



ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL
BLOCK AS AN ALTERNATIVE WALL MAKING MATERIAL**

A thesis submitted to School of Graduate Studies of Addis Ababa University in
partial fulfillment of the requirements for the degree of Master of Science in
Construction Technology and Management

BY
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November 2018

Addis Ababa

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DECLARATION

I hereby declare that this research has been carried out under the supervision of Prof. Abebe Dinku, School of Civil and Environmental Engineering, Addis Ababa University as part of Masters of Science program in Construction Technology and Management. In Addition I declare that this research is my original work, the findings presented are not found in any other previous work.

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ABSTRACT

Though cement is a popular stabilizer used in manufacturing of Compressed Stabilized Earth Blocks (CSEBs), much effort had not been done in utilizing lime in combination with cement. This research is intended to provide detailed technical and production cost information on the production of compressed cement and lime stabilized earth blocks to use as alternative wall making material. Laboratory tests conducted on the soil used for the research provided detailed information on the soils grading, plasticity, chemical composition and the result proved the soil's suitability for block production. The investigation has revealed that from the blocks produced at the varying total stabilizer contents from 4% in increments of 2% up to 10% at constant compressive pressure of 10MPa, the blocks stabilized with cement in combination with lime have an increased 56th day compressive strength than that of the blocks stabilized with cement only. The water absorption of the blocks stabilized with lime in combination with cement is lower than that of the blocks stabilized with cement only. Increment of compaction pressure with the same stabilizer content, have shown an increased compressive strength. Lime from two sources was used on this research, one from local market and the other from lime manufacturing factory (Senkale lime). Comparisons of the effects of lime, lime from source one (Generic lime) and Senkale lime showed that, Senkale lime has shown better stabilization effect based on the compressive strength of blocks and blocks water absorption test results. The cost of compressed earth blocks stabilized with lime in combination with cement is a higher than compressed earth blocks stabilized with lime, since the current price of lime is higher than that of cement. The cost comparison with the conventional wall making material, hollow concrete blocks, has revealed that CSEBs is preferred because it is more economical walling material in itself and permits the use of economical building techniques. This experimental study on CSEB prepared using lime as a replacement to cement in certain proportions has brought out the effectiveness of lime with cement in improving the 56th day compressive strength than using cement alone. The research findings show a need to relook at the grading of ingredients and quantity of stabilizers for achieving good building blocks.

Keywords: *Compressed Stabilized Earth Blocks, cement, lime, soil stabilization, compressive strength, water absorption*

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ABBREVIATIONS

| | |
|-----------|--|
| AA----- | Addis Ababa |
| AAiT----- | Addis Ababa institute of Technology |
| ACI----- | American Concrete Institute |
| ASTM----- | American Society for Testing and Materials |
| CEB----- | Compressed Earth Block |
| CSEB----- | Compressed Stabilized Earth Block |
| CSSB----- | Compressed Stabilized Soil Block |
| EBCS----- | Ethiopian Building Code Standard |
| ETB----- | Ethiopian Birr |

1 INTRODUCTION

1.1 Background

Housing provision for all in any country is very crucial in order to ensure social- economic stability and to promote national development. To most individuals housing represents the largest single investment item of a lifetime. This is especially true as family incomes increase and housing viewed less as a basic consumption and more as a key to a secure future. The majority of families in the developing countries go without adequate housing and related facilities [1].

According to Esayas [2], accesses to housing and affordability to the urban poor is also the major obstacle in the economic development of Ethiopia. Housing is still one of the major problems in the country. The existing housing stocks are slums that are characterized by poor standards, lack of basic sanitation, services, and infrastructure. Providing house for low and middle-income group is one of the components of urban development program in poverty reduction scheme [2].

The housing situations of Ethiopian cities are manifestation of the interplay of urbanization and demographic factors. Over-crowding of dwelling units and growing of squatter settlements, resulted from high rates of population growth and migration to urban areas. Insufficient housing productions have become distinguishing characteristics of Ethiopian cities. Although the extents of such problems differ from one urban area to another e.g. high density, sanitation problems, unsafe living conditions, and insecurity of tenure are some of the common constraints of urban areas [2].

Ethiopian urban population is currently estimated to be 11 Million; 80% of these live in substandard housing units and environmentally unfit living conditions in slum neighborhoods [3]. This fact coupled with high urbanization rate and other urban development challenges left urban areas with complex and rooted physical, environmental, economic and social problems where the urban poor, who reside in slums, are most vulnerable [4].

The investigation of alternative materials for the construction of low cost housing has been the focus of many studies in many developing countries [3]. The present rate of construction in developing countries is generally sufficient to meet the needs of only 10% of the net increase in

population per year [5]. This is partly due to the unavailability and the soaring costs of conventional building materials. As this shortage of building is becoming worse, more efforts are being made to develop cheap, serviceable and energy efficient construction materials for the construction of affordable sustainable buildings.

According to Afkari [6], there is a big need for sustainable low-cost dwellings for the population. It is important to develop and present technologies that are easily implemented with the available resources in the different regions in Ethiopia. One of these technologies is the Compressed Stabilized Soil Block-technique (CSSB) [6]. In this research compressed stabilized soil blocks are considered as an alternative wall making material.

Compressed Stabilized Soil Blocks (CSSBs) are manufactured using stabilizers to provide adequate compressive strength and durability, so, as to make them suitable as building blocks. This experimental study on CSSBs is prepared by using lime as partial replacement to cement in certain proportions, to stabilize the compressed soil blocks.

1.2 Problem Statement

As the urban population of Ethiopia is increasing rapidly, the need of basic services like housing, access to clear water and electric power is also increasing. Among the basic needs, housing is the most expensive. Furthermore, the gap between the demand from the residents and supply from government is very wide. Therefore, the burden of constructing residential houses is left to individual households.

Among other factors, cost of construction materials is the reason behind the shortage and expensiveness of housing. The poorest sector of the community is most affected by housing shortage, as it is least able to afford construction materials. Therefore, there is need for adequate and durable low cost housing in Ethiopia. Production of building components using techniques imported from the developed world is capital and energy intensive [4]. As Habtemariam suggested, by using improved locally available traditional building materials, the construction cost of housing can be reduced [3]. As such the aim of this research is, to come up with alternative wall making material which can be produced by locally available raw material. The need is to deliver more durable alternative wall making material of lower cost. With good

production control compressed stabilized soil block can perform adequately, but further improvement in material performance is required [4].

1.3 Objectives of the research

1.3.1 General objective

The general objective of this research is to study the suitability of compressed earth block stabilized with cement and lime as alternative walling material with respect to its cost and strength.

1.3.2 Specific objectives

- a. To investigate methods by which soil is stabilized.
- b. To study experimentally the effect of adding lime (as partial replacement to cement in certain proportions); on the compressive strength, block water absorption and cost of stabilized earth blocks.
- c. To compare the cost of stabilized earth blocks (with and without lime) with hollow concrete block.

1.4 Scope and Limitation of the Research

The research covers only the compressive strength, block water absorption and cost analysis of cement stabilized soil block and soil blocks stabilized by cement in combination with lime. The research is limited to soil sample from a single site, from Addis Ababa Kara area, because of time and budget constraints. Lime from two sources was used in the research.

1.5 Research Methodology

The following methodology has been employed to achieve the objectives of the research:

1. **Literature survey:** The study started with setting an outline of the research by assessing information from secondary resources (books, research papers, journals, etc) regarding soil block stabilization, its application, constituent materials, mechanism of soil stabilization and the factors that affect it.
2. **Sample preparation:** in this research locally available soil, Portland pozzolana cement, limes from two sources (from the local market and from lime manufacturing company) and

water were used for preparation of CSEB samples. Three mix series of sample blocks were prepared by varying the total stabilizer content and a constant of compaction pressure 10MPa, to understand the effect of stabilizer content and type on the effect of compressive strength and water absorption of compressed stabilized earth blocks.

The first series of mixes were prepared by using cement as stabilizer by varying the cement content by 2% from 4% to 10 %. The second series of mixes for sample preparation were prepared by using generic lime in combination with cement as stabilizer, with varying total stabilizer content by 2% from 4% to 10%. And the third series of mixes were prepared by using Senkale lime in combination with cement as stabilizer, by varying the total stabilizer content as the second series of mixes.

Additional sample blocks were also prepared by varying compaction pressure on the blocks from 5MPa to 14MPa, to see the effect of compaction pressure on compressive strength of CSEBs.

The sample blocks were prepared at Selam technical and vocational center, Addis Ababa.

3. **Tests:** Different tests were done on the sample of constituent materials and also on the final product of the mixing process. For the specific soil that was used on the research, different physical property tests were done based on ASTM standards in Addis Ababa Institute of technology Geotechnical laboratory. The chemical composition study of the soil and the lime were carried out in Ethiopian geological survey laboratory. The compressed stabilized soil blocks' compressive strength for 7th, 21st, 28th and 56th days were carried out in AAiT construction materials laboratory. Water absorption of the blocks was measured at the 28th day. Compressive strength and water absorption tests were conducted based on ASTM C140 standard.
4. **Analysis and discussion:** from the test results, analysis of findings were presented in graphical form and interpretation and discussion were made on the research findings.
5. **And finally conclusions and recommendations** were forwarded based on the obtained results.

1.6 Significance of the Research

Production of building components using techniques imported from the developed World is highly capital and energy intensive. By using improved locally available traditional building materials, the construction cost of housing can be reduced [4].

Earth construction is successful in arid/dry areas, but significant stabilization is required for adequate performance in humid areas. With good production control compressed stabilized soil block can perform quite adequately, but further improvement in material performance will help in meeting the same requirements as other present day wall making materials [5].

Compressed stabilized soil blocks are building components of growing importance in tropical countries. Though cement is a popular stabilizer used in manufacture of CSEBs, much effort had not been done in utilizing lime in combination of cement. Lime has been used in stabilizing clayey soils, and has been found to impart long-term strength gain as reported in literatures [8].

As lime is known to impart strength in the long term [8], its utilization in some proportion as a replacement to cement may be beneficial. This thesis will attempt to understand the role of lime in combination with cement as a stabilizer in CSEBs production.

This thesis addresses a critical aspect that affect the performance of CSEBs, by examining proportions between soil and stabilizer; and the compaction pressure taking into consideration the specific characteristics of the soil.

A further motivation of this research is using a local resource to help develop technologies that are energy saving, eco friendly and sustainable.

1.7 Structure of the Thesis

This thesis is divided in to seven chapters and each chapter contains a number of sections and further subsections. The organization of the chapters is as follows:

Chapter one provides an introduction to the whole thesis. It discusses the background to the research and the context in which it is based. This Chapter also summarizes the main aims and objectives of the research and explains the different methodologies that had been used for the research.

Chapter two is literature review. This Chapter identifies the main constituent materials in compressed stabilized soil blocks and discuss in detail about their property. It further gives introduction regarding mechanism of compressed stabilized soil and stabilization (cement and lime).

Chapter three describes the main experimental design and sample preparation methods used for laboratory tests. It explains the mix proportions and the type of material used in the research.

Chapter four this chapter presents the detail results of tests on soil. In this chapter the suitability of the soil is checked by cross checking the test results with different standards.

Chapter five this chapter presents the results of compressive strength and water absorption test on the produced soil blocks. In this chapter discussions and analyses are made based on the obtained test results.

Chapter six this section of the thesis discusses the cost analysis of the compressed stabilized soil blocks. And cost comparison of wall made by compressed cement (with and without lime) stabilized soil blocks with wall made by hollow concrete blocks (HCBs) will be presented in this chapter.

Chapter seven, the final chapter of the thesis integrates and summarizes the study. It provides conclusions, recommendations and highlights the implications of the research findings

2 LITERATURE REVIEW

2.1 Introduction

The choice of building materials is one of the important criteria, which determines the strength, quality, and economy of any construction. Stone, sand, earth, grass, woods, animal skin, etc. were used as building materials in their crude form. As technique advanced, the crude as well as the partly refined materials were replaced by others, especially made for different purposes [7]. The history of development of house facilities reveals that man has been modeling his environment throughout the ages for more comfortable living.

Soil is an ancient construction material used for centuries. As technologies advanced, much effort was made to increase the performance of soil as building material. Compressed stabilized earth block (CSEB) production is one of advanced form of soil as building material. Compressed stabilized earth block is a composite material made by mixing soil, stabilizer and water. Performance of CSEB depends on the quality of the constituent materials as well as on their proportion and on the class of construction and the amount of compaction pressure. Hence, to discuss about the performance of CSEBs it is mandatory to learn about the constituent materials and some other factors affecting its performance.

This chapter is, therefore, dedicated to discuss about the main constituent materials in compressed stabilized soil blocks and discuss in detail about their property. It further gives introduction regarding mechanism of compressed stabilized soil and stabilization.

2.2 Soil

2.2.1 Definition of soil

According to Soil Science society of America, soil is defined as

“Unconsolidated mineral or organic matter on the surface of the earth that has been subjected to and shows effects of genetic and environmental factors of: climate (including water and temperature effects), macro- and microorganisms, conditioned by relief, acting on parent material over a period of time. A product- soil differs from the material from

which it is derived in many physical, chemical, biological and morphological properties and characteristics.” [9]

2.2.2 Soil as Building material

Earth is an old material. From the time of evolution of man, earth is used for constructing the structures [10]. From the civilizations of Mesopotamia dated 6000 years back the use of earth as a building material is very evident. Earth, being available abundantly has invariably been the main construction material in providing housing systems. It offers a number of environmental benefits, including lower embodied energy levels; high thermal mass and maximizing the use of locally sourced materials [8].

Soil has been used for centuries in all parts of the world. Ancient temples, fortifications, and pyramids as well as part of the Great Wall of China were built with soil. Natural, compacted soil has good insulating and resistant qualities[3]. Figure 2.1 below shows one of the ancient tombs made of soil, it is the great Sphinx and tombs of Ramasseum, found in Egypt.



Figure 2-1: The Great Sphinx and tombs of Ramasseum [3].

Soil is, however, vulnerable to moisture and the erosive effects of weather. Soil is composed of microscopic or macroscopic discrete particles, which are not strongly bonded together as

crystals. Additives such as asphalts, cements, lime and other compounds, including salts, syrups, oils, and powders, stabilize soil in varying degrees [11].

Earth construction has been the most effective way of building homes for the population in third world countries and has shown promising results for an economical solution of the housing problems [5]. Soil is however often considered a low-grade material and people in general prefer modern materials such as concrete. Examples of poorly constructed and maintained soil buildings can easily discourage the population in need of sustainable low-cost houses. The knowledge regarding modern soil techniques in Ethiopia are poorly spread throughout the regions and this encourages traditional ways of building which may not be sustainable and can cause harm to the natural environment [6].

2.3 Traditional housing construction in Ethiopia

In Ethiopia soil is used extensively in the traditional construction of mud walls (Chika) both in the Kolla, Woina Dega and Dega area, especially in the central, northeast, northwest and in the southern eastern rift valley area of the country. “Chika” is a mixture of clay, fine and short straw of the Ethiopian common cereal,” Teff” (*Eragroetis Abyssinica*) and water. The mixture, after it has thoroughly been mixed by treading with the human feet is either immediately used, or is left for some time before it is used as a filling material of the opening between wood poles and finally as plaster [12].

Unfortunately, the traditional building techniques adopted for mud walls in Ethiopia have serious defects. The mud walls suffer from extended shrinkage cracks, which weaken the walls. Mud walls can easily be eroded by rain. The practice was to cover mud walls with protective coating consisting of animal dung. This was intended to serve as a wearing surface. The protective surface needed continued maintenance and sometimes renewal almost every year. These entire drawbacks lead most of the people to the misconception that buildings with soil are of inferior quality and should be avoided [4].

Additionally, the traditional building method requires a lot of woods for the construction of walls. Especially, this is common in forestry areas. However, this accelerates deforestation. Since deforestation is one of the main causes of widespread land degradation, it is a major issue in Ethiopia [6]. Figure 2.2. in the next page shows mud house in the middle of Addis Ababa.



Figure 2-2: Housing in the center of Addis Ababa [6]

Ethiopia, this technique has been practiced for long time in the traditional construction way of mud house construction called “Chika bet”. However, mud walls that are constructed using this traditional building technique have many defects [3].

According to Habtemariam, the main defects of mud house construction are: [3]

- a. Can easily be eroded by rain
- b. Walls suffer from extended shrinkage cracks
- c. Consume natural resource like woods (accelerate deforestation)
- d. External and internal appearance not much attractive
- e. The dwellers suffer from health problems due to dust
- f. Requires a regular repair.

2.4 Practices and Application of Earth in Building Construction

2.4.1 Adobe Blocks

Walls made from adobe blocks are the most popular and one of the oldest forms of earth housing. Adobe blocks are made by mixing clay soil with water and/or fiber to a mud-like consistency and then placing the mixture in boxes called "forms". The forms are removed a short time after the blocks are made and the adobe blocks are allowed to dry (or cure) for about a month before they are used to build a wall. The blocks are held together in the wall with a mortar which can be the same mud used for making the blocks [3].

The main advantage adobe has over the other methods is that it is the simplest method, and a satisfactory dwelling can be built with the least amount of construction skill. If it's done right, and it can be strong walls that is relatively free from cracks. Adobe has several disadvantages. Adobe blocks are likely to be "rough looking" and chip easily. Adobe is usually not suited to climates that have high rainfall [11].

Though adobes are most used for lightly loaded single and two-storey residential building, adobes have also been used to construct 10-storey high buildings in Yemen [13].

2.4.2 Rammed Earth

In this method, continuous walls are built by ramming moist soil into position between heavy wooden forms. When a short section of wall is completed the forms are moved upwards or sideways and the process is repeated until the walls are completed. The ramming may be done with either hand or pneumatic tampers, but either way the soil has to be rammed until it becomes dense and extremely firm. Pneumatic tampers require more skill for successful use than hand tampers. A well-made rammed earth wall is one of the most durable earth walls that can be made. Some have lasted for centuries. Rammed earth has the following disadvantages, it is-not easy to do well and the heavy wooden forms take time, money and some skill to build [12].

2.4.3 Cob

In the cob method of construction, stiff mud is molded into balls somewhat larger than a person's head. These balls are then piled up in thick layers to form the wall directly without the use of any kind of forms. The mud must be stiff enough so that it will not have a tendency to slump. If some

slumping or spreading does occur, the mud is put back in place or else the excess mud is sliced off and placed on top. The wall must be constructed slowly so that each layer has a chance to harden before more mud is stacked on top of it. Workers usually stand or sit across the walls so that scaffolding is not needed. The advantages of cob houses are easy to build and need very little construction equipment. However, shrinkage cracks can usually be expected and they may be serious [11].

2.4.4 Compressed Stabilized Soil Flooring Material

Pathways are a necessity in most landscapes to walk easily around and move equipment. Often pathways are a means to get from the front yard to backyard, particularly from the garage. Surface materials can range from colored stamped concrete to crushed rock. Concrete is the most formal material and expensive walkway surface. Asphalt has good durability and traction (for steep slopes) and is surprisingly cost-effective. Soil mixed with cement can also be used as a pathway material [11].

2.5 Compressed Earth Blocks

Considerable researches have been undertaken in the modern times to make earth as a sustainable construction material. This has led to development of technology using earth in the form of rammed earth and unfired bricks popularly known as Compressed Earth Blocks (CEBs) [6].

The compressed earth block is the modern descendent of the molded earth block, more commonly known as the adobe block. The idea of compacting earth to improve the quality and performance of moulded earth blocks [7].

The first attempts for compressed earth blocks were tried in the early days of the 19th century in Europe. The architect François Cointereaux precast small blocks of rammed earth and he used hand rammers to compress the humid soil into a small wooden mould held with the feet [14].

Figure 2.3 in the next page shows the first steel manual press which has been produced in the world in the 1950's was the Cinvaram. It was the result of a research programme for a social housing in Colombia to improve the hand moulded & sun-dried brick (adobe). This press could

get regular blocks in shape and size, denser, stronger and more water resistant than the common adobe [14].

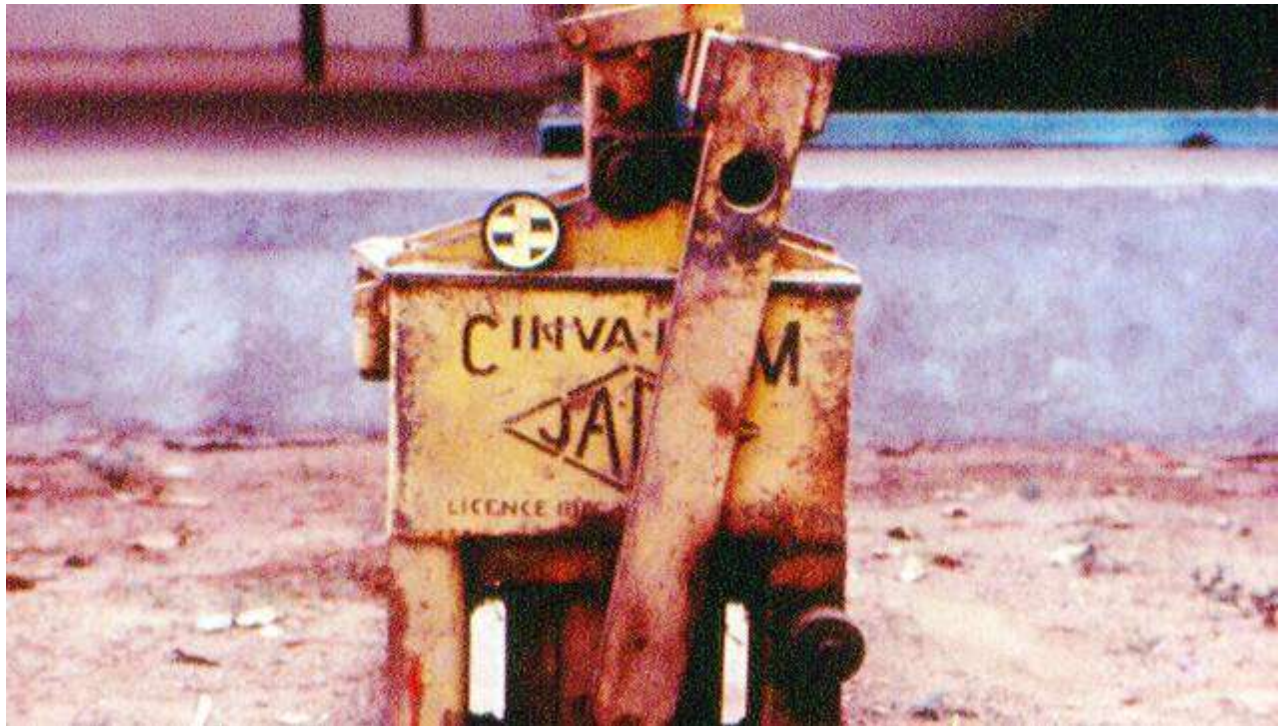


Figure 2-3: Cinvaram, the first press for compressed earth blocks [14]

Since then many more types of machines were designed and many laboratories got specialized and skilled to identify the soils for buildings. Many countries in Africa as well as South America, India and South Asia have been using a lot this technique.

The compressed earth blocks became widely used around the world in the last 30 years or more, not only in third world countries, but also in developed countries like the USA, France, Canada and Australia. In the past, the earth was compressed into block form in the mould by means of a small pestle, or by tamping a very heavy lid forcefully on the mould [12].

Nowadays, a wide variety of presses is used. The production technique of compressed earth blocks (CEBs) differs from rammed earth in that the latter uses a larger formwork into which earth is poured and tamped down, creating larger forms such as a whole wall or more at one time. Materials which are used in CEB production are similar with rammed earth. CEBs are

installed onto the wall by hand and mortar made of a soupy version of the same dirt/clay mix, is spread or brushed very thinly between the blocks for bonding [3].

These earth blocks have many advantages. They have approximately the strength and durability of rammed earth. Some blocks which have had stabilizers (or chemicals) added to them are nearly as satisfactory as burnt brick or certain other building materials. At the same time, walls can be built as easily as adobe block walls. The pressed blocks dry and shrink in the sun before they are laid so that walls essentially crack free, can be built even with soils that shrink a little. Walls made of pressed blocks have a very pleasing appearance and it is not necessary to use surface coatings as long as the right soils are used. It nevertheless must be remembered that much hard work is required for handling and mixing the soil and transporting the finished blocks [11]. Figure 2.4 below shows interlocking compressed stabilized soil blocks and the following Figure 2.5 in the following page shows, wall made from interlocking compressed stabilized soil blocks.



Figure 2-4: Interlocking CSSB at Selam Technical and Vocational Center, Addis Ababa.



Figure 2-5: Wall made from interlocking CEBs in Selam Technical and Vocational Center, Addis Ababa

2.6 Stabilizing compressed earth blocks

2.6.1 Back Ground

The stabilization of soil to improve its properties for building purposes is an ancient practice. The procedures were passed on from generation to generation without necessarily understanding the main mechanisms involved. It was only from the 1920s that systematic scientific approaches emerged [4].

This use of stabilizers such as cement has derived out of a need to improve wet strength and erosion resistance in very exposed walls. In Australia and USA, cement stabilization has become accepted routine practice to stabilize soil and use it as a road bed material [11].

Soil requires to be stabilized because the material as found in its natural state is not durable for long-term use in buildings. By properly modifying the properties of soil, its long-term performance can be significantly improved. The Soil stabilization processes focus on altering its phase structure, namely the soil-water-air interphase. The general goal is to reduce the volume of interstitial voids, fill empty voids, and improve bonding between the soil grains. In this way better mechanical property, reduced porosity, limited dimensional changes, and enhanced resistance to normal and severe exposure conditions can be achieved [10].

Some of the methods used to modify soil can result in irreversible changes, while others may result in reversible changes. The latter are likely to occur due to the lack of resistance offered by soil to environmental agents, especially water. Problems of this type can be effectively overcome by properly stabilizing the soil. Addition of a suitable stabilizer, especially a binder, enable the

soil retain its shape and dimensions. The soil will also gain compressive strength and durability [11].

As several input variables are involved, soil stabilization is likely to remain a complex process. There are several options for stabilizing soil, but the method which is more effective should be considered that will have target on its void and improvement of the bond between particles.

By improving the cohesion and bonding in a soil, action is taken to the stabilizer and links the soil particles together. The method also ensures that changes in volume that would normally occur due to shrinkage and swelling are significantly reduced. Improved bonding also minimizes the vulnerability of the soil to surface abrasion and erosions [3].

The stabilization of soil implies modification of properties of soil-air-water system in order to obtain lasting properties and strength when the soil gets wet. Silt and clay, which are binders of earth, are not stable when they get saturated. Stabilization is considered to be an important step in the manufacture of CSEBs, and is aimed at improving the performance of a soil as a construction material.

Therefore, the aim of soil stabilization is to stabilize soil against water so that, they can maintain some mechanical properties when saturated [10].

The objectives of stabilization are [3]:

- To reduce the volume of interstitial voids to reduce porosity and increase the density.
- To increase the bond between the grains especially when the soil is wet.
- To increase the cohesion and the mechanical characteristics.

There are several methods of soil stabilization widely used to improve the quality of soil blocks. Some of the major stabilization techniques are described below [10].

- i. Mechanical stabilization (by using a compressor)
- ii. Physical stabilization (by improving the soil grading)
- iii. Chemical stabilization (by using a binder to improve bonding between the soil particles).

The major benefits of soil stabilizations by adding binders are continued strength gain with time and long-term durability over decades of service [12]

2.6.2 Mechanical stabilization

Mechanical stabilization involves tamping or compacting the soil by using a heavy weight to bring about a reduction in the air void volume, thus leading to an increase in the density of the soil. The main effects of compaction on the soil are to increase its strength and reduce its permeability. The degree of compaction possible, however, is affected greatly by the type of soil used, the moisture content during compaction and the compression effort applied. Best results can be obtained by mixing the correct proportions of sand and clay in a soil [3].

Improved levels of compaction have a significant effect on the compressive strength of the sample and on the effectiveness of the stabilizer added. If a compressed stabilized soil block could be compacted to a higher density, then for the same ultimate strength the chemical stabilizer content could be reduced. The tradeoff is an increased energy cost for a reduction in chemical additives. [12].

2.6.3 Physical Stabilization

It involves modification of soil properties by introducing the missing size fractions in the soil particle size distribution. The texture of a soil can be altered by calculated and controlled mixing of the different fractions of soil particles together. When this is done, most of the voids that existed prior to physical stabilization are closed due to closer packing of the grains. An anisotropic network is created limiting the movement of the grains in a soil. Unfortunately, as was the case with mechanical stabilization, the effect of physical stabilization alone is not permanent. On saturation with water, soil grains are easily dispersed, or washed away. For better results, physical stabilization of soil should therefore be combined with the other methods [11].

2.6.4 Cement stabilization

Cement as a stabilizing material is well researched and understood and its properties are clearly defined. From different types of cement, Portland cement is readily available in most urban areas, and usually available in semi-urban areas, as it is one of the major components for any building construction. Earlier studies have shown that cement is a suitable stabilizer for use with soil in the production of compressed stabilized soil blocks [8].

Portland cement hydrates when water is added; the reaction produces a cementitious gel that is independent of the soil. This gel is made up of calcium silicate hydrates; calcium aluminate hydrates and hydrated lime. The first two compounds form the main bulk of the cementitious gel, whereas the lime is deposited as a separate crystalline solid phase. The cementing process results

in deposition between the soil particles of an insoluble binder capable of embedding soil particles in a matrix of cementitious gel [6].

The lime released during hydration of the cement reacts further with the clay fraction forming additional cementations bonds.

Cement is considered a good stabilizer for sandy soils but unsatisfactory for clays. Generally, cement can be used with any soil type, but with clays it is uneconomical because more cement is required. The range of cement content needed for good stabilization is between 4% and 16% by weight according to soil type [6].

2.6.5 Pozzolanas stabilization

Pozzolanas are fine silica and alumina rich materials which when mixed with hydrated lime produce cementitious materials suitable for stabilization and construction needs. Pozzolanas are found in their natural state as volcanic ash or pumice or it can be manmade [3].

2.6.6 Sodium Silicate Stabilization

Sodium silicate is used at quantities of around 5% to act as a binding agent to increase compressive strength in sandy and silty soils. Sodium silicate has diverse application as a raw material in the production of adhesives and cement, pulp and paper production, detergent and soap etc. Sodium silicate has also applications in sealing concrete products [11].

2.6.7 Bitumen Stabilization

There are two ways whereby bitumen can stabilize soil. The first way is a binding process that increases soil strength particularly in granular soils. Generally, small amounts of bitumen (2% to 6%) give the soil cohesion. When these percentages are exceeded the bitumen tends to act as a lubricant separating the particles and thus reducing the strength. The second way is when the bitumen acts as a water repellent. The two mechanisms usually occur together in any soil but to different degrees, depending on the type of soil. Soils suitable for bituminous stabilization are sandy soils. Clays need a larger amount for good results [11].

2.6.8 Gypsum Stabilization

Gypsum is a traditional material found in many Mediterranean and Middle Eastern countries. The earliest civilizations used gypsum for building purposes, mainly for plasters and mortars. The advantage that gypsum has over Portland cement and lime is that it requires a low

calcinations temperature (about $1/7^{\text{th}}$ of that needed for cement and $1/5^{\text{th}}$ of that needed for lime) [4].

2.6.9 Lime Stabilization

By adding lime to the soil for stabilization, four basic reactions occur: cation exchange, flocculation and agglomeration, carbonation, and pozzolanic reactions [15].

- A. Cation exchange:** when lime is added to a moistened soil, the latter is flooded with calcium ions. Cation exchange then takes place, with calcium ions being replaced by exchangeable cations in the soil compounds, such as magnesium, sodium, potassium, and hydrogen. The volume of the exchange depends on the quantity of exchangeable cations present in the overall cation exchange capacity of the soil.
- B. Flocculation and agglomeration:** as a result of the cationic exchange and the increase in the quantity of electrolytes in the pore water, the soil grains flocculate and tend to accumulate. The size of the accumulations in the fine fraction increases. Both grain size distribution and structure are altered.
- C. Carbonation:** the lime added to the soil reacts with carbon dioxide from the air to form weak carbonated cements. This reaction uses up part of the lime otherwise available for pozzolanic reaction.
- D. Pozzolanic reaction:** This is by far the most important reaction involved in lime stabilization. The strength of the material results largely from the dissolution of clay minerals in an alkaline environment produced by the lime, and the recombination of the silicate and alumina in the clays with the calcium to form complex aluminum and calcium silicates, thus cementing the grains together. The range of lime content needed for good stabilization is between 4% and 12% by weight according to soil type and will increase as clay content increases [11].

The pozzolanic reaction is believed to be the most important and it occurs between lime and certain clay minerals of moderate to high plasticity. Stabilization of soil using lime occurs because calcium cations supplied by the hydrated lime replace the cations normally present on the surface of the clay mineral, promoted by the high PH environment of the lime-water system. The reaction produces stable calcium silicate hydrates and calcium aluminate hydrates as the

calcium from the lime reacts with the aluminates and silicates solubilized from the clay. Lime can also reduce the degree, to which the clay absorbs water, and so can make the soil less sensitive to changes in moisture content and improve its workability. Lime is a suitable stabilizer for clay soils [7].

The full-term pozzolanic reaction can continue for a very long period of time, even decades, as long as enough lime is present. As a result, lime treatment can produce high and long-lasting strength gains. The key to pozzolanic reactivity and stabilization is a reactive soil, a good mix design protocol, and reliable construction practices [4].

Lime can be produced locally in traditional kilns. It is estimated that up to 40% of cement used in building construction in masonry mortars could be saved through use of lime and other lime associated binders. The advantages that lime has over Portland cement are that it requires less fuel to manufacture and requires relatively simple equipment to make [8].

2.7 Advantages and limitations of Compressed Stabilized Earth Blocks (CSEBs)

2.7.1 Advantages of Compressed Stabilized Earth Blocks (CSEBs)

According to Auroville Earth Institute report, some of the advantages of CSEBs are: [14]

A. A local material

Ideally, the production is made on the site itself or in the nearby area. Thus, it will save the transportation, fuel, time and money.

B. A bio-degradable material

Well-designed CSEB houses can withstand, with a minimum of maintenance, heavy rains, snowfall or frost without being damaged. The strength and durability has been proven since half a century. But let's imagine a building fallen down and that a jungle grows on it: the bio-chemicals contained in the humus of the topsoil will destroy the compressed stabilized soil mix in 10 or 20 years... And CEB will come back to our Mother Earth.

C. Limiting deforestation

Firewood is not needed to produce CSEB. It will save the forests, which are being depleted quickly in the world, due to short view developments and the mismanagement of resources.

D. An adapted material

Being produced locally it is easily adapted to the various needs: technical, social, cultural habits.

E. A transferable technology

It is a simple technology requiring semi skills, easy to get. Simple villagers will be able to learn how to do it in few weeks. Efficient training centre will transfer the technology in a week time.

F. Flexible production scale

Equipment for CSEB is available from manual to motorized tools ranging from village to semi industry scale. It will be easy to use the most adapted equipment for each case.

G. Social acceptance

Demonstrated, since long, CSEB can adapt itself to various needs: from poor income to well off people or governments. Its quality, regularity and style allow a wide range of final house products.

H. Energy efficiency and eco friendliness

Requiring only a little stabilizer the energy consumption in a m³ can be from 5 to 15 times less than a m³ of fired bricks. The pollution emission will also be 2.4 to 7.8 times less than fired bricks. [14]

I. Cost efficiency

Produced locally, with a natural resource and semi-skilled labour, almost without transport, it will be cost effective, more or less according to each context and to one's knowledge.

2.7.2 Limitations of Compressed Stabilized Earth Blocks (CSEBs)

- A. Because of their heavy weight (each block weight 9-10 kg), it is difficult to do wide spans, high & long building with CSEBs. Since weight of walls increase the load on the building foundation.

- B. Can be used in wetter climates but must be protected from moisture and heavy rain. Too much liquid can compromise the shape of the blocks resulting in lack of stability compared to concrete, because of the lack of resistance offered by soil to water. [15].
- C. Not good insulator in colder climate it requires additional insulator [7].

2.8 Compressive Strength of Compressed Stabilized Earth Blocks (CSEBs)

The compressive strength of compressed stabilized earth blocks (i.e. the amount of pressure they can resist without collapsing) depends upon the soil type, type and amount of stabilizer, and the compaction pressure used to form the block. Maximum strengths (described in MPa) are obtained by proper mixing of suitable materials and proper compacting and curing.

Several different minimum values of 28th day compressive strength, all above 1.0 MPa are proposed; some of the recommendations by different authors for the minimum compressive strength of compressed stabilized soil block include 1MPa, 1.4 MPa, from 1.4 to 2MPa and 2MPa [16]. African regional standard ARS 674 – technical specification for ordinary CEB suggest a minimum 28th day compressive strength of 2MPa.

2.9 Compressed stabilized earth block stabilized with lime and cement

Compressed Stabilized Earth Blocks (CSEBs) are manufactured using stabilizers to provide adequate compressive strength and durability, so, as to make them suitable as building blocks. This experimental study on CSEBs will be prepared by using lime as a replacement to cement in certain proportions.

Among the variety of soil stabilizers used, cement has been the most popular stabilizer in the manufacture of CSEBs. Attempts have been made by various researchers in the past to document the role of cement as a stabilizer in CSEBs.

However, compared to cement, utilization of lime as a stabilizer in the preparation of CSEBs has not found popularity. Lime has been used in stabilizing clayey soils, and has been found to impart long-term strength gain as reported in literatures [8].

As lime is known to impart strength in the long term, its utilization in some proportion as a replacement to cement may be beneficial.

This paper will attempt to understand the role of lime in combination with cement as a stabilizer in CSEBs production. Any effort to optimize the quantity of stabilizers used in combination would help in increasing the strength of the blocks' production.

2.10 Materials for production

2.10.1 Soil

Soil is the main component that the CSEB consist of. There are soil of different qualities and disposition, depending on where it comes from and it is important that the soil has the right composition before being mixed with the cement and water. Before producing CSSB, the soil must be tested to determine if it is suitable for the CSSB-production. Suitability criteria is based on the gradation, plasticity and chemical composition of the soil. Suitability criteria for soil to be used for CSSB production is described in section 2.11.3.

The finer fractions of the soil such as the clay and silt contribute to the fresh block not falling apart while the sand and gravel react with the stabilizer to stabilize the cured and dry block. Soil containing humus should not be used since it opposes the cement and it is therefore important not to use the topsoil (30-40 cm). The PH level is also of important factor; soil having a PH level below 4.5 or over 10 should be avoided as well as soils containing more than 2 % of sodium and potassium salts [17].

2.10.2 Cement

The cement works as a stabilizer and prevents the blocks from being decomposed when in contact with water. By adding cement, the blocks will have further improved durability, strength and volume stability due to the chemical reactions taking place between the cement and the soil. The effects will be in proportion to the cement quantity and the strengths of the blocks will generally increase linearly with the cement content, but at different rates for different soils. There is no need of adding more cement than needed for the purpose of the soil blocks due to the high costs of cement. The recommended cement rate is normally at a rate of 4-16 % (weight) depending on the type of soil [3].

2.10.3 Lime

The earliest used of lime can be traced back to 4000 B.C. when it was used in Egypt for constructing pyramids. First documentation on the usage of lime in construction on road stabilization was during the Roman Empire. The document was written by Marcus Vitruvius Pollio (80 BC – 15 BC) an architect, engineer and writer, and known as the world first known engineer. Lime has proven performances and played important role in masonry construction which has lasted for centuries such as Great Wall of China. [18]

Lime in the form of quicklime (calcium oxide – CaO), hydrated lime (calcium hydroxide – Ca (OH)₂), or lime slurry can be used to treat soils. Quicklime is manufactured by chemically transforming calcium carbonate (limestone – CaCO₃) into calcium oxide. Hydrated lime is created when quicklime chemically reacts with water. It is hydrated lime that reacts with clay particles and permanently transforms them into a strong cementitious matrix [17].

According to ASTM C977 [19], quicklime and hydrated lime for soil stabilization shall conform to the following chemical composition:

- Calcium and Magnesium Oxides (on a non-volatile basis, minimum %)...90.0
- Carbon Dioxide (taken at point of manufacture, maximum %)...5.0
- Free Moisture (taken at point of manufacture, maximum %)...2.0

“Lime” is also sometimes used to describe byproducts of the lime manufacturing process (such as lime kiln dust), which, although they contain some reactive lime, generally have only a fraction of the oxide or hydroxide content of the manufactured product [20].

2.10.4 Water

Soil contains pores filled with air and water and these spaces will be reduced during compaction. By adding more water to the mixture, the grains will be lubricated and air voids will be replaced making it easier for the grains to slide past one another. Water is also necessary in the hydration process of the stabilizer. It will together with the silt and clay make the fresh block not fall apart after being pressed. The amount of water varies depending on the dryness of the soil [6].

2.11 Properties of soil for compressed Stabilized soil blocks

2.11.1 General properties

Soil is the result of the transformation of the underlying rock under the influence of physical, chemical and biological processes related to biological and climatic conditions. It is found deposited on the surface of the earth and may consist of many different types. The variation in the soils present at the surface can be attributed to a series of natural effects working on the area over time. On the very surface of the soil one typically finds material with a large amount of organic compounds. This is unsuitable for block manufacture and can usually be distinguished by a musty smell especially on heating. Material underneath this organic layer is much better as it usually contains a cross section of particle sizes and includes a proportion of small soil particles called “fines”. These are usually defined as particles passing a 75 μ m mesh and consist of silt and clay. Clay is necessary in block production because it aids the workability of the mixture, increasing levels of consolidation and improving green strength. Larger particles “sands” found in soil can generally be assessed as minerals that are silicas, silicates or limestones. Soil has a proportion of water and air that fill the gaps between adjoining particles in the soil. This gives natural soil a nonhomogeneous and porous nature [5].

With so many different characteristics that one could discover about a sample of soil, it would be unwise to try and discover them all in every situation that soil is to be used for making compressed stabilized soil block. Only a small number of characteristics are of real relevance to the scientist testing the soil. The chemical composition of the soil is of little importance once the absence of unstable compounds and organic matter has been established.

The physical properties are of greater interest for making compressed stabilized soil block as these will help to determine its ease of mixing, forming, de-moulding, porosity, permeability, shrinkage, dry strength and apparent bulk density. Controlling or monitoring the clay fraction is important in making compressed stabilized soil blocks. Too much clay results in unacceptably high expansion upon wetting, requiring excessive amounts of cement to attune this. Too little clay causes low adhesion between particles and hence causes high breakage rates on de-moulding of the compressed stabilized soil block. The basic material, however, required to

manufacture compressed stabilized earth building blocks is a soil containing a minimum quantity of silt and clay so as to facilitate cohesion [6].

Chemical properties are also sometimes of interest particularly when a chemical additive is used. These chemical properties include the composition, mineral content, metallic oxides, PH levels and sulphates in the soil [4].

Using a suitable soil for CSEBs production will result in: [5]

- A. Strong blocks, namely those that after curing possess high compressive strength and erosion resistance.
- B. Handle able blocks that immediately upon demoulding can be transferred to a curing area without a high breakage rate.
- C. Block that will not seriously distort or crack during curing.
- D. Blocks, which will not expand and contract excessively in the building if subjected to wetting and drying cycles.

Specifically, disqualified soils are: [13]

- A. Those containing high excessive organic impurity.
- B. Those, which are highly expansive.
- C. Those containing excessive soluble salts

2.11.2 Classification of soil

Soils are classified in many different ways: by their use, origin, size, texture, color and density. For building purpose soil can be generally characterized in two ways, by a particle size distribution analysis and by a plasticity index. The particle size analysis will give information on the soil ability to pack into a dense structure and the quantity of fines present (combined silt and clay fraction), while the plasticity index gives an idea of cohesion of the fines.

A. Classification by grain size

All soils consist of disintegrated rock, decomposed organic matter and soluble mineral salts. Soil types are graded according to particle size using a system of classification widely used in civil

engineering. The classification of soils based on grain size, according to the Ethiopian Building Code of Practice, EBCS and ASTM, are summarized as shown in Table 2.1 and 2.2 respectively.

Table 2-1: Soil classification according to particle size in mm EBCS 7 [21].

| Stone | Gravel | | | Sand | | | Silt | | | Clay |
|--------|--------|--------|------|--------|---------|----------|-----------|------------|-------------|--------|
| | Coarse | Medium | Fine | Coarse | Medium | Fine | Coarse | Medium | Fine | |
| 60-200 | 20-60 | 6-20 | 2-6 | 0.6-2 | 0.2-0.6 | 0.06-0.2 | 0.02-0.06 | 0.006-0.02 | 0.002-0.006 | <0.002 |

Table 2-2: The grain size classification based on the ASTM D 2487 Standards [22].

| Pebbles | Gravel | Sand | Silt | Clay |
|--------------|-----------|--------------|------------------|--------------|
| 200 to 20 mm | 20 to 2mm | 2 to 0.006mm | 0.06 to 0.002 mm | 0.002 to 0mm |

Gravel is not usually used in soil- cement production, as the large particle size may lead to a poor (rough) surface finish. A suitable soil will contain a mixture of sand, silt and clay sized particles. The properties of each of these three fractions influence the properties of the block and will be discussed below.

A particle size analysis will determine the fraction of a soil’s particles that fall within each of the above size bands. If dense block is to be produced, it is important that the soil used is “well graded”. The theoretical distribution of particle sizes to provide a perfectly packed structure is called the fuller curve. The fuller distribution is an ideal model and never occurs naturally. However, a natural soil which has an even distribution of particle size, termed well graded is a good approximation.

The value of a well-graded soil for compressed stabilized earth blocks is that such a distribution of sizes gives a dense structure with a low specific surface area. A dense structure is important for several reasons. A densely packed arrangement will have a higher number of contacting particles, giving a better load-bearing skeleton. The number and size of the inter-particle voids will be reduced as will the number of linked voids, these will reduce the porosity of the soil and hence also its permeability, thereby reducing susceptibility to water penetration. As the interlocking calcium silicate matrix extends through the soil voids, a more compact void system requires less cement to provide a matrix of equal efficiency.

Similarly, if it is imagined that chemical stabilizer (cement or lime) coats the surfaces of soil particles, a high specific surface area soil will need high amount of chemical stabilizer for blinding, or a lower specific surface area soil will require less stabilizer to provide the same particle surface coverage and consequently the same strength and durability.

A coarse soil containing no fines (silt and clay) is non-plastic and will not have sufficient cohesion to retain its shape on ejection from the mould or to allow easy transportation to the curing area. The coarse soil could be considered to be a form of sand-cement containing large voids (a result of the lack of fines). Large voids would increase the porosity of the block and lead back to the common sand-cement problem of rapid drying before the cement has had time to adequately cure. Such a soil would be considered well graded but still be unsuitable for soil-cement block production.

Conversely a well-graded fine soil, containing little sand but high clay content, would have a high specific surface area and expansive behavior. The high clay content would give the soil cohesion and stability on ejection from the mould, but the high specific surface area would require a large amount of cement to provide reasonable particle coverage.

Thus, a suitable soil will be well graded but certain other limits should also be imposed: the largest particle size present should not be sufficiently large to cause a poor surface finish.

B. Classification by plasticity (Fine content)

The silt and clay content of a soil are responsible for soil cohesion and it is these fines that provide the fresh blocks with handle ability.

The degree of cohesion provided to the block is dependent both on the fines present and the degree of compaction used to form the block.

In general terms, a low-pressure moulding process will require higher fines content than a high pressure moulding process. This is because increased compaction will force the soil particles into more intimate contact, thus strengthening the fresh compact.

The fines also affect the final cured block's expansion on wetting. Clay usually exists in small agglomerations, which expand in three dimensions on wetting as water penetrates some of the numerous individual particle boundary fissures. The expansions of the clay fraction must be largely restrained by the calcium silicate matrix in order to minimize expansion and contracting of the cured block, on reported wetting and drying. Hence for durability the clay fraction should be as small as possible to allow the lowest cement content. It might be expected from the large difference between the specific surface area of the three clay types mentioned above that different clays significantly differing expansions characteristics on wetting. This is the case, in general as the surface area of the clay fraction rises, so does the amount it will expand on wetting. As a result, the type of clay as well as the quantity present will affect the block.

The fine fraction can be seen to be helpful to the block production process but to adversely affect the wet strength and durability of the final cured block. The quantity and type of clay should therefore be considered important soil parameters.

The Atterburg tests defining liquid limit, plastic limit and plasticity index are used to quantify the plasticity of the finer fraction of a soil (only particles less than 0.425 mm are tested). These tests measure the percentage water contents at which the soil passes from a liquid state to a plastic state (liquid limit) and from a plastic state to a solid state (plastic limit). The numerical difference between the liquid and plastic limit (the plasticity index) thus gives the range of water content over which the soil may be considered plastic. As plasticity is dependent on the soil cohesion, it has been found that this index reflects the cohesive characteristics of the soil. Furthermore, as cohesion is largely dependent on the specific surface area of the fines, these plasticity limits also reflects the expansiveness of the soil. A soil with a low plasticity index will display low cohesion and usually low expansion on wetting, while a high index soil will display the reverse [12].

2.11.3 Suitable Soil for Stabilized Compressed Earth Blocks

A suitable soil should not contain organic material or excessive soluble salts, which would interfere with the setting of the chemical stabilizer. Its sand fraction should be well graded to provide a densely packed load-bearing skeleton for the block and its largest size particle should be small enough to give a smooth surface finish. The fine fraction should be just sufficient to

provide enough cohesion to the fresh block to prevent damage on ejection and transportation from the mould. Too large fines content will either require large cement content for adequate stabilization or will reduce the durability and wet strength of the final cured block. The cohesion of the fresh block will depend on the compaction pressure used and the type as well as the quantity of clay present in the fines [4].

From the above it should now be possible to see the role that each of the soil's component fraction plays in a stabilized compressed earth block and the importance of selecting a suitable soil. If the soil available on site appears unsuitable, it should be remembered that natural soil exists in distinct strata with differing compositions. If the different strata are adequately tested then it is a comparatively simple operation to mix suitable masses of two or more strata to produce an acceptable soil.

2.11.4 Available criteria for soil suitability

Selecting a suitable type of earth can take place in the field using parameters, which are the fruit of experience acquired in the course of operational practice. If any doubt persists, laboratory identification tests should be carried out.

We need clay to be present in compressed stabilized soil block and it is impossible in humid climates to avoid moisture differentials so that the only characteristics that we can seek to reduce are the porosity and permeability.

In order to decide whether a soil sample is suitable for compressed stabilized soil block production or not, one should determine the particle size distribution. From such test results and previous practical experiences, one can get indication on the suitability of the soil sample in question.

A more useful range of particle sizes suitable for building with earth block is given in as follows [23]

- Sand/fine gravel: 40 - 75%
- Silt: 10 - 30%
- Clay: 15 - 30%

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Based on African Regional Standards and experiences from laboratory investigations, if the granular composition of soil falls within the limits of the recommended shaded area of Figure 2.6 below, the soil is usually considered as suitable for stabilized soil block production. Types of earth the granular composition of which fall outside the shaded area may still give acceptable results, but it is recommended that they be subjected to a series of tests enabling their suitability to be assessed. [24]

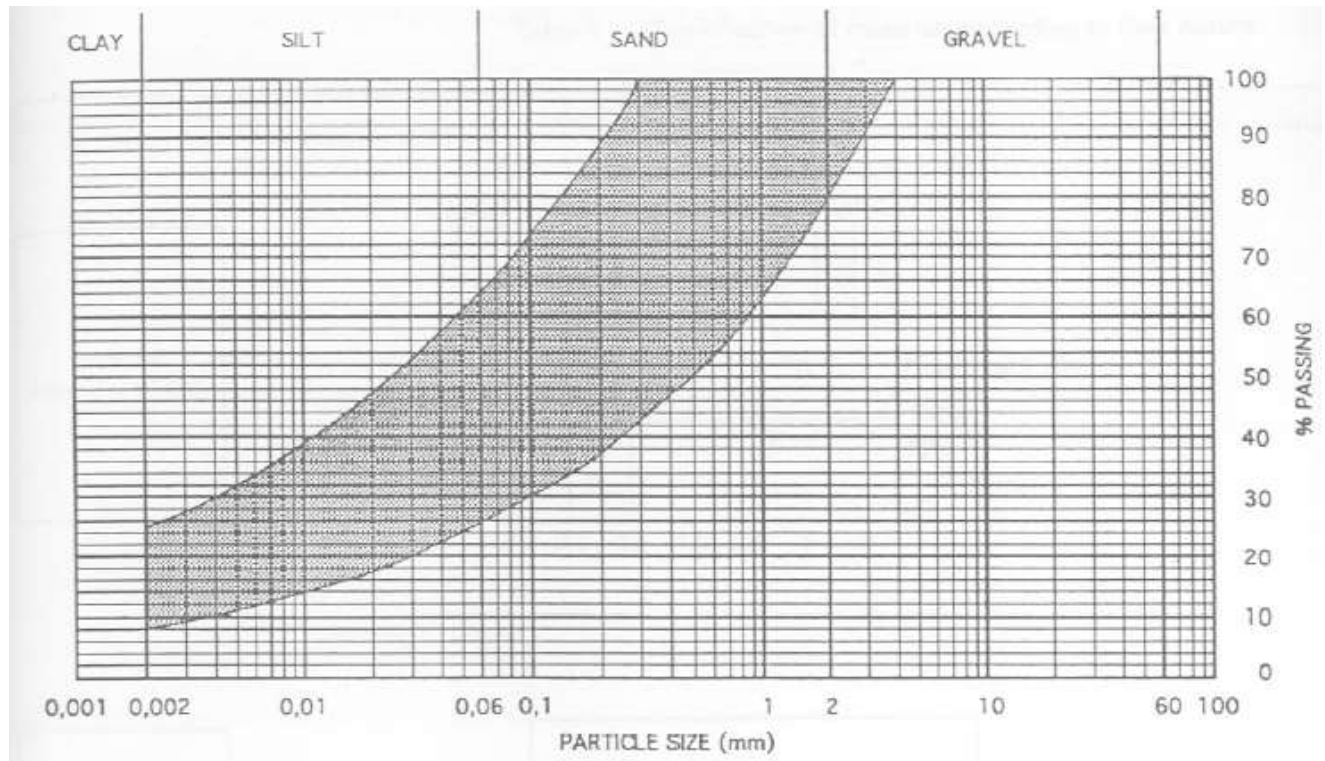


Figure 2-6: Granular Composition Criteria based on African Regional Standards [24]

Additional tests such as liquid and plastic limits can also be made. Such test results will give indication about the plasticity (workability) of the soil in question. If plasticity of the soil fall preferably with in the limits of the recommended shaded area of the diagram of plasticity as shown in Figure 2.7 in the following page, the soil is considered suitable for compressed stabilized soil block production. Types of earth the plasticity of which fall outside the shaded area may still give acceptable results, but it is recommended that they be subjected to a series of tests enabling their suitability to be assessed [24].

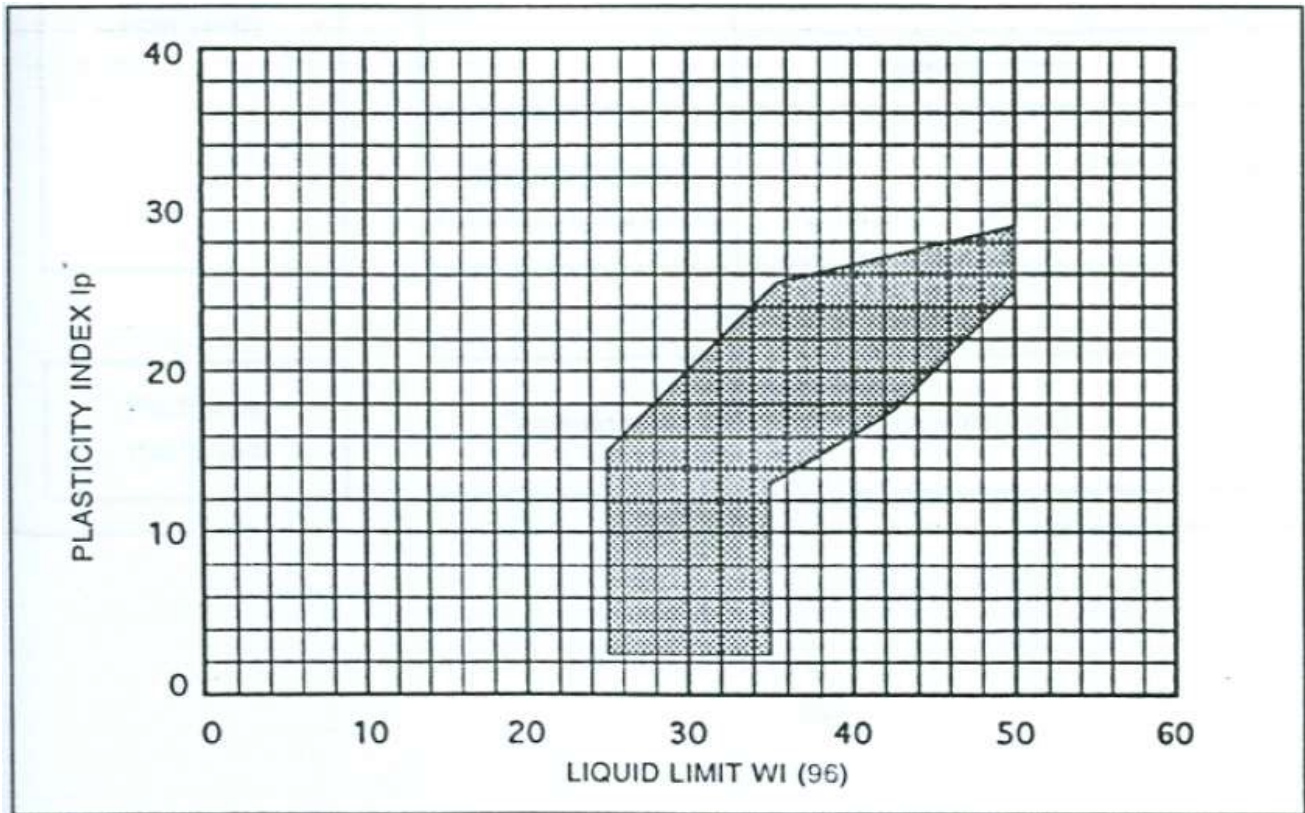


Figure 2-7: Plasticity Criteria based on African Regional Standards [24].

2.12 Tests for soils

Prior to compressed stabilized soil block production there are three main types of tests, which may be conducted: Field tests, Laboratory tests and trial production tests.

First, field tests can divide the soils in to two categories. These categories are suitable and unsuitable and if suitable in to potential high and low cement classes.

Second, Laboratory tests can be used to characterize the soils by particle size distribution, plasticity or other numerical measures for relation to the selection criteria (see section 3.4) and enable simple soil modification by blending.

Most small- scale manufacturers of blocks, especially those producing blocks at a rural building site, have little or no access to laboratory facilities and in particular accurate mass measurement. For these block makers, judicious use of the field tests, the shrinkage test, production trials and past experience has to suffice.

The laboratory tests are appropriate where medium or large- scale production is planned, where minimizing stabilizer content is especially important or when compressed stabilized soil block making is moving into a new area.

Third, trial production tests can be carried out on manufactured blocks to check that the final block properties required (dry strength, wet strength and durability) can be achieved.

2.12.1 Field tests

Field tests are for preliminary site surveying to identify if the soils are most likely suitable and so restrict the number of soils to be more rigorously assessed by laboratory tests or trial production. The tests will provide a rough idea of a soil's grading and plasticity and also indicate whether a soil contains significant organic matter (reject outright), a majority of gravel, a majority of sand or a majority of fines. They may also be able to distinguish whether silt or clay is a more significant fraction of the fines. They are generally fairly easy to perform and often require little or no experimental equipment, making them very simple to implement.

Simple field tests which are performed to get an indication of the composition of the soil sample includes: smell test, nibble test, touch test, sedimentation test, adhesion test, washing test, linear shrinkage test, dry strength test, water retention test, consistency test and cohesion test [4].

However field tests are frequently reported, without acknowledging the reliance they place on the operator's senses. Interpretation of the results is a skilled operation. Consider for example the dry strength test, the prepared soil sample is crushed between the fingers and the ease of crushing is taken as a measure of the soil's clay content. For a novice operator, the ease of crushing the soil and comparing the clay content is difficult but a skilled operator may compare the ease of crushing with that of soils he/ she has previously tested and hence arrives at a more precise conclusion.

Tests that rely on personal judgment are open to differing interpretation between operators and depend on the operator's skill for their accuracy. Training and experience of field tests may provide a fact, quite accurate determination of the soil's characteristics.

2.12.2 Laboratory tests

The laboratory tests establish numerical values for certain soil parameters, primarily the percentage distribution of the different sizes of soil particles present and the plasticity limits. These values are subsequently used to determine the best available soil or domination of soils. All of these tests rely on accurate weighing and or some form of laboratory equipment scales with a resolution higher than one thousandth of the chosen sample weights is desirable. There are four main types of tests: The sieving test, sedimentation test, Atterburg limit test and compaction test.

The sieving tests separate the different size fractions of the soil in to discrete parts thereby indicating the soil's particle grading. The silt and clay fraction are too small to particle grading. The silt and clay fractions are too small to be easily separated by sieving and as such are normally reported as a combined fraction. The larger particles may be separated in to a number of size fractions, depending on the number of sieve sizes available, according to the EBCS and ASTM particle classification boundaries. A full laboratory analysis would give the percentage by weight of each of these size bands.

The Atterburg or plasticity tests define the soil's liquid limit, plastic limit and plasticity. The Atterburg limits allow the soils plasticity characteristics to be related to the criteria given in section 2.9.4 above.

2.13 Current Application of compressed stabilized earth blocks

Since the very earliest of times, earth has been used as a major building material and today we can find evidence of this fact over vast areas of our planet. The earth-compressed blocks are widely used around the world in the last 30 years not only in the third world countries but also in the developed countries like USA, French, Canada and Australia. It is also the most popular material amongst Europe's bio-ecological constructors on account of its physical attributes and ability to regulate moisture and temperature [4].

The research centers in India Auroville, CRATerre in France, and the Hydraform Company in South Africa have made great progress on compressed earth block.

Now a days Compressed earth block, its flexible size and shape allows it to be used to achieve many different types of masonry and so to build houses of any style. In hot countries, and even

more in those with a wide thermal variation, a compressed earth block wall creates a truly comfortable living environment compared to sand, cement based materials. Occasionally, a social unwillingness to use the compressed earth block can be encountered when the compressed earth block has been too strongly associated with low cost or “cheap” building.

In India different researchers are doing researches on compressed stabilized earth blocks using different soil and stabilization techniques. The application of Compressed stabilized earth blocks in India are in different areas like schools, stores, offices and also low cost housing programs. The use of CSSBs in India is encouraging. Arches and rounded corners are an option that allow for flexibility in design as shown in Figure 2-8 below.



Figure 2-8 Soil block building in India [4]

African countries such as Zambia, Ghana, Kenya, Uganda, Nigeria, Tanzania and Southern Africa are experiencing new forms of housing construction using compressed stabilized earth blocks, due to massive influx of people from rural areas, resulting in high demand for housing. Notwithstanding, the CSSB application in housing construction has not been encouraging by the incorrect perception that it is strongly associated with traditional unstabilized soil. Another setback for stabilized-earth blocks has been the absence of quality control procedures and in particular of testing equipment to monitor quality. The apparent lack of attempts to address those problems has been compounded by taste of modernization for sand-cement or concrete housing construction technology.

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The use of CSIEB for building construction follows the principle of dry stacking. In dry stacking construction, the interlocking blocks are laid without mortar thereby leading to considerable savings in cost associated with mortar. The development of the interlocking block technique gained popularity in most developing countries around the world.

Today the application of these various dry-stack constructions extends from rural community houses, urban and suburban applications in medium-sized social and commercial buildings such as schools, hospitals, offices, shops and stores.

The first documented usage of the Compressed Stabilized Interlocking Earth Blocks (CSIEB) masonry in Nigeria was that of a 60-unit housing estate experimented in 1991 at the University of Lagos, Lagos. Professionals in the building industry showed high preference for the use of interlocking masonry unlike the conventional types and this is because of the shorter period of setting, higher strength, reduced number of labour involved in its operation and overall reduction in cost of masonry works. Also the use of CSIEB for building construction will give a cost effective construction, aesthetically pleasing finish and reduction in cost of finishes and maintenance.

The use of CSIEB by the Nigeria government for construction of public buildings such as schools, hospitals and markets can also serve as a means of increasing the awareness of this material among stakeholders and the public in general, hence increasing the level of usage in Nigeria[17].



Figure 2-9: CSIEB used for the construction of a caring heart mega school, Ondo state, Nigeria

In Ghana Kumasi, the Ashanti Regional capital there is production centre of the CSSBs at the Department of Housing and Planning Research (DHPR) which happened. This center had built a number of experimental buildings in and around Kumasi. The DHPR had to its credit, a number of experimental buildings including office, workshop, residential and school hall.

The effects of the activities of the department easily sprawled into the surrounding communities.

The classroom buildings for the Ayeduase Primary School were built with CSSBs.



Figure 2-10: Two-storey Office Block for DHPR on Kwame Nkrumah University Science and Technology (KNUST) campus built with CSSBs

2.14 CSSBs Application in Ethiopia

In Ethiopia, the application of CSSB as wall making material is in its earlier stage, this is mainly because of shortage of awareness in the society. This gives frustration for the block manufacturers. But now a days some are preferring using CSSB for constructing walls for schools, guard houses, fences, offices and halls, because of its lower cost and speed of construction specially in case of interlocking CSSBs.

A. Selam Technical and Vocational Center Addis Ababa

Selam Technical and Vocational Center (STVC) is located in Addis Ababa and was established over 25 years ago. The center provides child care for orphans, education, vocational training and development of appropriate and sustainable technology. By providing courses in different subjects the centre aims to train and educate the society and contribute to a more sustainable future. Since its establishment it has grown to a well equipped and organized training college and is currently in the forefront of CSSB-production.

Different types of CSSB are produced at their facilities, all with different shapes. The most common produced block is the interlocking CSSB, with a cement proportion of 8 %. Another type of block has one corner made as a quarter of a circle which is ideal for corners or freestanding columns. The productivity is approximately 4 blocks per minute using the electrical press and the blocks were then placed under shade for 28 days of drying.

Most of the office buildings and the training rooms in Selam Technical and Vocational Center compound are made with CSSBs.



Figure 2-11 The kitchen facility at STVC, built with interlocking CSSB [6].

B. Save the children, Office building

Save the children organization has an office building in Mekanissa, situated on the hill to the Akaki River in Addis Ababa, Ethiopia. The office consists of a two storey building with a concrete frame and a roof that is made out of; a corrugated asphalt impregnated cellulose sheet making the roof lightweight.

The interior and exterior walls consist of CSSB and were produced on the site with the soil from the site. The block production team was introduced to the block making methods and trained by Abako International Partners, an architecture and construction management company based in Gothenburg Sweden. The blocks in the exterior walls are 200 mm wide and have a cement content of 15 %. The blocks in the interior walls are built with 140 mm wide blocks and have a cement content of 7 %. The walls were then painted [6].

The building was built from 1995-1997 and has a gross area of 850 m². It is of good demonstration that the CSSBs can be used in office buildings and not only used in low-cost housing projects [6].



Figure 2-12 Save the children, Office building, Addis Ababa [6]

C. Ropack Realestate

Ropack international (Ethiopia) PLC is a real estate development company that has been operating in Ethiopia since 1998G.C. It is one of the real estate developer established through joint venture investment of local and foreign investors. The company had secured 600,000 sq. m plot of land around Lege T'afu, Oromia region, which is located 15 Kms from Addis Ababa and had built 270 villa houses having 500-1000 sq. m plot area. The walls of the houses are made from CSSBs.

The company was established to engage in diversified business lines including housing projects, corrugated iron sheet metal, CSSB production and car assembly.

Figure 2.13 shows villa houses in Ropack real estate whose wall is constructed by using CSSBs.



Figure 2-13: villa house in Ropack real estate, wall built with CSSBs. Lage T’afu, Ethiopia

2.15 Summary of literature review and gap identification

2.15.1 Summary of literature review

The compressed earth block is the modern descendent of the molded earth block. The idea of compacting earth to improve the quality and performance of moulded earth blocks.

The materials used for the construction of wall are normally required to possess adequate compressive strength and erosion resistance. Such properties of the soil can be improved by stabilizing it with different stabilizers like cement, lime etc. The strength of stabilized soil blocks can further be improved by the process of compaction which leads to higher densities, thereby higher compressive strength and better resistance to erosion. Exploring the stabilization and compacting techniques, a cheap yet strong and durable material for wall construction is the stabilized earth block. The merit of these blocks is low-cost, use of locally available material, blocks can be made at site with no transportation cost and simplicity in manufacture.

In preparing the soil for block production, there is need for careful and correct selection of the soil, gradation test and plasticity test should be performed and checked with standards for compressed earth blocks. Chemical analysis test should also be performed for the soil sample. The quality of the stabilizer should be checked before manufacturing the blocks. The stabilizer content also affects the quality of the blocks. To get the best result and after the mix was put in the mould, it should be given proper compaction. Proper curing should also be made which prevents rapid drying.

2.15.2 Gap identification

Considerable researches have been undertaken in the modern times to make earth as a sustainable construction material. This has led to development of technology using earth in the form of rammed earth and unfired bricks popularly known as Compressed stabilized earth blocks (CSEBs).

CSEBs are manufactured using stabilizers to provide adequate compressive strength and durability, so as to make them suitable as building blocks. Though cement is a popular stabilizer used in manufacture of CSEBs, much effort had not been done in utilizing lime in combination of cement.

However, compared to cement, utilization of lime as a stabilizer in the preparation of CSEBs has not found popularity. Lime has been used in stabilizing clayey soils, and has been found to impart long-term strength gain as reported in literatures [8].

As lime is known to impart strength in the long term, its utilization in some proportion as a replacement to cement may be beneficial.

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This paper will attempt to understand the role of lime in combination with cement as a stabilizer in CSEBs production. Any effort to optimize the quantity of stabilizers used in combination would help in increasing the strength of the blocks' production.

3 PROPERTIES OF MATERIALS, MIX PROPORTIONS AND TESTS

3.1 Introduction

In this section, the materials used in the investigation are described with respect to their physical and chemical properties. Furthermore, mix proportioning and sample preparation procedures undertaken in this research are discussed in detail. Physical investigations on soil were carried out in and Geotechnical Laboratory of Addis Ababa Institute of Technology. The chemical composition test of the soil and lime were performed at Geological Survey of Ethiopia; Geochemical laboratory.

3.2 Properties of material used

3.2.1 Soil

The soil used in this study was brought from Kara area, which is around 15km East of Addis Ababa. Soil samples were prepared by drying and sieving to the required size. The laboratory tests conducted helps to establish numerical values for the soil sample parameters.

These values are subsequently used to determine the suitability of the soil sample for compressed stabilized earth blocks. The physical properties and chemical composition of the soil are given in Table 3.1 and Table 3.2 respectively. The detail test results are given on the Appendix A and B. The suitability of the soil for the production of CSEBs is discussed in chapter 4.

Table 3-1: Physical properties of the soil

| | Physical properties | Values |
|---|----------------------------|---------------|
| 1 | Specific gravity | 2.59 |
| 2 | Natural moisture content | 5.33% |
| 3 | Silt content | 16.3% |
| 4 | Clay content | 15.2% |
| 5 | Sand content | 68.5% |
| 6 | Liquid limit | 33.8% |
| 7 | Plastic limit | 24.4% |
| 8 | Plasticity index | 9.4% |

Table 3-2: Chemical Composition of the soil

| Chemical Oxides | SiO ₂ | Al ₂ O ₃ | Fe ₂ O ₃ | CaO | MgO | Na ₂ O | K ₂ O | MnO | P ₂ O ₅ |
|-----------------|------------------|--------------------------------|--------------------------------|-----|------|-------------------|------------------|-----|-------------------------------|
| Composition (%) | 64.22 | 16.66 | 5.48 | 1.3 | 0.42 | 1.9 | 2.84 | 0.1 | 0.03 |

| Chemical Oxides | TiO ₂ | H ₂ O | LOI | SO ₃ | Cl ⁻ | PH |
|-----------------|------------------|------------------|------|-----------------|-----------------|------|
| Composition (%) | 0.24 | 1.82 | 4.95 | 0.22 | <0.01 | 7.44 |

3.2.2 Cements

The cement used in all the mixes was manufactured by Derba Portland pozzolana cement. The cement is produced as per CEM-II-32.5 grade and contains 67% clinker, 28% pumice and 5% gypsum [25] .

3.2.3 Water

Throughout the investigation tap water, which is supplied by the Addis Ababa water supply system of the city, is used.

3.2.4 Lime

Lime from two sources was used for the research work. The first lime was bought from the local market and its chemical composition was tested twice at Geological survey of Ethiopia; Geochemical laboratory. The first and second chemical analysis results of the lime are given in Table 3.3 and Table 3.4 respectively.

Table 3-3: The first chemical composition test result of lime from source one (Generic lime)

| Chemical Oxides | SiO ₂ | Al ₂ O ₃ | Fe ₂ O ₃ | CaO | MgO | Na ₂ O | K ₂ O | MnO | P ₂ O ₅ |
|-----------------|------------------|--------------------------------|--------------------------------|-------|------|-------------------|------------------|-------|-------------------------------|
| Composition (%) | 2.76 | 0.46 | 0.26 | 37.68 | 0.96 | 0.12 | <0.01 | <0.01 | 0.34 |

| Chemical Oxides | TiO ₂ | H ₂ O | LOI | SO ₃ | Cl ⁻ | PH |
|-----------------|------------------|------------------|------|-----------------|-----------------|------|
| Composition (%) | 0.01 | 5.88 | 1.41 | 48.64 | <0.01 | 7.96 |

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Table 3-4: The second chemical composition test result of lime from source one (Generic lime)

| Chemical Oxides | SiO ₂ | Al ₂ O ₃ | Fe ₂ O ₃ | CaO | MgO | Na ₂ O | K ₂ O | MnO | P ₂ O ₅ |
|-----------------|------------------|--------------------------------|--------------------------------|-------|------|-------------------|------------------|-------|-------------------------------|
| Composition (%) | 1.38 | 3.30 | 0.22 | 30.56 | 0.50 | 0.26 | 0.04 | <0.01 | 0.01 |

| Chemical Oxides | TiO ₂ | H ₂ O | LOI | SO ₃ | Cl ⁻ |
|-----------------|------------------|------------------|------|-----------------|-----------------|
| Composition (%) | 0.02 | 16.31 | 4.77 | 43.13 | <0.1 |

As both chemical test results above indicate the CaO content in the first test is 37.68% and 30.56% in the second test. And the SO₃ is 48.64% & 43.13% in the first and second test respectively. Therefore, the lime from source one (Generic lime) is not pure lime, since the SO₃ content is high it can be considered as gypsum. The impurity of lime will affect the performance of the produced stabilized compressed earth block. Therefore, the researcher brought hydrated lime from lime manufacturing factory, Senkale lime factory. And the chemical analysis result of the lime from Senkale Lime factory is presented in the Table 3.4 below and in Appendix B.

Table 3-5: Chemical composition result of the lime from second source (Senkale lime)

| Chemical Oxides | SiO ₂ | Al ₂ O ₃ | Fe ₂ O ₃ | CaO | MgO | Na ₂ O | K ₂ O | MnO | P ₂ O ₅ |
|-----------------|------------------|--------------------------------|--------------------------------|-------|------|-------------------|------------------|------|-------------------------------|
| Composition (%) | 9.48 | 5.16 | 2.64 | 48.80 | 1.02 | 0.4 | <0.01 | 0.24 | <0.01 |

| Chemical Oxides | TiO ₂ | H ₂ O | LOI | SO ₃ |
|-----------------|------------------|------------------|-------|-----------------|
| Composition (%) | 0.07 | 10.30 | 23.89 | 0.31 |

As the chemical composition of the lime from source two (Senkale lime) above indicates the CaO content of the lime is 46.8% and the SO₃ content is 0.31%. Since the SO₃ content is very low the lime from source two is considered as lime. The CaO and MgO content of the lime from senkale is 46.8% and 1.02% respectively and the total CaO and MgO content is 47.82% which is lower than the ASTM C977 standard for soil stabilization which is 90% [19]. And the lime powder contains 10.3% H₂O which is above the standard; the maximum moisture content based on the standard is 2%.

Loss on ignition is a test used in inorganic analytical chemistry. In a process in which materials are subjected to high temperatures such as lime, or cement manufacture, the loss on ignition is

roughly equivalent to the loss in mass that it undergo in a kiln. The loss on ignition of the product indicates the extent to which the calcination process was incomplete. The volatile materials lost usually consist of "combined water" (hydrates and hydroxy-compounds) and carbon dioxide from carbonates. It may be used as a quality test.

The loss on ignition of the sample is 23.89% which is high and it shows that the lime contains volatile materials like moisture and carbon di oxide. It also implies that the calcination process is incomplete.

3.3 Compaction pressure

Compacting is the process of mechanically densifying a soil by pressing the soil particles together in to a close state contact so that the entrapped air can be expelled from the soil mass. Compacting earth block is usually referred to us tamping. Compressed earth blocks are generally produced earth compacting earth in a hydraulic or electric bock making machines. In which static and control pressure is applied. The moulding(compacting) pressure for earth blocks can be characterized as below [26].

- Very low: 1-2 MPa
- Low: 2-4 MPa
- Average: 4-6 MPa
- High: 6-10 MPa
- Hyper: 10-20 MPa

3.4 Mix proportion

In order to analyze the effects of contents of cement, lime and soil four mix series were prepared. The mix proportions are made based on literature recommendations [5] [7] [10] [17]. And the mixes were prepared and casted at Selam Technical and Vocational center workshop. To this effect the following mix proportions are presented.

1. The first series of mixes (4 in number) are conducted to compare the difference in compressive strength values with age, rate of strength development of the block produced using Derba Portland pozzolona cement. They are made with 20% of water and cement content of 4%, 6%, 8% and 10% by weight of soil. No lime was added to these series of mixes. Constant compaction pressure of 10MPa was used for this series of mixes. The Mix proportions are given in Table 3.6 following page.

Table 3-6: Mix proportions for the 1st series

| Mix code | Soil | Cement | Lime | Water |
|----------|------|--------|------|-------|
| A | 96% | 4% | 0% | 20% |
| B | 94% | 6% | 0% | 20% |
| C | 92% | 8% | 0% | 20% |
| D | 90% | 10% | 0% | 20% |

2. The second series of mixes (8 in number) were conducted to compare the difference in compressive strength values with age, rate of strength development of the block produced using Portland pozzolona cement and lime from source one (Generic lime). They are also used to observe the effect of lime content on the compressive strength and water absorption of the stabilized blocks. They are made with varying cement and lime content with total stabilizer replacement of 4%, 6%, 8%, and 10% by weight of soil. Mould (compaction) pressure of 10MPa was used for this series of mixes. The Mix proportions are given in Table 3.7: below.

Table 3-7: Mix proportions for the second series

| Mix code | % replacement | Soil | Cement | Generic lime (Lime from source 1) | Water |
|----------|---------------|------|--------|-----------------------------------|-------|
| E | 4% | 96% | 2% | 2% | 20% |
| F | 6% | 94% | 4% | 2% | 20% |
| G | | | 3% | 3% | 20% |
| H | 8% | 92% | 6% | 2% | 20% |
| I | | | 4% | 4% | 20% |
| J | 10% | 90% | 8% | 2% | 20% |
| K | | | 6% | 4% | 20% |
| L | | | 5% | 5% | 20% |

3. The third series of mixes (8 in number) were conducted to compare the difference in compressive strength values with age, rate of strength development of the block produced using Portland pozzolona cement and lime from source two (Senkale lime). They are also

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used to observe the effect of lime content on the compressive strength and water absorption of the stabilized blocks. They are made with varying cement and lime content with total stabilizer replacement of 4%, 6%, 8%, and 10% by weight of soil. Constant compaction pressure of 10MPa was used for this series of mixes. The Mix proportions are given in Table 3.8: below.

Table 3-8: Mix proportions for the third series

| Mix code | % replacement | Soil | Cement | Senkale Lime (lime from source 2) | Water |
|-----------------|----------------------|-------------|---------------|--|--------------|
| P | 4% | 96% | 2% | 2% | 20% |
| Q | 6% | 94% | 4% | 2% | 20% |
| R | | | 3% | 3% | 20% |
| S | 8% | 92% | 6% | 2% | 20% |
| T | | | 4% | 4% | 20% |
| U | 10% | 90% | 8% | 2% | 20% |
| W | | | 6% | 4% | 20% |
| X | | | 5% | 5% | 20% |

- The fourth series of mixes (2 in number) are conducted to compare the effects of mould compaction pressure on the compressive strength of the sample and on the effectiveness of the stabilizers. These mix series are made with 5MPa, 7.5MPa, 10MPa, 12.5MPa and 14MPa compaction pressure. From average to hyper compacting pressure ranges was used, based on compaction pressure characterization which is shown in section 3.3. The first mix was stabilized with only cement whereas the second mix was stabilized with lime and cement. The mix proportions are given in Table 3.9 in the following page.

Table 3-9: Mix proportions for the fourth series

| Mix code | Cement | Lime 1 | Water | Compaction Pressure (MPa) |
|----------|--------|--------|-------|---------------------------|
| M1 | 10% | 0% | 20% | 5 |
| M2 | 10% | 0% | 20% | 7.5 |
| M3 | 10% | 0% | 20% | 10 |
| M4 | 10% | 0% | 20% | 12.5 |
| M5 | 10% | 0% | 20% | 14 |
| N1 | 5% | 5% | 20% | 6 |
| N2 | 5% | 5% | 20% | 8 |
| N3 | 5% | 5% | 20% | 10 |
| N4 | 5% | 5% | 20% | 4 |
| N5 | 5% | 5% | 20% | 6 |

3.5 Specimen preparation

3.5.1 Pulverization

The soil initially pulverized to obtain uniform mixing of the components. Lumps and larger pieces of soil were broken up by being pressed between two surfaces. Grains with a homogeneity structure such as stones and gravel left unbroken separated from the soil.

3.5.2 Screening

This is a necessary part of the process and is essential when the pulverization has been incomplete and there are large particles in the soil. To separate them from the soil, a fixed screen was set up at an angle or is suspended. Although there are mechanically available machines for this job, the operation was easily carried out manually. Raw soil was thrown with a shovel at the top of the fixed screen. The screened soil was then loaded onto a wheelbarrow and made ready to be mixed with the other components while the larger unscreened material was rejected. It can be used for other purposes or can be further grinded and pulverized and once again be screened.

3.5.3 Mixing

Proper mixing ensures the succeeding quality of the product and of the structure itself. It also guarantees that the blocks are built economically in the case that it optimizes the proportions of the components. The proportioning the mix of the soil raw material with the stabilizer was done

in varying quantities, by percentage weight of stabilizer from 4% up to 10% by weight of soil as follows: 4%, 6%, 8% and 10%. Before adding water, the dry soil and stabilizers were mixed until it was of a consistent color. Then water was added afterwards by progressive sprinkling. 2-3 minutes mixing was done by using a mechanical mixer. Mixing was done based on ARS 674 standard – technical specification for ordinary CEB.

3.5.4 Pressing

To produce the blocks, M7E380 hydra foam pressing machine was used for the entire samples. Before filling the mould for each compression, the mould lining was lightly oiled with used engine oil. Then wet mixture from the mixer pre weighted and then was poured in to the mould of size 220*220*115mm. The press compress the mixture by pumping action of the side pump, shaping it into a block with a compaction pressure of 10MPa for the first three series of mixes and varying compaction pressure for the forth series of mixes (the mix series are described in section 3.4). The mould cover (top ram) was then moved upward to expose the compressed block, which was then demoulded. The wet blocks were then removed and put over base plates, and immediately placed in a plastic bag and left to be cured in the shade. The pressed blocks were transported to a storage room, at a close distance to the pressing machine.

Different shapes such as angular or interlocking blocks can be produced by changing the form of the pressing mould. In this thesis all the produced blocks were interlocking blocks.

3.5.5 Curing

The curing phase is essential for the blocks future strength and durability. During the first 7 days the blocks were watered, by sprinkling once a day and covered with plastic sheeting.

4 TEST RESULTS AND DISCUSSIONS ON THE SUITABILITY OF SOIL SAMPLE TO PRODUCE COMPRESSED STABILIZED SOIL BLOCK

4.1 Introduction

The use of a suitable soil is fundamental to successful production of compressed cement stabilized soil block. Since soil from the Kara area of Addis Ababa is used to produce compressed stabilized earth block. This area was the prime target for investigation and testing. The following report examined the process of soil selection for the purpose of compressed stabilized soil block production. Soil suitable for compressed stabilized soil block production is then considered from a particle grading and plasticity viewpoint, with due consideration to the underlying mechanisms responsible for strength and durability.

In general, the literature concerned with soil testing provides a number of suitable tests but does not provide a logical testing plan for their implementation. The following section discusses and analyzes soil laboratory test results for soil suitability. From this discussion, it is hoped that the reader may be able to appreciate the need for different scales of soil testing. A full laboratory analysis includes soil grading, plasticity, and chemical composition. In this case a soil sample from the Kara area of Addis Ababa considered suitable by the field test selection process is taken to the Addis Ababa University, Faculty of Technology, Civil Engineering Department and Geological Survey of Ethiopia Geochemical laboratories and relevant soil tests are conducted.

Based on the results of soil testing, trial blocks by using different content and type of cement is produced and the block is tested for 7th day, 21st day, 28th day and 56th day compressive strength and water absorption capacity.

4.2 Laboratory tests and results on soil sample

Laboratory tests conducted provide more precise detailed information on the soil gradation and plasticity. This information helps to check the suitability of the soil based on the selection criteria given in Section 2.11.3.

With so many different characteristics that one could discover about a sample of soil, it would be unwise to try and discover them all in every situation that soil is to be used for making compressed stabilized soil block. In this research work only a small number of characteristics that are of real relevance to the production of compressed cement stabilized soil block is

considered. The physical properties are of greater interest for making compressed stabilized soil block as these will help to determine its ease of mixing, forming, de-moulding, porosity, permeability, shrinkage, dry strength and apparent bulk density.

The soil sample is generally characterized in two ways, by a particle size distribution analysis and by plasticity index. The particle size analysis gives information on the soil ability to pack in to a dense structure and the quantity of fines present (combined silt and clay fraction), while the plasticity index gives an idea of the cohesion of the fines

The laboratory tests conducted helps to establish numerical values for the soil sample parameters, primarily the percentage distribution of the different sizes of the soil particles present and the plasticity limits. These values are subsequently used to determine the suitability of the soil sample for block production.

A. Particle size distribution

The combined sieving and hydrometer tests separated the different size fractions of the soil sample into discrete parts thereby indicating the soil's particle grading. The results of these tests are plotted in Figure 4.1 below. Detail raw data's and test results are given in the Appendix A.

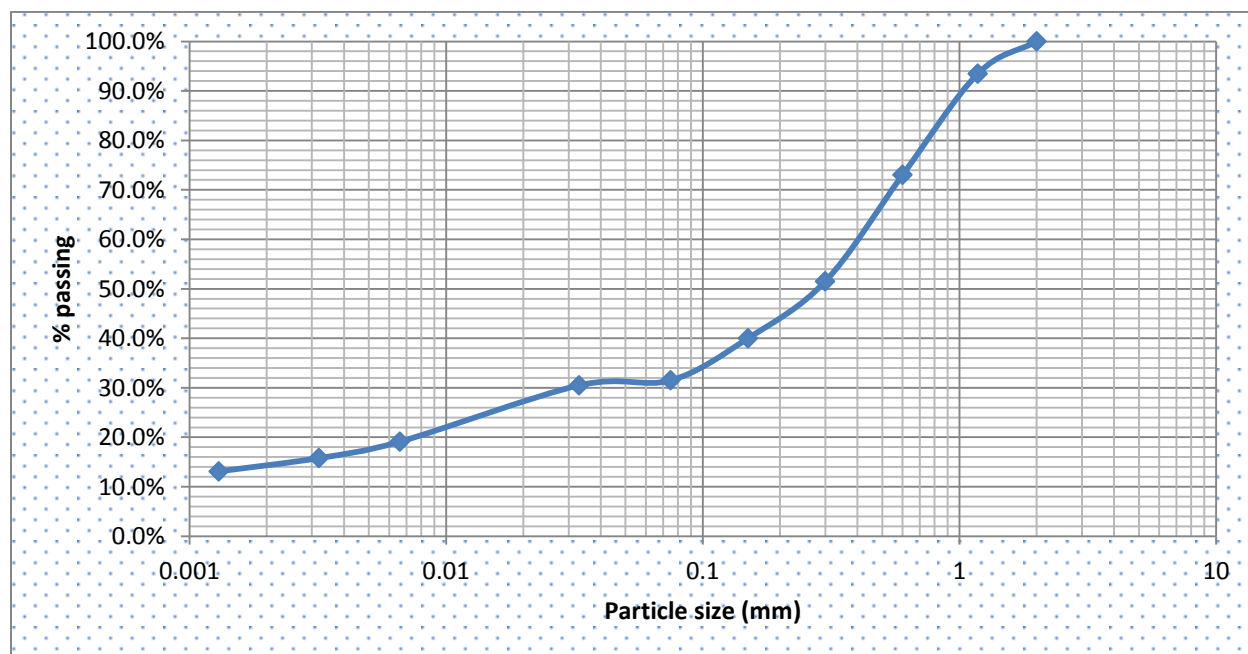


Figure 4-1: Particle size distribution of the soil used for the research.

From the above curve, actual composition of the soil used for the production of the compressed stabilized earth block is grouped as follows: Sand -68.5%, Silt -16.3% and Clay -15.2%.

Based on this result, now it is possible to check the suitability of the soil Based on African Regional Standard (ARS).

As per ARS 680:1996 Code of practice for the production of compressed earth blocks recommendations, if the granular composition of the soil fall within the shaded area on the diagram of texture as shown in Figure 2.6, it gives satisfactory result.

The gradation curve of the soil sample used for the research work shown in Figure 4.1 in the previous page falls completely with in the shaded area of the diagram of texture as shown in Figure 4.2 below.

This implies that the sample soil chosen fulfills this requirement.

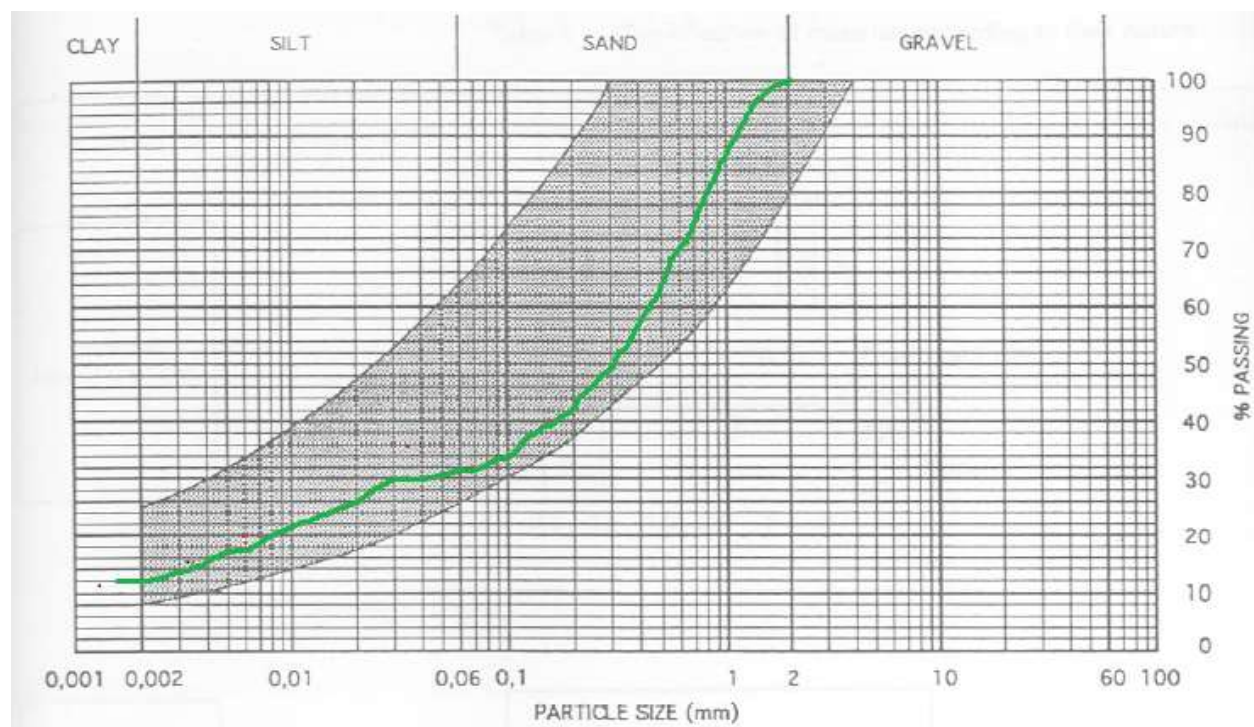


Figure 4-2: Particle size distribution of the sample soil on the diagram of Texture

B. Atterburg limit criteria (Plasticity)

The Atterburg or plasticity tests define the moisture content at which the soil passes from a liquid state to plastic state and from plastic state to a solid state; these boundary points are the liquid and plastic limits respectively. The atterburg limits allow the soil plasticity characteristics to be related to the suitable soil selection criteria given above in section 2.9.4.

The plastic limit and liquid limit tests described in the appendix A are prepared by using method of ASTM D 2216-92. Atterburg limit test results of the soil sample are given in Table 4.1 in the following page but full test measurements and data records are described in appendix A.

Table 4-1: Atterburg limit test results of soil used in the research

| Atterburg limits | % |
|------------------|-------|
| Liquid Limit | 33.8% |
| Plastic Limit | 24.4% |
| Plasticity Index | 9.4% |

The plasticity index (PI) is a measure of the plasticity of a soil. The plasticity index is the size of the range of water contents where the soil exhibits plastic properties. The PI is the difference between the liquid limit and the plastic limit.

Based on these results we can check the suitability of the sample soil for compressed stabilized soil block production. The soil sample is checked for suitability (based on African Regional Standard (ARS)) in the plasticity chart as shown below by using the Atterburg limit values from Table 4.1 above.

The plasticity index of 9.4 and liquid limit of 33.8 falls at point “A” in the plasticity chart of Figure 4.3 below.

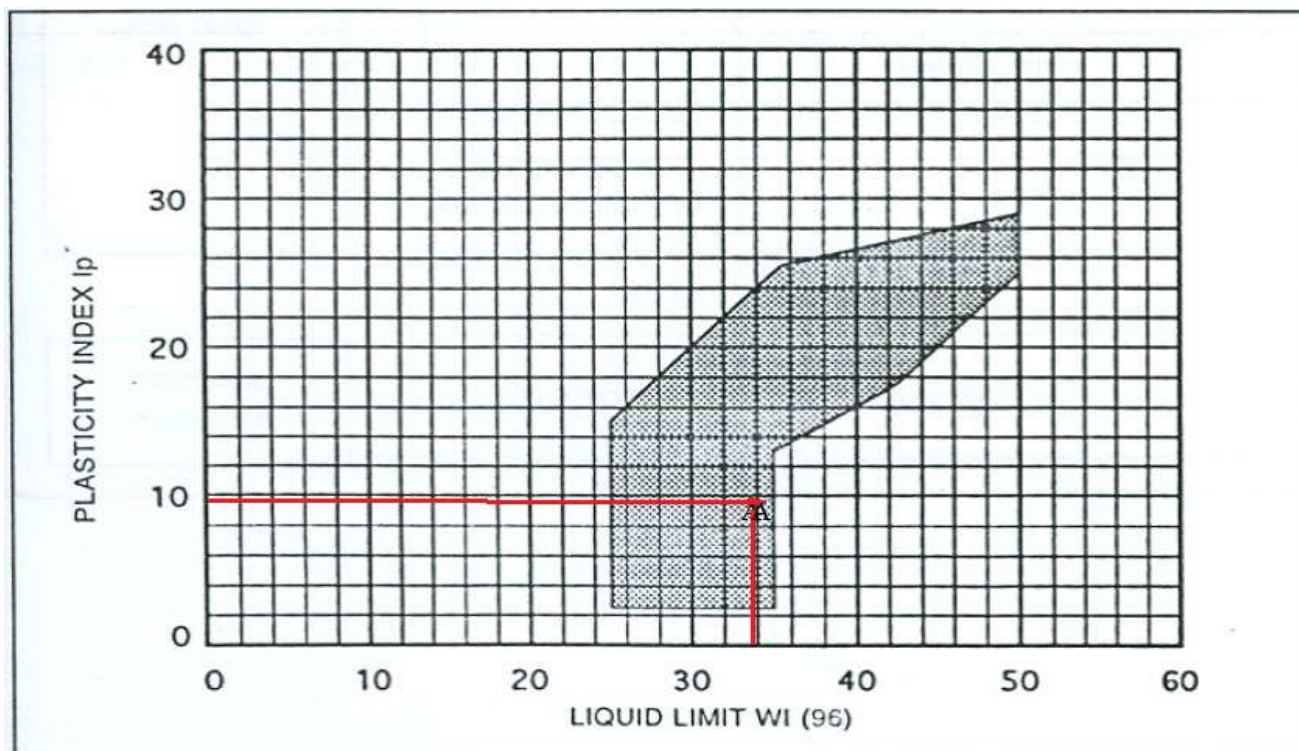


Figure 4-3: Plasticity Chart of the soil sample

Point “A” is located in the shaded area, which indicates the suitability of the Kara area soil for compressed stabilized soil production.

4.3 Chemical analysis

From the literature review chemical properties of the soil (the composition, mineral content, metallic oxides, PH levels and sulphates) are of interest particularly when a chemical additive are used. Since cement and lime are used as a stabilizer the chemical analysis of Soil from Kara area was conducted at Geological survey of Ethiopia, Geochemical laboratory.

The ultimate goal was to get the chemical components of the soil and to gain insight into the reactions occurring in Stabilized soil mixtures. The soil used for the research was investigated and the results are expressed in Table 3.2 in chapter 3 and in Appendix B. From the chemical components, we can see that the amount of SiO_2 (64.22%) is an indication of the composition of sand in the soil. Soil silica and alumina react with stabilizer to form a cementing agent. SiO_2 and Al_2O_3 from soil react with CaO from cement, lime and water. This implies that given sufficient cement and lime, soil properties control results. The higher the silica contents in the soil the more active the soil and better reactive. Even though low PH of the soil do not in themselves constitute a definite indication of poorly reacting soil, 7.44 PH level soil helps to consider the soil as good reacting soil. Because soil having a PH lower than 5.3 will generally not react normally with cement and lime. The PH level is also of important factor; soil having a PH level below 4.5 or over 10 should be avoided. Other important property of the soil is its small percentage of SO_3 (0.22%), which is important to reduce the amount of sulphates to be produced.

5 TEST RESULTS AND DISCUSSIONS ON THE PRODUCED COMPRESSED STABILIZED SOIL BLOCKS

5.1 Compressive strength

The compressive strength test of all the produced blocks was performed in Addis Ababa institute of technology construction materials laboratory. After the 7, 14, 28 and 56 days of casting, the blocks of average dimension $22 \times 22 \times 11.5$ cm was measured and weighed. The compression equipment used was the concrete compressive strength testing machine. The compressive strength test done was a standard test based on ASTM C140 - Standard test methods for sampling and testing concrete masonry units and related units.

Three blocks in each category of varying stabilizer content from 4% in increments of 2% up to 10% were tested for compressive strength. The samples were placed within the set marking pins of the compression-testing machine. The crushing load was then continuously applied without shock to the sample at a rate of 0.5 MN per minute till failure, and in this way the maximum crushing load was obtained for each sample. The compressive strength was then calculated in each case from the ratio of the maximum load and the cross sectional area of the block in N/mm^2 .

In this research work two types of lime from different source are used, the one bought from the local market is named 'Generic lime' which is the first source and the one brought from Senkale lime manufacturing factory is named 'Senkale lime', the second source.

5.1.1 Effect of cement content on the compressive strength of soil blocks (with no lime)

The 7th, 21st, 28th and 56th days mean compressive strength values of compressed soil blocks stabilized with cement contents of 4%, 6%, 8% and 10% with no lime, are shown in Table 5.1 in the following page and all the raw data's of cube compressive strength test results are presented in a tabulated form in Appendix C, D, E and F. And it is summarized in a graphical form in Figure 5.1 in the following page for blocks having no lime.

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Table 5-1: Mean compressive strength of CSEB using Portland pozzolana cement with no lime

| MIX | Mean Compressive Strength (MPa) | | | |
|--------------------------|---------------------------------|----------------------|----------------------|----------------------|
| | 7 th day | 21 st day | 28 th day | 56 th day |
| A (4% Cement & no lime) | 1.1 | 2.1 | 2.3 | 2.4 |
| B (6% Cement & no lime) | 1.5 | 2.3 | 2.7 | 2.9 |
| C (8% cement & no lime) | 1.8 | 2.8 | 3.1 | 3.3 |
| D (10% Cement & no lime) | 2.1 | 3.1 | 3.4 | 3.7 |

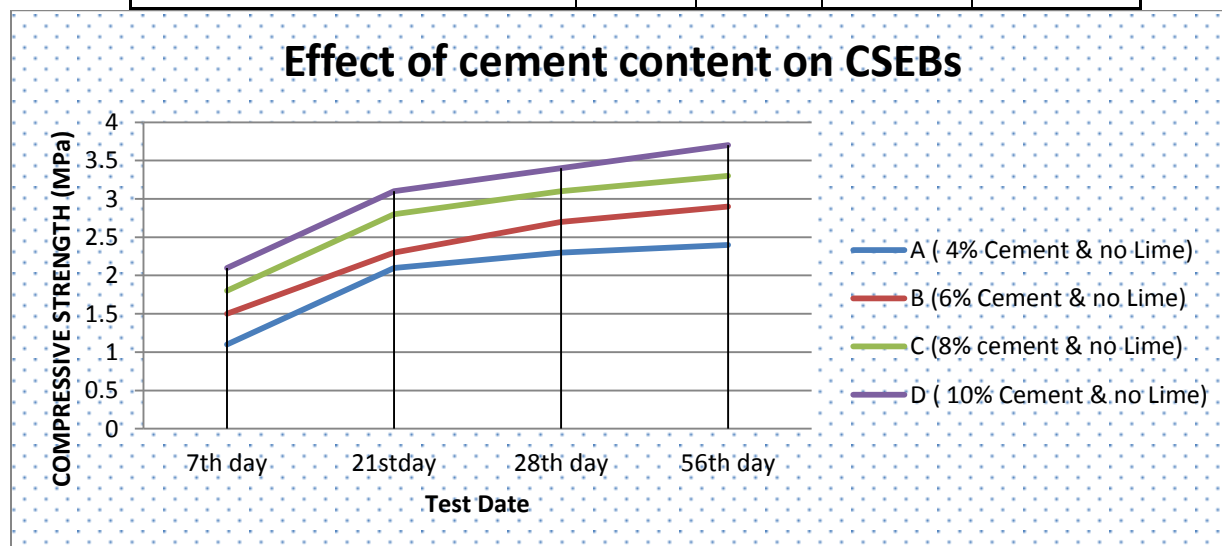


Figure 5-1: Effect of cement content on CSEBs with no lime

From these results, general and localized trends can be recognized. According to the obtained compressive strength results, it would be reasonable to conclude that for a given constant compaction pressure, an increase in absolute compressive strength can be achieved by increasing the cement content. This increment in cement content results in deposition of cement paste between soil particles. The interlocking cement paste between the soil particles binds the soil particles together and creates high strength. The results also show that from the blocks produced at the varying cement contents from 4% in increments of 2% up to 10% at constant compaction pressure of 10MPa, all the blocks produced have 28th day compressive strength values above most of the recommended minimum values for use in structural work as per the literature. According to the literature, several different minimum values of 28th day compressive strength, all above 1.0 MPa - 2MPa are proposed [16].

From the graphical presentation of the results shown above in Figure 5.1, the rate of increase in strength can be approximated. When the cement content is increased from 4% to 6% at constant compaction pressure, a compressive strength increase of 17.4% is achieved at the 28th day; further increasing of the cement content from 6% to 8% would produce an increase in compressive strength of up to 14.8%. And the blocks with cement content of 10% (mix D) have 47.8%, 25.9% and 9.7% increase in compressive strength at the 28th day that that of 4%, 6% and 8% cement content respectively.

5.1.2 Effect of adding lime on the compressive strength of cement stabilized earth blocks

The 7th, 21st, 28th and 56th days mean compressive strength values of compressed soil blocks stabilized with total stabilizer content of 4%, 6%, 8% and 10% with varying lime content are shown below and all the raw data of block compressive strength test results are presented in tabulated form in the Appendixes C, D, E & F. Two types of lime are used for each mix i.e. lime brought from market (Generic lime) and the other brought from manufacturer (Senkale lime) all comparisons are made for each mix.

A. 4% Stabilizer Replacement

According to the tabulated results in Table 5.2 and Figure 5.2 in the following page, the compressive strength of CSEB is tested for three mixes, one containing 4% Cement and no lime (mix A), the other containing 2% Cement and 2% Generic lime (mix E) and the last containing 2% Cement and 2% Senkale lime (mix P).

Both mix A (4% cement and no lime) and mix P (2% cement and 2% Senkale lime) attained 28th day compressive strength values above most of the recommended minimum values. According to the literature, several different minimum values of 28th day compressive strength, all above 1.0 MPa - 2MPa are proposed [16]. But mix E (2% cement and 2% generic lime) haven't attain the minimum 28th day compressive strength of 2MPa.

The results of this test proved that the early compressive strength of the mixes containing lime is lower than the compressive strength of the mix containing no lime. The 56th day compressive strength of mix containing no lime (mix A) is equal to the mix containing 2% Generic lime, whereas the mix containing 2% Senkale lime (mix P) showed an increased 56th day compressive

strength than the other two mixes. The 56th day compressive strength of mix P (mix containing 2% cement and 2% Senkale lime) is 8.3% higher than that of the other two mixes. As Figure 5.2 and Table 5.2 below show, the compressive strength results of mix with Senkale lime is higher than the respective results of the mix with Generic lime at all test days.

Table 5-2: Compressive strength results of samples with 4% Stabilizer replacement

| Mix | Mean Compressive Strength (MPa) | | | |
|---------------------------------|---------------------------------|----------------------|----------------------|----------------------|
| | 7 th day | 21 st day | 28 th day | 56 th day |
| A (4% cement & 0 % Lime) | 1.1 | 2.1 | 2.3 | 2.4 |
| E (2% cement & 2% Generic Lime) | 0.9 | 1.5 | 1.8 | 2.4 |
| P (2% cement & 2% Senkale Lime) | 1 | 1.6 | 2.2 | 2.6 |

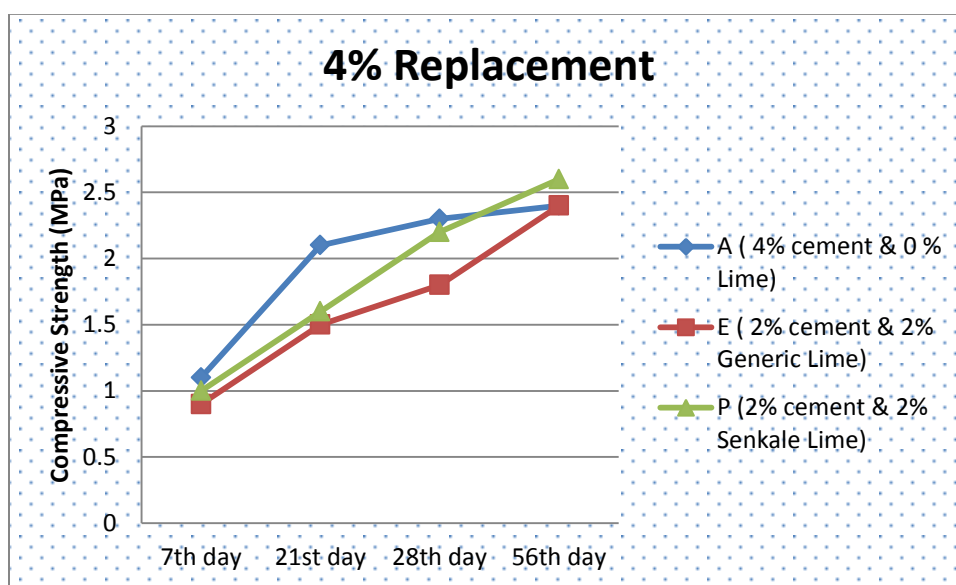


Figure 5-2: Compressive strength development for 4% stabilizer replaced earth blocks.

B. 6% Stabilizer Replacement

According to the tabulated results in Table 5.3 in the following page the compressive strength of CSEB is tested for five mixes. One mix containing no lime B (6% cement and no lime), two mixes with Generic lime F (4% cement and 2% lime) & G (3% cement and 3% lime) and the last two mixes with Senkale lime.

All the blocks produced with total stabilizer content of 6%, have attained 28th day compressive strength values above most of the recommended minimum values. According to the literature, several different minimum values of 28th day compressive strength, all above 1.0 MPa - 2MPa are proposed [16].

Table 5-3: Compressive strength results of samples with 6% stabilizer replacement

| Mix | Mean compressive Strength (MPa) | | | |
|---|---------------------------------|----------------------|----------------------|----------------------|
| | 7 th day | 21 st day | 28 th day | 56 th day |
| B (6 % Cement & 0% Lime) | 1.5 | 2.3 | 2.7 | 2.9 |
| F (4 %Cement & 2 % Generic Lime) | 1.3 | 2.1 | 2.7 | 3.1 |
| G (3 %Cement & 3 % Generic Lime) | 1.1 | 2 | 2.5 | 3.2 |
| Q (4% cement & 2% Senkale Lime) | 1.3 | 2.2 | 2.8 | 3.1 |
| R (3% cement & 3% Senkale Lime) | 1.2 | 2.1 | 2.7 | 3.3 |

i. Comparison between the control mix and mix containing Generic lime for 6% stabilizer replacement

As the Figure 5.3 the following page shows, early compressive strength of the mixes containing Generic lime (mix F and G) are lower than the compressive strength of the mix containing no lime (mix B). But the 56th day compressive strength of mix G (3% cement & 3% Generic lime) is 10.3% higher than mix B (6% cement & no lime) and the 56th day compressive strength of mix F (4% cement & 2% Generic lime) is 6.9% higher than mix B (6% cement & no lime).

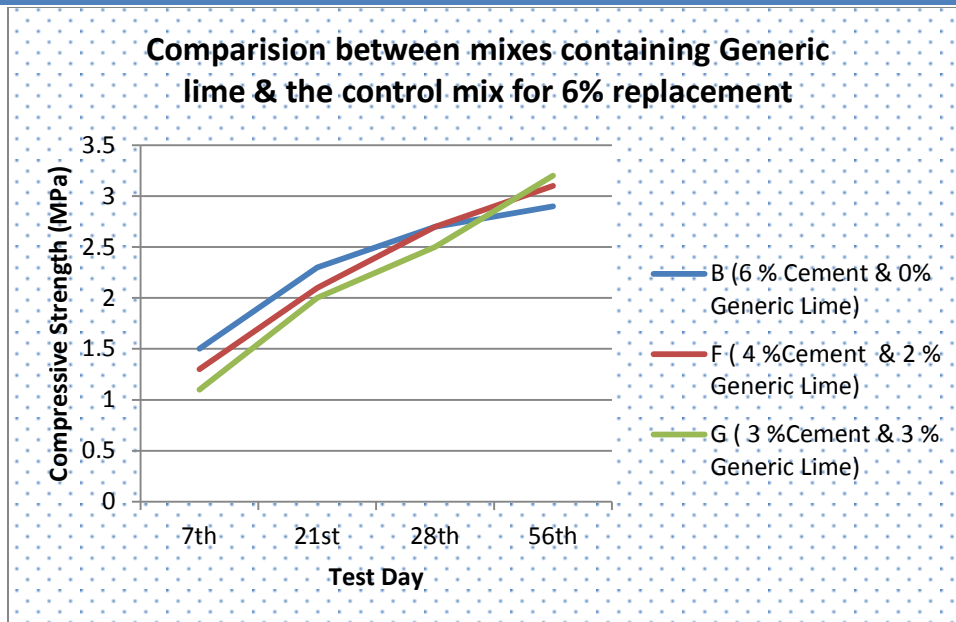


Figure 5-3: Compressive strength comparison- mixes containing Generic lime & the control mix for 6% replacement

ii. Comparison between the control mix and mix containing Senkale lime for 6% stabilizer replacement

As the Figure 5.4 in the following page shows, the 7th day compressive strength test result of the mixes containing Senkale lime (mix Q and R) are lower than the 7th day compressive strength of the mix containing no lime (mix B). Mix B showed 15.4% and 25% increase in the 7th day compressive strength than mix Q and R respectively. But the 56th day compressive strength of mix R (3% cement & 3% Senkale lime) is 13.8% higher than mix B (6% cement & no lime) and the 56th day compressive strength of mix Q (4% cement & 2% Senkale lime) is 6.9% higher than mix B (6% cement & no lime).

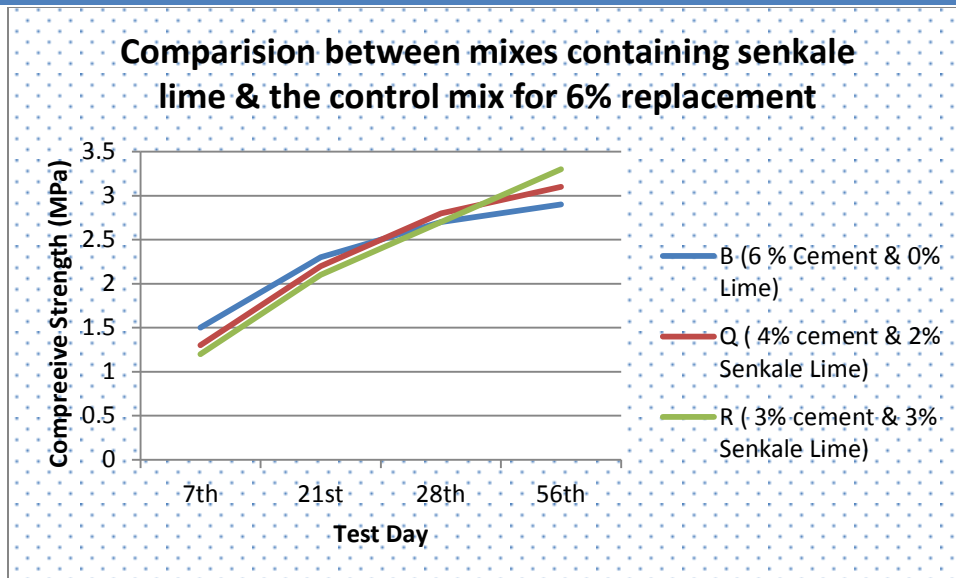


Figure 5-4: Compressive strength comparison-mixes containing Senkale lime & the control mix for 6% replacement

iii. Comparison between mixes with Senkale lime versus mixes with Generic lime for 6% replacement

The Figure 5.5 & Figure 5.6 in the following page show the compressive strength difference between stabilized blocks stabilized with Generic lime and Senkale lime in combination with cement. As the figure below indicates, the 21st & 28th day compressive strength of mix Q (4% cement & 2% Senkale lime) is higher than mix F (4% cement & 2% Generic lime). The 7th & 56th day compressive strength of the two mixes is equal.

According to Figure 5.5 in the following page the compressive strength of mix R (3% cement & 3% Senkale lime) is higher than mix G (3% cement & 3% Generic lime) at all ages. The 28th & 56th day compressive strength of mix R is 8% and 3.1% higher than mix G respectively.

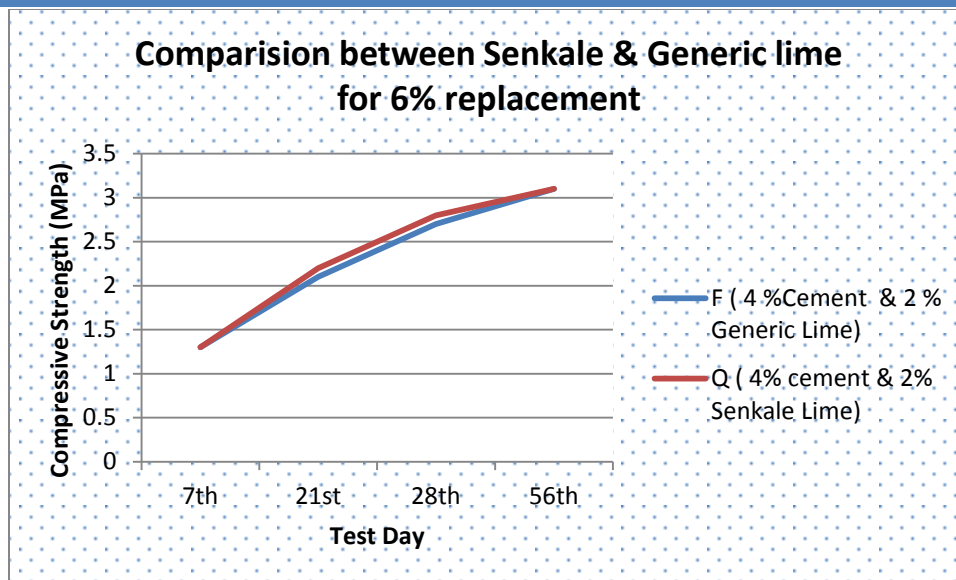


Figure 5-5: Compressive strength comparison- mixes containing Generic lime and the Senkale lime for 6% replacement (4% cement & 2% lime)

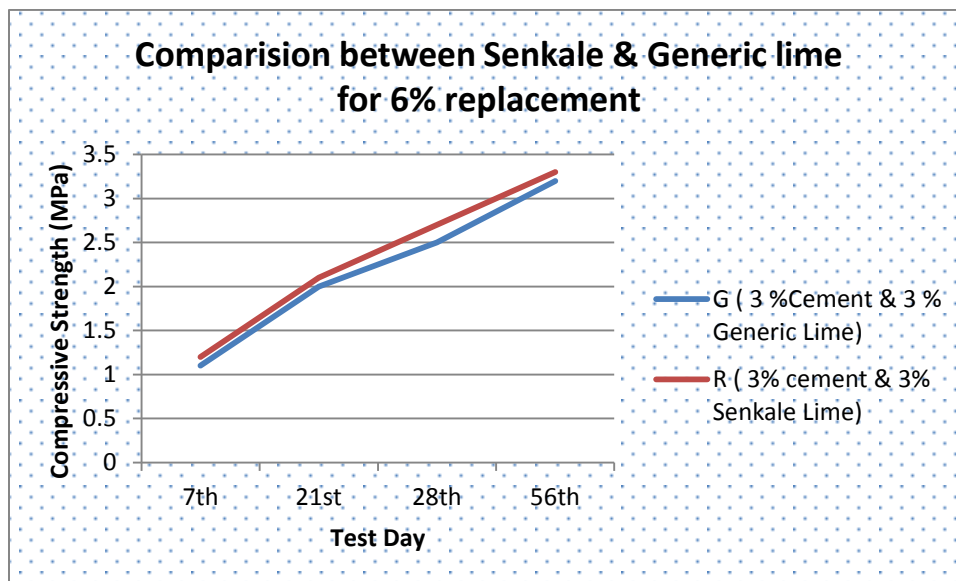


Figure 5-6: Compressive strength comparison- mixes containing Generic lime and the Senkale lime for 6% replacement (3% cement & 3% lime)

C. 8% Stabilizer Replacement

The tabulated results in Table 5.4 in the following page the compressive strength of CSSB tested for five mixes. One mix contain no lime mix C (8% cement and no lime), two mixes with Generic lime H (6% cement and 2% lime) & I (4% cement and 4% lime) and the last two mixes

with Senkale lime mix S (6% cement and 2% Senkale lime) and mix T (4% cement and 4% Senkale lime).

All the blocks produced with total stabilizer content of 8%, have attained 28th day compressive strength values above most of the recommended minimum values. According to the literature, several different minimum values of 28th day compressive strength, all above 1.0 MPa - 2MPa are proposed [16].

Table 5-4: Compressive strength results of samples with 8% stabilizer replacement.

| Mixes | Compressive Strength (MPa) | | | |
|----------------------------------|----------------------------|------------------|------------------|------------------|
| | 7 th | 21 st | 28 th | 56 th |
| C (8 % Cement & 0% Lime) | 1.8 | 2.8 | 3.1 | 3.3 |
| H (6 % Cement & 2% Generic Lime) | 1.6 | 2.5 | 3 | 3.5 |
| I (4 % Cement& 4% Generic Lime) | 1.3 | 2.3 | 2.8 | 3.5 |
| S (6 % Cement & 2% Senkale Lime) | 1.7 | 2.7 | 3 | 3.5 |
| T (4 % Cement & 4% Senkale Lime) | 1.6 | 2.6 | 3.1 | 3.6 |

i. Comparison between the control mix and mix containing Generic lime for 8% stabilizer replacement

According to the Figure 5.7 in the following page, the results of this test proved that the early compressive strength (7th & 21st day) of the mixes containing lime is lower than the compressive strength of the mix containing no lime. But the 56th day compressive strength of mix H (6% cement & 2% Generic lime) and mix I (4% cement & 4% Generic lime) is 6.1% higher than C.

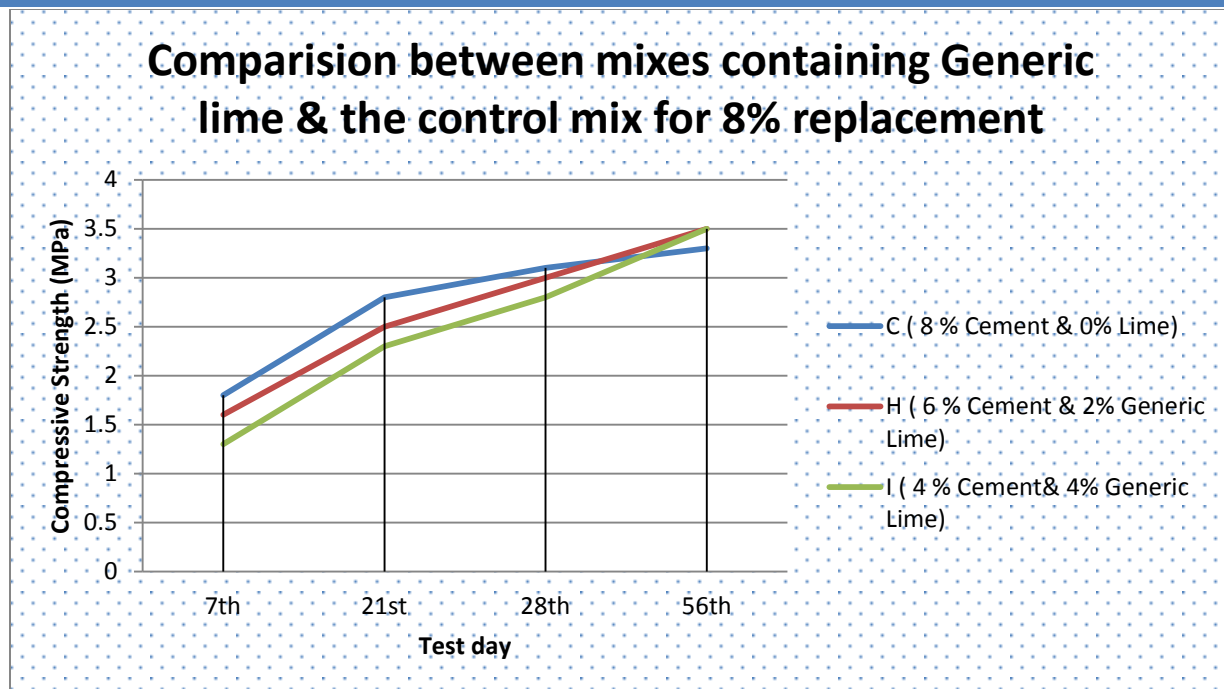


Figure 5-7: Compressive strength comparison- mixes containing Generic lime & the control mix for 8% replacement

ii. Comparison between the control mix and mix containing Senkale lime for 8% stabilizer replacement

As the Figure 5.8 in the following page indicates, the 7th day compressive strength test result of the mixes containing Senkale lime (mix S and T) are lower than the 7th day compressive strength of the mix containing no lime (mix C). Mix C showed 5.9% and 12.5% increase in the 7th day compressive strength than mix S and T respectively. But the 56th day compressive strength of mix T (4% cement & 4% Senkale lime) is 9.1% higher than mix C (8% cement & no lime) and the 56th day compressive strength of mix S (6% cement & 2% Senkale lime) is 6.1% higher than mix C (8% cement & no lime).

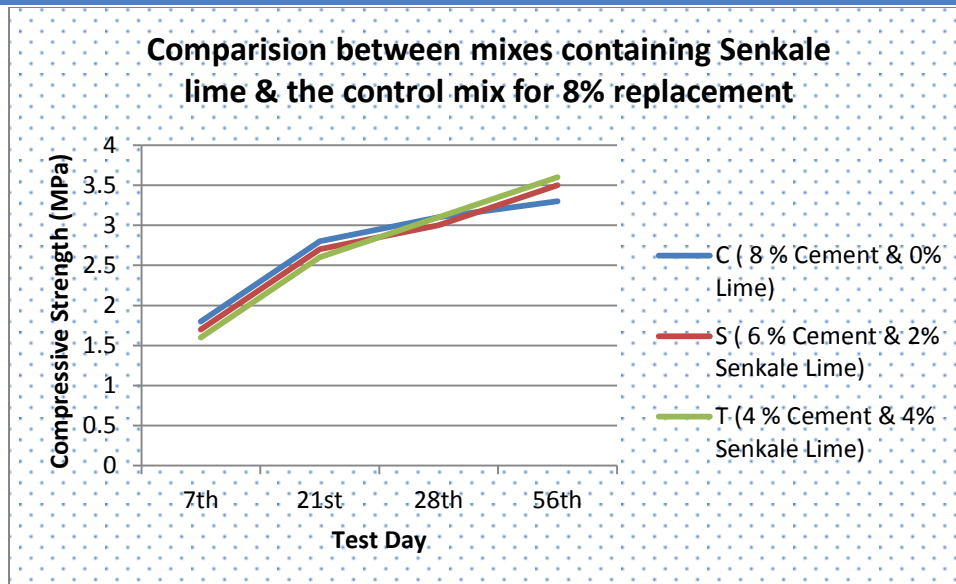


Figure 5-8: Compressive strength comparison- mixes containing Senkale lime & the control mix for 8% replacement

iii. Comparison between mixes with Senkale lime versus mixes with Generic lime for 8% replacement

Figure 5.9 & Figure 5.10 in the following page are used to compare the compressive strength development of stabilized earth blocks stabilized with Senkale lime versus the other Generic lime for total stabilizer replacement of 8%. As the Figure 5.9 below indicates, the 7th & 28th day compressive strength of mix S (6% cement & 2% Senkale lime) is higher than mix H (6% cement & 2% Generic lime). The 28th & 56th day compressive strength of the two mixes is equal.

According to Figure 5.10 in the following page the compressive strength of mix T (4% cement & 4% Senkale lime) is higher than mix G (4% cement & 4% Generic lime) at all ages. The 28th & 56th day compressive strength of mix T is 10.7% and 10% higher than mix I respectively.

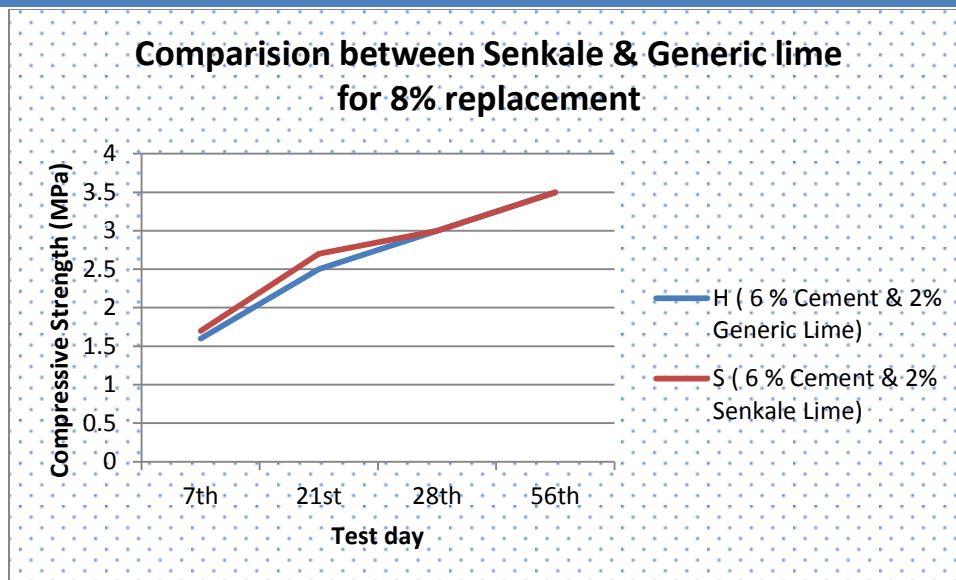


Figure 5-9: Compressive strength comparison between mixes containing Generic lime versus the Senkale lime for 8% replacement (6% cement & 2% lime)

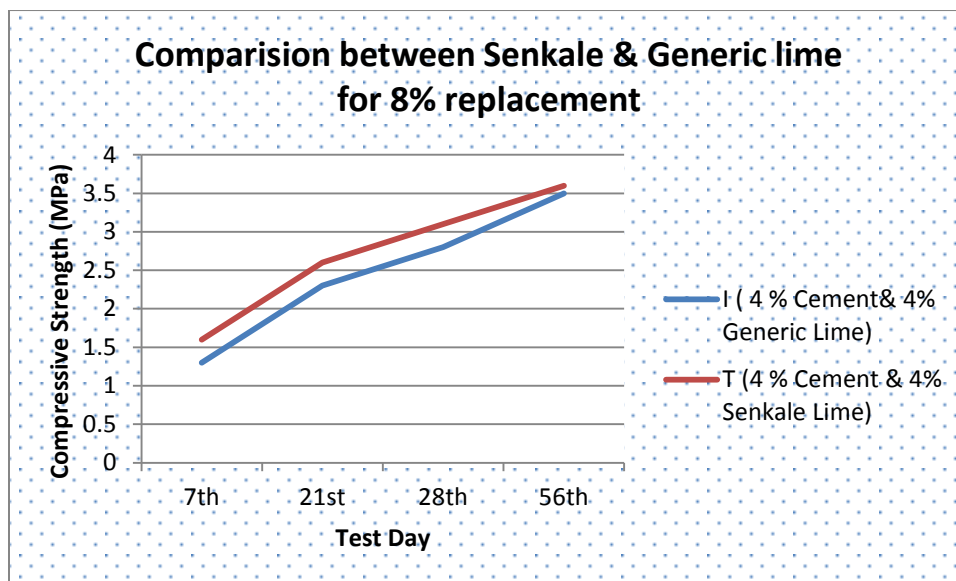


Figure 5-10: Compressive strength comparison between mixes containing Generic lime versus the Senkale lime for 8% replacement (4% cement & 4% lime)

D. 10% Stabilizer Replacement

The compressive strength of CSEB is tested for seven mixes, one mix with no lime D(10% cement and no lime), three mixes with Generic lime J (8% cement and 2% lime), K(6% cement and 4% lime) and L (5% cement and 5% lime) and the last three with Senkale lime U (8%

cement and 2% lime), W(6% cement and 4% lime) and X (5% cement and 5% lime). The results of this test are tabulated in the Table 5.5 below.

All the blocks produced with total stabilizer content of 10%, have attained 28th day compressive strength values above most of the recommended minimum values. According to the literature, several different minimum values of 28th day compressive strength, all above 1.0 MPa - 2MPa are proposed [16].

Table 5-5: Compressive strength results of samples with 10% stabilizer replacement.

| Mixes | Compressive Strength (MPa) | | | |
|---------------------------------|----------------------------|------------------|------------------|------------------|
| | 7 th | 21 st | 28 th | 56 th |
| D (10% Cement & 0% Lime) | 2.1 | 3.1 | 3.4 | 3.7 |
| J (8% Cement & 2% Generic Lime) | 1.8 | 3 | 3.3 | 3.7 |
| K (6% Cement & 4% Generic Lime) | 1.7 | 2.8 | 3.3 | 3.9 |
| L (5% Cement& 5% Generic Lime) | 1.6 | 2.7 | 3.2 | 3.8 |
| U (8% Cement & 2% Senkale Lime) | 1.8 | 3.1 | 3.3 | 3.9 |
| W (6% Cement & 4% Senkale Lime) | 1.8 | 3 | 3.4 | 4.1 |
| X (5% Cement & 5% Senkale Lime) | 1.7 | 2.8 | 3.4 | 4 |

i. Comparison between the control mix and mix containing Generic lime for 10% stabilizer replacement

The results of this test proved that the 7th, 21st and 28th day compressive strength of the mixes containing Generic lime is lower than the corresponding compressive strength of the mix containing no lime. But the 56th day compressive strength of mix K (6% cement & 4% Generic lime) is 5.41% higher than mix D (10% cement & no lime) and mix J (8% cement & 2% Generic lime). And the 56th day compressive strength of mix L (5% cement & 5% Generic lime) is 2.7% higher than mix D. The graphical presentation is presented in the Figure 5.11 in the following page.

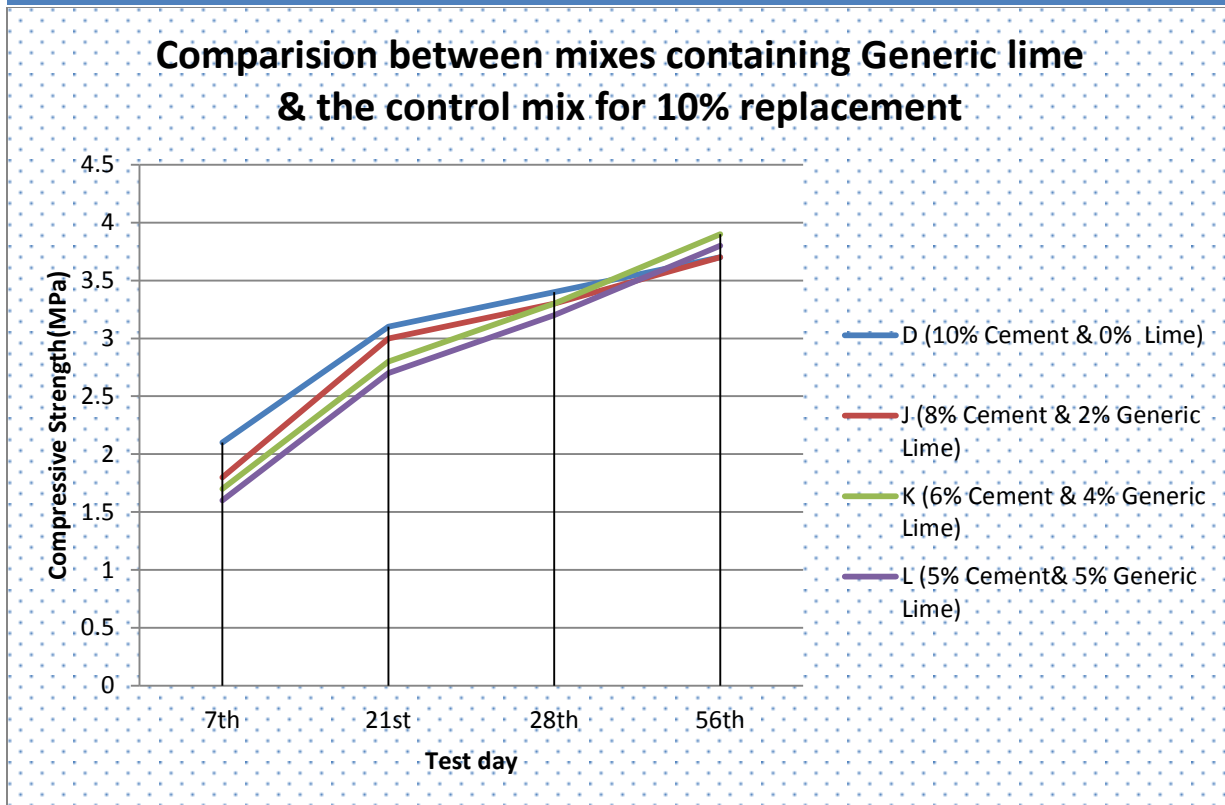


Figure 5-11: Compressive strength comparison between mixes containing Generic lime & the control mix for 10% replacement

ii. Comparison between the control mix and mix containing Senkale lime for 10% stabilizer replacement

According to Figure 5.12 in the following page, the 7th day compressive strength of the mixes containing Senkale lime (mix U, W and X) are lower than the 7th day compressive strength of the mix containing no lime (mix D). The 7th day compressive strength of Mix D is 16.7% higher than mix U & W, and 23.5% higher than mix X. But the 56th day compressive strength of mix U (8% cement & 2% Senkale lime) is 5.4% higher than mix D (10% cement & no lime) and the 56th day compressive strength of mix W (6% cement & 4% Senkale lime) is 10.8% higher than mix D, whereas the 56th day compressive strength of mix X (5% cement & 5% Senkale lime) is 8.1% higher than mix D.

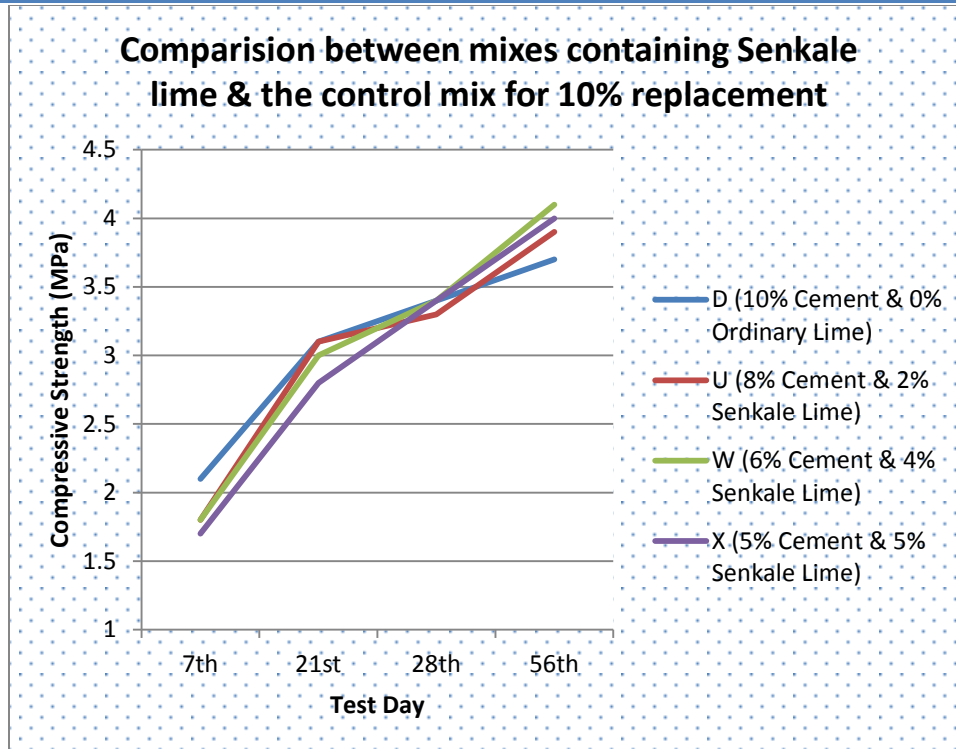


Figure 5-12: Compressive strength comparison between mixes containing Senkale lime & the control mix for 10% replacement

iii. Comparison between mixes with Senkale lime versus mixes with Generic lime for 10% replacement

Figure 5.13, Figure 5.14 & Figure 5.15 in the following pages, are used to compare the compressive strength development of stabilized earth blocks stabilized with Senkale lime versus the other Generic lime for total stabilizer replacement of 10%.

As the Figure 5.13 in the following page indicates, the 21st & 56th day compressive strength of mix U (8% cement & 2% Senkale lime) is higher than mix J (8% cement & 2% Generic lime). The 7th & 28th day compressive strength of the two mixes is equal. The 56th day compressive strength of mix U is 5.4% higher than that of mix J.

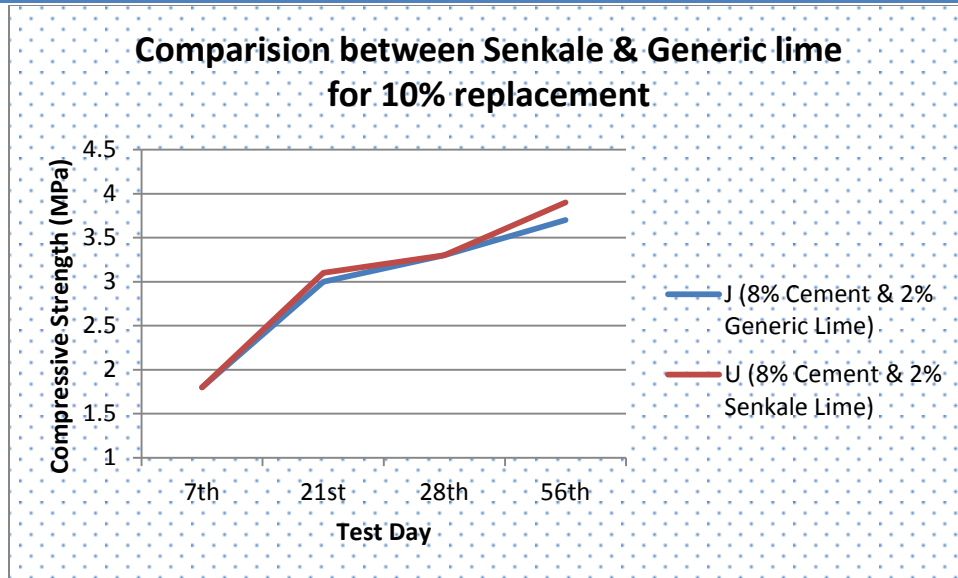


Figure 5-13: Compressive strength comparison between mixes containing Generic lime versus the Senkale lime for 10% replacement (8% cement & 2% lime)

According to Figure 5.14 below, the compressive strength of mix W (6% cement & 4% Senkale lime) is higher than mix K (6% cement & 4% Generic lime) at all ages. The 28th & 56th day compressive strength of mix W is 3% and 5.1% higher than mix K respectively.

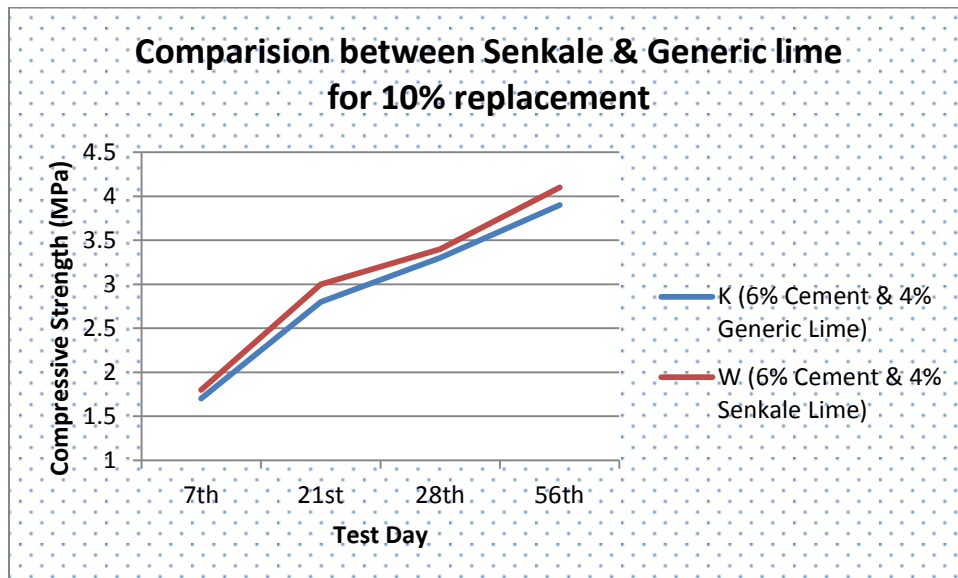


Figure 5-14: Compressive strength comparison between mixes containing Generic lime versus the Senkale lime for 10% replacement (6% cement & 4% lime)

As the Figure 5.15 below shows the compressive strength of mix X (5% cement & 5% Senkale lime) is higher than mix L (5% cement & 5% Generic lime) at all ages. The 28th & 56th day compressive strength of mix X is 6.3% and 5.3% higher than mix L respectively.

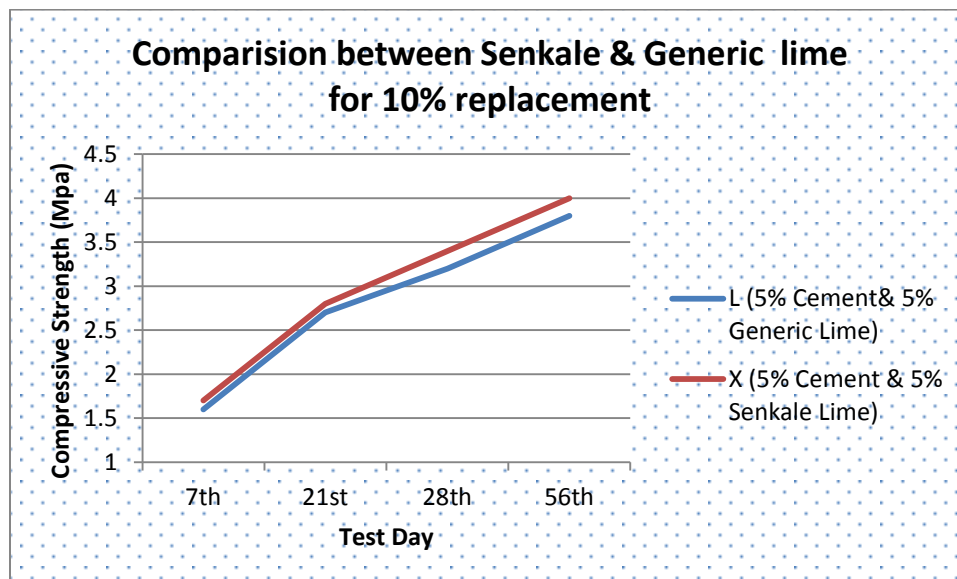


Figure 5-15: Compressive strength comparison between mixes containing Generic lime versus the Senkale lime for 10% replacement (5% cement & 5% lime)

5.2 Effects of compaction pressure on compressive strength of soil blocks

Although the stabilizer content could be responsible for binding, sealing, reinforcing and imparting flexibility to the block, compaction pressure could contribute towards increasing the densification and thereby reducing voids. The stabilizer increases the compressive strength and impact resistance of the block, as well as reducing its tendency to swell and shrink; by sealing all voids and pores and providing a waterproofing film. The stabilizer may help to reduce cracking; conversely, by reinforcing the soil, the stabilizer may reduce excessive expansion and contracting. The effect of stabilization is greatly increased when the soil is compacted. In the previously conducted experiments, all blocks were compacted prior to curing to a compaction pressure 10 MPa.

In subsequent experiments to follow, the compaction pressure are varied for two different mixes (one with 10% cement and no lime and the other 5% cement and 5% lime content)

From the literature, improved levels of compaction have a significant effect on the compressive strength of the sample and on the effectiveness of the stabilizer added.

The researcher proved this fact in the laboratory by using different compaction pressure for two different mixes.

Table 5.6 and Figure 5.16 below indicate test results of the relationship between compaction pressure and 28-day compressive strength of blocks containing 10% cement and no lime.

Table 5-6: Effect of compaction pressure on the 28th day compressive strength of blocks stabilized with 10% cement and no lime

| Code | Compaction Pressure | Mean Compressive strength (MPa) |
|------|---------------------|---------------------------------|
| M1 | 5 MPa | 2.3 |
| M2 | 7.5 MPa | 2.7 |
| M3 | 10 MPa | 3.4 |
| M4 | 12.5 MPa | 3.7 |
| M5 | 14 MPa | 4.4 |

Table 5-7: Effect of compaction pressure on the 28th day compressive strength of blocks stabilized with 5% cement and 5% lime

| Code | Compaction Pressure | Mean Compressive strength (MPa) |
|------|---------------------|---------------------------------|
| N1 | 5MPa | 1.9 |
| N2 | 7.5 MPa | 2.4 |
| N3 | 10 MPa | 3.0 |
| N4 | 12.5 MPa | 3.3 |
| N5 | 14 MPa | 3.5 |

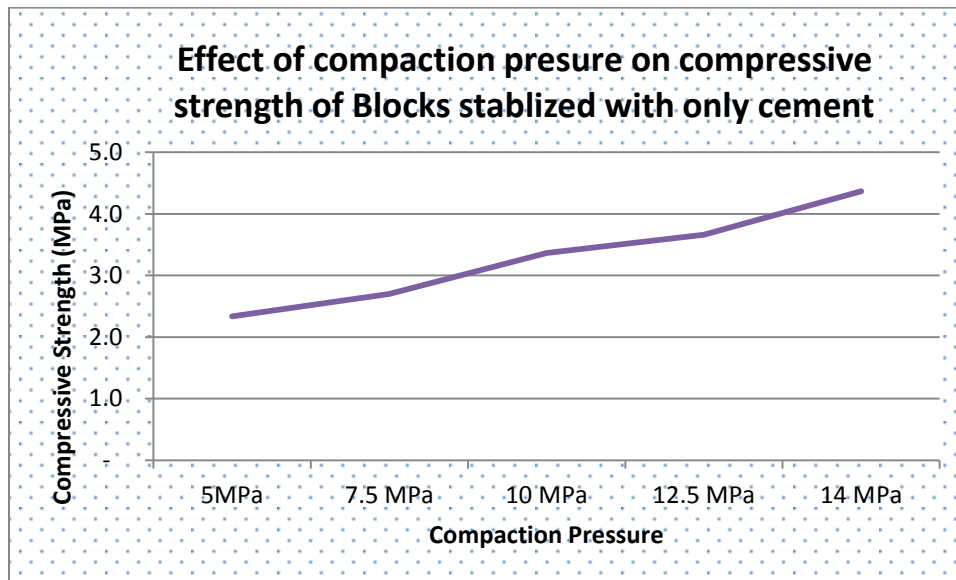


Figure 5-16: Effect of compaction pressure on the 28th day compressive strength of blocks stabilized with 10% cement and no lime

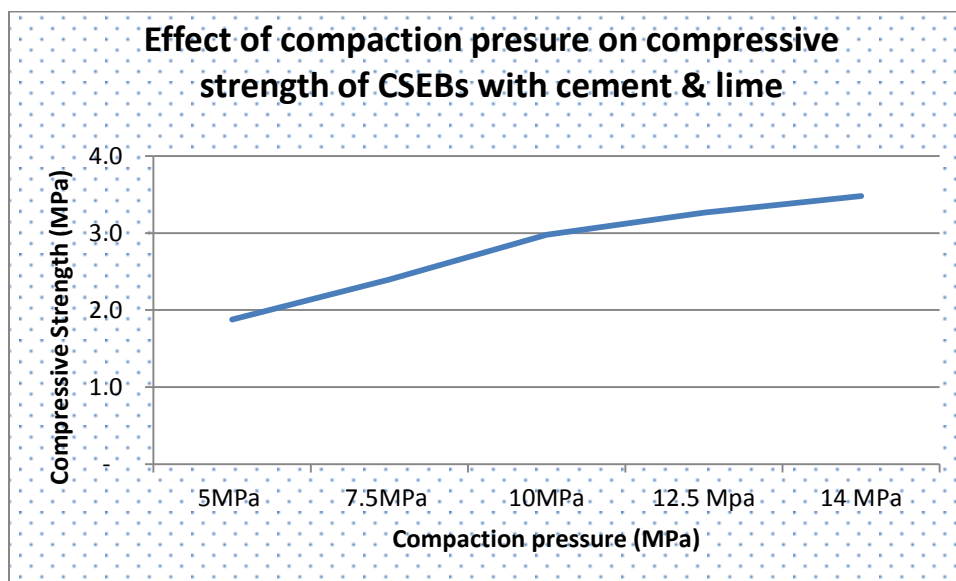


Figure 5-17: Effect of compaction pressure on the 28th day compressive strength of blocks stabilized with 5% cement and 5% lime

According to the tabulated results in Table 5.6 and Table 5.7 in the previous page, the compressive strength of CSSB is tested for two mixes, one containing 10% Cement and no lime and the other containing 5% Cement and 5% lime. The results of this test proved that the higher the compaction pressure the higher the compressive strength. When the compaction pressure is increased from 5MPa to 14MPa at constant cement/lime content of 10%/0% and 5%/5%, a compressive strength is increased by 87% and 85% respectively.

5.3 Water absorption

Water absorption is the main cause of the deterioration of earth blocks. The high absorption of water contributes to a rapid deterioration of earth blocks. The increase of the moisture content reduces the strength which is more related to the porosity of the material. The durability of earth blocks is mainly affected by the water absorption. The basic principle of the stabilization is to prevent water attacks to obtain a durable material.

Earth blocks are durable when it is not saturated. The problems of durability arise when the brick material is exposed to the saturation and wet conditions. The deterioration of earth blocks occur rapidly with the high value of the water absorption [16]. To increase durability, for example, the problem of rain penetration in buildings must be solved. The durability of earth blocks can be improved by using suitable soil, reducing the absorption of water of the material by good stabilization method.

The major factors affecting the water absorption of compressed stabilized earth blocks are amount of compaction pressure used, amount and type of stabilizer and type of soil used [15]

The general goal of stabilizers is to reduce the volume of interstitial voids, fill empty voids, and improve bonding between the soil grains. In this way better mechanical property, reduced porosity, limited dimensional changes, and enhanced resistance to normal and severe exposure conditions can be achieved, the varying types of stabilizers is used for different types of soil [4].

Compacting is the process of mechanically densifying a soil by pressing the soil particles together in to a close state contact so that the entrapped air can be expelled from the soil mass. By compacting the density of the block will be increased as the result the water absorption will be reduced. [16]

The particle size distribution of the soil particles and the origin of the soil affect the water absorption of the blocks formed. In the case of well graded soil, most of the voids that exist are closed due to closer packing of the grains as the result it helps to minimize the water absorption of the blocks. Soil containing a lot of organic particles is not suitable for block production; it will result in higher block water absorption [5].

The aim of the water absorption test was to determine the percentage moisture absorption capacity of the block samples. Block samples were weighed in the laboratory dry condition and, immersed in water for 24 hours, removed and weighed again. Block water absorption test was done based on ASTM C140 - Standard test methods for sampling and testing concrete masonry units and related units.

5.3.1 Water Absorption Test Result for Cement Stabilized Blocks with No Lime

The experimental results of the water absorption test are tabulated in Appendix H. The tabulated water absorption result of the blocks with no lime added is shown on Table 5.8 below. Result of the Figure 5.18 below, shows the effect of cement content increase on the water absorption capacity of the blocks.

Table 5-8: The effect of cement content on water absorption of the soil blocks

| Mixes | Cement content | Mean Water Absorption (%) |
|-------|----------------|---------------------------|
| A | 4% | 13.9% |
| B | 6% | 13.5% |
| C | 8% | 11.9% |
| D | 10% | 11.6% |

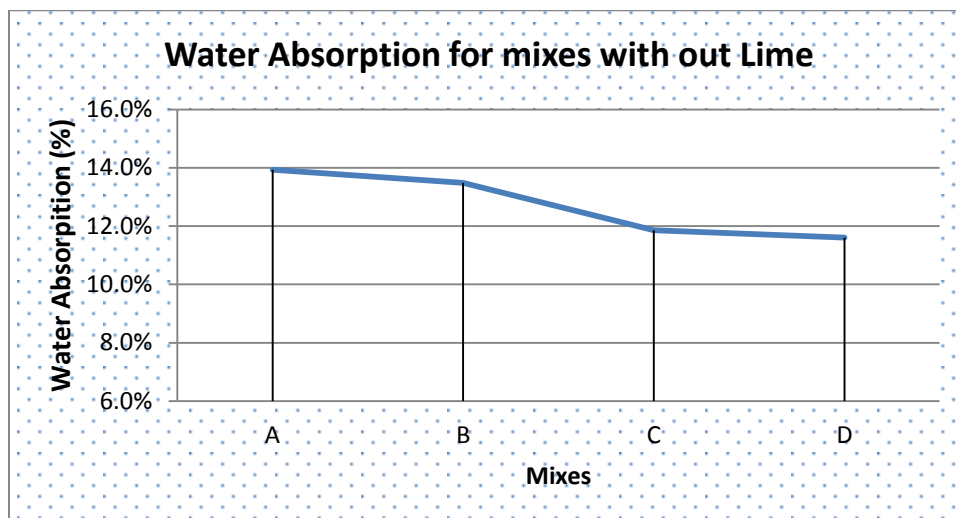


Figure 5-18: The effect of cement content on water absorption of the soil blocks

According to the results in Table 5.8 and Figure 5.18 above, the mean water absorption values for the various sample blocks stabilized with cement range from 11.6% for the 10% cement content samples to 13.9% for the 4% cement content samples. From literatures[15] [16], the recommended maximum block water absorption value for blocks is 15%. 16.5% reduction in block water absorption was observed for 4 % cement and 10% cement contents.

5.3.2 Water Absorption Test Result for 4 % stabilizer replacement (with cement and lime)

According to the results in Figure 5.19 below, the mean water absorption values of the three samples A (4% cement and no lime), E (2% cement and 2% Generic lime) and P (2% cement and 2% Senkale lime) is 13.9% , 13.5% and 11.3% respectively . From literature, the recommended maximum water absorption value for blocks is 15% [15] [16].

2.88% reduction in block water absorption was observed for mix A to mix E. The block water absorption of mix P is 18.9%, 16.5% lower than mix A and mix E respectively.

Table 5-9: The effect of lime addition on water absorption of the soil blocks (for 4% replacement)

| Mixes | cement | Lime from source 1 | Lime from source 2 | Block water absorption |
|-------|--------|--------------------|--------------------|------------------------|
| A | 4% | 0% | 0% | 13.9% |
| E | 2% | 2% | 0% | 13.5% |
| P | 2% | 0% | 2% | 11.3% |

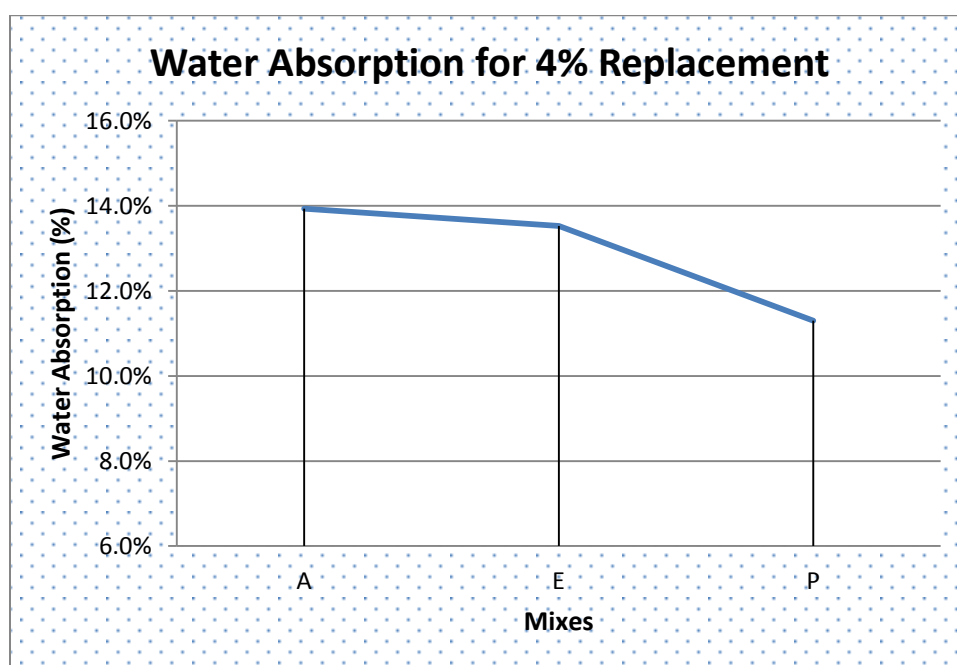


Figure 5-19: The effect of lime addition on water absorption of the soil blocks (for 4% replacement)

5.3.3 Water Absorption Test Result for 6 % stabilizer replacement (with cement and lime)

According to the results in Figure 5.20 in the following page, the mean water absorption values of the five samples B (6% cement and no lime), F (4% cement and 2% Generic lime) , G (3% cement and 3% ordinary lime) , Q (4% cement and 2% Senkale lime) and R (3% cement and 3% Senkale lime) is 13.5%, 13.0% , 12.4% , 11.4% and 10.9% respectively . From the literature, the recommended maximum water absorption value for blocks is below 15% [15] [16].

STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN ALTERNATIVE WALL MAKING MATERIAL

Compared to mix B, mix F showed 3.6% reduced in block water absorption. 8.1% reduction in block water absorption was observed for mix B to mix G. The block water absorption of mix Q is 15.3% lower than mix B, and mix R's block water absorption is 19.5% lower than that of mix B.

12.7% reduction in block water absorption was observed from mix F to mix Q and 12.1% reduction from mix G to mix R.

Table 5-10: The effect of lime addition on water absorption of the soil blocks (for 6% replacement)

| Mixes | Cement | Lime from source 1 | Lime from source 2 | Block water absorption |
|-------|--------|--------------------|--------------------|------------------------|
| B | 6% | 0% | 0% | 13.5% |
| F | 4% | 2% | 0% | 13.0% |
| G | 3% | 3% | 0% | 12.4% |
| Q | 4% | 0% | 2% | 11.4% |
| R | 3% | 0% | 3% | 10.9% |

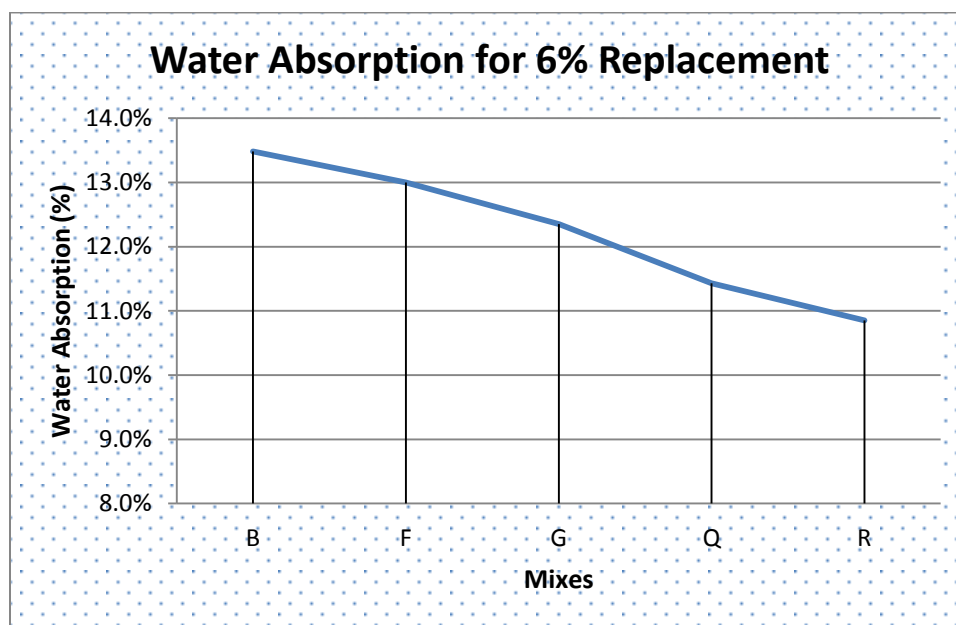


Figure 5-20: The effect of lime addition on water absorption of the soil blocks (for 6% replacement)

5.3.4 Water Absorption Test Result for 8 % stabilizer replacement (with cement and lime)

According to the results in Figure 5.21 below, the mean water absorption values of the five samples C (8% cement and no lime), H (6% cement and 2% Generic lime), I (4% cement and 4% Generic lime), S (6% cement and 2% Senkale lime), T (4% cement and 4% Senkale lime) is 11.9%, 11.7%, 11.4%, 10.3% and 10.1% respectively . From the literature, the recommended maximum water absorption value for blocks is 15% [15] [16].

Compared to mix C, mix H showed 1.6% reduced in block water absorption. 4.1% reduction in block water absorption was observed for mix C to mix I.

The block water absorption of mix S is 13.4% lower than mix C, and mix T's block water absorption is 14.8% lower than that of mix C.

12 % reduction in block water absorption was observed from mix H to mix S and 11% reduction from mix I to mix T.

Table 5-11: The effect of lime addition on water absorption of the soil blocks (for 8% replacement)

| Mixes | Cement | Lime from source 1 | Lime from source 2 | Block water absorption |
|-------|--------|--------------------|--------------------|------------------------|
| C | 8% | 0% | 0% | 11.9% |
| H | 6% | 2% | 0% | 11.7% |
| I | 4% | 4% | 0% | 11.4% |
| S | 6% | 0% | 2% | 10.3% |
| T | 4% | 0% | 4% | 10.1% |

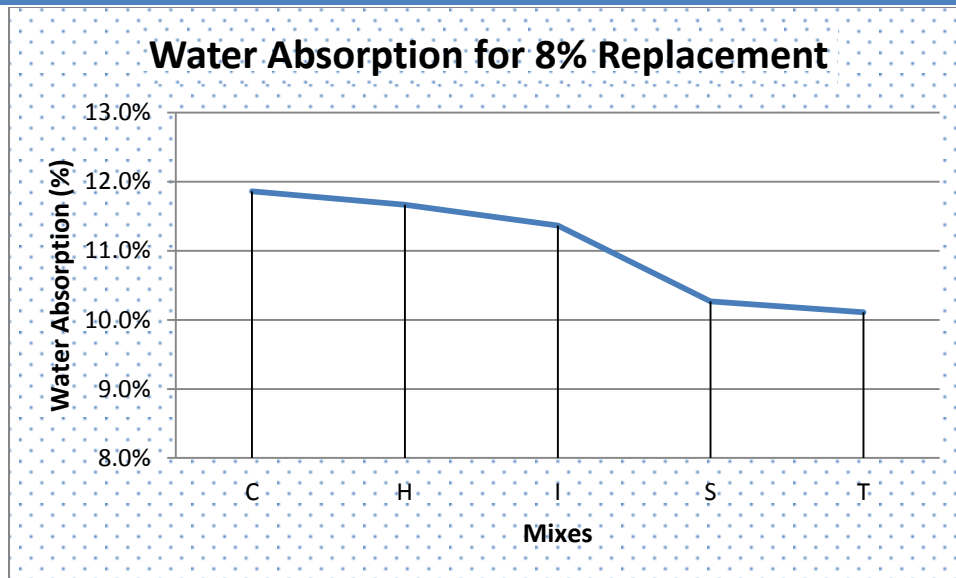


Figure 5-21: The effect of lime addition on water absorption of the soil blocks (for 8% replacement)

5.3.5 Water Absorption Test Result for 10 % stabilizer replacement (with cement and lime)

According to the results in Figure 5.22 below, the mean water absorption values of samples D (10% cement and no lime), J (8% cement and 2% lime), K (6% cement and 4% lime) and L (5% cement and 5% lime) is 11.6%, 11.4% , 11.3% and 11.1% respectively . And the mean water absorption values of samples U (8% cement and 2% Senkale lime), W (6% cement and 4% Senkale lime) and X (5% cement and 5% Senkale lime) is 10.7%, 9.6% and 9.4% respectively.

Compared to mix D, mix J showed 2.1% reduced in block water absorption. 3% reduction in block water absorption was observed for mix K to mix D. and 4.7% reduction from mix L to mix D was observed.

The block water absorption of mix U is 7.8% lower than mix D, and mix W's & X's block water absorption is 17.2% & 19.1% lower than that of mix D respectively.

5.8 % reduction in block water absorption was observed from mix J to mix U and 14.6% reduction from mix K to mix W. block water absorption result of mix X is 15.7% lower than that of mix L.

Table 5-12: The effect of lime addition on water absorption of the soil blocks (for 10% replacement)

| Mixes | Cement | Lime from source 1 | Lime from source 2 | Block water absorption |
|-------|--------|--------------------|--------------------|------------------------|
| D | 10% | 0% | 0% | 11.6% |
| J | 8% | 2% | 0% | 11.4% |
| K | 6% | 4% | 0% | 11.3% |
| L | 5% | 5% | 0% | 11.1% |
| U | 8% | 0% | 2% | 10.7% |
| W | 6% | 0% | 4% | 9.6% |
| X | 5% | 0% | 5% | 9.4% |

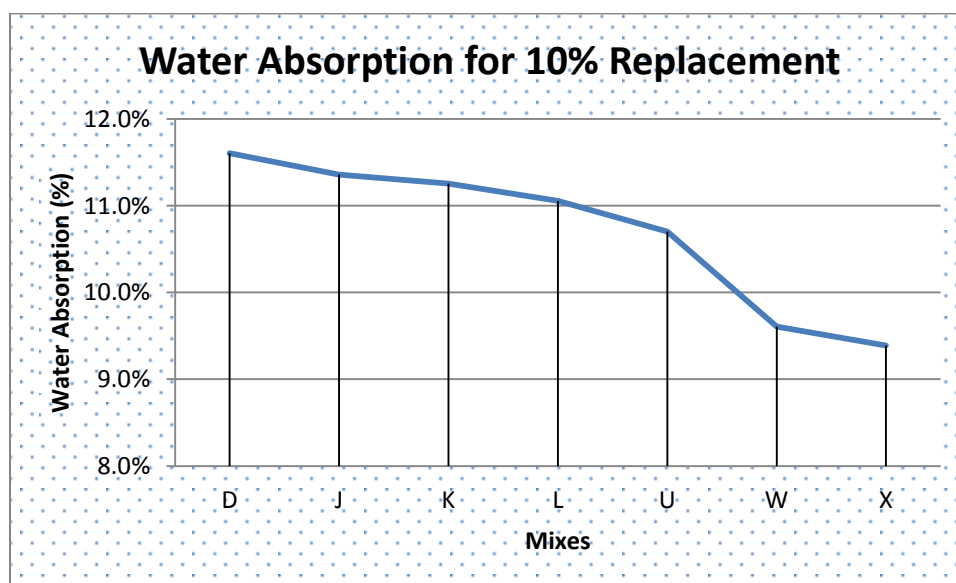


Figure 5-22: The effect of lime addition on water absorption of the soil blocks (for 10% replacement)

5.4 Summary

Stabilization of soil for the production of compressed stabilized soil blocks improves the performance characteristics of soil block. In this research work, by using soil from Kara area of Addis Ababa, Portland pozzolana cements from Derba cement factory, and lime from two sources (from the local market and from Senkale lime manufacturing company) four different series of mixes were prepared and more than 200 soil blocks were produced. By using these test

blocks, different standard performance tests were conducted at Addis Ababa institute of technology construction materials laboratory. The effects of varying the stabilizer content with 2% from 4% to 10 % on the performance of soil block, the effects of compaction pressure on the quality of soil cement block, the effects of adding lime as a stabilizer in combination with cement, the effects of stabilizer content on the absorption capacity of soil blocks were also examined. Based on the results obtained the following points are concluded:

- Increment of stabilizer content increases the compressive strength and decreases the water absorption capacity of the compressed stabilized soil block.
- Increment of the compaction pressure improves the compressive strength of compressed stabilized earth blocks.
- The effects of using lime as stabilizer in combination with cement were examined and comparisons were made, the 56th day compressive strength of compressed cement in combination with lime stabilized soil block was higher than the 56th day compressive strength of cement stabilized earth blocks.
- Addition of lime in combination with cement shows reduced block water absorption than that of using cement alone.
- From the two sources of lime, lime from source two (Senkale lime) shows better stabilization than that of lime from source one (from local market).

6 COST ANALYSIS OF COMPRESSED STABILIZED EARTH BLOCKS

6.1 Production cost of compressed stabilized earth block

In this research work for the production cost calculation of compressed stabilized soil block, relevant data of working conditions are taken from Selam Technical and Vocational center. And prices of raw materials used for the production of the blocks are from the current market price of construction materials.

The optimum stabilizer content is taken as 6% for the cost analysis because the 28th day compressive strength of CSEBs stabilized with cement alone and cement together with lime is more than 2.5MPa which is higher than the recommended 28th compressive strength which is 1MPa- 2MPa [16], further increasing the stabilizer content will increase the cost of the blocks. For 4% stabilizer content (2% cement and 2% lime from source one), the 28th day compressive strength doesn't fulfill the minimum requirement.

6.2 Parameters that influence the production cost of CSEB

A) Machine life span

This represents the total number blocks, which can be produced by the Hydrafoam block making machine. About 1.5 million blocks can be produced by using M7E380 Hydraform block making machine over a period of 5 years with proper maintenance. The specification of M7E380 is presented in Appendix J.

B) Daily production

It varies with the block size. In the case of 220×220×115 mm block the daily production is 1500. In this research work 1200 blocks per day are taken as daily production.

C) Annual production

It is the monthly production (26 days) over a period of 11 months. Every year, one month is deducted for the maintenance of the equipment. In this research work 343,200 blocks per year are taken as yearly production.

D) Equipment cost

Main equipment and machineries used for the production of compressed stabilized earth blocks are Hydraform block making machine (M7E380), soil mixer, soil sieve, wheel barrow, water can and plastic sheet. Based on the current price the cost of the Hydrafoam making machine with all

the accessories is around 1,000,000ETB. Equipment depreciation is calculated on the lifespan of the press on average it serves for 5 years. Therefore, the depreciation can be estimated as 20% per year. Straight line depreciation method was used for calculation.

E) Buildings & Infrastructure

Building and infrastructure cost was taken as 50,000 ETB. And its building depreciation is taken as 5% per year by taking the life span of the building 20 years.

F) Maintenance

Maintenance cost of the machine includes the daily maintenance and the yearly repairs, once in a year. In this research work, yearly maintenance cost of the machine is taken as 5% of the initial cost of the hydra foam block making machine.

G) Labor

Based on the current market, per diem cost of daily laborers is taken as 90ETB/day. And 15 laborers are required to produce the daily production.

H) Stabilizers content

6% stabilizer content was used as optimum stabilizer content because the 28th day compressive strength of CSEBs stabilized with cement alone and cement together with lime is more than 2.5MPa which is higher than the recommended 28th compressive strength which is 1MPa - 2 MPa [16], further increasing the stabilizer content will increase the cost of the blocks.

- i. **For mix without lime-** 6% cement (by weight) is taken for the cost calculations.
- ii. **For mix with lime-** There are two options of mixes for 6% total stabilizer content that contain lime, 3% lime and 3% cement and the other option 4% cement and 2% lime. Both options have satisfied the 28th day compressive strength requirement. From the two options 3% lime and 3% cement by weight is taken for the cost calculations, because its 56th day compressive strength is higher than the other options (it can be referred from Table 5-3).

I) Soil

Based on the current market price 150 ETB/m³ of soil is taken as cost of the soil includes the excavation cost of the soil from the source, loading unloading and transportation costs.

J) Profit Margin

Profit margin of 15% (of the direct cost) is taken in this research work.

6.3 Unit cost

The unit cost calculation for the production of CSEB without lime and with lime, are shown in Table 6.2 and 6.3 respectively. Information used for the unit cost calculations are summarized in the Table 6.1 below.

Table 6-1: Factors affecting the unit cost calculations

| | Units | Production/ Cost |
|------------------------------------|--------------------|--------------------------|
| Daily production | Blocks | 1,200 |
| Annual production | Blocks | 343,200 |
| Material cost | | |
| Soil cost | ETB/m ³ | 150 |
| Cement price excluding VAT | ETB/Quintal | 197 |
| Lime price excluding VAT | ETB/ Quintal | 336 |
| Labor cost | | |
| Daily Laborers | ETB/day/person | 150 |
| Forman Salary | ETB/Month | 8000 |
| Equipment and Building cost | | |
| Equipment cost (with Accessories) | ETB | 1,000,000 (initial cost) |
| Buildings and infrastructure cost | ETB | 50,000 (initial cost) |
| Maintenance cost per year | ETB/year | 50,000 |

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Table 6-2: Unit cost calculation table for (220x220x115 mm) block using 6% cement

| Variable Costs | Required Amount | Cost | Cost/block (ETB) |
|---------------------------------------|------------------------|---------------------------|-------------------------|
| Daily Laborer | 15 laborer/day | 90 ETB/day/person | 1.13 |
| Forman salary | 1 | 8000 ETB/month | 0.28 |
| Soil | 12 m ³ /day | 150 ETB/m ³ | 1.50 |
| Cement (6%) | 7.2 quintal/ day | 197 ETB/quintal | 1.18 |
| Maintenance cost | | | 0.15 |
| Total (ETB) | | | 4.23 |
| Fixed Costs | Amount | Initial cost (ETB) | Cost/Block (ETB) |
| Investment cost | 7% per year (interest) | 450,000 | 0.07 |
| Equipment depreciation (lifespan) | 20% per year | 1,000,000 | 0.58 |
| Building depreciation (site duration) | 5% per year | 50,000 | 0.01 |
| Miscellaneous | 5%* | | 0.18 |
| Profit margin | 15%** | | 0.76 |
| Over Head | 15%*** | | 0.76 |
| Total cost (ETB) | | | 6.59 |

* 5% of the direct cost

** 15% of the direct cost

*** 15% of the direct cost

Table 6-3: Unit cost calculation table for (220x220x115 mm) block using 3% cement and 3% lime

| Variable costs | Required Amount | Cost | Cost/block (ETB) |
|---|----------------------------|------------------------|------------------|
| Labor per day | 15 laborer/day | 90 ETB /person/day | 1.13 |
| Forman salary | 1 | 8,000 ETB/month | 0.28 |
| Soil | 12 m ³ /day | 150 ETB/m ³ | 1.50 |
| Cement (3%) | 3.6 quintal/day | 197 ETB/quintal | 0.59 |
| Lime (3%) | 3.6 quintal/day | 336 ETB/quintal | 1.01 |
| Maintenance cost | | | 0.15 |
| Total variable Costs (ETB) | | | 4.65 |
| Fixed Costs | Amount | Initial Cost (ETB) | Cost/Block (ETB) |
| Investment cost | 7% per year (interest) | 450,000 | 0.07 |
| Equipment depreciation (Press lifespan) | 20% per year | 1,000,000 | 0.58 |
| Building depreciation (site duration) | 5% per year | 50,000 | 0.01 |
| Miscellaneous | 5%* | | 0.08 |
| Profit margin | 15%** | | 0.83 |
| Over Head | 15%*** | | 0.83 |
| Total cost (ETB) | | | 7.00 |

* 5% of the direct cost

** 15% of the direct cost

*** 15% of the direct cost

6.4 Unit cost calculation for production of Hollow Concrete Blocks (HCBs) class B

Mix design of 2.5kg of cement, 0.004m³ of sand, 0.004m³ of crushed stone (01) and 0.004m³ of red ash per block is used for the unit cost calculation of wall made with class B HCB. Other information required for unit cost calculations for HCBs production is summarized in Table 6.4 below. The Unit cost calculation is presented in the Table 6.5.

STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL

Table 6-4: Factors affecting the unit cost calculations of HCBS

| Factors Affecting Unit cost of HCB | Unit | Production or Cost |
|------------------------------------|--------------------|--------------------|
| Daily production | Blocks | 1000 |
| Annual production | Blocks | 286,000 |
| Equipment cost with accessories | ETB | 100,000 |
| Buildings and infrastructure cost | ETB | 50,000 |
| Cost of sand | ETB/m ³ | 400 |
| Cost of cement excluding VAT | ETB/quintal | 197 |
| Cost of Red sand | ETB/m ³ | 200 |
| Cost of Crushed stone 01 | ETB/m ³ | 200 |
| Maintenance | ETB/year | 10000 |

Table 6-5: Unit Cost calculation for (200x200x400) mm HCB “Class B”

| VARIABLE COSTS | Units | Cost | Cost/Block (ETB) |
|-----------------------------------|-------------------------|------------------------|------------------|
| Labor cost per day | 12 laborer/ day | 90 ETB/person | 1.08 |
| Sand cost per day | 4 m ³ /day | 400 ETB/m ³ | 1.60 |
| Red sand per day | 4 m ³ /day | 200 ETB/m ³ | 0.80 |
| Crushed stone 01 per day | 4 m ³ /day | 200 ETB/m ³ | 0.80 |
| Cement per day | 25 Quintal/day | 197 ETB/Quintal | 4.93 |
| Maintenance per block | | | 0.03 |
| Total variable Costs (ETB) | | | 9.24 |
| Fixed Costs | Amount | Initial Cost | Cost/Block (ETB) |
| Investment cost | 7% per year (interest) | 200,000 ETB | 0.03 |
| Equipment depreciation (lifespan) | 20% | 100,000 ETB | 0.07 |
| Building depreciation | 5% | 50,000 ETB | 0.01 |
| Miscellaneous | 5%* | | 0.16 |
| Profit margin | 15%** | | 1.43 |
| Over Head | 15%*** | | 1.43 |
| Total cost (ETB) | | | 12.37 |

5%*- 5% of the direct cost,

15%**and 15***- 15 % of the direct cost

6.5 Comparison of compressed stabilized soil block with hollow concrete blocks per m² area of wall

The first question a potential user will ask is whether a building built with compressed stabilized earth block is more economical than one built with any other material. First of all, one must consider the type of building. In luxury villa, the cost of the wall building materials accounts very little of the total cost [4]. But in the case of low cost houses, such as those social housing programs, the cost of walls is a major component of the total cost [6]. This implies that the choice of building materials and the wall building techniques are more critical.

The use of hollow concrete blocks is increasing rapidly in every part of the world. But their thermal performance is poor and their cost is very dependent on the local cost and availability of cement [12]. Furthermore, HCB wall always requires plastering and/or rendering.

Replacing cement in block production with soil is environmentally safe and simple as the raw materials are readily available.

The high thermal mass (the ability of to absorb and store heat energy) of compressed earth walls compared to concrete blocks act naturally to regulate the internal temperature of a building. In colder climate CEB use passive solar energy to heat building by absorbing heat during the day and releasing it at night. Allowing thermal mass to control the building's temperature decreases the need of air conditioning or heating [16]. CEB absorb heat slower than the surrounding air, therefore in hotter climate it takes along time to penetrate the thick wall. Therefore in the afternoon the interior surface of the wall will be cool and so is the interior house. CEB construction contributes to the overall energy efficiency of buildings. However in rainy climates, additional insulation and a large roof is required for CEB walls to ensure that the overhangs protect the walls from moisture [5]. The mass of CEB walls provides superior thermal and acoustic properties. As a result they are also naturally earthquake resistant than HCBs [23].

Walls constructed with the interlocking compressed earth blocks are laid without mortar thereby leading to considerable savings in cost associated with mortar and also save a considerable time of construction than that of HCB walls.

CEBs can be left un plastered since their surface is smooth and aesthetically pleasing. But HCBs require plastering, which increase the walling cost.

To make a realistic comparison, it was important to consider a complete section of wall including the cost of plastering and structural elements. In this research, wall made of HCB plastered on both sides in one hand and HCB wall pointed on both sides on the other hand compared with compressed stabilized soil blocks (with and without lime) wall varnished on both sides per m² area of wall. To reduce the moisture penetration in to the compressed stabilizes earth blocks, varnish was used. Cost comparisons are prepared and tabulated in Table 6.6 below. Material and labor breakdown calculations are presented in Appendix I.

According to Table 6.6, one m² of CSEB (stabilized with cement) wall varnished both internally and externally costs 321.60 Birr and CSEB (stabilized with cement and lime) wall varnished both internally and externally costs 338.70 Birr. This implies that the cost of CSEB with lime wall 5.3% more expensive than CSEB without lime.

According to Table 6.6 the cost of HCB wall plastered and painted internally and externally costs 612.6 Birr per m², 90.45% more expensive than wall made from compressed stabilized earth block without lime (varnished inside and outside) and 80.88% more expensive than wall made from compressed stabilized earth block with cement and lime (varnished inside and outside).

As per the analysis in table 6.6 below, the unit cost of HCB wall pointed inside and outside is 365.8 birr per m², 13.7% more expensive than wall made from compressed stabilized earth block without lime (varnished inside and outside) and 8.0% more expensive than wall made from compressed stabilized earth block with cement and lime (varnished inside and outside).

STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
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Table 6-6: Cost comparison of CSEB with Hollow Concrete Blocks per m² area of wall (in ETB)

| S/N | Description | HCB1 | HCB2 | CSEB1 (without lime) | CSEB2 (without lime) | CSEB1 (with lime) | CSEB2 (with lime) |
|----------|---|--------------|--------------|----------------------------|----------------------------|-------------------------|-------------------------|
| 1 | Block | 154.6 | 154.6 | 272.1 | 272.1 | 289.2 | 289.2 |
| 2 | Mortar for fixing | 114.0 | 114.0 | | | | |
| 3 | Plastering | 234.0 | | 117.0 | | 117.0 | |
| 4 | Pointing | | 97.2 | | | | |
| 5 | Painting | 110.0 | | 17.0 | | 17.0 | |
| 6 | Varnish | | | 15.0 | 30.0 | 15.0 | 30.0 |
| 7 | Labor | | | 19.5 | 19.5 | 19.5 | 19.5 |
| 8 | Total walling cost (ETB) | 612.6 | 365.8 | 440.6 | 321.6 | 457.7 | 338.7 |

HCB 1 – Hollow concrete block class B (HCB) blocks per m² Plastered and painted (outside & inside)

HCB 2 - Hollow concrete block class B (HCB) blocks per m² Pointed (outside & inside)

CSEB 1 (without lime) - compressed cement stabilized earth block without lime plastered internally and varnished outside. (6% cement)

CSEB 2 (without lime) - compressed cement stabilized earth block without lime varnished inside and outside. (6% cement)

CSEB 1 (with lime) - compressed cement and lime stabilized earth block plastered internally and varnished outside. (3% cement & 3% lime)

CSEB 2 (with lime) - compressed cement and lime stabilized earth block without lime varnished inside and outside. (3% cement & 3% lime)

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Based on the investigations made and as reported in the previous chapters, the following conclusions are drawn.

1. Soil from Kara area shows acceptable properties regarding its physical and chemical compositions for the production of compressed stabilized earth blocks as alternative wall making materials.
2. Increase in stabilizer content results in an increase in the compressive strength and decrease in water absorption capacity of blocks made at constant compaction pressure. And increasing compaction pressure results in an increase in the compressive strength of blocks for the same stabilizer content.
3. This experimental study on CSEBs has shown the effectiveness of using lime (in combination with cement), in improved 56th day compressive strength and reduced block water absorption than using cement alone.
4. Because of the higher Sulphate content of the Generic lime used in this research as lime from source one, its stabilization capacity is lower than that of Senkale lime (lime from source two) based on the respective compressive strength and block water absorption test results.
5. Based on the experimental study, from the two sources of lime used for stabilization, lime from source one (Generic lime) showed decreased compressive strength than that of lime from source two (Senkale lime). The blocks made with total stabilizer content of 4% by using generic lime in combination with cement, haven't attained the minimum 28th day compressive strength of 2MPa based on ARS 674 standard – technical specifications for ordinary compressed earth blocks. Whereas all the blocks prepared by using Senkale lime in combination with cement have attained the minimum 28th day compressive strength of 2MPa. (Can be refer from Chapter five)
6. The combination of cement and lime has been found to be mutually beneficial in imparting strength to the blocks in better way, because cement has taken care of stabilizing the sand portion with hydration products obtained from cement and lime to stabilize clay fraction present in the mix.

7. The cost comparison between compressed stabilized soil block prepared using lime as a replacement to cement in certain proportions and compressed stabilized soil block prepared using cement alone has revealed that the cost of compressed stabilized soil block with lime in combination with cement is 3.9% higher than using cement alone for wall varnished inside and outside, since the current price of lime is higher than that of Portland pozzolana cement.
8. The cost comparison between wall made from compressed stabilized soil block and hollow concrete block has revealed that wall made from compressed stabilized soil blocks (with and without lime) is 42% and 48% lower than wall with Hollow concrete blocks (HCBs) respectively. In the case of low cost housing, compressed stabilized earth blocks can be used as alternative wall making material.

7.2 Recommendations

Based on the findings of this research the following recommendations are drawn;

1. The results of this research work have revealed that compressed stabilized soil block can be used as an alternative wall making material. Significant cost cut can be achieved in low cost housing projects especially town houses. Any concerned body can use this material as an alternative wall making material with proper quality control.
2. The use of compressed stabilized soil block as a walling material in Ethiopia has shown different defects. These defects include time related loss of quality of the block under direct or indirect influence of environment. This can be reduced by proper quality control during production; Plastering of the first two courses of the wall and increasing the overhangs of the roof.
3. The research findings show a need to relook at the grading of ingredients and quantity of stabilizers for achieving good building blocks. Lime used for stabilization should be pure to obtain a better performance.
4. Using stabilizers in combination would help in reducing the use of cement. This has serious implications in terms of the reduction of energy consumed in the manufacture of blocks when done in large scale. This would also help in a sustainable growth of the society by optimizing the resources used, reduction in energy consumed and lesser pollution of the environment.

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APPENDIX A

Soil Physical property test result

Table A 1: Natural moisture content Determination

Method used ASTM D 2216

MOISTURE CONTENT

| Determination No: | 1 | 2 | 3 |
|---------------------------------------|--------------|--------|--------|
| Weight of Can + moist soil, W_1 (g) | 197.65 | 197.4 | 197.42 |
| Weight of Can + dry soil, W_2 (g) | 190.55 | 190.2 | 190.33 |
| Weight of can, W_c (g) | 64.93 | 62.51 | 63.45 |
| weight of water, W_w (g) | 7.1 | 7.2 | 7.09 |
| weight of dry soil, W_s (g) | 125.62 | 127.69 | 126.88 |
| Moisture content, | 5.35% | 5.34% | 5.29% |
| | 5.33% | | |

Table A 2: Specific Gravity Test

Method used ASTM D 854

SPECIFIC GRAVITY

| Determination No: | 1 | 2 | 3 |
|---------------------------------------|-------------|-------|-------|
| Weight of pycnometer +soil +water(M3) | 80.35 | 84.42 | 82.55 |
| Weight of pycnometer + water(M4) | 75.86 | 79.12 | 77.42 |
| Weight of pycnometer + Soil (M2) | 33.29 | 37.91 | 36.52 |
| Weight of pycnometer (M1) | 25.98 | 29.25 | 27.62 |
| Temperature, T (°C) | 23 | 23 | 23 |
| Specific gravity | 2.59 | 2.58 | 2.6 |
| Average specific Gravity | 2.59 | | |

Table A 3: Plastic Limit Determination

Method used ASTM D 2216-92

PLASTIC LIMIT

| Determination No: | 1 | 2 | 3 |
|------------------------------------|--------------|-------|-------|
| Weight of can + Moist soil, W1 (g) | 21.4 | 21.07 | 21.1 |
| Weight of can + Dry soil, W2 (g) | 20.63 | 20.27 | 20.3 |
| Weight of can, Wc (g) | 17.5 | 17 | 17 |
| Weight of water, Ww (g) | 0.77 | 0.8 | 0.8 |
| Weight of dry soil, Ws (g) | 3.13 | 3.27 | 3.3 |
| Plastic Limit (%) | 24.6% | 24.5% | 24.2% |
| | 24.4% | | |

Table A 4: Liquid Limit Determination

Method used ASTM D 2216-92

LIQUID LIMIT

| Determination No: | 1 | 2 | 3 | 4 |
|----------------------------------|--------------|-------|-------|-------|
| Number of drops | 150 | 210 | 235 | 245 |
| Weight of can +Moist soil, W1(g) | 44.2 | 37.1 | 36.5 | 37.8 |
| Weight of can +Dry soil, W2(g) | 41.9 | 35.3 | 34.1 | 35.3 |
| Weight of can, Wc(g) | 35 | 30 | 27 | 28 |
| Weight of water, Ww(g) | 2.3 | 1.8 | 2.4 | 2.5 |
| Weight of dry soil, Ws(g) | 6.9 | 5.3 | 7.1 | 7.3 |
| LL (%) | 33.3% | 34.0% | 33.8% | 34.2% |
| | 33.8% | | | |

Table A 5: Sieve analysis

Method used ASTM D 422

Sieve Analysis

| SIEVE Size (mm) | Weight retained (gm) | % retained | Cumulative % retained | Cumulative % passing |
|----------------------------|---------------------------------|-----------------------|----------------------------------|---------------------------------|
| 2 | 0 | 0.00% | 0.00% | 100.00% |
| 1.18 | 13 | 6.50% | 6.50% | 93.50% |
| 0.6 | 41 | 20.50% | 27.00% | 73.00% |
| 0.3 | 43 | 21.50% | 48.50% | 51.50% |
| 0.15 | 23 | 11.50% | 60.00% | 40.00% |
| 0.075 | 17 | 8.50% | 68.50% | 31.50% |
| PAN | 63 | 31.50% | 100.00% | 0.00% |
| | 200 | | | |

Table A 6: Hydrometer Analysis

Method used ASTM D 422

| Elapsed time (T in min) | Hydrometer reading | Composite correction (C) | Corrected hydrometer reading | Temperature (°C) | D(particle diameter) | % finer (P) |
|--|-------------------------------|---|---|-----------------------------|---------------------------------|------------------------|
| 2 | 1.018 | 0.002 | 1.016 | 21 | 0.033672948 | 30.5 |
| 5 | 1.017 | 0.002 | 1.015 | 21 | 0.021471926 | 29.1 |
| 15 | 1.015 | 0.002 | 1.013 | 21 | 0.012695584 | 24.3 |
| 30 | 1.013 | 0.002 | 1.011 | 21.5 | 0.00923968 | 21.8 |
| 60 | 1.012 | 0.002 | 1.01 | 21.5 | 0.006606171 | 19.1 |
| 250 | 1.011 | 0.002 | 1.009 | 20 | 0.00326814 | 15.8 |
| 1440 | 1.01 | 0.002 | 1.008 | 20 | 0.001376341 | 13.1 |

APPENDIX B

Chemical Analysis of Soil and lime

STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN ALTERNATIVE WALL MAKING MATERIAL

Geological Survey of Ethiopia: Geochemical Laboratory Directorate
 Geochemical Laboratory Complete Silicate Analysis Report Format
 FILE ID :0108/17 pvt
 Originator: Gobilu Tekle
 Sample type: Soil
 Date Submitted: 01/02/2017
 Form G0004

Preparation :- 200 MESH
 Number of Sample: 1
 Element to be determined Major Oxides & Minor Oxides
 Analytical Method: LIBO2 FUSION, HFATTACK, GRAVIMETRIC, COLORIMETRIC and AAS

Analytical Results in PERCENT

| FIELD NO | Lab No | SiO ₂ | Al ₂ O ₃ | Fe ₂ O ₃ | CaO | MgO | Na ₂ O | K ₂ O | MnO | P ₂ O ₅ | TiO ₂ | H ₂ O | LOI | SO ₃ | Cl ⁻ | PH |
|----------|---------|------------------|--------------------------------|--------------------------------|------|------|-------------------|------------------|------|-------------------------------|------------------|------------------|------|-----------------|-----------------|------|
| Soil-A | 0108/17 | 64.22 | 16.66 | 5.48 | 1.30 | 0.42 | 1.90 | 2.84 | 0.10 | 0.03 | 0.24 | 1.82 | 4.95 | 0.22 | <0.01 | 7.44 |

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Date Reported

3/15/2017



STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN ALTERNATIVE WALL MAKING MATERIAL

Geological Survey of Ethiopia:Geochemical Laboratory Directorate
 Geochemical Laboratory Complete Silicate Analysis Report Format
 FILE ID :0108/17 pvt
 Originator:Gobiitu Tekle
 Sample type:Lime
 Preparation :-200 MESH
 Date Submitted:01/02/2017

Form G0004

Number of Sample: 1 **Element to be determined Major Oxides & Minor Oxides**

Analytical Method: LIBO2 FUSION , HFattack, GRAVIMETRIC,COLORIMETRIC and AAS

Analytical Results in PERCENT

| FIELD NO | Lab No | SiO ₂ | Al ₂ O ₃ | Fe ₂ O ₃ | CaO | MgO | Na ₂ O | K ₂ O | MnO | P ₂ O ₅ | TiO ₂ | H ₂ O | LOI | So ₃ | Cl- | PH |
|----------|---------|------------------|--------------------------------|--------------------------------|-------|------|-------------------|------------------|-------|-------------------------------|------------------|------------------|------|-----------------|-------|------|
| Lime -B | 0109/17 | 2.76 | 0.46 | 0.26 | 37.68 | 0.96 | 0.12 | <0.01 | <0.01 | 0.34 | 0.01 | 5.88 | 1.41 | 48.64 | <0.01 | 7.96 |

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STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN ALTERNATIVE WALL MAKING MATERIAL

Geological Survey of Ethiopia:Geochemical Laboratory Directorate
 Geochemical Laboratory Complete Silicate Analysis Report Format
 FILE ID :0759/17 pvt
 Originator; Gobitu Tekle
 Sample type;lime
 Date Submitted; 04/06/2017
 Preparation :-200 MESH

Form G0004

Number of Sample: 1 Element to be determined Major Oxides & Minor Oxides
 Analytical Method: LiBOZ FUSION , HFattack, GRAVIMETRIC, COLORIMETRIC and AAS

Analytical Results in PERCENT

| FIELD NO | Lab No | SiO ₂ | Al ₂ O ₃ | Fe ₂ O ₃ | CaO | MgO | Na ₂ O | K ₂ O | MnO | P ₂ O ₅ | TiO ₂ | H ₂ O | LOI | So ₃ | Cl ⁻ |
|----------|---------|------------------|--------------------------------|--------------------------------|-------|------|-------------------|------------------|-------|-------------------------------|------------------|------------------|------|-----------------|-----------------|
| G.T-LIME | 0759/17 | 1.38 | 3.30 | 0.22 | 30.56 | 0.50 | 0.26 | 0.04 | <0.01 | 0.01 | 0.02 | 16.31 | 4.77 | 43.13 | <0.1 |

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STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN ALTERNATIVE WALL MAKING MATERIAL

Geological Survey of Ethiopia:Geochemical Laboratory Directorate
 Geochemical Laboratory Complete Silicate Analysis Report Format
 FILE ID :1460/17 pvt
 Originator;Gobitu Tekle
 Sample type;Powder
 Date Submitted;06/15/2017
 Form G0004

Preparation :-200 MESH
 Number of Sample: 1
 Element to be determined Major Oxides & Minor Oxides
 Analytical Method: LIBO2 FUSION , HFAttack,GRAVIMETERIC,COLORIMETRIC and AAS

Analytical Results in PERCENT

| FIELD NO | Lab No | SiO ₂ | Al ₂ O ₃ | Fe ₂ O ₃ | CaO | MgO | Na ₂ O | K ₂ O | MnO | P ₂ O ₅ | TiO ₂ | H ₂ O | LOI | SO ₃ |
|----------|---------|------------------|--------------------------------|--------------------------------|-------|------|-------------------|------------------|------|-------------------------------|------------------|------------------|-------|-----------------|
| G.T.01 | 1460/17 | 9.48 | 5.16 | 2.64 | 46.80 | 1.02 | 0.40 | <0.01 | 0.24 | <0.01 | 0.07 | 10.30 | 23.89 | 0.31 |
| | 1460-d | 9.60 | 5.08 | 2.64 | 46.64 | 0.90 | 0.36 | <0.01 | 0.28 | <0.01 | 0.07 | 10.30 | 24.11 | 0.52 |

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APPENDIX C
7th Day Compressive Strength Test Result

Table C 1: Seventh Day Compressive Strength Test Result

| Mix A (4 % cement and 0% Lime) | | | | | | | | | | | | |
|---------------------------------|-----------|------------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| A1 | 10/3/2017 | 17/03/2017 | 7 | 9.6 | 20.5 | 22.5 | 11.5 | 5,304.4 | 1,809.8 | 55.4 | 1.2 | 1.1 |
| A2 | 10/3/2017 | 17/03/2017 | 7 | 9.5 | 21 | 22.5 | 11.5 | 5,433.8 | 1,748.3 | 52.0 | 1.1 | |
| A3 | 10/3/2017 | 17/03/2017 | 7 | 9.5 | 22 | 21 | 11.5 | 5,313.0 | 1,788.1 | 46.2 | 1.0 | |

| Mix B (6 % cement and 0% Lime) | | | | | | | | | | | | |
|---------------------------------|-----------|------------|------------|------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| B1 | 10/3/2017 | 17/03/2017 | 7 | 9.9 | 22 | 23 | 11.5 | 5,819.0 | 1,701.3 | 75.9 | 1.5 | 1.5 |
| B2 | 10/3/2017 | 17/03/2017 | 7 | 9.6 | 22.5 | 23 | 11.5 | 5,951.3 | 1,613.1 | 77.6 | 1.5 | |
| B3 | 10/3/2017 | 17/03/2017 | 7 | 9.5 | 22 | 23.4 | 11.5 | 5,920.2 | 1,604.7 | 77.2 | 1.5 | |

| Mix C (8 % cement and 0% Lime) | | | | | | | | | | | | |
|---------------------------------|-----------|------------|------------|------|----|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| C1 | 10/3/2017 | 17/03/2017 | 7 | 10.1 | 22 | 22 | 11.4 | 5,517.6 | 1,830.5 | 84.7 | 1.8 | 1.8 |
| C2 | 10/3/2017 | 17/03/2017 | 7 | 9.9 | 21 | 22.5 | 11.5 | 5,433.8 | 1,821.9 | 89.8 | 1.9 | |
| C3 | 10/3/2017 | 17/03/2017 | 7 | 9.7 | 22 | 22.5 | 11.5 | 5,692.5 | 1,704.0 | 89.1 | 1.8 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

Mix D (10 % cement and 0% Lime)

| Marking | Date | | Age (days) | Mass | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|------------|------------|------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| D1 | 10/3/2017 | 17/03/2017 | 7 | 10 | 22 | 21.5 | 11.5 | 5,439.5 | 1,838.4 | 99.3 | 2.1 | 2.0 |
| D2 | 10/3/2017 | 17/03/2017 | 7 | 10.1 | 22.5 | 23 | 11.5 | 5,951.3 | 1,697.1 | 98.3 | 1.9 | |
| D3 | 10/3/2017 | 17/03/2017 | 7 | 9.7 | 21.5 | 22 | 11.5 | 5,439.5 | 1,783.3 | 99.3 | 2.1 | |

Mix E (2 % cement and 2% Generic lime)

| Marking | Date | | Age (days) | Mass | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|------------|------------|------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| E1 | 10/3/2017 | 17/03/2017 | 7 | 9.2 | 21.5 | 22.6 | 11.5 | 5,587.9 | 1,646.4 | 36.4 | 0.8 | 0.9 |
| E2 | 10/3/2017 | 17/03/2017 | 7 | 9.1 | 22.5 | 21 | 11.5 | 5,433.8 | 1,674.7 | 40.2 | 0.9 | |
| E3 | 10/3/2017 | 17/03/2017 | 7 | 9.4 | 22 | 22 | 11.5 | 5,566.0 | 1,688.8 | 53.2 | 1.1 | |

Mix F (4 % cement and 2% Generic Lime)

| Marking | Date | | Age (days) | Mass | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|------------|------------|------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| F1 | 10/3/2017 | 17/03/2017 | 7 | 9.7 | 21.5 | 22.6 | 11.5 | 5,587.9 | 1,735.9 | 53.4 | 1.1 | 1.3 |
| F2 | 10/3/2017 | 17/03/2017 | 7 | 9.7 | 22.5 | 21 | 11.5 | 5,433.8 | 1,785.1 | 61.4 | 1.3 | |
| F3 | 10/3/2017 | 17/03/2017 | 7 | 9.7 | 22 | 22 | 11.5 | 5,566.0 | 1,742.7 | 67.8 | 1.4 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

Mix G (3 % cement and 3% Generic Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|------------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| G1 | 10/3/2017 | 17/03/2017 | 7 | 9.5 | 21.5 | 22.6 | 11.5 | 5,587.9 | 1,700.1 | 48.6 | 1.0 | 1.1 |
| G2 | 10/3/2017 | 17/03/2017 | 7 | 9.7 | 22.5 | 21 | 11.5 | 5,433.8 | 1,785.1 | 52.0 | 1.1 | |
| G3 | 10/3/2017 | 17/03/2017 | 7 | 9.7 | 22 | 22 | 11.5 | 5,566.0 | 1,742.7 | 53.2 | 1.1 | |

Mix H (6 % cement and 2% Generic Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|------------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| H1 | 10/3/2017 | 17/03/2017 | 7 | 10.1 | 22.5 | 22.5 | 11.5 | 5,821.9 | 1,734.8 | 75.9 | 1.5 | 1.6 |
| H2 | 10/3/2017 | 17/03/2017 | 7 | 9.9 | 22.3 | 22 | 11.5 | 5,641.9 | 1,754.7 | 78.5 | 1.6 | |
| H3 | 10/3/2017 | 17/03/2017 | 7 | 10 | 22 | 22 | 11.5 | 5,566.0 | 1,796.6 | 77.4 | 1.6 | |

Mix I (4 % cement and 4% Generic Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|------------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| I1 | 10/3/2017 | 17/03/2017 | 7 | 9.8 | 22 | 22.5 | 11.4 | 5,643.0 | 1,736.7 | 59.4 | 1.2 | 1.3 |
| I2 | 10/3/2017 | 17/03/2017 | 7 | 10 | 22.5 | 22 | 11.4 | 5,643.0 | 1,772.1 | 69.3 | 1.4 | |
| I3 | 10/3/2017 | 17/03/2017 | 7 | 9.7 | 22 | 22.5 | 11.5 | 5,692.5 | 1,704.0 | 69.3 | 1.4 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

Mix J (8 % cement and 2% Generic Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|------------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| J1 | 10/3/2017 | 17/03/2017 | 7 | 9.6 | 22 | 22.5 | 11.4 | 5,643.0 | 1,701.2 | 94.1 | 1.9 | 1.8 |
| J2 | 10/3/2017 | 17/03/2017 | 7 | 10.2 | 22.5 | 22 | 11.4 | 5,643.0 | 1,807.5 | 79.2 | 1.6 | |
| J3 | 10/3/2017 | 17/03/2017 | 7 | 9.5 | 22 | 22.5 | 11.5 | 5,692.5 | 1,668.9 | 89.1 | 1.8 | |

Mix K (6 % cement and 4% Generic Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|------------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| K1 | 10/3/2017 | 17/03/2017 | 7 | 9.7 | 22 | 22.5 | 11.5 | 5,692.5 | 1,704.0 | 94.1 | 1.9 | 1.7 |
| K2 | 10/3/2017 | 17/03/2017 | 7 | 9.9 | 22.5 | 22 | 11.5 | 5,692.5 | 1,739.1 | 69.3 | 1.4 | |
| K3 | 10/3/2017 | 17/03/2017 | 7 | 9.7 | 22.5 | 22 | 11.5 | 5,692.5 | 1,704.0 | 84.2 | 1.7 | |

Mix L (5 % cement and 5% Generic Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|------------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| L1 | 10/3/2017 | 17/03/2017 | 7 | 10.2 | 23.5 | 22.5 | 11.5 | 6,080.6 | 1,677.5 | 79.3 | 1.5 | 1.6 |
| L2 | 10/3/2017 | 17/03/2017 | 7 | 10.3 | 22.9 | 23.4 | 11.6 | 6,216.0 | 1,657.0 | 91.1 | 1.7 | |
| L3 | 10/3/2017 | 17/03/2017 | 7 | 10 | 23 | 24 | 11.6 | 6,403.2 | 1,561.7 | 82.8 | 1.5 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

Mix P (2 % cement and 2% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| P1 | 13/6/2017 | 20/6/2017 | 21 | 9.1 | 21.5 | 21.6 | 11.5 | 5340.6 | 1,703.9 | 45.7 | 1.0 | 1.0 |
| P2 | 13/6/2017 | 20/6/2017 | 21 | 8.9 | 21.2 | 21 | 11.5 | 5119.8 | 1,738.3 | 50.2 | 1.1 | |
| P3 | 13/6/2017 | 20/6/2017 | 21 | 9 | 21.5 | 21.5 | 11.5 | 5315.9 | 1,693.0 | 47.8 | 1.0 | |

Mix Q (4 % cement and 2% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| Q1 | 13/6/2017 | 20/6/2017 | 21 | 9.4 | 21.1 | 21 | 11.5 | 5095.7 | 1,844.7 | 62.5 | 1.4 | 1.3 |
| Q2 | 13/6/2017 | 20/6/2017 | 21 | 9.3 | 21.2 | 21 | 11.5 | 5119.8 | 1,816.5 | 59.3 | 1.3 | |
| Q3 | 13/6/2017 | 20/6/2017 | 21 | 9.3 | 21.4 | 21.2 | 11.5 | 5217.3 | 1,782.5 | 54.9 | 1.2 | |

Mix R (3 % cement and 3% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| R1 | 13/6/2017 | 20/6/2017 | 21 | 9.3 | 21.4 | 21.5 | 11.5 | 5291.2 | 1,757.7 | 52.9 | 1.1 | 1.2 |
| R2 | 13/6/2017 | 20/6/2017 | 21 | 9.2 | 21.3 | 21.5 | 11.5 | 5266.4 | 1,746.9 | 53.7 | 1.2 | |
| R3 | 13/6/2017 | 20/6/2017 | 21 | 9 | 21.4 | 21.4 | 11.5 | 5266.5 | 1,708.9 | 51.8 | 1.1 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

Mix S (6 % cement and 2% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| S1 | 13/6/2017 | 20/6/2017 | 21 | 9.2 | 21.4 | 21.5 | 11.5 | 5291.2 | 1,738.8 | 80.5 | 1.7 | 1.7 |
| S2 | 13/6/2017 | 20/6/2017 | 21 | 9.3 | 21.3 | 21.5 | 11.5 | 5266.4 | 1,765.9 | 75.7 | 1.7 | |
| S3 | 13/6/2017 | 20/6/2017 | 21 | 9.4 | 21.4 | 21.2 | 11.5 | 5217.3 | 1,801.7 | 82.4 | 1.8 | |

Mix T (4 % cement and 4% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| T1 | 13/6/2017 | 20/6/2017 | 21 | 9.1 | 21.1 | 21.3 | 11.5 | 5168.4 | 1,760.7 | 70.6 | 1.6 | 1.6 |
| T2 | 13/6/2017 | 20/6/2017 | 21 | 9 | 21.2 | 21.2 | 11.5 | 5168.6 | 1,741.3 | 75.8 | 1.7 | |
| T3 | 13/6/2017 | 20/6/2017 | 21 | 9.1 | 21.4 | 21.3 | 11.5 | 5241.9 | 1,736.0 | 69.7 | 1.5 | |

Mix U (8 % cement and 2% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| U1 | 13/6/2017 | 20/6/2017 | 21 | 9.2 | 21.5 | 21.4 | 11.4 | 5245.1 | 1,754.0 | 85.4 | 1.9 | 1.8 |
| U2 | 13/6/2017 | 20/6/2017 | 21 | 9.3 | 21.6 | 21.5 | 11.3 | 5247.7 | 1,772.2 | 80.5 | 1.7 | |
| U3 | 13/6/2017 | 20/6/2017 | 21 | 9.2 | 21.5 | 21.4 | 11.5 | 5291.2 | 1,738.8 | 79.2 | 1.7 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

Mix W (6 % cement and 4% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| W1 | 13/6/2017 | 20/6/2017 | 21 | 9.5 | 21.2 | 21.4 | 11.4 | 5172.0 | 1,836.8 | 78.4 | 1.7 | 1.8 |
| W2 | 13/6/2017 | 20/6/2017 | 21 | 9.5 | 21.5 | 21.4 | 11.3 | 5199.1 | 1,827.2 | 84.2 | 1.8 | |
| W3 | 13/6/2017 | 20/6/2017 | 21 | 9.4 | 21.5 | 21.4 | 11.5 | 5291.2 | 1,776.6 | 89.2 | 1.9 | |

Mix X (5 % cement and 5% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| X1 | 13/6/2017 | 20/6/2017 | 21 | 9.5 | 21.2 | 21.4 | 11.4 | 5172.0 | 1,836.8 | 78.4 | 1.7 | 1.7 |
| X2 | 13/6/2017 | 20/6/2017 | 21 | 9.7 | 21.4 | 21.2 | 11.3 | 5126.6 | 1,892.1 | 72.4 | 1.6 | |
| X3 | 13/6/2017 | 20/6/2017 | 21 | 9.6 | 21.3 | 21.3 | 11.5 | 5217.4 | 1,840.0 | 76.5 | 1.7 | |

APPENDIX D

21st Day Compressive Strength Test Result

Table D 1: 21st Day Compressive Strength Test Result

| Mix A (4 % cement and 0% Lime) | | | | | | | | | | | | |
|---------------------------------|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| A1 | 10/3/2017 | 31/3/2017 | 21 | 8.8 | 20.5 | 22.5 | 11.5 | 5304.4 | 1,659.01 | 92.00 | 2.0 | 2.1 |
| A2 | 10/3/2017 | 31/3/2017 | 21 | 8.9 | 21 | 22.5 | 11.5 | 5433.8 | 1,637.91 | 102.40 | 2.2 | |
| A3 | 10/3/2017 | 31/3/2017 | 21 | 9.5 | 22 | 21 | 11.5 | 5313.0 | 1,788.07 | 105.00 | 2.3 | |
| Mix B (6 % cement and 0% Lime) | | | | | | | | | | | | |
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| B1 | 10/3/2017 | 31/3/2017 | 21 | 9.1 | 22 | 23 | 11.5 | 5819.0 | 1,563.8 | 110.0 | 2.2 | 2.3 |
| B2 | 10/3/2017 | 31/3/2017 | 21 | 9.2 | 22.5 | 23 | 11.5 | 5951.3 | 1,545.9 | 125.0 | 2.4 | |
| B3 | 10/3/2017 | 31/3/2017 | 21 | 9.5 | 22 | 23.4 | 11.5 | 5920.2 | 1,604.7 | 119.0 | 2.3 | |
| Mix C (8 % cement and 0% Lime) | | | | | | | | | | | | |
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| C1 | 10/3/2017 | 31/3/2017 | 21 | 9.2 | 22 | 22 | 11.4 | 5517.6 | 1,667.4 | 139.0 | 2.9 | 2.8 |
| C2 | 10/3/2017 | 31/3/2017 | 21 | 9.3 | 21 | 22.5 | 11.5 | 5433.8 | 1,711.5 | 135.0 | 2.9 | |
| C3 | 10/3/2017 | 31/3/2017 | 21 | 9.7 | 22 | 22.5 | 11.5 | 5692.5 | 1,704.0 | 129.0 | 2.6 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

| Mix D (10 % cement and 0% Lime) | | | | | | | | | | | | |
|---|----------------|----------------|-------------------|------------------|----------|----------|----------|--------------------------------|---|--------------------------|-----------------------------------|---|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm³) | Unit Weight (Kg/ m³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| D1 | 10/3/2017 | 31/3/2017 | 21 | 9.4 | 22 | 21.5 | 11.5 | 5439.5 | 1,728.1 | 153.0 | 3.2 | 3.1 |
| D2 | 10/3/2017 | 31/3/2017 | 21 | 9 | 22.5 | 23 | 11.5 | 5951.3 | 1,512.3 | 146.0 | 2.8 | |
| D3 | 10/3/2017 | 31/3/2017 | 21 | 9.7 | 21.5 | 22 | 11.5 | 5439.5 | 1,783.3 | 150.0 | 3.2 | |

| Mix E (2 % cement and 2% Generic lime) | | | | | | | | | | | | |
|--|----------------|----------------|-------------------|------------------|----------|----------|----------|--------------------------------|---|--------------------------|-----------------------------------|---|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm³) | Unit Weight (Kg/ m³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| E1 | 10/3/2017 | 31/3/2017 | 21 | 8.4 | 21.5 | 22.6 | 11.5 | 5587.9 | 1,503.3 | 67.1 | 1.4 | 1.5 |
| E2 | 10/3/2017 | 31/3/2017 | 21 | 9.5 | 22.5 | 21 | 11.5 | 5433.8 | 1,748.3 | 74.3 | 1.6 | |
| E3 | 10/3/2017 | 31/3/2017 | 21 | 9.4 | 22 | 22 | 11.5 | 5566.0 | 1,688.8 | 69.0 | 1.4 | |

| Mix F (4 % cement and 2% Generic lime) | | | | | | | | | | | | |
|--|----------------|----------------|-------------------|------------------|----------|----------|----------|--------------------------------|---|--------------------------|-----------------------------------|---|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm³) | Unit Weight (Kg/ m³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| F1 | 10/3/2017 | 31/3/2017 | 21 | 9.2 | 21.5 | 22.6 | 11.5 | 5587.9 | 1,646.4 | 98.0 | 2.0 | 2.1 |
| F2 | 10/3/2017 | 31/3/2017 | 21 | 9.2 | 22.5 | 21 | 11.5 | 5433.8 | 1,693.1 | 102.0 | 2.2 | |
| F3 | 10/3/2017 | 31/3/2017 | 21 | 9.3 | 22 | 22 | 11.5 | 5566.0 | 1,670.9 | 100.0 | 2.1 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

| Mix G (3 % cement and 3% Generic lime) | | | | | | | | | | | | |
|--|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| G1 | 10/3/2017 | 31/3/2017 | 21 | 9 | 21.5 | 22.6 | 11.5 | 5587.9 | 1,610.6 | 97.1 | 2.0 | 2.0 |
| G2 | 10/3/2017 | 31/3/2017 | 21 | 8.9 | 22.5 | 21 | 11.5 | 5433.8 | 1,637.9 | 92.1 | 1.9 | |
| G3 | 10/3/2017 | 31/3/2017 | 21 | 9 | 22 | 22 | 11.5 | 5566.0 | 1,617.0 | 101.5 | 2.1 | |

| Mix H (6 % cement and 2% Generic lime) | | | | | | | | | | | | |
|--|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| H1 | 10/3/2017 | 31/3/2017 | 21 | 9.4 | 22.5 | 22.5 | 11.5 | 5821.9 | 1,614.6 | 128.8 | 2.5 | 2.5 |
| H2 | 10/3/2017 | 31/3/2017 | 21 | 9.2 | 22.3 | 22 | 11.5 | 5641.9 | 1,630.7 | 115.0 | 2.3 | |
| H3 | 10/3/2017 | 31/3/2017 | 21 | 10 | 22 | 22 | 11.5 | 5566.0 | 1,796.6 | 120.5 | 2.5 | |

| Mix I (4 % cement and 4% Generic lime) | | | | | | | | | | | | |
|--|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| I1 | 10/3/2017 | 31/3/2017 | 21 | 9.1 | 22 | 22.5 | 11.4 | 5643 | 1,612.6 | 115.2 | 2.3 | 2.3 |
| I2 | 10/3/2017 | 31/3/2017 | 21 | 9.2 | 22.5 | 22 | 11.4 | 5643 | 1,630.3 | 109.4 | 2.2 | |
| I3 | 10/3/2017 | 31/3/2017 | 21 | 9.7 | 22 | 22.5 | 11.5 | 5692.5 | 1,704.0 | 112.1 | 2.3 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

| Mix J (8 % cement and 2% Generic lime) | | | | | | | | | | | | |
|--|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| J1 | 10/3/2017 | 31/3/2017 | 21 | 9.4 | 22 | 22.5 | 11.4 | 5643 | 1,665.8 | 150.1 | 3.0 | 3.0 |
| J2 | 10/3/2017 | 31/3/2017 | 21 | 9.5 | 22.5 | 22 | 11.4 | 5643 | 1,683.5 | 149.1 | 3.0 | |
| J3 | 10/3/2017 | 31/3/2017 | 21 | 9.5 | 22 | 22.5 | 11.5 | 5692.5 | 1,668.9 | 152.9 | 3.1 | |

| Mix K (6 % cement and 4% Generic lime) | | | | | | | | | | | | |
|--|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load(KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| K1 | 10/3/2017 | 31/3/2017 | 21 | 9.3 | 22 | 22.5 | 11.5 | 5692.5 | 1,633.7 | 146.5 | 3.0 | 2.8 |
| K2 | 10/3/2017 | 31/3/2017 | 21 | 9 | 22.5 | 22 | 11.5 | 5692.5 | 1,581.0 | 140.0 | 2.8 | |
| K3 | 10/3/2017 | 31/3/2017 | 21 | 9.7 | 22.5 | 22 | 11.5 | 5692.5 | 1,704.0 | 132.2 | 2.7 | |

| Mix L (5 % cement and 5% Generic lime) | | | | | | | | | | | | |
|--|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| L1 | 10/3/2017 | 31/3/2017 | 21 | 10.2 | 23.5 | 22.5 | 11.5 | 6080.6 | 1,677.5 | 147.2 | 2.8 | 2.7 |
| L2 | 10/3/2017 | 31/3/2017 | 21 | 10.3 | 22.9 | 23.4 | 11.6 | 6216.0 | 1,657.0 | 140.8 | 2.6 | |
| L3 | 10/3/2017 | 31/3/2017 | 21 | 10 | 23 | 24 | 11.6 | 6403.2 | 1,561.7 | 143.0 | 2.6 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

| Mix P (2 % cement and 2% Senkale Lime) | | | | | | | | | | | | |
|--|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| P1 | 13/6/2017 | 4/7/2017 | 21 | 9.1 | 21.5 | 21.6 | 11.5 | 5340.6 | 1,703.9 | 75.0 | 1.6 | 1.6 |
| P2 | 13/6/2017 | 4/7/2017 | 21 | 8.9 | 21.2 | 21 | 11.5 | 5119.8 | 1,738.3 | 74.3 | 1.7 | |
| P3 | 13/6/2017 | 4/7/2017 | 21 | 9 | 21.5 | 21.5 | 11.5 | 5315.9 | 1,693.0 | 73.4 | 1.6 | |

| Mix Q (4 % cement and 2% Senkale Lime) | | | | | | | | | | | | |
|--|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| Q1 | 13/6/2017 | 4/7/2017 | 21 | 9.4 | 21.1 | 21 | 11.5 | 5095.7 | 1,844.7 | 100.1 | 2.3 | 2.2 |
| Q2 | 13/6/2017 | 4/7/2017 | 21 | 9.3 | 21.2 | 21 | 11.5 | 5119.8 | 1,816.5 | 98.9 | 2.2 | |
| Q3 | 13/6/2017 | 4/7/2017 | 21 | 9.3 | 21.4 | 21.2 | 11.5 | 5217.3 | 1,782.5 | 98.1 | 2.2 | |

| Mix R (3 % cement and 3% Senkale Lime) | | | | | | | | | | | | |
|--|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| R1 | 13/6/2017 | 4/7/2017 | 21 | 9.3 | 21.4 | 21.5 | 11.5 | 5291.2 | 1,757.7 | 101.2 | 2.2 | 2.1 |
| R2 | 13/6/2017 | 4/7/2017 | 21 | 9.2 | 21.3 | 21.5 | 11.5 | 5266.4 | 1,746.9 | 98.7 | 2.2 | |
| R3 | 13/6/2017 | 4/7/2017 | 21 | 9 | 21.4 | 21.4 | 11.5 | 5266.5 | 1,708.9 | 94.6 | 2.1 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

| Mix S (6 % cement and 2% Senkale Lime) | | | | | | | | | | | | |
|--|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| S1 | 13/6/2017 | 4/7/2017 | 21 | 9.2 | 21.4 | 21.5 | 11.5 | 5291.2 | 1,738.8 | 130.2 | 2.8 | 2.7 |
| S2 | 13/6/2017 | 4/7/2017 | 21 | 9.3 | 21.3 | 21.5 | 11.5 | 5266.4 | 1,765.9 | 125.4 | 2.7 | |
| S3 | 13/6/2017 | 4/7/2017 | 21 | 9.4 | 21.4 | 21.2 | 11.5 | 5217.3 | 1,801.7 | 121.1 | 2.7 | |

| Mix T (4 % cement and 4% Senkale Lime) | | | | | | | | | | | | |
|--|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| T1 | 13/6/2017 | 4/7/2017 | 21 | 9.1 | 21.1 | 21.3 | 11.5 | 5168.4 | 1,760.7 | 120.0 | 2.7 | 2.6 |
| T2 | 13/6/2017 | 4/7/2017 | 21 | 9 | 21.2 | 21.2 | 11.5 | 5168.6 | 1,741.3 | 115.2 | 2.6 | |
| T3 | 13/6/2017 | 4/7/2017 | 21 | 9.1 | 21.4 | 21.3 | 11.5 | 5241.9 | 1,736.0 | 112.7 | 2.5 | |

| Mix U (8 % cement and 2% Senkale Lime) | | | | | | | | | | | | |
|--|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| U1 | 13/6/2017 | 4/7/2017 | 21 | 9.2 | 21.5 | 21.4 | 11.4 | 5245.1 | 1,754.0 | 150.1 | 3.3 | 3.1 |
| U2 | 13/6/2017 | 4/7/2017 | 21 | 9.3 | 21.6 | 21.5 | 11.3 | 5247.7 | 1,772.2 | 140.2 | 3.0 | |
| U3 | 13/6/2017 | 4/7/2017 | 21 | 9.2 | 21.5 | 21.4 | 11.5 | 5291.2 | 1,738.8 | 138.7 | 3.0 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

Mix W (6 % cement and 4% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| W1 | 13/6/2017 | 4/7/2017 | 21 | 9.5 | 21.2 | 21.4 | 11.4 | 5172.0 | 1,836.8 | 135.4 | 3.0 | 3.0 |
| W2 | 13/6/2017 | 4/7/2017 | 21 | 9.5 | 21.5 | 21.4 | 11.3 | 5199.1 | 1,827.2 | 141.3 | 3.1 | |
| W3 | 13/6/2017 | 4/7/2017 | 21 | 9.4 | 21.5 | 21.4 | 11.5 | 5291.2 | 1,776.6 | 139.3 | 3.0 | |

Mix X (5 % cement and 5% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| X1 | 13/6/2017 | 4/7/2017 | 21 | 9.5 | 21.2 | 21.4 | 11.4 | 5172.0 | 1,836.8 | 122.1 | 2.7 | 2.8 |
| X2 | 13/6/2017 | 4/7/2017 | 21 | 9.7 | 21.6 | 21.6 | 11.3 | 5272.1 | 1,839.9 | 130.2 | 2.8 | |
| X3 | 13/6/2017 | 4/7/2017 | 21 | 9.6 | 21.6 | 21.5 | 11.5 | 5340.6 | 1,797.6 | 140.1 | 3.0 | |

APPENDIX E

28th Day Compressive Strength Test Result

Table E 1: 28th Day Compressive Strength Test Result

| Mix A (4 % cement and 0% Lime) | | | | | | | | | | | | |
|---------------------------------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| A1 | 10/3/2017 | 7/4/2017 | 28 | 8.4 | 22.3 | 22.3 | 11.5 | 5718.8 | 1,468.83 | 112.50 | 2.3 | 2.4 |
| A2 | 10/3/2017 | 7/4/2017 | 28 | 8.4 | 22.4 | 22.5 | 11.5 | 5796.0 | 1,449.28 | 125.40 | 2.5 | |
| A3 | 10/3/2017 | 7/4/2017 | 28 | 8.9 | 22.4 | 22.3 | 11.5 | 5744.5 | 1,549.31 | 117.60 | 2.4 | |

| Mix B (6 % cement and 0% Lime) | | | | | | | | | | | | |
|---------------------------------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| B1 | 10/3/2017 | 7/4/2017 | 28 | 9 | 22 | 23 | 11.5 | 5819.0 | 1,546.7 | 143.4 | 2.8 | 2.7 |
| B2 | 10/3/2017 | 7/4/2017 | 28 | 9 | 22.5 | 23 | 11.5 | 5951.3 | 1,512.3 | 140.1 | 2.7 | |
| B3 | 10/3/2017 | 7/4/2017 | 28 | 9 | 22 | 23.4 | 11.5 | 5920.2 | 1,520.2 | 129.0 | 2.5 | |

| Mix C (8 % cement and 0% Lime) | | | | | | | | | | | | |
|---------------------------------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| C1 | 10/3/2017 | 7/4/2017 | 28 | 9.1 | 22 | 22 | 11.4 | 5517.6 | 1,649.3 | 150.2 | 3.1 | 3.1 |
| C2 | 10/3/2017 | 7/4/2017 | 28 | 9 | 22.2 | 22.5 | 11.5 | 5744.3 | 1,566.8 | 156.6 | 3.1 | |
| C3 | 10/3/2017 | 7/4/2017 | 28 | 9.1 | 22 | 22.5 | 11.5 | 5692.5 | 1,598.6 | 149.6 | 3.0 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

Mix D (10 % cement and 0% Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| D1 | 10/3/2017 | 7/4/2017 | 28 | 9.4 | 22.4 | 21.5 | 11.5 | 5538.4 | 1,697.2 | 170.5 | 3.5 | 3.4 |
| D2 | 10/3/2017 | 7/4/2017 | 28 | 9.2 | 22.5 | 22.6 | 11.5 | 5847.8 | 1,573.3 | 165.2 | 3.2 | |
| D3 | 10/3/2017 | 7/4/2017 | 28 | 9.1 | 22.5 | 22 | 11.5 | 5692.5 | 1,598.6 | 169.5 | 3.4 | |

Mix E (2 % cement and 2% Generic lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| E1 | 10/3/2017 | 7/4/2017 | 28 | 8.4 | 21.5 | 22.6 | 11.5 | 5587.9 | 1,503.3 | 91.9 | 1.9 | 1.8 |
| E2 | 10/3/2017 | 7/4/2017 | 28 | 8.5 | 22.5 | 21 | 11.5 | 5433.8 | 1,564.3 | 79.5 | 1.7 | |
| E3 | 10/3/2017 | 7/4/2017 | 28 | 8.9 | 22 | 22 | 11.5 | 5566.0 | 1,599.0 | 83.6 | 1.7 | |

Mix F (4 % cement and 2% Generic lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| F1 | 10/3/2017 | 7/4/2017 | 28 | 8.9 | 21.5 | 22.6 | 11.5 | 5587.9 | 1,592.7 | 127.2 | 2.6 | 2.7 |
| F2 | 10/3/2017 | 7/4/2017 | 28 | 8.6 | 22.5 | 21 | 11.5 | 5433.8 | 1,582.7 | 135.6 | 2.9 | |
| F3 | 10/3/2017 | 7/4/2017 | 28 | 8.9 | 22 | 22 | 11.5 | 5566.0 | 1,599.0 | 120.2 | 2.5 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

Mix G (3 % cement and 3% Generic lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| G1 | 10/3/2017 | 7/4/2017 | 28 | 8.6 | 21.5 | 22.6 | 11.5 | 5587.9 | 1,539.1 | 112.9 | 2.3 | 2.5 |
| G2 | 10/3/2017 | 7/4/2017 | 28 | 8.7 | 22.5 | 21 | 11.5 | 5433.8 | 1,601.1 | 125.9 | 2.7 | |
| G3 | 10/3/2017 | 7/4/2017 | 28 | 8.9 | 22 | 22 | 11.5 | 5566.0 | 1,599.0 | 119.7 | 2.5 | |

Mix H (6 % cement and 2% Generic lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| H1 | 10/3/2017 | 7/4/2017 | 28 | 9.2 | 22.5 | 22.5 | 11.5 | 5821.9 | 1,580.2 | 139.6 | 2.8 | 3.0 |
| H2 | 10/3/2017 | 7/4/2017 | 28 | 9.3 | 22.3 | 22 | 11.5 | 5641.9 | 1,648.4 | 159.0 | 3.2 | |
| H3 | 10/3/2017 | 7/4/2017 | 28 | 9.1 | 22 | 22 | 11.5 | 5566.0 | 1,634.9 | 145.9 | 3.0 | |

Mix I (4 % cement and 4% Generic lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| I1 | 10/3/2017 | 7/4/2017 | 28 | 9 | 22 | 22.5 | 11.4 | 5643 | 1,594.9 | 150.2 | 3.0 | 2.8 |
| I2 | 10/3/2017 | 7/4/2017 | 28 | 9.3 | 22.5 | 22 | 11.4 | 5643 | 1,648.1 | 140.0 | 2.8 | |
| I3 | 10/3/2017 | 7/4/2017 | 28 | 8.9 | 22 | 22.5 | 11.5 | 5692.5 | 1,563.5 | 132.0 | 2.7 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

Mix J (8 % cement and 2% Generic lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| J1 | 10/3/2017 | 7/4/2017 | 28 | 9.2 | 22 | 22.5 | 11.4 | 5643 | 1,630.3 | 172.0 | 3.5 | 3.3 |
| J2 | 10/3/2017 | 7/4/2017 | 28 | 9.3 | 22.5 | 22 | 11.4 | 5643 | 1,648.1 | 167.7 | 3.4 | |
| J3 | 10/3/2017 | 7/4/2017 | 28 | 9 | 22 | 22.5 | 11.5 | 5692.5 | 1,581.0 | 157.0 | 3.2 | |

Mix K (6 % cement and 4% Generic lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load(KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| K1 | 10/3/2017 | 7/4/2017 | 28 | 9 | 22.3 | 22.5 | 11.5 | 5770.125 | 1,559.8 | 162.4 | 3.2 | 3.3 |
| K2 | 10/3/2017 | 7/4/2017 | 28 | 9 | 22.5 | 22.4 | 11.5 | 5796 | 1,552.8 | 172.6 | 3.4 | |
| K3 | 10/3/2017 | 7/4/2017 | 28 | 9 | 22.5 | 22 | 11.5 | 5692.5 | 1,581.0 | 159.0 | 3.2 | |

Mix L (5 % cement and 5% Generic lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| L1 | 10/3/2017 | 7/4/2017 | 28 | 9 | 22.9 | 22.5 | 11.5 | 5925.4 | 1,518.9 | 175.0 | 3.4 | 3.2 |
| L2 | 10/3/2017 | 7/4/2017 | 28 | 9.2 | 22.9 | 22.6 | 11.6 | 6003.5 | 1,532.4 | 165.0 | 3.2 | |
| L3 | 10/3/2017 | 7/4/2017 | 28 | 9.3 | 23 | 24 | 11.6 | 6403.2 | 1,452.4 | 169.0 | 3.1 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

Mix P (2 % cement and 2% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| P1 | 13/6/2017 | 11/7/2017 | 28 | 9.1 | 21.5 | 21.6 | 11.5 | 5340.6 | 1,703.9 | 101.5 | 2.2 | 2.2 |
| P2 | 13/6/2017 | 11/7/2017 | 28 | 8.9 | 21.2 | 21 | 11.5 | 5119.8 | 1,738.3 | 98.9 | 2.2 | |
| P3 | 13/6/2017 | 11/7/2017 | 28 | 9 | 21.5 | 21.5 | 11.5 | 5315.9 | 1,693.0 | 95.7 | 2.1 | |

Mix Q (4 % cement and 2% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| Q1 | 13/6/2017 | 11/7/2017 | 28 | 9.3 | 21.1 | 21 | 11.5 | 5095.7 | 1,825.1 | 125.5 | 2.8 | 2.8 |
| Q2 | 13/6/2017 | 11/7/2017 | 28 | 9.2 | 21.2 | 21 | 11.5 | 5119.8 | 1,796.9 | 130.2 | 2.9 | |
| Q3 | 13/6/2017 | 11/7/2017 | 28 | 9.3 | 21.4 | 21.2 | 11.5 | 5217.3 | 1,782.5 | 120.6 | 2.7 | |

Mix R (3 % cement and 3% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| R1 | 13/6/2017 | 11/7/2017 | 28 | 9.3 | 21.4 | 21.5 | 11.5 | 5291.2 | 1,757.7 | 118.6 | 2.6 | 2.7 |
| R2 | 13/6/2017 | 11/7/2017 | 28 | 9.2 | 21.3 | 21.5 | 11.5 | 5266.4 | 1,746.9 | 122.5 | 2.7 | |
| R3 | 13/6/2017 | 11/7/2017 | 28 | 9 | 21.4 | 21.4 | 11.5 | 5266.5 | 1,708.9 | 128.7 | 2.8 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

Mix S (6 % cement and 2% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| S1 | 13/6/2017 | 11/7/2017 | 28 | 9.2 | 21.4 | 21.2 | 11.5 | 5217.3 | 1,763.4 | 141.7 | 3.1 | 3.0 |
| S2 | 13/6/2017 | 11/7/2017 | 28 | 9.3 | 21.3 | 21.5 | 11.5 | 5266.4 | 1,765.9 | 135.4 | 3.0 | |
| S3 | 13/6/2017 | 11/7/2017 | 28 | 9.4 | 21.4 | 21.2 | 11.5 | 5217.3 | 1,801.7 | 134.7 | 3.0 | |

Mix T (4 % cement and 4% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| T1 | 13/6/2017 | 11/7/2017 | 28 | 9.1 | 21.1 | 21.3 | 11.5 | 5168.4 | 1,760.7 | 139.9 | 3.1 | 3.1 |
| T2 | 13/6/2017 | 11/7/2017 | 28 | 9 | 21.2 | 21.2 | 11.5 | 5168.6 | 1,741.3 | 145.4 | 3.2 | |
| T3 | 13/6/2017 | 11/7/2017 | 28 | 9.1 | 21.4 | 21.3 | 11.5 | 5241.9 | 1,736.0 | 135.7 | 3.0 | |

Mix U (8 % cement and 2% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| U1 | 13/6/2017 | 11/7/2017 | 28 | 9.2 | 21.5 | 21.4 | 11.4 | 5245.1 | 1,754.0 | 154.7 | 3.4 | 3.3 |
| U2 | 13/6/2017 | 11/7/2017 | 28 | 9.3 | 21.6 | 21.5 | 11.3 | 5247.7 | 1,772.2 | 147.8 | 3.2 | |
| U3 | 13/6/2017 | 11/7/2017 | 28 | 9.2 | 21.5 | 21.4 | 11.5 | 5291.2 | 1,738.8 | 150.7 | 3.3 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

Mix W (6 % cement and 4% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| W1 | 13/6/2017 | 11/7/2017 | 28 | 9.5 | 21.6 | 21.5 | 11.4 | 5294.2 | 1,794.4 | 154.5 | 3.3 | 3.4 |
| W2 | 13/6/2017 | 11/7/2017 | 28 | 9.5 | 21.5 | 21.4 | 11.3 | 5199.1 | 1,827.2 | 159.7 | 3.5 | |
| W3 | 13/6/2017 | 11/7/2017 | 28 | 9.4 | 21.5 | 21.4 | 11.5 | 5291.2 | 1,776.6 | 157.8 | 3.4 | |

Mix X (5 % cement and 5% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|-----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| X1 | 13/6/2017 | 11/7/2017 | 28 | 9.5 | 21.2 | 21.4 | 11.4 | 5172.0 | 1,836.8 | 160.5 | 3.5 | 3.4 |
| X2 | 13/6/2017 | 11/7/2017 | 28 | 9.7 | 21.6 | 21.6 | 11.3 | 5272.1 | 1,839.9 | 155.4 | 3.3 | |
| X3 | 13/6/2017 | 11/7/2017 | 28 | 9.6 | 21.6 | 21.5 | 11.5 | 5340.6 | 1,797.6 | 157.1 | 3.4 | |

APPENDIX F

56th Day Compressive Strength Test Result

Table F 1: 56th Day Compressive Strength Test Result

| Mix A (4 % cement and 0% Lime) | | | | | | | | | | | | |
|---------------------------------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| A1 | 10/3/2017 | 5/5/2017 | 56 | 8.3 | 22.3 | 22.5 | 11.5 | 5770.1 | 1,438.44 | 132.50 | 2.6 | 2.5 |
| A2 | 10/3/2017 | 5/5/2017 | 56 | 8.1 | 22.3 | 22.5 | 11.5 | 5770.1 | 1,403.78 | 120.30 | 2.4 | |
| A3 | 10/3/2017 | 5/5/2017 | 56 | 8.4 | 22.4 | 22.3 | 11.5 | 5744.5 | 1,462.27 | 130.40 | 2.6 | |
| Mix B (6 % cement and 0% Lime) | | | | | | | | | | | | |
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| B1 | 10/3/2017 | 5/5/2017 | 56 | 8.7 | 22.5 | 22.4 | 11.5 | 5796.0 | 1,501.0 | 146.4 | 2.9 | 2.9 |
| B2 | 10/3/2017 | 5/5/2017 | 56 | 8.6 | 22.5 | 22.4 | 11.5 | 5796.0 | 1,483.8 | 154.1 | 3.1 | |
| B3 | 10/3/2017 | 5/5/2017 | 56 | 8.9 | 22.4 | 22.5 | 11.5 | 5796.0 | 1,535.5 | 140.2 | 2.8 | |
| Mix C (8 % cement and 0% Lime) | | | | | | | | | | | | |
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| C1 | 10/3/2017 | 5/5/2017 | 56 | 8.9 | 22.4 | 22.5 | 11.4 | 5745.6 | 1,549.0 | 169.5 | 3.4 | 3.3 |
| C2 | 10/3/2017 | 5/5/2017 | 56 | 8.8 | 22.2 | 22.5 | 11.5 | 5744.3 | 1,532.0 | 162.4 | 3.3 | |
| C3 | 10/3/2017 | 5/5/2017 | 56 | 8.8 | 22.3 | 22.5 | 11.5 | 5770.1 | 1,525.1 | 158.4 | 3.2 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

| Mix D (10 % cement and 0% Lime) | | | | | | | | | | | | |
|---|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| D1 | 10/3/2017 | 5/5/2017 | 56 | 8 | 22 | 22.5 | 11.5 | 5692.5 | 1,405.4 | 185.4 | 3.7 | 3.7 |
| D2 | 10/3/2017 | 5/5/2017 | 56 | 8 | 22.5 | 22.4 | 11.5 | 5796.0 | 1,380.3 | 190.4 | 3.8 | |
| D3 | 10/3/2017 | 5/5/2017 | 56 | 8.6 | 22.5 | 22.3 | 11.5 | 5770.1 | 1,490.4 | 180.4 | 3.6 | |

| Mix E (2 % cement and 2% Generic lime) | | | | | | | | | | | | |
|--|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| E1 | 10/3/2017 | 5/5/2017 | 56 | 8.5 | 21.5 | 22.6 | 11.5 | 5587.9 | 1,521.2 | 115.6 | 2.4 | 2.4 |
| E2 | 10/3/2017 | 5/5/2017 | 56 | 8.4 | 22.5 | 21 | 11.5 | 5433.8 | 1,545.9 | 120.3 | 2.5 | |
| E3 | 10/3/2017 | 5/5/2017 | 56 | 8.5 | 22 | 22 | 11.5 | 5566.0 | 1,527.1 | 109.8 | 2.3 | |

| Mix F (4 % cement and 2% Generic lime) | | | | | | | | | | | | |
|--|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| F1 | 10/3/2017 | 5/5/2017 | 56 | 8.6 | 21.5 | 21.5 | 11.5 | 5315.9 | 1,617.8 | 142.1 | 3.1 | 3.1 |
| F2 | 10/3/2017 | 5/5/2017 | 56 | 8.7 | 21.2 | 21 | 11.5 | 5119.8 | 1,699.3 | 143.2 | 3.2 | |
| F3 | 10/3/2017 | 5/5/2017 | 56 | 8.6 | 21.2 | 21.5 | 11.5 | 5241.7 | 1,640.7 | 132.2 | 2.9 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

Mix G (3 % cement and 3% Generic lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| G1 | 10/3/2017 | 5/5/2017 | 56 | 8.4 | 21.5 | 22.6 | 11.5 | 5587.9 | 1,503.3 | 151.7 | 3.1 | 3.2 |
| G2 | 10/3/2017 | 5/5/2017 | 56 | 8.5 | 22.5 | 21 | 11.5 | 5433.8 | 1,564.3 | 156.6 | 3.3 | |
| G3 | 10/3/2017 | 5/5/2017 | 56 | 8.5 | 22 | 22 | 11.5 | 5566.0 | 1,527.1 | 149.5 | 3.1 | |

Mix H (6 % cement and 2% Generic lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| H1 | 10/3/2017 | 5/5/2017 | 56 | 8.6 | 22.5 | 22.5 | 11.5 | 5821.9 | 1,477.2 | 166.5 | 3.3 | 3.4 |
| H2 | 10/3/2017 | 5/5/2017 | 56 | 8.8 | 22.3 | 22 | 11.5 | 5641.9 | 1,559.8 | 170.5 | 3.5 | |
| H3 | 10/3/2017 | 5/5/2017 | 56 | 8.7 | 22 | 22 | 11.5 | 5566.0 | 1,563.1 | 160.2 | 3.3 | |

Mix I (4 % cement and 4% Generic lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| I1 | 10/3/2017 | 5/5/2017 | 56 | 8.8 | 22.3 | 22.5 | 11.4 | 5719.95 | 1,538.5 | 175.4 | 3.5 | 3.6 |
| I2 | 10/3/2017 | 5/5/2017 | 56 | 8.7 | 22.5 | 22.4 | 11.5 | 5796 | 1,501.0 | 182.5 | 3.6 | |
| I3 | 10/3/2017 | 5/5/2017 | 56 | 8.9 | 22.5 | 22.5 | 11.5 | 5821.875 | 1,528.7 | 185.6 | 3.7 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

| Mix J (8 % cement and 2% Generic lime) | | | | | | | | | | | | |
|--|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| J1 | 10/3/2017 | 5/5/2017 | 56 | 8.8 | 22.3 | 22.5 | 11.4 | 5719.95 | 1,538.5 | 180.2 | 3.6 | 3.7 |
| J2 | 10/3/2017 | 5/5/2017 | 56 | 8.9 | 22.5 | 22.4 | 11.4 | 5745.6 | 1,549.0 | 197.2 | 3.9 | |
| J3 | 10/3/2017 | 5/5/2017 | 56 | 8.8 | 22.3 | 22.5 | 11.5 | 5770.125 | 1,525.1 | 185.2 | 3.7 | |

| Mix K (6 % cement and 4% Generic lime) | | | | | | | | | | | | |
|--|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load(KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| K1 | 10/3/2017 | 5/5/2017 | 56 | 8.7 | 22.3 | 22.5 | 11.5 | 5770.125 | 1,507.8 | 189.5 | 3.8 | 3.9 |
| K2 | 10/3/2017 | 5/5/2017 | 56 | 8.6 | 22.5 | 22.4 | 11.5 | 5796 | 1,483.8 | 195.5 | 3.9 | |
| K3 | 10/3/2017 | 5/5/2017 | 56 | 8.9 | 22.5 | 22.4 | 11.5 | 5796 | 1,535.5 | 200.1 | 4.0 | |

| Mix L (5 % cement and 5% Generic lime) | | | | | | | | | | | | |
|--|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| L1 | 10/3/2017 | 5/5/2017 | 56 | 9 | 22.5 | 22.5 | 11.5 | 5821.9 | 1,545.9 | 187.5 | 3.7 | 3.8 |
| L2 | 10/3/2017 | 5/5/2017 | 56 | 8.8 | 22.3 | 22.4 | 11.6 | 5794.4 | 1,518.7 | 189.2 | 3.8 | |
| L3 | 10/3/2017 | 5/5/2017 | 56 | 9 | 22.5 | 22.4 | 11.6 | 5846.4 | 1,539.4 | 192.2 | 3.8 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

| Mix P (2 % cement and 2% Senkale Lime) | | | | | | | | | | | | |
|--|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| P1 | 13/6/2017 | 7/8/2017 | 56 | 9.1 | 21.5 | 21.6 | 11.5 | 5340.6 | 1,703.9 | 120.2 | 2.6 | 2.6 |
| P2 | 13/6/2017 | 7/8/2017 | 56 | 8.9 | 21.2 | 21 | 11.5 | 5119.8 | 1,738.3 | 112.5 | 2.5 | |
| P3 | 13/6/2017 | 7/8/2017 | 56 | 9 | 21.5 | 21.5 | 11.5 | 5315.9 | 1,693.0 | 118.5 | 2.6 | |

| Mix Q (4 % cement and 2% Senkale Lime) | | | | | | | | | | | | |
|--|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| Q1 | 13/6/2017 | 7/8/2017 | 56 | 9.3 | 21.1 | 21 | 11.5 | 5095.7 | 1,825.1 | 132.4 | 3.0 | 3.1 |
| Q2 | 13/6/2017 | 7/8/2017 | 56 | 9.2 | 21.2 | 21 | 11.5 | 5119.8 | 1,796.9 | 138.2 | 3.1 | |
| Q3 | 13/6/2017 | 7/8/2017 | 56 | 9.3 | 21.4 | 21.2 | 11.5 | 5217.3 | 1,782.5 | 141.5 | 3.1 | |

| Mix R (3 % cement and 3% Senkale Lime) | | | | | | | | | | | | |
|--|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| R1 | 13/6/2017 | 7/8/2017 | 56 | 9.3 | 21.4 | 21.5 | 11.5 | 5291.2 | 1,757.7 | 145.2 | 3.2 | 3.3 |
| R2 | 13/6/2017 | 7/8/2017 | 56 | 9.2 | 21.3 | 21.5 | 11.5 | 5266.4 | 1,746.9 | 151.8 | 3.3 | |
| R3 | 13/6/2017 | 7/8/2017 | 56 | 9 | 21.4 | 21.4 | 11.5 | 5266.5 | 1,708.9 | 154.3 | 3.4 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

Mix S (6 % cement and 2% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| S1 | 13/6/2017 | 7/8/2017 | 56 | 9.2 | 21.4 | 21.2 | 11.5 | 5217.3 | 1,763.4 | 152.9 | 3.4 | 3.5 |
| S2 | 13/6/2017 | 7/8/2017 | 56 | 9.3 | 21.3 | 21.5 | 11.5 | 5266.4 | 1,765.9 | 158.5 | 3.5 | |
| S3 | 13/6/2017 | 7/8/2017 | 56 | 9.4 | 21.4 | 21.2 | 11.5 | 5217.3 | 1,801.7 | 160.2 | 3.5 | |

Mix T (4 % cement and 4% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| T1 | 13/6/2017 | 7/8/2017 | 56 | 9.1 | 21.1 | 21.3 | 11.5 | 5168.4 | 1,760.7 | 165.7 | 3.7 | 3.6 |
| T2 | 13/6/2017 | 7/8/2017 | 56 | 9 | 21.2 | 21.2 | 11.5 | 5168.6 | 1,741.3 | 162.2 | 3.6 | |
| T3 | 13/6/2017 | 7/8/2017 | 56 | 9.1 | 21.4 | 21.3 | 11.5 | 5241.9 | 1,736.0 | 159.9 | 3.5 | |

Mix U (8 % cement and 2% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| U1 | 13/6/2017 | 7/8/2017 | 56 | 9.2 | 21.5 | 21.4 | 11.4 | 5245.1 | 1,754.0 | 177.5 | 3.9 | 3.9 |
| U2 | 13/6/2017 | 7/8/2017 | 56 | 9.3 | 21.6 | 21.5 | 11.3 | 5247.7 | 1,772.2 | 180.2 | 3.9 | |
| U3 | 13/6/2017 | 7/8/2017 | 56 | 9.2 | 21.5 | 21.4 | 11.5 | 5291.2 | 1,738.8 | 185.2 | 4.0 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

Mix W (6 % cement and 4% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| W1 | 13/6/2017 | 7/8/2017 | 56 | 9.5 | 21.6 | 21.5 | 11.4 | 5294.2 | 1,794.4 | 200.1 | 4.3 | 4.1 |
| W2 | 13/6/2017 | 7/8/2017 | 56 | 9.5 | 21.7 | 21.7 | 11.3 | 5321.1 | 1,785.4 | 185.9 | 3.9 | |
| W3 | 13/6/2017 | 7/8/2017 | 56 | 9.4 | 21.5 | 21.4 | 11.5 | 5291.2 | 1,776.6 | 190.2 | 4.1 | |

Mix X (5 % cement and 5% Senkale Lime)

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| X1 | 13/6/2017 | 7/8/2017 | 56 | 9.5 | 21.2 | 21.4 | 11.4 | 5172.0 | 1,836.8 | 187.2 | 4.1 | 4.0 |
| X2 | 13/6/2017 | 7/8/2017 | 56 | 9.7 | 21.6 | 21.6 | 11.3 | 5272.1 | 1,839.9 | 192.9 | 4.1 | |
| X3 | 13/6/2017 | 7/8/2017 | 56 | 9.6 | 21.6 | 21.5 | 11.5 | 5340.6 | 1,797.6 | 180.0 | 3.9 | |

APPENDIX G

Effect of Compaction Pressure on 28th day Compressive Strength Test Result

Table G 1: Effect of Compaction Pressure on 28th Compressive Strength Test Result

| Mix M (10 % cement and 0% lime) With compaction pressure 5 MPa | | | | | | | | | | | | |
|---|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| M1 | 10/3/2017 | 7/4/2017 | 28 | 9 | 22.3 | 22.3 | 11.5 | 5718.8 | 1,573.75 | 113.50 | 2.3 | 2.3 |
| M1 | 10/3/2017 | 7/4/2017 | 28 | 9.1 | 22.4 | 22.5 | 11.5 | 5796.0 | 1,570.05 | 123.80 | 2.5 | |
| M1 | 10/3/2017 | 7/4/2017 | 28 | 9.3 | 22.4 | 22.3 | 11.5 | 5744.5 | 1,618.95 | 113.10 | 2.3 | |
| Mix M (10 % cement and 0% lime) With compaction pressure 7.5 MPa | | | | | | | | | | | | |
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| M2 | 10/3/2017 | 7/4/2017 | 28 | 9.2 | 22 | 22.5 | 11.5 | 5692.5 | 1,616.2 | 130.5 | 2.6 | 2.7 |
| M2 | 10/3/2017 | 7/4/2017 | 28 | 9.2 | 22.5 | 22.4 | 11.5 | 5796.0 | 1,587.3 | 135.4 | 2.7 | |
| M2 | 10/3/2017 | 7/4/2017 | 28 | 8.8 | 22 | 22.5 | 11.5 | 5692.5 | 1,545.9 | 137.4 | 2.8 | |
| Mix M (10 % cement and 0% lime) With compaction pressure 10 MPa | | | | | | | | | | | | |
| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
| | Casting | Testing | | | | | | | | | | |
| M3 | 10/3/2017 | 7/4/2017 | 28 | 9.1 | 22 | 22 | 11.4 | 5517.6 | 1,649.3 | 165.4 | 3.4 | 3.4 |
| M3 | 10/3/2017 | 7/4/2017 | 28 | 9 | 22.2 | 22.5 | 11.5 | 5744.3 | 1,566.8 | 162.5 | 3.3 | |
| M3 | 10/3/2017 | 7/4/2017 | 28 | 9.1 | 22 | 22.5 | 11.5 | 5692.5 | 1,598.6 | 169.7 | 3.4 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

Mix M (10 % cement and 0% lime) With compaction pressure 12.5 MPa

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| M4 | 10/3/2017 | 7/4/2017 | 28 | 9 | 22.4 | 22.3 | 11.5 | 5744.5 | 1,566.7 | 175.4 | 3.5 | 3.7 |
| M4 | 10/3/2017 | 7/4/2017 | 28 | 9.2 | 22.5 | 22.3 | 11.5 | 5770.1 | 1,594.4 | 189.4 | 3.8 | |
| M4 | 10/3/2017 | 7/4/2017 | 28 | 9.1 | 22.5 | 22 | 11.5 | 5692.5 | 1,598.6 | 183.2 | 3.7 | |

Mix M (10 % cement and 0% lime) With compaction pressure 14 Mpa

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|------------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| M5 | 10/3/2017 | 7/4/2017 | 28 | 9.2 | 22.3 | 22.5 | 11.5 | 5770.1 | 1,594.4 | 229.7 | 4.6 | 4.4 |
| M5 | 10/3/2017 | 7/4/2017 | 28 | 8.5 | 22.5 | 22.3 | 11.5 | 5770.1 | 1,473.1 | 215.2 | 4.3 | |
| M5 | 10/3/2017 | 7/4/2017 | 28 | 8.9 | 22 | 22 | 11.5 | 5566.0 | 1,599.0 | 204.7 | 4.2 | |

Mix N (5 % cement and 5% lime) With compaction pressure 5 MPa

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|-----------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| N1 | 10/3/2017 | 7/4/2017 | 28 | 9 | 21.5 | 22.6 | 11.5 | 5587.9 | 1,610.6 | 95.1 | 2.0 | 1.9 |
| N1 | 10/3/2017 | 7/4/2017 | 28 | 8.9 | 22.5 | 21 | 11.5 | 5433.8 | 1,637.9 | 87.9 | 1.9 | |
| N1 | 10/3/2017 | 7/4/2017 | 28 | 8.9 | 22 | 22 | 11.5 | 5566.0 | 1,599.0 | 87.8 | 1.8 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

Mix N (5 % cement and 5% lime) With compaction pressure 7.5 MPa

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|-----------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| N2 | 10/3/2017 | 7/4/2017 | 28 | 8.9 | 22.5 | 22.6 | 11.5 | 5847.8 | 1,522.0 | 122.3 | 2.4 | 2.4 |
| N2 | 10/3/2017 | 7/4/2017 | 28 | 8.8 | 22.5 | 22.3 | 11.5 | 5770.1 | 1,525.1 | 120.9 | 2.4 | |
| N2 | 10/3/2017 | 7/4/2017 | 28 | 8.9 | 22.5 | 22.4 | 11.5 | 5796.0 | 1,535.5 | 119.7 | 2.4 | |

Mix N (5 % cement and 5% lime) With compaction pressure 10 MPa

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg/ m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|-----------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| N3 | 10/3/2017 | 7/4/2017 | 28 | 9.2 | 22.5 | 22.5 | 11.5 | 5821.9 | 1,580.2 | 145.2 | 2.9 | 3.0 |
| N3 | 10/3/2017 | 7/4/2017 | 28 | 9.3 | 22.3 | 22 | 11.5 | 5641.9 | 1,648.4 | 147.5 | 3.0 | |
| N3 | 10/3/2017 | 7/4/2017 | 28 | 9.1 | 22 | 22 | 11.5 | 5566.0 | 1,634.9 | 148.2 | 3.1 | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

Mix N (5 % cement and 5% lime) With compaction pressure 12.5 MPa

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|-----------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| N4 | 10/3/2017 | 7/4/2017 | 28 | 9.1 | 22 | 22.5 | 11.4 | 5643 | 1,612.6 | 165.2 | 3.3 | 3.3 |
| N4 | 10/3/2017 | 7/4/2017 | 28 | 9.3 | 22.5 | 22 | 11.4 | 5643 | 1,648.1 | 160.1 | 3.2 | |
| N4 | 10/3/2017 | 7/4/2017 | 28 | 9.2 | 22 | 22.5 | 11.5 | 5692.5 | 1,616.2 | 159.5 | 3.2 | |

Mix N (5 % cement and 5% lime) With compaction pressure 14 MPa

| Marking | Date | | Age (days) | Mass (Kg) | L | W | H | Volume (cm ³) | Unit Weight (Kg /m ³) | Failure load (KN) | Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---------|-----------|----------|------------|-----------|------|------|------|---------------------------|-----------------------------------|-------------------|----------------------------|------------------------------------|
| | Casting | Testing | | | | | | | | | | |
| N5 | 10/3/2017 | 7/4/2017 | 28 | 9.2 | 22 | 22.5 | 11.4 | 5643 | 1,630.3 | 169.5 | 3.4 | 3.5 |
| N5 | 10/3/2017 | 7/4/2017 | 28 | 9.3 | 22.5 | 22 | 11.4 | 5643 | 1,648.1 | 172.4 | 3.5 | |
| N5 | 10/3/2017 | 7/4/2017 | 28 | 9 | 22 | 22.5 | 11.5 | 5692.5 | 1,581.0 | 175.2 | 3.5 | |

APPENDIX H

Water Absorption Test Result

Table H 1: Water Absorption Test Result (ASTM C140)

| | Sample | W _d | W _w | Absorbed water | Water Absorption (%) | Mean Absorption |
|----------|--------|----------------|----------------|----------------|----------------------|-----------------|
| A | 1 | 8.3 | 9.5 | 1.2 | 14% | 13.9% |
| | 2 | 8.2 | 9.3 | 1.1 | 13% | |
| B | 1 | 9 | 10.2 | 1.2 | 13% | 13.5% |
| | 2 | 8.8 | 10 | 1.2 | 14% | |
| C | 1 | 8.8 | 9.8 | 1 | 11% | 11.9% |
| | 2 | 8.9 | 10 | 1.1 | 12% | |
| D | 1 | 9.1 | 10.1 | 1 | 11% | 11.6% |
| | 2 | 9 | 10.1 | 1.1 | 12% | |
| E | 1 | 8.5 | 9.7 | 1.2 | 14% | 13.5% |
| | 2 | 8.5 | 9.6 | 1.1 | 13% | |
| F | 1 | 8.9 | 10 | 1.1 | 12% | 13.0% |
| | 2 | 8.8 | 10 | 1.2 | 14% | |
| G | 1 | 8.5 | 9.6 | 1.1 | 13% | 12.4% |
| | 2 | 8.5 | 9.5 | 1 | 12% | |
| H | 1 | 9 | 10.1 | 1.1 | 12% | 11.7% |
| | 2 | 9 | 10 | 1 | 11% | |
| I | 1 | 8.7 | 9.7 | 1 | 11% | 11.4% |
| | 2 | 8.9 | 9.9 | 1 | 11% | |
| J | 1 | 8.95 | 10 | 1.05 | 12% | 11.4% |
| | 2 | 9.1 | 10.1 | 1 | 11% | |
| K | 1 | 9 | 9.95 | 0.95 | 11% | 11.3% |
| | 2 | 9.2 | 10.3 | 1.1 | 12% | |
| L | 1 | 9.1 | 10 | 0.9 | 10% | 11.1% |
| | 2 | 9 | 10.1 | 1.1 | 12% | |
| P | 1 | 8.9 | 9.9 | 1 | 11% | 11.3% |
| | 2 | 8.8 | 9.8 | 1 | 11% | |
| Q | 1 | 8.7 | 9.7 | 1 | 11% | 11.4% |
| | 2 | 8.8 | 9.8 | 1 | 11% | |
| R | 1 | 8.7 | 9.6 | 0.9 | 10% | 10.9% |
| | 2 | 8.8 | 9.8 | 1 | 11% | |
| S | 1 | 9.2 | 10.1 | 0.9 | 10% | 10.3% |
| | 2 | 9.3 | 10.3 | 1 | 11% | |
| | | | | | | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

| | Sample | Wd | Ww | Absorbed water | Water Absorption (%) | Mean Absorption |
|----------|---------------|-----------|-----------|---------------------------|---------------------------------|----------------------------|
| T | 1 | 8.9 | 9.8 | 0.9 | 10% | 10.1% |
| | 2 | 8.9 | 9.8 | 0.9 | 10% | |
| U | 1 | 9.3 | 10.4 | 1.1 | 12% | 10.7% |
| | 2 | 9.4 | 10.3 | 0.9 | 10% | |
| W | 1 | 8.8 | 9.7 | 0.9 | 10% | 9.6% |
| | 2 | 8.9 | 9.7 | 0.8 | 9% | |
| X | 1 | 9 | 9.8 | 0.8 | 9% | 9.4% |
| | 2 | 9.1 | 10 | 0.9 | 10% | |

**STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN
ALTERNATIVE WALL MAKING MATERIAL**

APPENDIX I

Material and labor cost breakdown

Table I- 1: Walling cost of 20cm thick HCB wall

| ANALYSIS SHEET FOR DIRECT & INDIRECT UNIT COSTS | | | | | | | | | | | | | | | |
|--|----------------|--------|---------------------|------------------------------------|-----------------------|--------|---------------------|------------------------|----------------------------|-------------------|---------------------|--|-------------|--|------|
| PROJECT: WALLING | | | | | | | | | | | | LABOUR HOURLY OUTPUT: 0.65 m ² /hr. | | | |
| WORK ITEM: 20 cm. thick HCB Wall Both Sides Left For Plastering. | | | | | | | | | | | | | | | |
| TOTAL QUANTITY OF WORK ITEM: 1 m ² | | | | | | | | | | | | | | | |
| Material Cost (1:01) | | | | Labour (1:02) | | | | | Equipment Cost (1:03) | | | | | | |
| Type of Material | Unit | Qty * | Rate | Cost per Unit | Labour by Grade | No. | UF | ** Indexed Hourly Cost | Hourly Cost | Type of Equipment | No. | Hourly Rental | Hourly Cost | | |
| 20 cm. Thick HCB | Pcs. | 13 | 12.37 | 160.81 | Foreman | 1 | 0.25 | 38.4615 | 9.62 | | | | 0 | | |
| Cement | Qt. | 0.08 | 21.4125 | 1.713 | Mason | 1 | 1 | 37.5 | 37.5 | | | | 0 | | |
| Sand | m ³ | 0.02 | 450 | 9 | D/L | 2 | 1 | 10 | 20 | | | | 0 | | |
| Water | m ³ | 0.004 | 0.75 | 0.0030 | | | | | 0 | | | | 0 | | |
| | | | | 0 | | | | | 0 | | | | 0 | | |
| | | | | 0 | | | | | 0 | | | | 0 | | |
| | | | | 0 | | | | | 0 | | | | 0 | | |
| Total (1:-01) | | | | 171.53 | Total (1:02) | | | | | 67.12 | Total (1:03) | | | | 0.00 |
| A= Materials Unit Cost | | 171.53 | Birr/m ² | B= Manpower Unit Cost | | 103.25 | Birr/m ² | C=Equipment Unit Co | | 0 | Birr/m ² | | | | |
| | | | | <u>Total of (1:02)</u> | | | | | <u>Total of (1:03)</u> | | | | | | |
| | | | | Hourly Output: | | | | | Hourly output: | | | | | | |
| | | | | Direct Cost of Work Item = A+B+C = | | | | | 274.78 Birr/m ² | | | | | | |

Table I- 2: Painting cost

| PROJECT: PAINTING. | | | | | | | | | | | | LABOUR HOURLY OUTPUT: 3.76 m ² /hr. | | | |
|--|--------|---------|---------------------|------------------------------------|---------------------|------|---------------------|------------------------|---------------------------|-------------------|---------------------|--|-------------|--|------|
| WORK ITEM: Two coats of plastic paint to wall. | | | | | | | | | | | | | | | |
| TOTAL QUANTITY OF WORK ITEM: 1 m ² | | | | | | | | | | | | | | | |
| Material Cost (1:01) | | | | Labour Cost (1:02) | | | | | Equipment Cost (1:03) | | | | | | |
| Type of Material | Unit | Qty * | Rate | Cost per Unit | Labour by Grade | No. | UF | ** Indexed Hourly Cost | Hourly Cost | Type of Equipment | No. | Hourly Rental | Hourly Cost | | |
| plastic paint | lit | 0.18 | 144.43 | 25.9974 | foreman | 1 | 0.2 | 5 | 1.00 | tools | 1 | 0.16 | 0.16 | | |
| stucco | kg | 0.05 | 547.83 | 27.3915 | painter | 1 | 1 | 2.5 | 2.50 | | | | | | |
| PVC glue 717 | gallon | 0.00264 | 350.00 | 0.9247 | DL | 1 | 1 | 1.25 | 1.25 | | | | 0 | | |
| brush | pcs | 0.01 | 82.00 | 0.82 | | | | | 0 | | | | 0 | | |
| sand paper #120 | m | 0.01 | 40.00 | 0.4 | | | | | 0 | | | | 0 | | |
| gypsum | kg | 0.03 | 2.43 | 0.0729 | | | | | 0 | | | | 0 | | |
| | | | | 0 | | | | | 0 | | | | 0 | | |
| | | | | 0 | | | | | 0 | | | | 0 | | |
| | | | | 0 | | | | | 0 | | | | 0 | | |
| Total (1:-01) | | | | 55.6065 | Total (1:02) | | | | | 4.75 | Total (1:03) | | | | 0.16 |
| A= Materials Unit Cost | | 55.6 | Birr/m ² | B= Manpower Unit Cost | | 1.26 | Birr/m ² | C= Equipment Unit Cost | | 0.04 | Birr/m ² | | | | |
| | | | | <u>Total of (1:02)</u> | | | | | <u>Total of (1:03)</u> | | | | | | |
| | | | | Hourly Output: | | | | | Hourly output: | | | | | | |
| | | | | Direct Cost of Work Item = A+B+C = | | | | | 56.91 Birr/m ² | | | | | | |

STUDY OF COMPRESSED CEMENT AND LIME STABILIZED SOIL BLOCK AS AN ALTERNATIVE WALL MAKING MATERIAL

Table I- 3: Cost of two coats plastering cost to wall surface

| PROJECT: FINISHING WORKS. | | | | | | | | LABOUR HOURLY OUTPUT: 0.67 m ² /hr | | | | | | |
|---|----------------|--------|---------------------|------------------------------------|---------------------|-----|-----|---|---------------------|------------------------|-----|---------------------|---------------------|---|
| WORK ITEM: 2 Coats of cement plastering. | | | | | | | | | | | | | | |
| TOTAL QUANTITY OF WORK ITEM: 1 m ² | | | | | | | | | | | | | | |
| Material Cost (1:01) | | | | Labour Cost (1:02) | | | | Equipment Cost (1:03) | | | | | | |
| Type of Material | Unit | Qty * | Rate | Cost per Unit | Labour by Grade | No. | UF | Indexed Hourly Cost | Hourly Cost | Type of Equipment | No. | Hourly Rental | Hourly Cost | |
| cement | qt. | 0.076 | 171.3 | 13.019 | Foreman | 1 | 0.2 | 38.4615 | 7.69 | | | | 0 | |
| sand | m ³ | 0.0186 | 400 | 7.44 | Plasterer | 1 | 1 | 31.25 | 31.25 | | | | 0 | |
| water | m ³ | 0.001 | 0.75 | 0.001 | Chilser | 1 | 1 | 16.25 | 16.25 | | | | 0 | |
| | | | | 0 | D/L | 1 | 1 | 10 | 10 | | | | 0 | |
| | | | | 0 | | | | | 0 | | | | 0 | |
| | | | | 0 | | | | | 0 | | | | 0 | |
| | | | | 0 | | | | | 0 | | | | 0 | |
| | | | | 0 | | | | | 0 | | | | 0 | |
| Total (1:01) | | | | 20.46 | Total (1:02) | | | | 65.19 | Total (1:03) | | | | 0 |
| A= Materials Unit Cost | | 20.46 | Birr/m ² | B= Manpower Unit Cost | | | | 97.30 | Birr/m ² | C= Equipment Unit Cost | | 0 | Birr/m ² | |
| | | | | Total of (1:02) | | | | Total of (1:03) | | | | | | |
| | | | | Hourly Output: _____ | | | | Hourly output: _____ | | | | | | |
| | | | | Direct Cost of Work Item = A+B+C = | | | | 117.76 | | | | Birr/m ² | | |

Table I- 4: Cost of cement pointing to wall surface

| PROJECT: FINISHING WORKS. | | | | | | | | LABOUR HOURLY OUTPUT: 1.5 m ² /hr | | | | | | |
|---|----------------|-------|---------------------|------------------------------------|---------------------|-----|------|--|---------------------|------------------------|-----|---------------------|---------------------|---|
| WORK ITEM: Cement pointing to wall surface | | | | | | | | | | | | | | |
| TOTAL QUANTITY OF WORK ITEM: 1 m ² | | | | | | | | | | | | | | |
| Material Cost (1:01) | | | | Labour Cost (1:02) | | | | Equipment Cost (1:03) | | | | | | |
| Type of Material | Unit | Qty * | Rate | Cost per Unit | Labour by Grade | No. | UF | Indexed Hourly Cost | Hourly Cost | Type of Equipment | No. | Hourly Rental | Hourly Cost | |
| cement | qt. | 0.009 | 171.3 | 1.5417 | Foreman | 1 | 0.25 | 38.4615 | 9.62 | | | | 0 | |
| sand | m ³ | 0.003 | 450 | 1.35 | Plasterer | 1 | 1 | 31.25 | 31.25 | | | | 0 | |
| water | m ³ | 0.01 | 0.75 | 0.008 | Chilser | 1 | 1 | 16.25 | 16.25 | | | | 0 | |
| | | | | 0 | D/L | 1 | 1 | 10 | 10 | | | | 0 | |
| | | | | 0 | | | | | 0 | | | | 0 | |
| | | | | 0 | | | | | 0 | | | | 0 | |
| | | | | 0 | | | | | 0 | | | | 0 | |
| | | | | 0 | | | | | 0 | | | | 0 | |
| | | | | 0 | | | | | 0 | | | | 0 | |
| | | | | 0 | | | | | 0 | | | | 0 | |
| Total (1:01) | | | | 2.90 | Total (1:02) | | | | 67.12 | Total (1:03) | | | | 0 |
| A= Materials Unit Cost | | 2.90 | Birr/m ² | B= Manpower Unit Cost | | | | 44.74 | Birr/m ² | C= Equipment Unit Cost | | 0 | Birr/m ² | |
| | | | | Total of (1:02) | | | | Total of (1:03) | | | | | | |
| | | | | Hourly Output: _____ | | | | Hourly output: _____ | | | | | | |
| | | | | Direct Cost of Work Item = A+B+C = | | | | 47.64 | | | | Birr/m ² | | |

APPENDIX J

Specification of M7E380 block making machine



M7 E380 Interlocking Blockmaking Machine

Quick Specs

- ◆ Produces 1500 blocks per 8 hour shift*
- ◆ = +/- 40m² of walling/day*
- ◆ = 8 x 50²m houses/month
- ◆ Inclusive of a 7.5kW 380V electric motor
- ◆ Single block chamber
- ◆ Hydraulic power pack & cylinders
- ◆ Ideal for small to medium sized projects



N.B Pan mixer highly recommended

AUTOMATION AVAILABLE
Increase production to 2300 blocks per day

ADDITIONAL INFO

Operating Staff: 9 Individuals
Moulds: Standard 220mm Moulds fitted

Optional Accessories:

- ◆ Various moulds available
- ◆ 1 Year maintenance spares pack
- ◆ Blockyard tools
- ◆ Protective Gear for on site health & safety
- ◆ Block Cutter
- ◆ Block Tester

Accessory Products:

- ◆ Pan Mixer for consistent mixture of aggregate
- ◆ Jaw Crusher for rocks, overburden & waste materials
- ◆ Rotary Sieve for soil preparation

Available mould options

| NAME | BLOCK | PURPOSE |
|--|-------|--|
| 220mm Interlocking Block Fitted Standard 230mm x 220mm x 115mm | | Dry-stacked, interlocking block which is suitable for load bearing construction, boundary walling and for most building purposes |
| 180mm Interlocking Block 230mm x 180mm x 115mm | | Dry -stacked, interlocking block for single story construction only, suitable for most building purposes |
| 140mm Internal Block 230mm x 140mm x 115mm | | Semi-drystack block for internal non-load bearing walls. A slurry is used to fill the internal joints to solidify the wall |
| 220mm Capping Block 230mm x 220mm x 115mm | | Top course boundary wall block for water run-off and for aesthetic finishing. Can also be use for window-sills |
| 220mm Conduit Block 230mm x 220mm x 115mm | | Conduit block for laying of horizontal cables and piping within a wall or for ring beam construction |
| 220mm Curved Conduit Block 230mm x 220mm x 115mm | | Curved conduit block for ease of building curved/round structures with a minimum 6m radius |
| 220mm Retaining Block 230mm x 220mm x 115mm | | Retaining block, ideal for small garden retaining walls |
| 220mm Splitter Block 230mm x 220mm x 115mm | | Rough face-brick finish block using mortar joints in construction. When split, there are three 73 x 115 x 230mm blocks |
| 140 Non-Interlocking Block 230mm x 140mm x 115mm | | The Non-Interlocking 140mm block is for normal construction methods with mortar |

