7 days	14 days	21 days	28 days	7 days	14 days	21 days	28 days
SIZE OF SPECIMENS								
Length (L) in cm	28.80	28.40	28.50	28.30	28.50	28.80	28.90	28.80
Larger (l) in cm	13.80	13.65	13.70	13.50	13.85	13.85	13.80	13.70
Height (h) in cm	11.80	11.50	11.80	11.20	11.80	11.80	11.90	11.50
Area (A) in cm^2	397.44	387.66	390.45	382.05	394.73	398.88	398.82	394.56
CRUSHING								
Breaking load (F) in kN	28.34	67.35	74.55	85.03	25.42	26.29	70.80	83.38
	20.43	77.07	84.81	75.53	33.66	42.18	66.09	97.70
	24.40	76.26	90.42	68.61	29.54	35.85	99.69	90.00
Average of Breaking load (kN)	24.39	73.56	83.26	76.39	29.54	34.77	78.86	90.36
STRENGTH								
Compressive strength (dry) of blocks in MPa: fb=F/A	0.73	1.74	1.87	2.23	0.64	0.66	1.78	2.13
	0.51	1.99	2.13	1.98	0.85	1.06	1.66	2.49
	0.62	1.97	2.27	1.80	0.75	0.90	2.50	2.30
Average of Compressive strength in (MPa)	0.62	1.90	2.09	2.00	0.75	0.87	1.98	2.31

Table2: Dry compressive strength of stabilized blocks specimens 3 at 7, 14 and 28 days

SPECIMEN 3 : CSSB with Cement											
% of cement	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**
AGE OF BLOCKS : 7 days											
SIZE OF SPECIMENS											
Length (L) in cm	28.7	28.7	28.7	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9
Larger (l) in cm	13.8	13.9	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.1	14.1
Height (h) in cm	11.7.5	11.8	12.3	11.9	11.9	11.9	11.9	11.9	119.0	12.0	12.1
Area (A) in cm^2	396.1	397.5	400.4	404.6	404.6	404.6	404.6	404.6	404.6	407.5	407.5
CRUSHING											
	24.9	31.7	47.5	70.8	129.6	122.2	116.1	115.0	132.9	150.7	193.4
	34.2	53.5	32.1	96.9	110.3	106.4	139.3	183.6	167.9	152.1	198.3
Breaking load (F) in kN	29.6	42.6	39.8	89.4	97.7	131.8	140.8	162.8	154.5	146.1	186.5
Average of Breaking load (kN)	29.6	42.6	39.8	85.7	112.5	120.1	132.1	153.8	151.7	149.6	192.7
STRENGTH											
Compressive strength (dry) of blocks in MPa: fb=F/A	0.6	0.8	1.2	1.8	3.2	3.0	2.9	2.8	3.3	3.7	4.8
	0.9	1.3	0.8	2.4	2.7	2.6	3.4	4.5	4.1	3.7	4.9
	0.7	1.1	1.0	2.2	2.4	2.3	3.5	4.0	3.8	3.6	4.6
Average of Compressive strength in (MPa)	0.75	1.07	1.00	2.12	2.78	2.64	3.26	3.80	3.737	3.7	4.7
AGE OF BLOCKS : 14 days											
% of cement	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**
SIZE OF SPECIMENS											
Length (L) in cm	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	29.0	29.0	29.0
Larger (l) in cm	13.9	13.9	13.9	14.0	14.0	14.0	14.0	14.0	14.1	14.1	14.1
Height (h) in cm	11.9	11.9	12.1	11.8	11.8	11.8	11.6	11.6	11.8	12.0	12.0
Area (A) in cm^2	401.7	401.7	401.7	404.6	404.6	404.6	404.6	404.6	406.8	408.9	408.9
CRUSHING											
	60.5	43.1	76.0	70.1	150.1	170.4	173.7	181.3	199.9	218.4	182.0
	70.7	58.7	48.8	115.0	79.7	135.6	167.1	168.7	194.2	219.6	157.7
Breaking load (F) in kN	52.6	98.8	62.4	86.8	89.9	134.9	163.5	202.5	215.6	228.6	179.4
Average of Breaking load (kN)	61.3	66.9	62.4	90.6	106.6	147.0	168.1	184.2	203.2	222.2	173.0
STRENGTH											
Compressive strength (dry) of blocks in MPa: fb=F/A	1.51	1.07	1.89	1.73	3.71	4.21	4.29	4.48	4.91	5.34	4.45
	1.98	1.46	1.22	2.84	1.97	3.35	4.13	4.17	4.77	5.37	3.86
	1.31	2.26	1.55	2.15	2.22	3.33	4.04	5.00	5.292	5.58	4.39
Average of Compressive strength in (MPa)	1.60	1.60	1.55	2.24	2.63	3.63	4.15	4.55	4.991	5.4	4.2
AGE OF BLOCKS : 28 days											
% of cement	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**
SIZE OF SPECIMENS											
Length (L) in cm	28.8	28.8	28.9	28.9	28.9	28.9	28.9	28.9	29.0	29.0	29.0
Larger (l) in cm	13.8	13.9	14.0	14.0	13.9	14.0	14.0	14.0	14.0	14.0	14.0
Height (h) in cm	11.7	11.6	11.8	11.8	11.9	11.9	12.0	11.9	12.0	12.0	12.0
Area (A) in cm^2	397.4	400.3	404.6	404.6	401.7	404.6	404.6	404.6	405.3	406.0	406.0
CRUSHING											
	96.4	103.9	96.9	114.3	151.6	207.8	177.5	219.9	237.3	254.7	230.6
	85.7	98.1	113.7	123.6	170.2	152.6	185.4	237.0	237.7	238.4	204.0
Breaking load (F) in kN	106.4	86.3	84.3	139.3	145.5	167.8	192.8	182.6	206.0	229.4	224.6
Average of Breaking load (kN)	96.2	96.1	98.3	125.7	155.8	176.1	185.2	213.2	227.0	240.8	219.7
STRENGTH											
Compressive strength (dry) of blocks in MPa: fb=F/A	2.41	2.61	2.40	2.83	3.77	5.14	4.39	5.47	5.752	6.03	5.66
	2.14	2.47	2.81	3.05	4.24	3.77	4.54	5.86	5.609	5.36	5.01
	2.66	2.17	2.08	3.44	3.62	4.15	4.77	4.52	5.073	5.63	5.51
Average of Compressive strength in (MPa)	2.40	2.42	2.43	3.11	3.88	4.35	4.56	5.28	5.478	5.67	5.39

Table3: Dry compressive strength of stabilized blocks specimens 4 at 7, 14 and 28 days

SPECIMEN 4 : CSSB with Lime											
% of lime	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**
AGE OF BLOCKS : 7 days											
SIZE OF SPECIMENS											
Length (L) in cm	28.7	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9
Larger (l) in cm	14.0	14.1	14.1	14.1	13.9	13.9	13.9	13.9	13.9	14.1	14.0
Height (h) in cm	11.9	11.9	12.0	12.0	11.9	11.9	11.9	11.9	12.0	12.0	12.2
Area (A) in cm^2	401.1	407.5	407.5	407.5	401.7	401.7	401.7	401.7	401.7	407.5	404.6
CRUSHING											
Breaking load (F) in kN	27.0	28.5	34.2	39.8	101.3	43.4	74.6	71.6	75.0	68.9	84.8
	30.9	28.2	32.8	37.4	71.7	66.7	81.3	71.9	105.9	54.5	101.0
	29.8	30.1	32.6	35.0	61.5	76.1	86.4	68.7	90.4	51.4	92.9
Average of Breaking load (kN)	29.2	28.9	33.2	37.4	78.2	62.0	80.7	70.7	90.4	58.2	92.9
STRENGTH											
Compressive strength (dry) of blocks in MPa: fb=F/A	0.67	0.70	0.84	0.97	2.52	1.89	1.86	1.78	2.25	1.69	2.13
	0.77	0.69	0.81	0.92	1.79	1.66	2.02	1.79	1.87	1.39	2.53
	0.75	0.74	0.80	0.86	1.53	1.08	2.15	1.71	2.64	1.26	2.33
Average of Compressive strength in (MPa)	0.73	0.71	0.81	0.92	1.95	1.54	2.01	1.76	2.3	1.4	2.3
AGE OF BLOCKS : 14 days											
% of lime	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**
SIZE OF SPECIMENS											
Length (L) in cm	28.9	29.0	29.0	29.0	28.9	28.9	28.9	28.9	28.9	29.0	28.9
Larger (l) in cm	14.0	14.1	14.1	14.1	14.0	14.0	14.0	14.0	14.0	14.1	14.0
Height (h) in cm	11.9	11.9	11.9	11.9	12.3	12.3	12.3	12.3	12.3	12.0	12.3
Area (A) in cm^2	403.9	408.9	408.9	408.9	404.6	404.6	404.6	404.6	404.6	408.9	404.6
CRUSHING											
Breaking load (F) in kN	29.1	32.0	51.5	71.1	119.3	115.6	114.1	141.9	118.7	124.2	105.7
	44.7	47.1	57.1	67.0	96.9	96.4	114.7	136.8	154.0	100.6	139.6
	39.6	43.3	50.9	58.5	134.1	86.1	126.5	130.2	119.4	101.7	149.0
Average of Breaking load (kN)	37.8	40.8	53.2	65.5	116.8	99.3	118.4	136.3	130.7	108.8	131.4
STRENGTH											
Compressive strength (dry) in MPa: fb=F/A	0.72	0.79	1.27	1.74	2.95	2.86	2.82	3.56	2.98	3.04	2.65
	1.10	1.15	1.40	1.64	2.39	2.38	2.83	3.43	3.86	2.46	3.47
	0.98	1.06	1.25	1.43	3.32	2.13	3.13	3.26	2.99	2.49	3.71
Average of strength in (MPa)	0.94	1.00	1.30	1.60	2.89	2.46	2.93	3.42	3.3	2.7	3.3
AGE OF BLOCKS : 28 days											
% of lime	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**
SIZE OF SPECIMENS											
Length (L) in cm	28.9	29.0	29.0	29.0	28.9	28.9	28.9	28.9	28.9	29.0	28.9
Larger (l) in cm	13.9	14.0	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1
Height (h) in cm	11.7	11.8	11.8	11.8	11.9	12.0	11.9	11.9	11.9	11.9	12.1
Area (A) in cm^2	400.3	406.0	407.5	408.9	407.5	407.5	407.5	407.5	407.5	408.9	407.5
CRUSHING											
Breaking load (F) in kN	86.3	89.2	95.1	101.0	111.0	124.1	174.1	131.2	147.0	93.0	145.7
	91.0	84.3	95.8	107.3	108.4	122.3	192.3	180.7	170.8	105.8	170.8
	83.7	77.4	105.2	132.9	159.8	153.4	157.4	114.2	140.0	113.5	152.1
Average of Break load (kN)	87.0	83.6	98.7	113.7	126.4	133.3	174.6	142.0	152.6	104.1	156.2
STRENGTH											
Compressive strength (dry) in MPa: fb=F/A	2.16	2.19	2.33	2.48	2.72	3.05	4.27	3.22	3.6	2.28	4.1
	2.28	2.07	2.35	2.63	2.66	3.00	4.72	4.43	4.19	2.6	4.8
	2.10	1.90	2.58	3.26	3.92	3.76	3.86	2.80	3.44	2.79	4.3
Average of strength in (MPa)	2.18	2.05	2.42	2.79	3.10	3.27	4.28	3.48	3.7	2.6	4.4

Table 4: Dry compressive strength of stabilized blocks specimens 5 at 28 days

SPECIMEN 5 : CSSB with Plastic fibers			
Amount Fiber used in roll	1/2	2	4
AGE OF BLOCKS : 28 days			
SIZE OF SPECIMENS			
Length (L) in cm	28.8	28.8	28.8
Larger (l) in cm	13.8	13.8	13.8
Height (h) in cm	117.0	117.0	117.0
Area (A) in cm^2	397.4	397.4	397.4
CRUSHING			
	131.5	198.5	159.3
	132.2	174.2	153.1
Breaking load (F) in kN	130.2	187.3	152.1
Average of Breaking load (kN)	131.3	186.7	154.8
STRENGTH			
	3.30	5.00	4.00
Compressive strength (dry) of blocks in MPa: fb=F/A	3.33	4.38	3.85
	3.28	4.71	3.82
Average of Compressive strength in (MPa)	3.30	4.70	3.89

APPENDIX 7: ABRASION COEFFICIENT OF BLOCKS.

Table1: Abrasion coefficient of blocks specimens 1 and 2

	SPECIMEN 1	SPECIMEN 2
Age of blocks : 28 days		
Composition of the specimens	100% Soil	Soil + 60% Sand
MASS OF BLOCKS		
	7441	8583
	6935	8354
Mass before brushing (m1) in g	6937	8342
Average (m1) in g	7104.33	8426.33
	7386	8360
Mass after brushing (m2) in g	6855	8123
	6881	8079
Average (m2) in g	7040.67	8187.33
Mass of displaced(lost) material(m1-m2) in g	63.67	239.00
COEFFICIENT OF ABRASION		
(m1-m2) x100/m1 in %	0.90	2.84
Length of brushing (L) in cm	28.4	28.8
Larger of brushing (l) in cm	2.5	2.5
Area of brushing (cm2)	71.00	72.00
Penetration of brush after 1minute in (cm)	0.5	2
Coefficient of abrasion (Ca)		
Ca=A/(m1-m2) in cm2/g	1.12	3.32

Table 2: Abrasion coefficient of stabilized blocks specimens 3

SPECIMEN 3 CSSB with CEMENT											
Age of blocks: 28 days											
% of cement added	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**
MASS OF BLOCKS											
Mass before brushing (m1) in g	8511	8657	8901	9007	8918	9038	9046	9098	9101	9103	9113
	8783	8593	9254	9140	8986	8838	9084	9174	9035	8895	9331
	8917	8736	8791	8672	8960	9059	9189	9221	9168	9114	9075
Average (m1) in g	8737	8662	8982	8940	8955	8978	9106	9164	9101	9037	9173
	8111	8445	8829	8895	8820	8985	9008	9046	9065	9083	9093
	8642	8337	9115	9042	8904	8761	9044	9129	8998	8867	9315
Mass after brushing (m2) in g	8816	8411	8584	8609	9010	9010	9151	9180	9137	9093	9057
Average (m2) in g	8523	8398	8843	8849	8911	8919	9068	9118	9066	9014	9155
Mass of displaced (lost) material(m1-m2) in g	214.00	264.33	139.33	91.00	43.33	59.67	38.67	46.00	34.5	23.00	18.00
COEFFICIENT OF ABRASION											
(m1-m2)x100/m1 in %	2.45	3.05	1.55	1.02	0.48	0.66	0.42	0.50	0.38	0.25	0.20
Length of brushing (L) in cm	28.90	28.90	28.90	28.90	28.90	28.90	28.90	28.90	28.95	29.00	29.00
Larger of brushing (l) in cm	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Brushed Area (cm^2)	72.25	72.25	72.25	72.25	72.25	72.25	72.25	72.25	72.38	72.50	72.50
Penetration of brush after 1minute in (mm)	14.00	16.00	10.00	5.00	3.00	3.00	2.00	1.00	1.00	0.50	0.50
Coefficient of abrasion (C_a)											
C_a=A/(m1-m2) in cm^2/g	2.96	3.66	1.93	1.26	0.60	0.83	0.54	0.64	0.48	0.32	0.25

Table 3: Abrasion coefficient of stabilized blocks specimens 4

SPECIMEN 3 CSSB with LIME											
Age of blocks: 28 days											
% of cement added	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**
MASS OF BLOCKS											
	8632	8680	9000	9319	8594	8623	9027	8835	8664	8901	8506
	8538	8722	8875	9028	8433	8538	8937	8512	8890	8761	8616
Mass before brushing (m1) in g	8482	8622	8874	9126	8687	8300	8940	8400	8975	9033	8467
Average (m1) in g	8551	8675	8916	9158	8571	8487	8968	8582	8843	8898	8530
	8425	8489	8893	9297	8552	8602	8942	8814	8640	8876	8420
	8377	8631	8821	9011	8369	8450	8919	8474	8858	8736	8514
Mass after brushing (m2) in g	8287	8494	8796	9098	8611	8170	8857	8275	8958	9001	8386
Average (m2) in g	8363	8538	8837	9135	8511	8407	8906	8521	8819	8871	8440
Mass of displaced(lost) material(m1-m2) in g	187.8	136.67	79.50	22.33	60.67	79.67	62.00	61.33	24.33	27.33	89.67
COEFFICIENT OF ABRASION											
(m1-m2)x100/m1 in %	2.20	1.58	0.89	0.24	0.71	0.94	0.69	0.71	0.28	0.31	1.05
Length of brushing (L) in cm	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9
Larger of brushing (l) in cm	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Brushed Area (cm^2)	72.3	72.25	72.3	72.3	72.3	72.3	72.3	72.3	72.3	72.3	72.3
Penetration of brush after 1minute in (mm)	18	15	9	4	9	13	7	7	2	3	1
Coefficient of abrasion (C_a)											
C_a=A/(m1-m2) in cm^2/g	2.60	1.89	1.10	0.31	0.84	1.10	0.86	0.85	0.34	0.38	1.24

APPENDIX 8: WATER ABSORPTION ON BLOCKS

Table1: Water absorption by capillarity of blocks specimens 1 and 2

SAMPLE	**SPECIMEN 1**	**SPECIMEN 2**
	CSB	**CSSB withsand**
AGE OF BLOCKS	21 days	21 days
SIZE OF SPECIMENS		
Length (L) in mm	28.3	28.8
Larger (l) in mm	13.5	13.7
Area (A) in mm^2	382.1	394.6
MASS OF BLOCK		
	6656	7600
	6197	7420
Mass of dry blocks (md) in (g)	6250	7366
Average of dry mass (g)	6367.7	7462.0
	6892	7866
	6299	7898.59
Mass of wet blocks (mh) after 10 minutes in (g)	6323	7285.855589
Average of wet mass After 10 minutes(g)	6504.7	7683.5
Mass of absorbed water after 10 minutes (md-mh) in g	137.0	221.5
	6939	7438
	6319	7144
Mass of wet blocks (mh) after 20 minutes in (g)	6338	6930
Average of wet mass After 20 minutes(g)	6532.0	7170.7
Mass of absorbed water(md-mh) after 20 minutes in g	164.3	-291.3
	6939	7438
	6319	7144
Mass of wet blocks (mh) after 30 minutes in (g)	6338	6930
Average of wet mass After 30 minutes(g)	6532.0	7170.7
Mass of absorbed water(md-mh) after 30 minutes in g	164.3	-291.3
	6939	7360
	6319	7083
Mass of wet blocks (mh) after 30 minutes in (g)	6338	7066
Average of wet mass After 30 minutes(g)	6532	7169.666667
Mass of absorbed water(md-mh) after 30 minutes in g	164.3	-292.3
Mass of Absorbed after 10 minutes	137.0	221.5
Coefficient of absorption by Capillarity		
$Cb=100x(mh-md)/S\sqrt{10}$ in %	11.33966862	17.75109355

Table 2: Water absorption by capillarity of stabilized blocks specimens 3

SPECIMEN 3 : CSSB with Cement											
% of cement	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**
AGE OF BLOCKS : 28 days											
SIZE OF SPECIMENS											
Length (L) in cm	28.7	28.7	28.7	28.9	28.9	28.9	28.9	28.9	29	29	29
Larger (l) in cm	13.8	13.9	13.9	14	14	14	14	14	14.1	14.1	14.1
Area (A) in cm^2	396	397	397	405	405	405	405	405	407	409	409
MASS OB BLOCKS											
	7906	7677	7964	8089	8010	8162	8155	8133	8228	8323	8334
	7863	7664	8281	8242	8111	7983	8243	8298	8214	8130	8538
Mass of dry blocks in (g)	8001	7592	8173	7995	8088	8221	8343	8343	8339	8335	8301
Average of dry mass (g)	7923	7644	8139	8109	8070	8122	8247	8258	8260	8263	8391
	7981	7837	8058	8134	8075	8234	8206	8184	8294	8404	8408
	7938	7824	8375	8287	8156	8055	8294	8349	8302	8254	8598
Mass of wet blocks (mh) after 10 minutes in (g)	8076	7671	8267	8040	8133	8293	8394	8394	8392	8390	8349
Average of wet mass After 10 minutes(g)	7998	7777	8233	8154	8121	8194	8298	8309	8329	8349	8452
Mass of absorbed water(md-mh) after 10 minutes in g	75.0	133.0	94.0	45.0	51.7	72.0	51.0	51.0	68.8	86.7	60.7
	8018	7917	8105	8156	8107	8270	8231	8209	8313	8416	8422
	7975	7904	8422	8309	8188	8091	8319	8374	8325	8276	8611
Mass of wet blocks (mh) after 20 minutes in (g)	8113	7751	8314	8062	8165	8329	8419	8419	8411	8403	8362
Average of wet mass After 20 minutes(g)	8035	7857	8280	8176	8153	8230	8323	8334	8350	8365	8465
Mass of absorbed water (md-mh) after 20 minutes in g	112.0	213.0	141.0	67.0	83.7	108.0	76.0	76.0	89.2	102.3	74.0
	8138	7926	8133	8231	8150	8298	8273	8264	8346	8428	8438
	7981	8004	8477	8360	8241	8151	8363	8385	8343	8300	8627
Mass of wet blocks (mh) after 30 minutes in (g)	8099	7962	8370	8007	8208	8350	8413	8430	8424	8418	8379
Average of wet mass After 30 minutes(g)	8073	7964	8327	8199	8200	8266	8350	8360	8371	8382	8481
Mass of absorbed water (md-mh) after 30 minutes in g	149.3	319.7	187.3	90.7	130.0	144.3	102.7	101.7	111	119.3	90.3
	8236	8026	8194	8375	8191	8333	8324	8313	8380	8446	8467
	8044	8094	8544	8477	8281	8203	8400	8408	8373	8338	8650
Mass of wet blocks (mh) after 01 hour in (g)	8167	8061	8438	8177	8250	8391	8437	8453	8447	8440	8408
Average of wet mass After 01 hour (g)	8149	8060	8392	8343	8241	8309	8387	8391	8400	8408	8508
Mass of absorbed water (md-mh) after 01 hour in g	225.7	416.0	252.7	234.3	171.0	187.0	140.0	133.3	139	145.3	117.3
	8371	8166	8292	8395	8255	8386	8396	8367	8422	8477	8510
	8195	8230	8631	8494	8339	8284	8451	8435	8417	8399	8693
Mass of wet blocks (mh) after 02 hours in (g)	8286	8202	8529	8203	8312	8458	8472	8478	8478	8477	8450
Average of wet mass After 02 hours (g)	8284	8199	8484	8364	8302	8376	8440	8427	8439	8451	8551

Mass of absorbed water (md-mh) after 02 hours in g	360.7	555.0	344.7	255.3	232.3	254.0	192.7	168.7	179	188.3	160.0
Mass of wet blocks (mh) after 05 hours in (g)	8537	8338	8398	8494	8334	8455	8505	8447	8471	8495	8532
	8327	8381	8736	8573	8410	8384	8518	8480	8456	8431	8713
	8425	8308	8640	8320	8388	8542	8525	8525	8510	8495	8470
Average of wet mass After 05 hours (g)	8430	8342	8591	8462	8377	8460	8516	8484	8479	8474	8572
Mass of absorbed water (md-mh) after 05 hours in g	506.3	698.0	452.0	353.7	307.7	338.3	269.0	226.0	219	211.0	180.7
Mass of wet blocks (mh) after 24 hours in (g)	8593	8489	8697	8865	8708	8790	8840	8777	8682	8587	8669
	8255	8421	9039	8936	8750	8704	8827	8685	8660	8635	8849
	8371	8351	8951	8579	8740	8910	8834	8737	8680	8622	8631
Average of wet mass After 24 hours (g)	8406	8420	8896	8793	8733	8801	8834	8733	8674	8615	8716
Mass of absorbed water (md-mh) after 24 hours in g	483.0	776.0	756.3	684.7	663.0	679.3	586.7	475.0	414	352.0	325.3
Mass of wet blocks (mh) after 48 hours in (g)	8597	8508	8709	8684	8820	8922	8862	8890	8767	8644	8709
	8239	8428	9060	8961	8861	8737	8938	8862	8790	8718	8884
	8318	8369	8971	8596	8796	8953	9024	8926	8817	8707	8659
Average of wet mass After 48 hours (g)	8385	8435	8913	8747	8826	8871	8941	8893	8791	8690	8751
Mass of absorbed water (md-mh) after 48 hours in g	461.3	790.7	774.0	638.3	756.0	748.7	694.3	634.7	531	427.0	359.7
Mass of wet blocks (mh) after 72 hours in (g)	8614	8527	8732	8897	8845	8946	8884	8912	8750	8587	8669
	8222	8446	9066	8978	8888	8758	8963	8997	8816	8635	8849
	8209	8377	8990	8622	8823	8974	9047	9065	8844	8622	8631
Average of wet mass After 72 hours (g)	8348	8450	8929	8832	8852	8893	8965	8991	8803	8615	8716
Mass of absorbed water (md-mh) after 72 hours in g	425.0	805.7	790.0	723.7	782.3	770.7	717.7	733.3	543	352.0	325.3
Mass of wet blocks (mh) after 96 hours in (g)	8614	8525	8729	8895	8844	8947	8884	8913	9317	9720	8738
	8222	8441	9065	8977	8886	8755	8963	9000	8886	8771	8912
	8209	8377	8987	8616	8815	8974	9047	9068	8944	8819	9686
Average of wet mass After 96 hours (g)	8348	8448	8927	8829	8848	8892	8965	8994	9049	9103	9112
Mass of absorbed water (md-mh) after 96 hours in g	425.0	803.3	787.7	720.7	778.7	770.0	717.7	735.7	788	840.7	721.0
Mass of water absorbed after 10 minutes	75.0	133.0	94.0	45.0	51.7	72.0	51.0	51.0	68.8	86.7	60.7
Coefficient of absorption by Capillarity											
Mean Cb=100x(mh-md)/S√10	5.99	10.58	7.48	3.52	4.04	5.63	3.99	3.99	5.35	6.70	4.69

Table 3: Water absorption by capillarity of stabilized blocks specimens 4

SPECIMEN 3 : CSSB with LIME											
% of lime	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**
AGE OF BLOCKS : 28 days											
SIZE OF SPECIMENS											
Length (L) in mm	29	29	29	29	28.9	28.9	28.9	28.9	28.9	29	28.9
Larger (l) in mm	14	14	14	14	14.1	14.1	14.1	14.1	14.1	141	14.1
Area (A) in mm^2	406	406	406	406	407.5	407.5	407.5	407.5	407.5	4089	407.5
MASS OB BLOCKS											
Mass of dry blocks in (g)	7690	7780	8149	8518	7709	7735	8116	7621	7793	8133	7528
	7664	7908	8082	8255	7590	7656	8030	7903	8000	7996	7672
	7573	7780	8059	8337	7765	7371	8022	7433	8069	8249	7811
Average of dry mass (g)	7642	7823	8096	8370	7688	7587	8056	7652	7954	8126	7670
Mass of wet blocks (mh) after 10 minutes in (g)	7835	7803	8168	8532	7943	7809	8182	7711	7988	8171	7700
	7923	7948	8123	8298	7831	7777	8115	7991	8135	8068	7833
	7547	7808	8102	8396	7952	7481	8105	7572	8146	8289	7977
Average of wet mass After 10 minutes(g)	7768	7853	8131	8409	7909	7689	8134	7758	8090	8176	7837
Mass of absorbed water(md-mh) after 10 minutes in g	126	30.3	34.5	38.7	220.7	101.7	78.0	105.7	135.7	50.0	166.3
Mass of wet blocks (mh) after 20 minutes in (g)	7821	7814	8175	8535	8012	7844	8214	7739	8036	8182	7742
	7962	7955	8127	8298	7895	7814	8152	8009	8173	8090	7815
	7821	7814	8105	8396	8006	7536	8132	7606	8175	8302	8013
Average of wet mass After 20 minutes(g)	7868	7861	8135	8410	7971	7731	8166	7785	8128	8191	7857
Mass of absorbed water (md-mh) after 20 minutes in g	44.8	38.3	39.0	39.7	283.0	144.0	110.0	132.3	174.0	65.3	186.3
Mass of wet blocks (mh) after 30 minutes in (g)	7829	7822	8180	8538	8035	7869	8235	7750	8067	8195	7774
	7980	7973	8144	8314	7922	7835	8177	8014	8193	8115	7909
	7823	7816	8112	8408	8026	7565	8151	7629	8195	8314	8045
Average of wet mass After 30 minutes(g)	7877	7870	8145	8420	7994	7756	8188	7798	8152	8208	7909
Mass of absorbed water (md-mh) after 30 minutes in g	54.2	47.7	48.8	50.0	306.3	169.0	131.7	145.3	197.7	82.0	239.0
Mass of wet blocks (mh) after 01 hour in (g)	7838	7831	8187	8543	8082	7934	8300	7783	8139	8221	7829
	8007	8000	8159	8318	7972	7885	8236	8030	8240	8159	7967
	7834	7827	8123	8418	8069	7649	8199	7685	8241	8339	8102
Average of wet mass After 01 hour (g)	7893	7886	8156	8426	8041	7823	8245	7833	8207	8240	7966
Mass of absorbed water (md-mh) after 01 hour in g	69.8	63.3	59.8	56.3	353.0	235.3	189.0	180.3	252.7	113.7	295.7
Mass of wet blocks (mh) after 02 hours in (g)	7861	7854	8204	8553	8147	8020	8376	7834	8249	8284	7927
	8074	8067	8202	8336	8042	7967	8320	8056	8318	8258	8065
	7861	7854	8149	8443	8130	7743	8267	7759	8314	8395	8190
Average of wet mass After 02 hours (g)	7932	7925	8185	8444	8106	7910	8321	7883	8293	8312	8060
Mass of absorbed water (md-mh) after 02 hours in g	109	102.3	88.2	74.0	418.2	322.5	264.5	230.3	339.2	186.3	390.0
Mass of wet blocks (mh) after 05 hours in (g)	7875	7868	8214	8559	8147	8020	8376	7834	8249	8322	8094
	8101	8094	8219	8344	8042	7967	8320	8056	8318	8315	8233
	7877	7870	8163	8456	8130	7743	8267	7759	8314	8395	8341
Average of wet mass After 05 hours (g)	7951	7944	8199	8453	8106	7910	8321	7883	8293	8344	8223
Mass of absorbed water (md-mh) after 05 hours in g	128	121.3	102.2	83.0	418.2	322.5	264.5	230.3	339.2	218.0	552.3
Mass of wet blocks (mh) after	8018	8011	8309	8607	8852	8532	8825	8252	8630	8725	8518

24 hours in (g)	8293	8286	8342	8397	8463	8489	8794	8330	8796	8679	8603
	8009	8002	8286	8570	8524	8162	8733	8266	8854	8807	8651
Average of wet mass After 24 hours (g)	8106	8100	8312	8525	8613	8394	8784	8283	8760	8737	8591
Mass of absorbed water (md-mh) after 24 hours in g	284	277.0	215.8	154.7	925.0	807.0	728.0	630.3	806.0	611.0	920.3
Mass of wet blocks (mh) after 48 hours in (g)	8090	8083	8362	8640	8552	8532	8825	8252	8630	8817	8518
	8355	8348	8388	8427	8463	8489	8794	8330	8796	8711	8603
	8082	8075	8355	8634	8524	8162	8733	8266	8854	8929	8651
Average of wet mass After 48 hours (g)	8175	8169	8368	8567	8513	8394	8784	8283	8760	8819	8591
Mass of absorbed water (md-mh) after 48 hours in g	353	346.0	271.5	197.0	825.0	807.0	728.0	630.3	806.0	693.0	920.3
Mass of wet blocks (mh) after 72 hours in (g)	8132	8125	8427	8729	8583	8563	8856	8308	8654	8817	8546
	8395	8388	8644	8900	8489	8523	8817	8438	8821	8711	8630
	8124	8117	8397	8676	8560	8189	8758	8299	8883	8929	8677
Average of wet mass After 72 hours (g)	8217	8210	8489	8768	8544	8425	8810	8348	8786	8819	8618
Mass of absorbed water (md-mh) after 72 hours in g	394	387.3	392.8	398.3	856.0	837.7	754.3	696.0	832.0	693.0	947.3
Mass of wet blocks (mh) after 96 hours in (g)	8154	8147	8420	8693	8615	8594	8884	8363	8678	8850	8574
	8409	8402	8441	8479	8515	8557	8839	8545	8845	8730	8657
	8137	8130	8432	8734	8596	8217	8782	8331	8911	8969	8702
Average of wet mass After 96 hours (g)	8233	8226	8431	8635	8575	8456	8835	8413	8811	8811	8644
Mass of absorbed water (md-mh) after 96 hours in g	410	403.7	334.5	265.3	887.0	868.7	779.0	760.7	857.0	685.0	973.7
Mass of Water Absorbed after 10 minutes	36.8	30.3	34.5	38.7	220.7	101.7	78.0	105.7	135.7	50.0	166.3
Coefficient of absorption by Capillarity											
Cb=100x(mh-md)/S√10											
Mean Cb	2.87	2.36	2.69	3.01	17.12	7.89	6.05	8.20	10.53	0.39	12.91

APPENDIX 9: SIZE, MASSES AND DENSITIES OF BLOCKS

Table 1: Sizes, masses and densities of blocks specimens(1, 2, 3, 4)

SAMPLE	SPECIMEN 1	SPECIMEN 2	SPECIMEN 3	SPECIMEN 4
AGE OF BLOCKS	28 days			
Length (L) in mm	28.30	28.80	28.90	28.90
Larger (l) in mm	13.50	13.70	14.00	14.10
Height (h) in mm	11.20	11.50	11.90	12.00
Area (A) in mm^2	382.05	394.56	404.60	407.49
Volume of Blocks in cm3	4278.96	4537.44	4814.74	4889.88
Mass of blocks (g)	7186.00	8442.30	9068.00	8591.00
Density of blocks (g/cm3)	1.68	1.86	1.88	1.76

APPENDIX 10: Standard on Soils Classification, Casagrande and ASTM(HBR)

Low plasticity	Medium Plasticity	High Plasticity

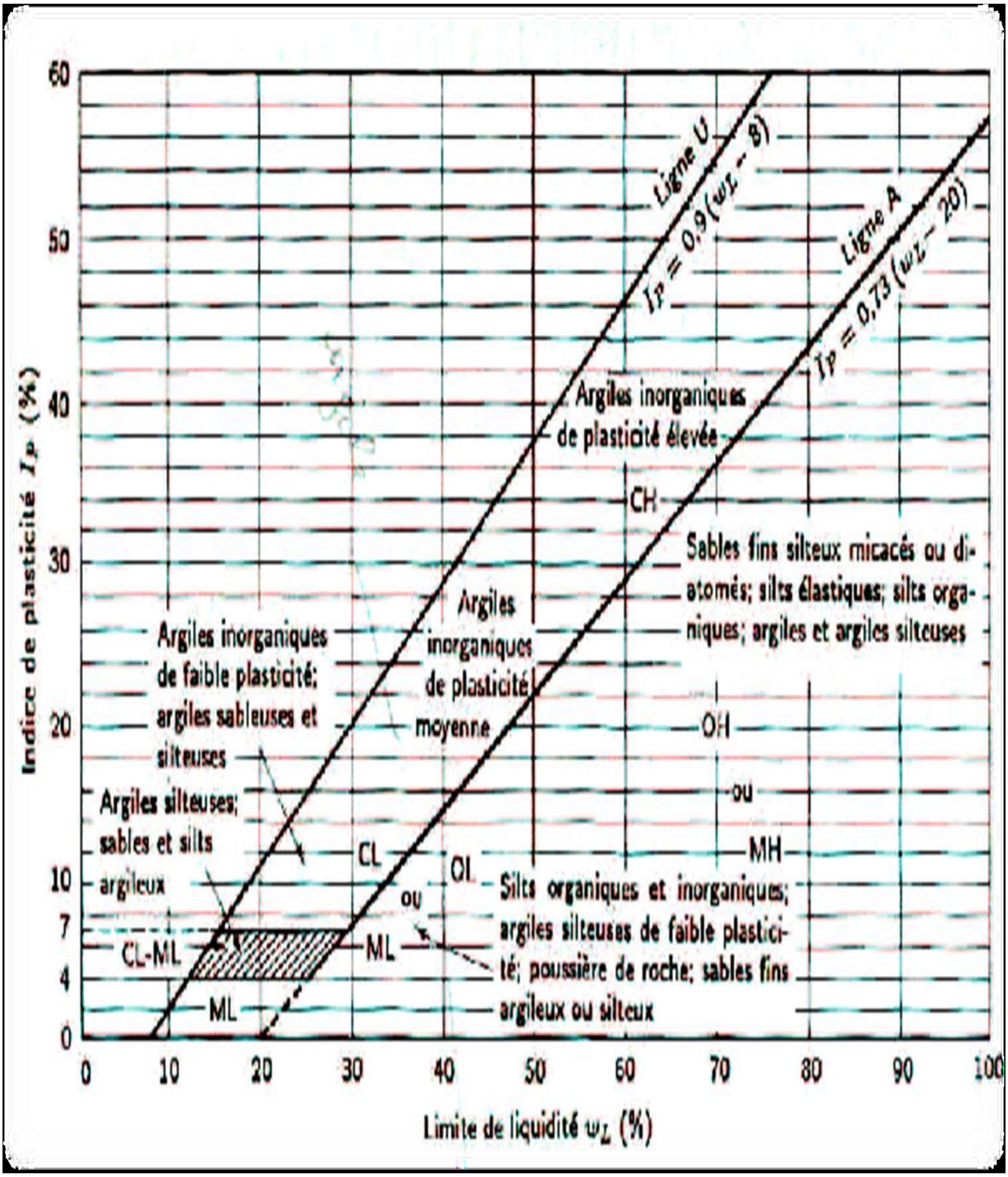


Figure 1: Spectrum of plasticity from casagrande, 1948 et Howard, 1977.

Table 1: American classification of soils (HBR) shift in units and French sieves

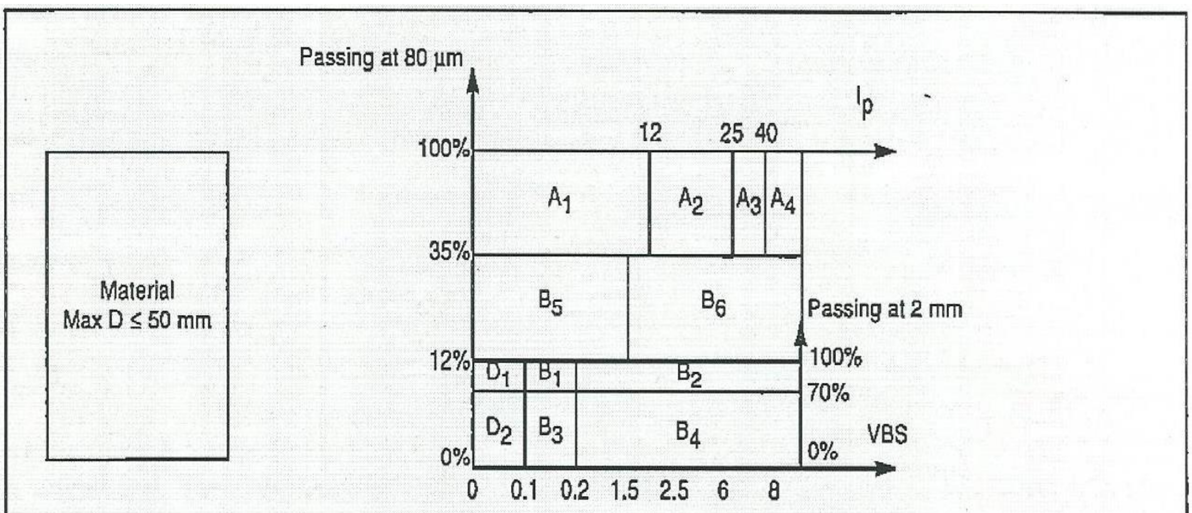
General Classification	Grainedsoils 35% au maximum passing on 80µm sieve							Fine soils more than 35% passing through80µm sieve				
Group and Su-group	A-1		A-3	A-2				A-4	A-5	A-6	A-7	
	A-1a	A-1b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5	A-7-6
% passing on sieves 2mm…………… 0.050mm………. 80µm…………..	≤50 ≤30 ≤15	≤50 ≤25	≤50 ≤10	≤35	≤35	≤35	≤35	≥35	≥35	≥35	≥35	≥35
LiquidLimit				≤40	≥40	≥40	≤40	≤40	≤40	≥40	≥40	
PasticLimit	≤6	≤6		≤10	≤10	≥10	≥10	≥10	≥10	≥10	≥10	
Group index	0	0	0	0	0	≤4	≤4	≤8	≤12	≤16	≤20	≤20
Types of materials	Stones, Gravel, Sand		Fine Sand	Gravel and Sand limoneous or argileous				LimoneousSoils		ClayeySoils		
Estimationas sub layer of road for road construction	Exellent à bon			Acceptable to bad								
X<35 → a = 0 35<X<75 → a = x - 35 X>75 → a = 40	X<15 → b = 0 15<X<55 → a = x - 15 X>35 → b = 40			IG=0,2a + 0,05ac + 0,01 bd WL<40 → c = 0 40<WL<60 → c = WL - 40 WL>60→ c = 20				IP<10 → d = 0 10<IP<30 → d= IP - 40 X>00→ d = 20				

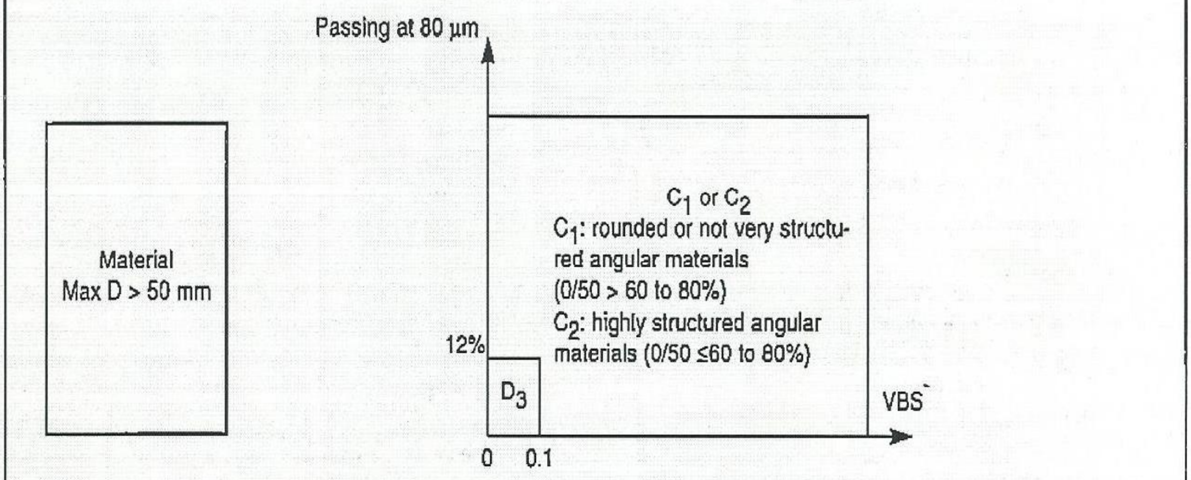
- x represent % of retained on 80 µm sieve ;

- A-1, A-2, A-3 represent fat soils;

- A-4, A-5, A-6, A-7 represent fine soils

Figure 1: Classification of materials according their nature (% passing and Plasticity Index) from (Boubekeur S., 1998)





Rocky materials	Sedimentary rocks	Carbonated rocks	Chalks	R_1
			Limestones	R_2
		Clayey rocks	Marls, argils, etc.	R_3
		Siliceous rocks	Sandstones, etc.	R_4
		Saline rocks	Rock salt, gypsum	R_5
	Magmatic and metamorphic rocks	Granites, basalts, gneiss metamorphic schists and slates, etc.		R_6
Particular materials	Organic soils or industrial by-products			F

The nature of types of earth is determined by the combination of values resulting from tests for particle size distribution, plasticity and methylene blue value. The overall suitability of soils is as follows:

A1: an acceptable material but with slightly too many fines.

A2: an acceptable material but with too many fines.

A3: an acceptable material but requiring particular care, as it is relatively active.

A4: a material which is difficult to use, as it is very active.

B1: a sandy material requiring fines to be added to make it acceptable.

B2: an acceptable material slightly lacking in fines.

B3: a sandy material requiring a considerable addition of fines to make it acceptable.

B4: an acceptable material lacking in fines.

B5: an acceptable material but slightly lacking in fines.

B6: an acceptable material but slightly lacking in fines.

C1: a material containing too much gravel, which should be sieved to change its nature.

C2: a material containing too much gravel, which should be sieved to change its nature.

D1: a sandy material requiring fines to be added to make it acceptable.

D2: a sandy material requiring a considerable addition of fines to make it acceptable.

D3: a material containing too much gravel, which should be sieved to change its nature and which requires a considerable addition of fines to make it acceptable.

R: unsuitable materials.

F: materials requiring advanced identification tests notably with regard to their chemical analysis and mechanical tests in order to be able to determine their suitability. Testing pre-production stage CEBs should be considered.

2.2 Recommendations for the use of stabilisation additives

2.2.1 Precautions to take when stabilising by adding a physicochemical additive

The presence of certain salts or organic materials can affect the efficacy of stabilising by the addition of an additive. In these cases, some chemical analysis should be therefore be undertaken to determine the presence, the value and the concentration of the following factors:

Figure 2: Nature and designation of types of earth from results resulting from tests for particle size distribution and plasticity (Boubekeur S., 1998)