STRUCTURAL PERFORMANCE OF SILICATE -LIMESTONE COMPRESSED BRICKS

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DECLARATION

This thesis is my original work and, has not been submitted for a degree in any other University.

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This thesis has been submitted for examination with our approval as University Supervisors.

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DEDICATION

This thesis is humbly dedicated to my friends, my beloved family: my mum and my dad.

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I like to thank ALMIGHTY GOD for giving me his grace, strength and health during my studies

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ABSTRACT

Present concerns for sustainable development have led to a revival of traditional building practices using natural or recycled resources. Silicate-limestone bricks are alternative building materials, which are significantly cheaper than using conventional concrete block sand are environmentally sustainable. The use of limestone, which makes up about 10% of the total volume of all sedimentary rocks saves environmental pollution, energy and manufacturing cost. In order to demonstrate silicate limestone as a suitable appropriate construction material, tests on blocks and walls made from limestone and silicate materials were investigated to establish their structural performance and suitability for eco-friendly house construction on the Africa continent.

Water absorption and the density tests of the bricks were done, and the physical properties of silicate limestone compressed bricks were observed and analyzed as the lime content was varied between 0 to 100%. The results obtained show that as lime content increases, water absorption also increases. Nevertheless, the results were within the recommended values i.e. less than 15%.ofmass ratio. The density of bricks decreased when lime contents were added. They were all considered as heavy blocks because the values were more than 1000kg/m^3. From these two tests, it was noted that above 60% of lime content, the bricks become unstable.

The compressive and flexural tests on the bricks were done using a Universal Testing Machine for vertical and transversal loading for the determination of the crushing strength. These tests were done compared to the blocks available on the Kenya market. Compared to the blocks available in the Kenya market, the silicate limestone had better strength, with the exception of bricks at 100% of lime content, in which the compressive strength of 1.324 MPa was lower than the minimum requirement for compressive strength, which is 2.5 MPa.

The tests done on the bricks showed clearly that the optimum percentage of lime replacement in terms of physical and strength properties was 60%.The silicate limestone bricks wall was made with this percentage of lime content and compared to clay brick and natural stone blocks wall. The results of these tests showed that the strength properties of natural stone wall were higher than those of silicate limestone wall, which is contrary to the results from the compressive strength of their unit blocks.

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ABBREVIATIONS AND ACRONYMS

w/c	water to cement ratio
SLB	Silicate Limestone Brick
USA	United States of America
UK	United Kingdom
µm	Micrometer (micron)
MPa	Mega Pascal
°C	Degrees Celcius
%	percent
N/mm^2	Newton per square millimeters
kN	kilo Newton
kg/m^3	kilogram per cubic meters
kg	kilogram
tons	tonnes
SG_D:	Specific gravity on an oven dried basis
SG_S:	Specific gravity on a saturated and surface dried basis
SG_A:	Apparent specific gravity
VS:	Versus
W_A	Water absorption

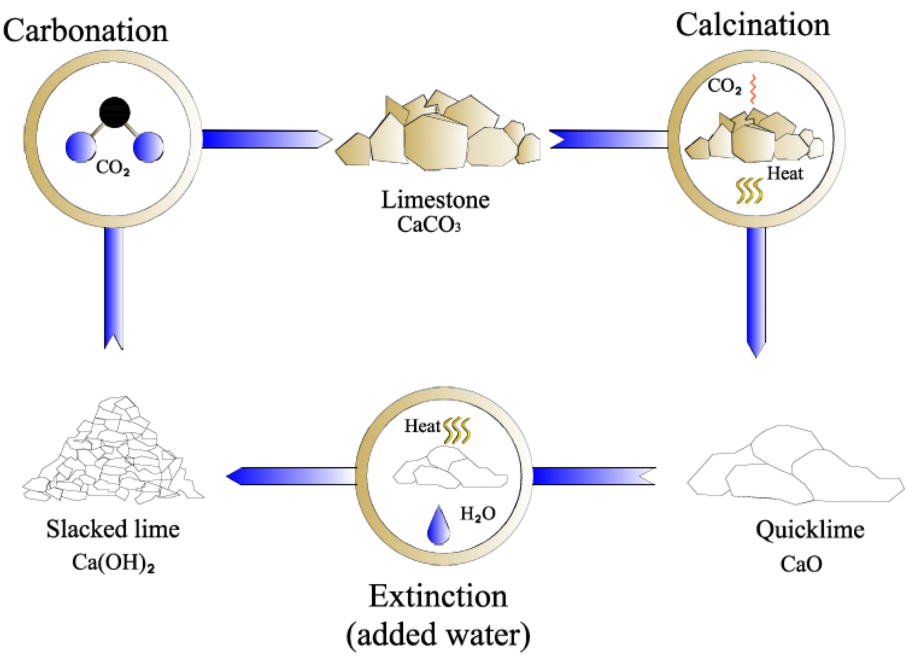
CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Within many regions in Africa, there are large quantities of various raw materials such as bauxite, and clay from which respectively refined materials are made such as aluminum, bricks and tiles for civil engineering and construction related works but these can be optimally and economically improved for use in constructions. Materials such as silica, limestone, and sand when combined with water suitably can yield bricks used in various building construction. The term “lime” refers to products derived from limestone by heating to various degrees of temperatures, including quicklime and slaked lime.

Products derived from limestone ($CaCO_3$) possess the unique ability to be processed and resume their original form. The cycle of the lime is to bake limestone to form quicklime (CaO). Slaked lime ($Ca(OH)_2$) can be produced by adding water to quick lime. In this state, the carbon dioxide content in the atmosphere or from industrial processes can then react with slaked lime to reconvert to limestone. This cycle of continuity is called the cycle of lime. The required time for lime to return to limestone state using industrial processes ranges from a few minutes to several years using atmospheric conditions.



(www.britishlime.org)

Figure 1-1: Cycle of lime

Slaked lime is used in various applications whose needs are minimizing the environmental impact of industrial processes; it also allows a stabilization of most metals by converting them under more stable chemical forms. Silicate is a salt that comes from silica (SiO_2) and constitutes 97% of the earth's crust. It can be found in the material like clay. This ore is almost fire-proof hence it is important in the manufacture of fire resistant or refractory bricks.

Silicate-limestone bricks are obtained by mixing hydraulic limestone with sand and water in appropriate proportion or percentages. They are pressed under high hydraulic pressures to form the required size of bricks/blocks, after that they are autoclaved for a specified time, temperature and pressure to harden the bricks. Silicate limestone bricks have numerous advantages (www.kalksandstein.ch)

- ✓ They offer a good acoustic insulation
- ✓ They have a good thermal insulation because they respire. This characteristic contributes to healthy interior climate and prevents nuisances caused by moulds and humidity.

- ✓ They also accumulate and release heat. In this way, at any season it will always provide favourable indoor climate
- ✓ They are fire-proof materials due to the silicates that they contain
- ✓ And they are sustainable and eco-friendly.

This material is not widely used as a construction alternative in within Africa; however, its application as an alternative construction material is possible.

1.2 Problem statement

In the construction sector of many developing nations, there are quite a number of persistent challenges especially in the building construction industry. These issues include exorbitantly high costs of the construction materials and building process, reduced serviceability, and lack of or reduced sustainability of the materials used and/or buildings (Ruuska, 2014). Therefore, there is a need to obtain a material or class of materials that will ultimately minimize the cost of construction but at the same time maintain the structural safety needed. Furthermore, there is need to improve sustainability through improving the thermal and acoustic attributes of the buildings, while concurrently reducing the overall cost of construction through the reduction of the amount of cement used and replacing it with natural available resources.

To the advantage of several regions in Africa and to the benefit from this research, materials do exist that are able to solve the shortfalls highlighted above. Nevertheless, these materials have their related limitations. They include such materials like mud brick, and compressed stabilized earth block (CSEB) or clay brick, which have the following limitations poor abrasive action of rain and lack of stability when exposed to excess wet condition. Therefore, this research has explored the structural performance and possibility of using silicate-limestone to address the limitations present in the traditional bricks used in the construction industry.

1.3 Study justification

The choice of this research is to study the possible utilization of silicate-limestone in construction industry and to contribute to sustainable and ecological use of building materials in the developing world. Limestone, sand and water, are the three natural resources that form the ingredients in the manufacture of silicate limestone bricks. Limestone powder has good properties, which are:

i. It is fire-proof,
ii. Offers a good acoustic insulation,
iii. It contributes in the control of humidity in the building, and controls heat gain in buildings.

In order to contribute to the sustainable development, there is a need for alternative cheap, durable and lightweight but environmentally benign materials in construction. The use of silicate limestone bricks takes into consideration two key values addressed by the global sustainability concept (Imbabi,2012) Social value (use of readily available and familiar local materials,); Environmental value (with the objective of conserving the environment). Silicate limestone bricks leads to the potential extensive use of a local resource (limestone) as the main building material with technologies that are energy saving, eco-friendly, and sustainable; since the raw materials are abundantly available.

1.4 Significance of the study

The importance of this study is to investigate the use of silicate limestone bricks as eco-friendly and cost effective alternative construction materials.

1.5 Objectives

1.5.1 General objective

The main objective of this study is to investigate the properties and structural performance of compressed silicate - limestone bricks.

1.5.2 Specific objectives

i) To investigate the effect of varying lime content on the physical and strength properties of silicate-limestone bricks.

ii) To compare strength performance of silicate limestone bricks with those of clay bricks and natural stone

iii) To determine the structural performance of silicate – limestone wall in comparison with those clay bricks and natural stone

1.6 Scope of the study

The research focused on the silicate limestone bricks and covered only the technical and physical analysis of this material. Hence, the physical, mechanical and the structural properties of bricks and wall made from silicate, hydrated lime powder was the focus of this study.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

Stone and clay were used as construction material since pre-historic times. As the civilization progressed, more versatile, durable materials have continued to be manufactured. Man's ingenuity and desire to make better and bigger structures gave birth to the use of bricks. After stone and clay, brick is the oldest construction material and has been recognized as the longest lasting and strongest building material ever used. Lime has been used as a material of construction from ancient times. Egyptians used lime for plastering, while Romans used this material extensively for making mortar, plaster and concrete. Silicates are important constituents of most of the ceramic products since they are plentiful, cheap and have certain distinct properties, necessary for certain engineering applications as hydraulics bond in the Portland cement.

2.2 Material used in concrete and brick making

2.2.1 Sand

Sand is a major component of concrete and without the sand, concrete will not function as intended. The properties of a specific concrete mix will be determined by the proportion and type of sand used to formulate the concrete. Sand is usually a larger component of the mix than cement.

Sand for concrete can be classified as soft or sharp sand. Soft sand has a smooth surface on the individual granules. It is natural sand formed by erosion factors such as water movement on a beach. Sharp sand granules have a rough surface. This sand is the result of manufacturing by crushing larger forms of aggregate. The most important factor concerning sand used in concrete is that it must be clean sand. Impurities in the sand such as silt or organic matter will weaken the final hardened concrete.

2.2.2 Cement

Cement is a binding material, for the constructional purposes the cement is restricted to the bonding materials used with stones, sand, bricks, and building blocks (Rajput 2000).

Good cement possesses the following properties:

a. Provides strength to masonry
b. Possesses good plasticity
c. Stiffens or hardens early
d. Easily workable
e. An excellent building material
f. Good moisture- resistant

Ordinary Portland Cement (OPC) is most common in use in the construction, it is an extremely fine ground product obtained by burning together at high temperatures (1450^0C) specifically proportioned amount of calcareous and argillaceous raw materials and adding gypsum in small quantities (3 to 4%) (Fopossi, 2014). Ordinary Portland Cement has the followings properties:

a. It has medium rate of strength development and heat generation
b. It has adequate resistance dry shrinkage and cracking, but has less resistance to chemical attack.

OPC is suitable for use in general concrete construction when there is no exposure to sulfate in the soil, and it is used in small structures where heat of hydration will not cause any defect. (Rajput, 2000)

2.2.3 Water

Water is one of the most important elements in concrete production. Water is needed for the hydration process by reacting with the cement to produce concrete. There has to be a sufficient amount of water available so that the reaction can take its full course but if too much water is added, this will in fact decrease the strength of the concrete (Neville, 2011).The quality and quantity of water has much effect on the strength of mortar and cement concrete in construction work.

The water used for mixing and curing should be clean and free from injurious quantities of alkalis, acid, oils, salt, sugar, organic materials, vegetable growth and other substances that may be deleterious to bricks, stone, concrete or steel. Potable water is generally considered satisfactory for mixing. The pH value of water should be not less than 6.

The water cement-ratio is one most important aspect when it comes to maintaining the strength of concrete. The ratio depends on the grade. It affects the workability of concrete and thus should be taken into careful consideration. In addition, if the ratio exceeds the normal value, segregation of concrete occurs and the coarse aggregate settles at the bottom thus affecting the strength of concrete greatly (Nagayach,2015).

2.3 Sand Lime Bricks (SLB)

Sand lime bricks are manufactured by mixing sand, fly ash and lime in desired proportion that may be followed by chemical accelerator during wet mixing. This mixture is molded under pressure. The green bricks can be air cured for 24-48 hours and then steam cured in autoclave at desired pressure and temperature. The green bricks may be steam / hot water cured at atmospheric pressure also. In presence of moisture, fly ash reacts with lime at ordinary temperature and forms a compound possessing cementitious properties. After reactions between lime and fly ash, calcium silicate hydrate is produced this is responsible for the high strength of the compound. Bricks made by mixing lime and fly ash are, therefore, chemically bonded bricks. These bricks are suitable for use in masonry just like common burnt clay bricks. These bricks have the following advantages over the clay bricks:

a. Possess adequate crushing strength as load-bearing members.
b. Have cement color in appearance, are uniform in shape and smooth in finish and require no plastering for building work.
c. They are lighter in weight than ordinary clay bricks. Generally, dry fly ash available from power plants meets the properties specified in IS: 3812 and is suitable for manufacture of Fly Ash – lime bricks in accordance with the requirements of IS12894.

2.3.1 Dense sand-lime bricks

The mixture of silicate and lime generally does not constitute hydraulic binder at ambient temperature. However, at high temperature and pressure, as obtained in an autoclave, they are able to form a good binder. The first patents regarding the manufacture of bricks sand-lime, by Michael (1886)was obtained by a carefully balanced mixture of lime and crushed silica, followed by pressure molding and treatment with steam. The first industrial application was made in Germany around 1894. The highest producers of dense brick sand-lime are Russia, Germany, and France (Djouhri Mohamed, 2007).

The mixture consists of quicklime (CaO) (5-12 %), clean sand (88-95%) and the water (4-8 % of the mass of dry matter). The mixture is subjected to a pressure of 15-45 MPa depending on the type of pressure machine. Afterwards, the brick is removed from the machine and treated in an autoclave at a pressure of 0.8-1.2 MPa and temperature of 170-190^{o}C for 6-14 h. (Hakkoum, 2015).

2.3.2 Light sand-lime bricks

The light sand-lime bricks are made from the same materials as the dense sand-lime, but with an added component, aluminum powder, producing hard artificial voids, in form gas bubbles obtained by chemical reaction. They belong to the class of materials called improperly aerated concrete or concrete gas.

These materials are obtained by autoclaving a mixture of sand siliceous (60 to 65%), lime and cement (35 to 40 % overall).Numerous voids are being created in the mixture by gassing resulting from addition of aluminum powder at the time of mixing (Samri, 2008).

The Swedish,Ja Eriksson, who was considered as an expert on the use of these products, held patents from 1923 and in 1929. These products were first marketed in Sweden in 1924, in Denmark in 1928 and in the USSR in 1930. The main producers are Russia, Japan, Germany and Great Britain (Djouhri Mohamed, 2007).

2.4 Autoclave process

Under normal conditions, the lime mixed with the sand hardens very slowly. The elements obtained after curing have strength ranging from 1 to 2 MPa and are easily diluted in the presence of water. But in the presence of saturated steam at a temperature of 170°C, the silica sand becomes chemically active and begins to react rapidly with the lime, according to reaction (I.1), forming a calcium hydro silicate which is solid and water resistant.

$$\mathbf{Ca\ (OH)_2 + SiO_2 + (n\text{-}1)H_2O \rightarrow\ x\ CaO + y\ SiO_2 + n\ H_2O \quad (I.1)}$$

The increased temperature and vapor pressure is followed by the dissolution of components. The solubility of the constituents varies with temperature i.e., the solubility of Ca $(OH)_2$ decreases with increasing temperature while SiO_2increases (Saadieh, 2014).

2.5 Characteristic properties of sand-lime bricks

Sand-lime bricks in general have very good behavior to frost. Their non-frost resistance makes them noninflammable at temperatures up to 550°C. The sand-lime bricks were in general use as well as clay brick but with certain restrictions. It is prohibited to use the sand-lime bricks for laying foundations because they are less water resistant than clay brick. Table 2.1 shows the sand-lime brick properties.

Table 2.1: Sand-lime brick properties

Type of brick SL	**Light sand lime brick**	**Sand-lime brick**
Density δ (kg/m^3)	300-800	800-2 200
Compressive strength f_c (MPa)	1.5-7	7-60
Thermal conductivity λ ($W/m.^0C$)	0.08 for $\delta = 300\ kg/m^3$	1.16 to 1.63 for $1700<\delta<2100$
Water absorption (%)	4-8	-
Acoustic insulation (dB)	48	-

Source: Djouhri Mohamed, (2007)

2.6 Theoretical review of different type of stabilized wall panels

2.6.1 The performance of compressed stabilized earth block

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. Cement is a suitable stabilizer for use with soil in the production of compressed stabilized soil block. Normally the amount of cement used is small but sufficient to improve the engineering properties of the soil and further improved action exchange of clay (Gregory, 2012). Cement stabilized soils have the following improved properties:

- ✓ Decreased cohesiveness (Plasticity)
- ✓ Decreased volume expansion or compressibility
- ✓ Increased strength

Soil cement blocks (SCB) are also known as stabilized mud blocks (SMB) or stabilized compressed earth block (SCEB). The new development with earth construction started with the technology of compressed stabilized earth blocks (CSEB) (Asmamaw, 2007).The compressed earth block is a modern descendent of molded earth block, more commonly known as the adobe block (Sadek and Hashim, 2010).Compressed earth blocks represent a considerable improvement over traditional earth building techniques. The quality of the block depends on the properties and mix of soil types, the amount of force applied for compaction, and the addition of chemical or natural products to further stabilize and strengthen the blocks (UN-HABITAT, 2009). Adam and Agid (2001), describe in the Table 2.2 that when guaranteed by quality control, compressed earth block products can very easily bear comparison with other materials such as the sand-cement block or the fired brick.

Table 2.2: Properties of compressed stabilized earth blocks VS walling materials

Property	Compressed stabilized earth blocks	Fired clay bricks	Calcium silicate brick	Dense concrete block	Aerated concrete blocks	Lightweight concrete block
Wet compressive	1-40	5-60	10-55	7-50	2-6	2-20

(MPa)						
Moisture movement (%)	0.02-0.2	0.002-0.02	0.01-0.035	0.02-0.5	0.05-0.10	0.04-0.08
Density (kg/m^3)	1700-2200	1400-2400	1600-2100	1700-2200	400-950	600-1600
Thermal conductivity (w/m^0c)	0.81-1.04	0.7-1.30	0.10-0.16	1.00-1.70	0.10-0.20	0.15-0.70
Durability against rain	Good to very poor	Excellent to very poor	Good to moderate	Good to poor	Good to moderate	Good to poor

Adam &Agid (2001)

According to Fetra et al., (2011), CSEB offered numbers of advantages:

a. it increases the utilization of local material and reduces the transportation cost as the production is *in situ*.
b. It makes quality housing available to more people, and generates local economy rather than spending for import materials.
c. faster and easier construction method resulted in less skilled labor required,
d. good strength, insulation and thermal properties,
e. less carbon emission, extremely low level of waste and can be easily disposed off, without any direct environmental pollution during the whole life cycle.

2.6.2 Strength and Durability Properties of Cow Dung Stabilized Earth Brick

Paa-Kofi and Manu (2013) in their work investigated the strength and the durability properties of earth brick stabilized with cow dung. They (op. cit) did not mention the state (dry or wet) at which cow dung was used. Preliminary tests such as dry density and moisture content of the earth in the natural state were first conducted on the earth bricks without stabilization and with

15%, 20%, 25%, and 30% cow dung stabilization to ascertain the optimum water content for each batch.

Afterwards investigation was conducted on bricks with 0%, 15%, 20%, 25%, and 30% of cow dung by weight of earth material and its effect on the dry density, compressive strengths, abrasive resistance and water absorption coefficients at the optimum moisture contents were analyzed after 28days. From the test conducted, they found out that:

a. a better compressive strength at the dry state and after 10 minutes of immersion in water is obtained with cow dung stabilization at content of 20% by weight of earth; bricks stabilized with 20% cow dung contents by weight of earth has a dry and wet compressive strength of 6.64 and 2.27MPa respectively;
b. an increase of about 25% in the dry compressive strength of bricks stabilized with 20% cow dung content over that of the plain earth brick without stabilizer and also the abrasive resistance increased with increase in the cow dung content up to 20%.

Because of the high decrease in compressive strength after 10 minutes of immersion in water, Paa-Kofi (2013) recommends that appropriate construction specification is necessary to prevent cow dung stabilized earth bricks from coming into any prolonged direct contact with rainwater.

2.7 Masonry walls panel testing

2.7.1 Testing on stabilized laterite quarry dust block wall

Musiomi (2009) worked on stabilized laterite quarry dust block wall. Stabilized laterized quarry dust masonry blocks were made by mixing cement; with quarry dust from hard rock i.e. ballast, quarry dust from soft rock and laterite in appropriate proportions to produce blocks. The variables investigated included the strength of mortar joint, the effect of reinforcement on wall behavior and the effect of size of the panel on wall behavior. The laterized quarry dust blocks and conventional blocks were used to build masonry wall panels.

From the results obtained, it is noted that the effect of strength of the mortar joint on the behavior of walls is similar for both the alternative and conventional block walls. In addition, the effect of bedding joint reinforcement on behavior of walls was found to be similar for alternative and conventional wall panels.

However, the compressive strengths of reinforced and unreinforced conventional block walls were 3.25 and 3.18 N/mm^2 respectively. The corresponding values for alternative block walls were 1.37 and 1.38 N/mm^2 (Musiomi, 2009). In both wall types, the effect of bedding joint reinforcement delayed the formation of the first crack in the wall panels and reduced final crack width at failure load of the walls. They also found out that the compressive strengths of conventional block walls were generally higher than the alternative block walls. The results in this study revealed that when alternative blocks are used, it is possible to achieve strength and ductility in wall panels at the same time.

2.7.2 Testing on Burnt clay bricks wall panel

Juzar et al (2013) determined the compressive and flexural strength of a wall panel constructed using an ancient mixture (consisting of paddy -husk- ash, Calicut roof tile powder, hydrated lime powder and anthill clay) and compared the results to a standard masonry wall (burnt clay).

The result obtained shows that the wall constructed using the ancient mixture fractured to a force of 15kN, while the masonry wall cracked at a load of approximately 19kN. They therefore concluded that the panel built using the ancient mixture behaved very similarly to the masonry wall.

2.8 Critique of the existing literature and research gaps

The use of autoclave machine is the only method of production of silicate limestone blocks. This machine is not affordable for countries with low income, that is why the blocks are too expensive in the market, and they are not used in Africa. In this research, the method to make the silicate limestone bricks will be the same as the process to make earth compressed blocks, which takes less time, energy and cost like autoclave machine. The relative performance of silicate limestone bricks will be better than the conventional blocks as concrete blocks and earth compressed blocks.

CHAPTER THREE

MATERIALS AND METHODS

3.1 General

This chapter discusses in detail the sources, properties of materials used and the methods applied in the manufacture of bricks and the testing program. Materials used include sand, lime, cement, and natural stone (machine cut) from a local factory and clay bricks from Kenya Clay products. Material properties were determined according to our research objectives. All the laboratory test on the material were carried out at Jomo Kenyatta University of Agriculture and Technology (JKUAT) Civil Engineering laboratories, Kenya

3.2 Materials properties

3.2.1 River sand

The sand used in the experimental study was river sand obtained from Meru County, Kenya. Sieve analysis, water absorption, moisture content and specific gravity tests were done according to BS1377–1:1990. Plate 3.1 below shows a heap of the sand obtained for this research study. The river sand was sieved through 5 mm sieve before used.

Plate 3.1: Pile of river sand used in the research

3.2.2 Cement

Cement used was Ordinary Portland Cement (OPC) of class 42.5 as per KS EAS 18-1 (2001) from Bamburi Cement Factory, in Kenya. OPC was selected because it has a good binding capacity and widely available in Kenya. Plate 3.2 below shows the bag of cement used in the research study.

Plate 3.2: Bag of cement used in the research

3.2.3 Lime

Lime used in the experimental study was hydrated lime from Coast Calcium Company sourced from Hardwares around Juja and Thika. They are widely available in any part of Kenya. Plate 3.3 below shows the bag of lime used in the research study.

Plate 3.3: Bag of lime used in the research

3.3 Test on Meru's sand

The tests as sieve analysis, silt content test, water absorption and specific gravity were done in this research.

3.3.1 Sieve analysis

The goal of this test was to determine the particle size distribution of aggregates by sieving analysis. This test was performed and used to determine the grading and fineness modulus of fine aggregate (BS 812-103.1, 1985). The sieve sizes used for this test were, 10, 5, 2.36, 1.18, 0.6, 0.3, 0.15mm and pan. An approximately 1 kg of sand was taken from the original sample by quartering. The sieves were dried and cleaned before their use. The sieving process was done manually and the procedure was as given below:

Procedure

- The required sample was weighed
- The sieves were arranged on top of each other with the largest mesh size on the top and the weighed sample was put into sieve.
- The arranged sets of sieves were shaken horizontally with a jerking motion in all directions for at least 2 minutes. All material passing were ensured fallen in to tray.
- Any material retained on the sieve was weighed.
- Material collected was passed in the tray through the sieve of the next smaller mesh size, and any material retained was weighed.
- The procedure was repeated for the remaining sieves in the order of diminishing size.

The results were recorded and tabulated; cumulative weight passing through each sieve was calculated as a percentage of the total sample to the nearest whole number. The grading curve was also plotted in the grading chart.

3.3.2 Silt content test

The objective was to determine the cleanliness of the sand. The silt content tests for fine aggregate (sand) were done in accordance to the BS 812 (1990) standard. It is recommended to wash the sand or reject if the silt content exceeds a value of 6% (Neville, 2011). The silt content of the sand was determined using following procedure in accordance to the BS.

Procedure

- A solution of sodium of chloride was prepared, about two tea spoonful of salt was added to 1 liter of water (1% solution).
- 50 ml of this solution was poured into 250 ml measuring cylinder,
- The sand was added gradually until the volume was 100ml, then the volume was made up to 150ml by addition of more salt solution.
- The mixture was shaken vigorously until adherent silt particle had been dispersed, and then cylinder was placed on a level bench and it was gently tapped until the surface of aggregate was level.
- The silt being of finer particles than sand was settle above the sand in a form of layer and the measurement of its thickness was made.

3.3.3 Water absorption and specify gravity

The goal was to determine the specific gravity and the water absorption values of sand. The following procedure was used to determine the specific gravity and the water absorption.

Procedure

- The washed sample was transferred to the tray and the water was added to ensure that the sample was completely immersed.
- After immersion, bubbles were removed of entrapped air by gentle agitation with a rod. The sample was kept immersed in water for 24 hours.
- After that the water from the sample was drained by decantation through a 0.075mm test sieve. Then the saturated and surface dry sample was weighed (C).
- The sand was placed in the pycnometer and it was filled with water. The cone into place was screwed and any trapped air was eliminated by rotating on its sides.
- The bottle on the outside was dried and it was weighed (A).
- The sample into the tray had been empty; the pycnometer was refilled with water to the same level as before. It was dried on the outside and weighed (B)
- .The water from the sample was drained by decantation. The sample was dried at a temperature of 105^0C for 24 hours, during which period it was stirred occasionally to facilitate drying. The sample was cooled by air and weighed (D).

Calculations

a. Specific gravity on an oven dried basis

$$SG_D=\frac{\boldsymbol{D}}{\boldsymbol{C}-(\boldsymbol{A}-\boldsymbol{B})}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{3.1}$$

b. Specific gravity on a saturated and surface dried basis

$$SG_S=\frac{\boldsymbol{C}}{\boldsymbol{C}-(\boldsymbol{A}-\boldsymbol{B})}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{3.2}$$

c. Apparent specific gravity

$$SG_A=\frac{D}{D-(A-B)}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{3.3}$$

d. Water absorption (% of dry mass)

$$W_A=\frac{100(C-D)}{D}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ \mathbf{3.4}$$

3.4 Production of silicate limestone bricks

In order to produce the silicate limestone compressed bricks, two steps were done: The first step consisted to determine the optimum mix ratio (in term of mass) of control mixture, which contained cement, sand and water. The table 3.1 below shows the outline of process of mixture proportions.

Table 3.1: Control mixtures with ordinary Portland cement

Sample	**Cement ratio**	**Sand ratio**	**Water/cement ratio**	**Number of samples**
A	1	3	0.4	5
B	1	3	0.5	5
C	1	3	0.6	5
D	1	3	0.7	5
E	1	3	0.8	5
F	1	4	0.4	5

G	1	4	0.5	5
H	1	4	0.6	5
I	1	4	0.7	5
J	1	4	0.8	5
K	1	5	0.4	5
L	1	5	0.5	5
M	1	5	0.6	5
N	1	5	0.7	5
O	1	5	0.8	5

The process was done by making cubes (100mm) of mortar by vibrating and in varying sand and water cement ratio, after that the samples were cured under water and tested after 7days.Plate 3.4 below shows mortar cubes used in the research study.

Plate 3.4: Cube mortars by vibration

After the optimum ratio of mortar was determined, it was applied as the ratio of silicate limestone bricks. The second step consisted of replacing the cement in the composition with lime ranging from 0 to 100%while sand and water cement ratio are fixed (table 3.2). The compaction machine was used to produce the silicate limestone bricks, which gave the bricks of 140x140x290 mm.

Table 3.2: Mix proportion of silicate limestone brick

Sample	Binder		Sand (S)	Water /cement ratio	Number of sample
	Cement (OPC)	Limestone Powder (LP)			
1	0%	100%	Fixed	Fixed	5
2	20%	80%	Fixed	Fixed	5
3	40%	60%	Fixed	Fixed	5
4	60%	40%	Fixed	Fixed	5
5	80%	20%	Fixed	Fixed	5
6	100%	0%	Fixed	Fixed	5

The stages of production of bricks are as follows:

- Mix the Limestone powder, silicate sand and cement using by hand in the mixing tray.
- Pour the appropriate amount of water in the mix.
- Fill the mixture in the compression machine and press until the arm reaches the maximum pressure.
- Remove the sample from the compression machine and put them on the ground.
- Cover them with tissues and spray water on them during 7, 14 and 28 days depending on testing day.

Plate 3.5 below shows the silicate limestone products and the compression machine used for its making.

(a) Silicate limestone bricks

(b) compression machine

Plate 3.5: Silicate limestone bricks and block compression machine

3.5 Testing on blocks

3.5.1 Water absorption test

The tests to determine the water absorption was carried out in accordance to BS EN 772 Part 11 (2010). The coefficient of water absorption characterizes the stability of materials in water. It is determined from ratio of dry strength to wet strength (Chaibeddra. S.& F. Kharchi, 2013). The aim of the water absorption test was to determine the percentage of moisture absorption capacity of the brick samples.

Procedure

- The specimens were placed inside the oven for a period of 48 hours.
- After removing in the oven, the specimens were removed and cooled for 12 hours.
- The dry weight of each specimen was measured (W_d) using an electronic weighing machine.
- Immediately after dry bricks were weighed, they were immersed in water for 24 hours, after which they were removed and weighed again (Ww).

The percentage moisture absorption by weight was calculated as follow:

$$M_C = \frac{W_w - W_d}{W_d} \cdot 100\% \qquad \textbf{3.5}$$

Where

M_c=percentage moisture absorption (%)

W_w= mass of wetted sample

W_d=mass of dry sample

This test was done after spraying the bricks for a period of 28 days.

3.5.2 Dry density of blocks

According to TahminaBanu, Md., (2013), after 7 days of curing period bricks were dried at 110^0C for 24 hours and then allowed to cool to room temperature. Dry weight Wd (kg) was determined.

Procedure

- The specimens were placed inside the oven for a period of 48 hours
- After removing in the oven, the specimens were removed and cooled for 12 hours.
- The dry weight of each specimen was measured (Wd) using an electronic weighing machine.
- The volume of each specimen was calculated (V)

The dry density of specimen was calculated as follows:

$$d_d = \frac{W_d}{V} \cdot 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{3.6}$$

Where:

d_d=dry density (kg/m^3)

W_d=mass of dry sample

V=volume of sample

This test was done after spraying the bricks for a period of 28 days.

3.5.3 Compressive strength test

The compressive strength tests of the blocks were carried out using a Universal Testing Machine according to BS 1881 part 166: 1983. The compression loading was applied continuously to failure at a uniform rate of 0.2 MPa/sec using block specimens at 7, 14 and 28 days. A total of 10 specimens for each block type were tested in compression for each age. See plates 3.6(a) to 3(d) for the experimental setups and tests.

Remark: for clay bricks (interlocking blocks), layers of mortar were placed on the top and bottom of brick to have flat area.

Procedure

- The compression machine was set and all the necessary information such as width and length of blocks, the rate at which the load was applied to the block.
- The block was aligned in the Universal Testing Machine (UTM).
- After the load set up, the maximum load at which the brick crushed and the respective compressive strength were recorded automatically.

The compressive strength of each specimen was then calculated using the formula:

$$C_d = \frac{W_D}{A} \qquad \textbf{3.7}$$

Where:

C_d=Compressive strength in N/mm^2

W_D=Total load at which the dry specimen was failed in Newtons

A=The surface area on which the load was applied in mm^2

(a) Silicate limestone brick

(c) Concrete block

(b) Natural stone

(d) Clay brick

Plate 3.6: Compressive strength in a universal testing machine

3.5.4 Flexural strength test

The flexural strengths of the blocks were tested in the Universal Testing Machine according to BS 6073-1, 2008 using transversal loading as shown in the plate3.7 (a) to(d). A total of 10 specimens of each block type were tested at age of 14 and 28 days.

Remark: for clay bricks (interlocking blocks), layers of mortar (75 mm of width) were placed transversally on top of the brick to have flat area.

Procedure

The blocks were weighed and the dimensions were recorded:

- The Universal Testing Machine was set and all the necessary information recorded such as width, length and height of blocks, the rate at which the load was applied transversally at the mid span of block.
- The block was aligned in the Universal Testing Machine (UTM).
- After the load set up, the maximum load at which the brick crushed and the respective flexural strength were recorded automatically.

This test was done after spraying the bricks with water, to increase their strength, for a period of 14 days and 28 days respectively. The flexural strength of each specimen was then calculated using the formula:

$$\sigma = \frac{3Fl}{2bd^2} \qquad \text{3.8}$$

Where:

$\boldsymbol{\sigma}$= Flexural strength in MPa

$\boldsymbol{F}$ = Total load at which the dry specimen failed in N

$\boldsymbol{l}$ = the length of the specimen in mm

$\boldsymbol{b}$ = the width of the specimen in mm

$\boldsymbol{d}$= the height of the specimen in mm

(a) Silicate limestone brick

(b) Concrete block

(c) Clay brick

(d) Natural stone

Plate 3.7: Test Flexural strength in universal testing machine

3.6 Test on panel wall

The tests to determine the structural capacities of the wall were performed in accordance to BS 5628 part 1 (1992). Lime silicate bricks made from 60% replacement of cement were used to make the test wall. In addition, two other walls made of natural stone blocks and clay bricks were tested for comparison.

The equipment and accessories used were load cell, data logger, strain gauges, hydraulic loading jack, transducers, steel plate.

Three (03) walls for each type of blocks were made and the averages were recorded.

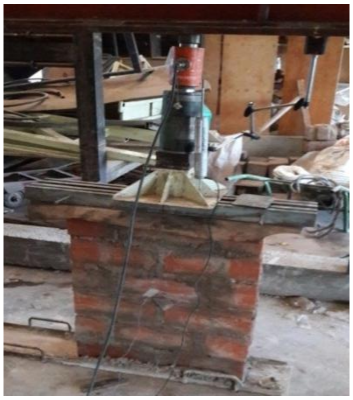
Procedure

- The set up area was prepared
- Elevation of the wall was done by the superposition of bricks and mortar corresponding to the strength of unit block
- After one week age of curing by spraying water, a steel plate was positioned on the wall in order to transfer the applied load uniformly along the length of the wall
- Loading jack was positioned on the steel plate and a load cell placed against the loading jack and the frame.
- The transducer was attached at one side of the wall with aim of determining the deflection produced in response to the respective applied load.
- Strains gauges were attached at the center of the wall to measure the strain in both X and Y directions.
- The loading jack was slightly pumped and released to firm up the set up.

Loading data recording

Loading was carried out by applying gradual increments of load through the hydraulic

loading jack, for every increment, the loads, displacements, strains were printed in the data logger. Plate 3.8 shows the set-up of walls in the loading frame



(a) Clay wall

(b) Silicate Limestone wall

(c) Natural stone wall

Plate 3.8: Test setup for walls in the loading frame

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Sand properties

The results of the river sand were satisfactory as shown in Table 4.1 below and the grading was within the lower and the upper limits as shown in Figure 4.1. It reveals that sand from Meru can be used to produce concrete of good quality. The detailed data of sand properties are represented in Appendix A.

Table 4.1: Physical properties of Meru sand

Designation	Results	Limit	Remarks	Code
Silt content	3.56 %	<6%	good	BS 1377 – 1:1990.
Water absorption	0.1%	<3%	Good	BS 1377 – 1:1990.
Fineness modulus	2.86	2.6-2.9	Good	BS 1377 – 1:1990.

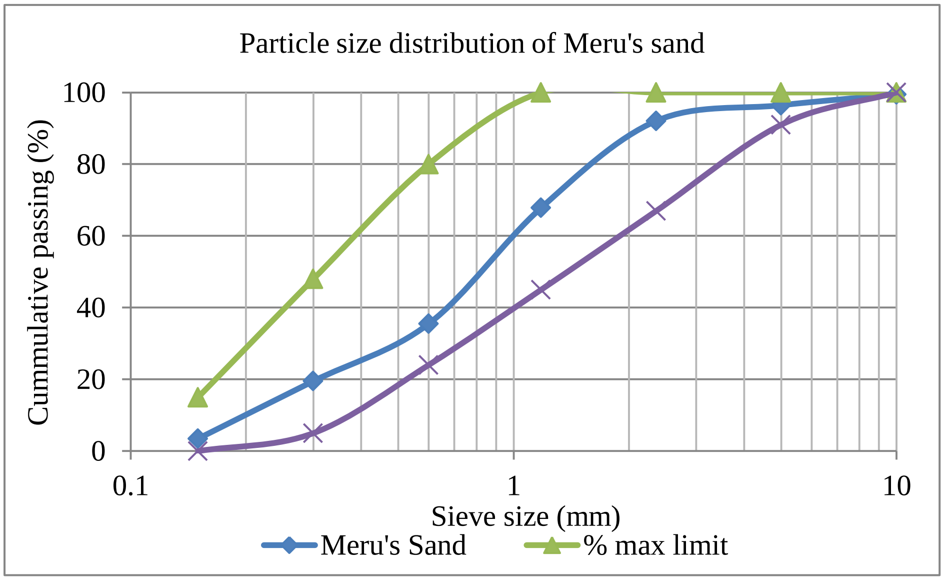


Figure 4.1: Particle sizes distribution curves of Meru sand

4.2 The optimum mix ratio by vibration of control with ordinary Portland cement

Table B2 represented in appendix B shows the compressive strength in MPa of the bricks made from the different mix ratio (in term of mass) at 7 days of curing of control mixture, which is constituted of sand, cement and water. The goal of this section was to determine the optimum ratio of cement, sand and water /cement ratio which were to serve as control in the study. This was achieved by compressive strength of the control closed to 8.5MPa at 7 days which correspond to 13 MPa at 28 days according to the guidance on the selection and specification of concrete blocks in masonry construction can be found in BS 5628: Part 3 and BS EN 771-3 respectively.

Figure 4-2 below shows that the ratio 1:5:0.4 was the optimum ratio in term of the compressive strength, which is 8.74 MPa, close to the 8.5 MPa, the control. The compressive strength curves for the control mix are represented in the Figure 4-2. The detailed data are presented in Appendix B.

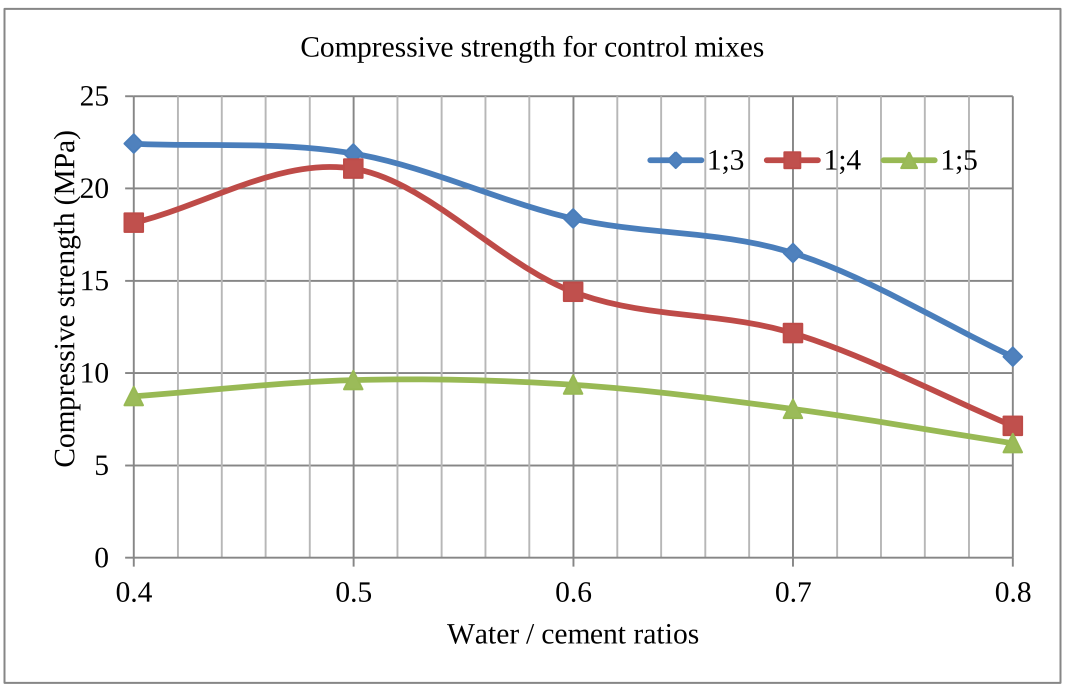


Figure 4-2: Compressive strength curves of control mixes

4.3 Effects of silicate-limestone content on physical and strength properties of bricks

4.3.1 Water absorption

Figure4-3 below shows the results from water absorption test performed for different percentage proportions of lime ranging from 0 to 100% at 7,14 and 28 days properties of the blocks.

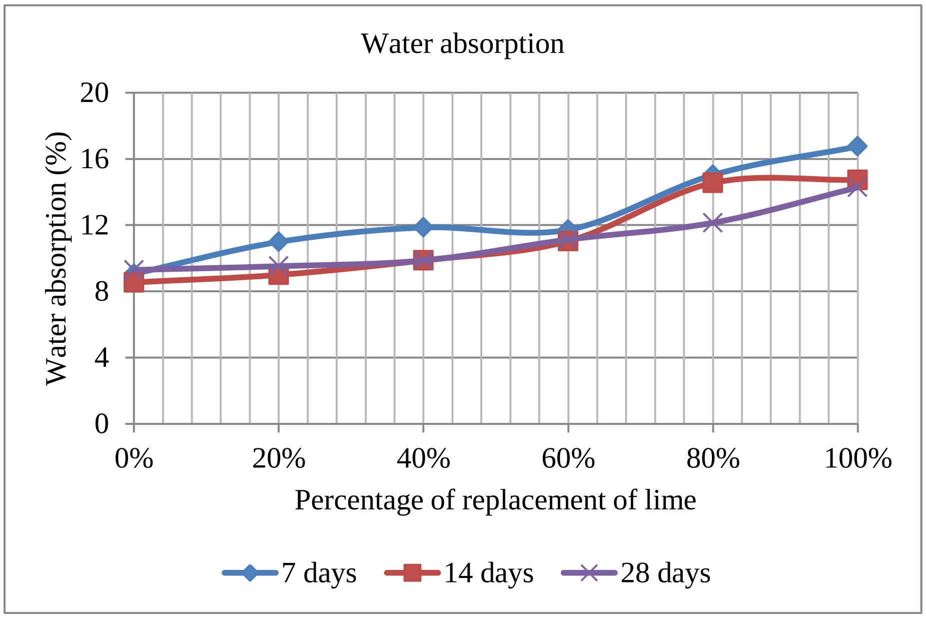


Figure 4-3: Water absorption curves of silicate limestone bricks

It is noted that the water absorption of the silicate limestone bricks decreases with time and increases when we added lime. That means that lime absorbs more water than cement.

From the Figure it is observed that from 0% up to 60% of lime content, the curves remain stable and at 14 and 28 days there is no variation.

It is also noted that the values of water absorption of silicate limestone bricks ranging from 0 to 100% of lime content at 28 days are within the recommended values which is 20% according to the Standard IS 456 (2000). This means that they can be used in a capillary environment, provided with protection against water damage. The detailed data of water absorption are presented in Appendix C.

4.3.2 Dry density

Figure 4-4 below shows the results from dry density test performed for different percentage of lime content, ranging from 0 to 100% at 7, 14 and 28 days.

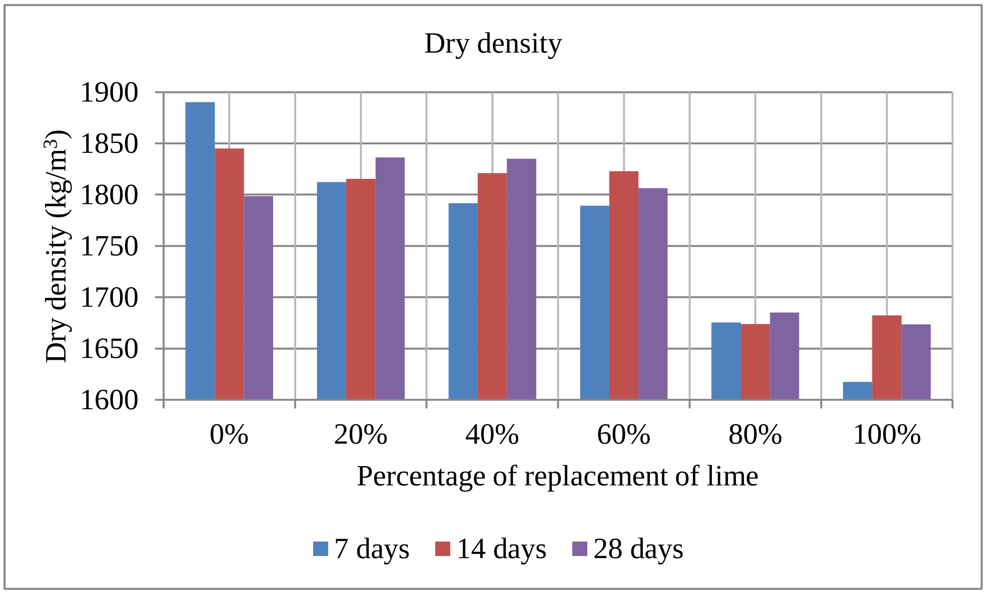


Figure 4-4: Bar chart of dry density of silicate limestone bricks

From this figure, the dry density decreases when the percentage of lime increases, which is expected since the lime is less heavy than cement.

- From 0% to 60% the trend is stable because the slope is too slow.
- The variation of density for 20% to 0% does not vary much from these result though at 60% the density is slightly lower
- From 60% to 80% the trend is unstable due to the higher slope. This is due to the density of lime which is higher than the density of the cement and the lime is more compressible than the cement.
- From 80 % to 100%, the trend becomes again stable because the slope is slow.
- The silicate limestone bricks with variation from 0% to 100% are considered as High density according to Chanakya Arya (2009), bricks with a gross density of less than or equal to 1000 kg/m^3 are classified as LD (low density) units and those with a gross density exceeding 1000 kg/m^3 as HD (high density) units.

The detailed data of dry density are presented in Appendix D

In conclusion, it is good to have bricks which are less heavy and stable so that their handling during the construction will be easy to the workers, so SLB 60% is the best type of silicate limestone bricks compared to the others in term of dry density because they are more stable.

4.3.3 Compressive strength of silicate limestone bricks (SLB)

Figure 4-5 below shows the results for compression strength performed for percentage proportional compositions ranging from 0 to 100% by mass of lime content at 7, 14 and 28 days.

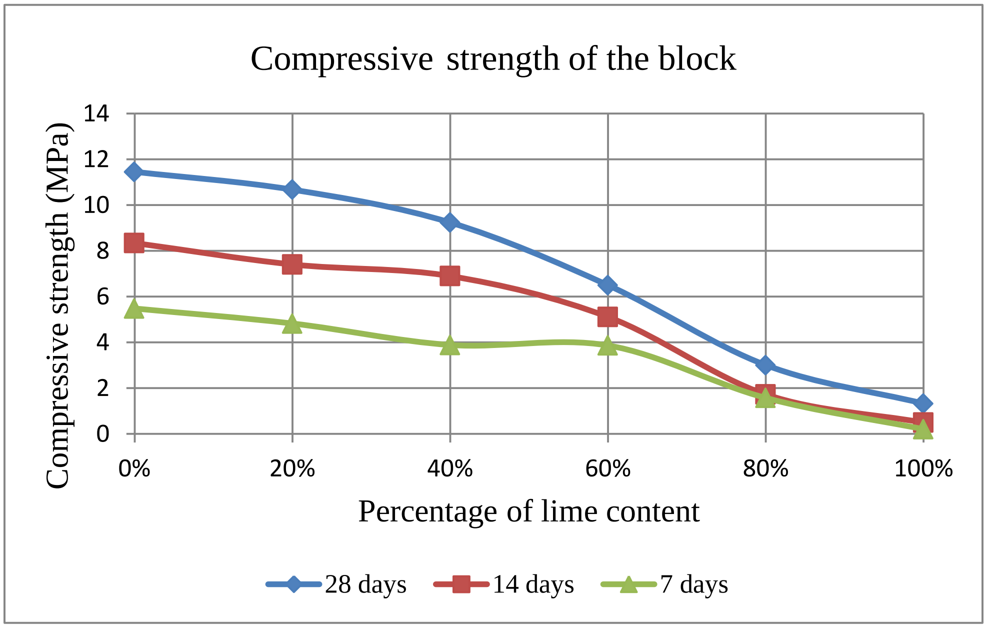


Figure 4-5: Compressive strength of SLB with varying lime contents

It was noted:

- The strength decreases when the percentage of lime increases, which means the strength of lime is lower than the strength of the cement used for making the blocks.
- From 60% to 80%, the slope is too high compared to the other, which means the lime is predominant than the cement.

4.3.4 Flexural strength of silicate limestone bricks (SLB)

Figure 4-6 below shows the results from flexural strength performed for percentage proportional composition ranging from 0 to 100% at 14 and 28 days.

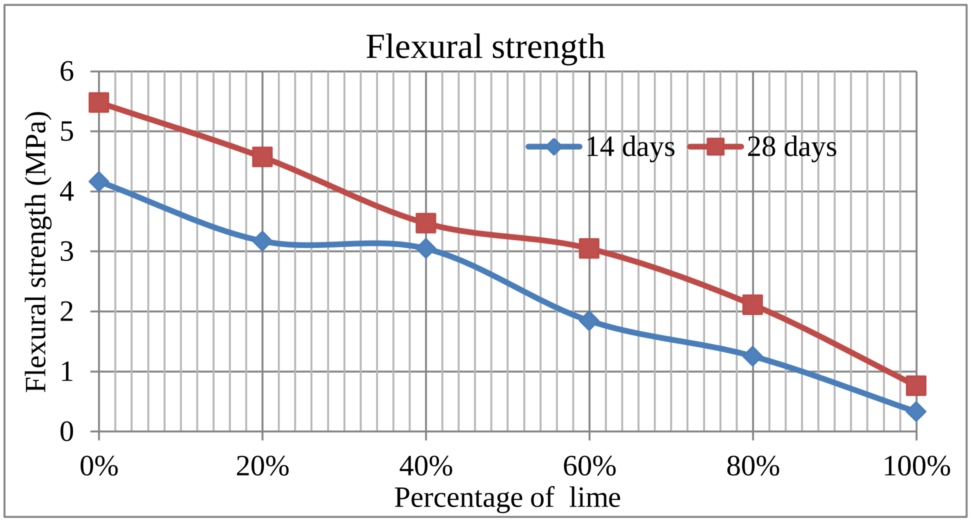


Figure 4-6: Flexural strength of SLB with varying lime contents

It was noted that:

- The strength decreases when the percentage of lime increases which means the lime is weaker than cement in the bending that is why the values of flexural strength reduce with increase percentage of lime.
- From the curve at 28 days, the slope of the curve is lowest from 40% to 60%, which means the optimum ratio of lime content in block seems stable within this interval.

4.4 Performance comparison of SLB with local blocks in Kenya

Figure 4-7 shows the strength (compressive and flexural strengths) performance of silicate limestone bricks prepared with various percentages of lime ranging from 0 to 100%. The blocks were compared to those available in the Kenyan market such as concrete blocks, natural stone (machine cut) blocks and clay bricks.

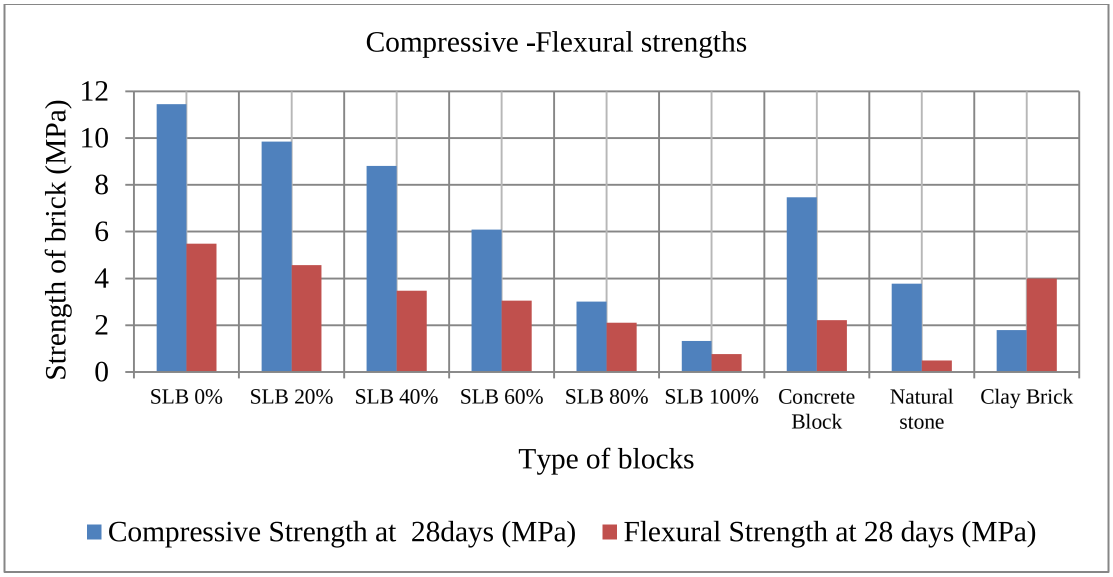


Figure 4-7: Structural performance of SLB and other blocks.

It was noted that:

- The compressive strength of blocks is greater than their flexural strength, except for clay brick, which the flexural strength is higher than compressive strength. This is due to the section depth
- In terms of compressive strength silicate limestone blocks with up to 80% of lime content have better strength characteristics than clay brick, but the clay brick has a better flexural strength than SLB from 40% up to 100% of lime.
- Silicate limestone bricks up to 60% of lime have better strength characteristics than natural stone (machine cut), in term of compressive and flexural strength.
- Natural stone is very weak in flexure due to their composition i.e. they are not homogenous. The silicate limestone with 100% of lime has better bending strength than natural stone, which means that natural stones should not be used as flexural structural element such as beams, slabs and columns. They are low load bearing elements as in wall infills.
- The concrete block used in Kenya has a very good compressive strength but they are weaker than silicate limestone bricks with 40% of lime. This is due to its composition because the ratio of concrete block was 1:5:6 (cement: sand: ballast) .The cement used in

making blocks has a strength of 32.5MPa which is less than the cement in making of Silicate limestone bricks (42.5 Mpa). Nevertheless, the use of this concrete is for the non-load bearing structures.

- Silicate limestone brick has 6 MPa and 3Mpa respectively for compressive and flexural strength.These values were obtained at 60% of lime.

The detailed data of strength performance of blocks are presented in Appendix E

4.5 Comparison of the structural performance of the three types of wall tested.

The result of panel wall tested in axial compression are presented in this chapter. Three types of panel wall were built, cured and tested at 7 days. Silicate limestone wall was built with 60% of lime; wall two was built with the clay bricks from Kenya Clay product and wall three was built with the conventional stone blocks from Juja, Kenya. The walls were loaded up to the maximum load that leads to failure. The main objective of the compressive test was to compare the structural behavior of the wall. For the entire wall, the proportion of mortar mix depended on compressive strength of each brick and block corresponding to the table 1, BS 5628. The silicate limestone and clay wall had a dimension of 600 x 750x 140mm while the conventional stone blocks wall has a dimension of 600 x 800 x 140mm and clay wall has a dimension of 600 x800 x155 mm. Table 4-2 below shows the dimensions of the tested walls, strength of blocks and mortar mix proportions.

Table 4.2: Walls characteristics

Walls designation	Strength of block (MPa)	Wall size (mm)	Mortar ratio (Table 1)
Silicate limestone bricks (60% of lime)	6.08	600 x 750 x 140	1:3
Natural stone	3.77	600 x 800 x 140	1:5
Clay brick	1.80	600 x 800 x 155	1:7

4.5.1 Load-displacement curves

Figure 4-8 shows load-displacement characteristics of the various walls prepared in this research.

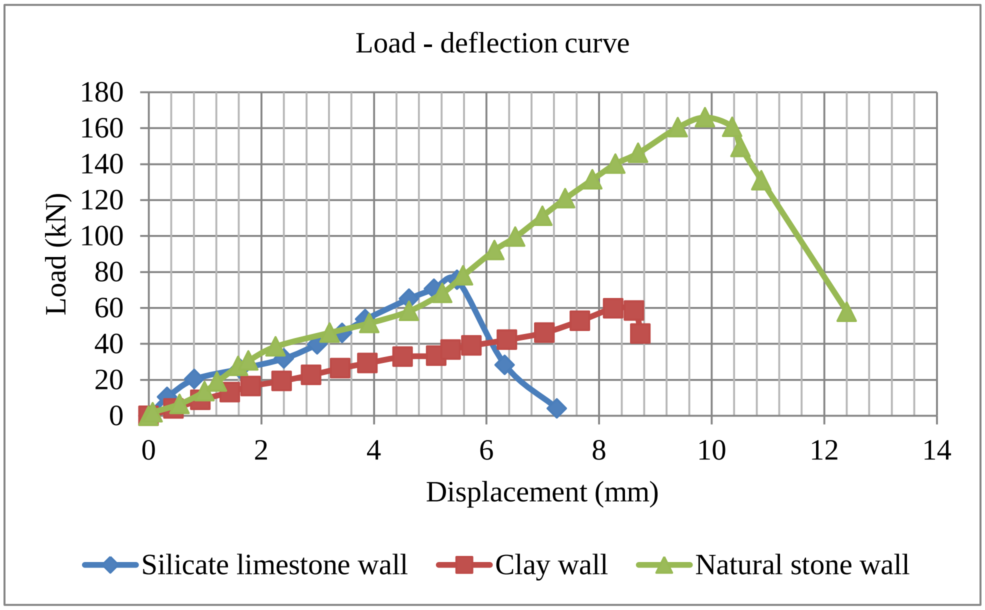


Figure 4-8: Load- deflection curve

It represents the load-deflection curve of the wall and shows that, at application of 75.52kN load, the displacement in silicate limestone was 5.48 mm while for natural stone wall, the displacement was 9.89 mm at anapplied load of 165.92 kN. For the clay wall, at a load of 59.68 kN, the displacement is 8.26 mm. Figure 4-8 reveals also that the wall made of silicate limestone bricks had higher stiffness compared to the other two types of walls, which was due to the higher homogeneity of its composition made by compaction and the compressive strength of the unit brick which was higher than the other unit blocks. The detailed data of load- displacement test are presented in Appendix F.

4.5.2 Compressive capacity of walls

Figure 4-9 shows the maximum stress of each wall. The stress was calculated using the relation in equation (4.1).

$$C_D = \frac{W_D}{A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.1$$

Where:

C_D = Compressive strength in N/mm^2

W_D = Total load at which the dry specimen was failed in Newtons

A = the surface area on which the load was applied in mm^2

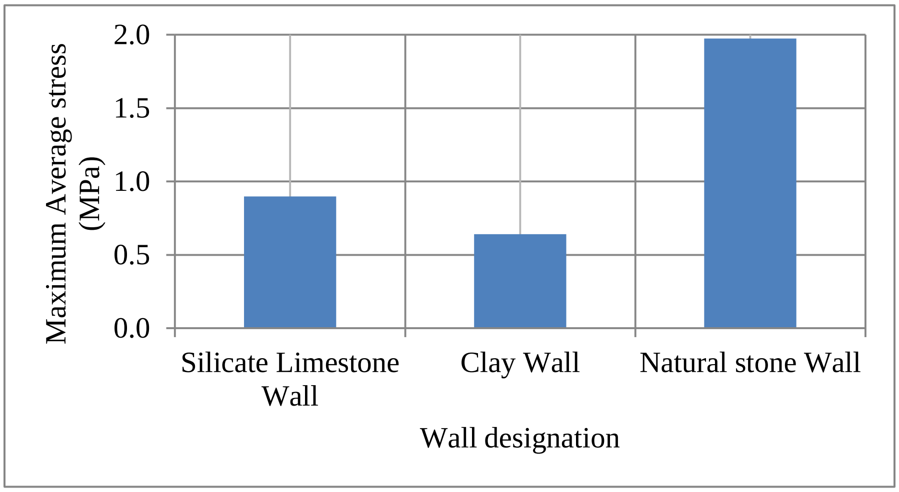


Figure 4-9: Maximum stress in the walls

The maximum stress in each type of wall was 0.90 N/mm^2, 0.64 N/mm^2 and 1.98 N/mm^2 respectively for silicate limestone wall, clay wall and natural stone wallas presented in Figure 4-9.

It was observed that the maximum compressive stress of the walls was lower than that of the individual bricks. Hemant&al, (2007) examined the relationship between the compressive strength of a masonry and the brick units, and concludes that walls prisms have low compressive strength than bricks units due to non linearity and composite behavior of masonry prisms.

The current situation is similar to that of Hemant&al.(2007), our study also suggests that the composite nature of the masonry wall reduces the ultimate load carrying capacity of the wall.

The wall made of natural stone gives the highest strength however; the compressive strength of its unit block is lower than silicate limestone brick. Many factors can explain it:

- The bonding inside the silicate limestone brick were not stable

- The geometry model of blocks are not the same, the dimensions 140x140x290 mm; 150x200x390 mm and 150x300x115 mm are respectively for silicate limestone brick, natural stone and clay bricks. It was observed that the natural stone had highest volume and clay brick, lowest volume.
- The number of layers of mortar is different for each wall. For the silicate limestone wall, the number of layer was 4, for the clay brick was 5 and the natural stone, the number was 3.
- The depth of mortar to obtain the desired height of wall, which was 750mm was different for each wall.

4.5.3 Stress- strain characteristic of walls

The Figures 4-10 and 4-11 show respectively the vertical and the horizontal stress-strain curves at the center of each type of wall. The stress-strain curve represents the relationship between the applied load and the result deformations in the wall. Stress / strain curve characteristic shows the behavior of the wall panel throughout the loading period (Musiomi, 2009).

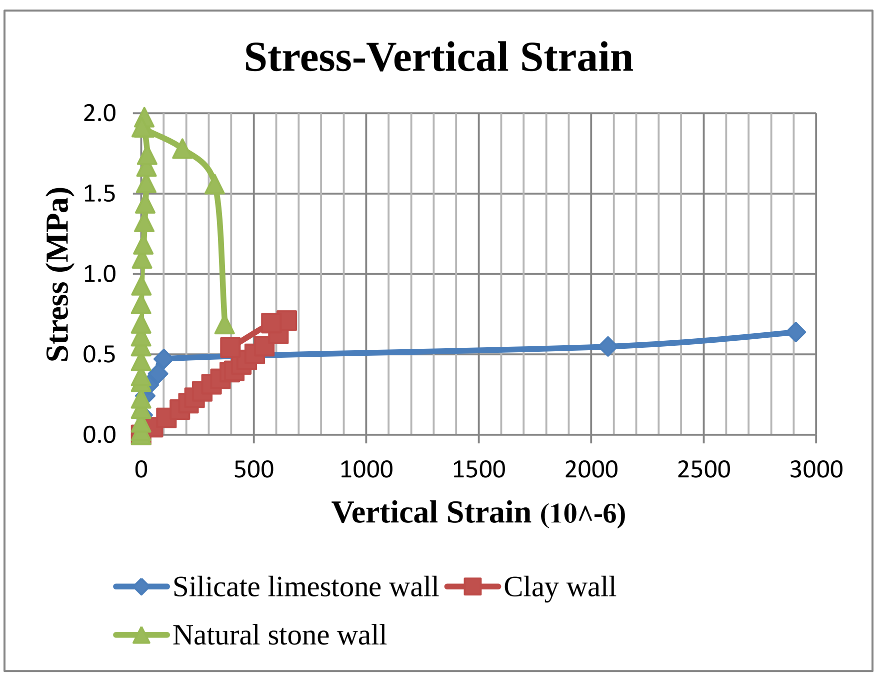


Figure 4-10: Stress-vertical strain at the centre of the wall liaison

Figure 4-10 above shows that:

a) The first crack of natural stone appeared at approximatively2 N/mm^2 corresponding to a strain of 15µ, which is negligible while the first crack of silicate limestone appeared at 0.5 N/mm^2 with a strain of 100 µ, this first stage which means silicate limestone wall is weaker than stone wall due its quick deformation.

b) It shows also that after the first crack the natural stone wall and clay wall collapsed while the silicate limestone continued to increase with increasing strain, which means the silicate limestone has highest ductility. Natural stone wall is a non-ductile structure as compared to clay and limestone structure. This is due to the properties of binders (cement and lime) in the silicate limestone bricks.

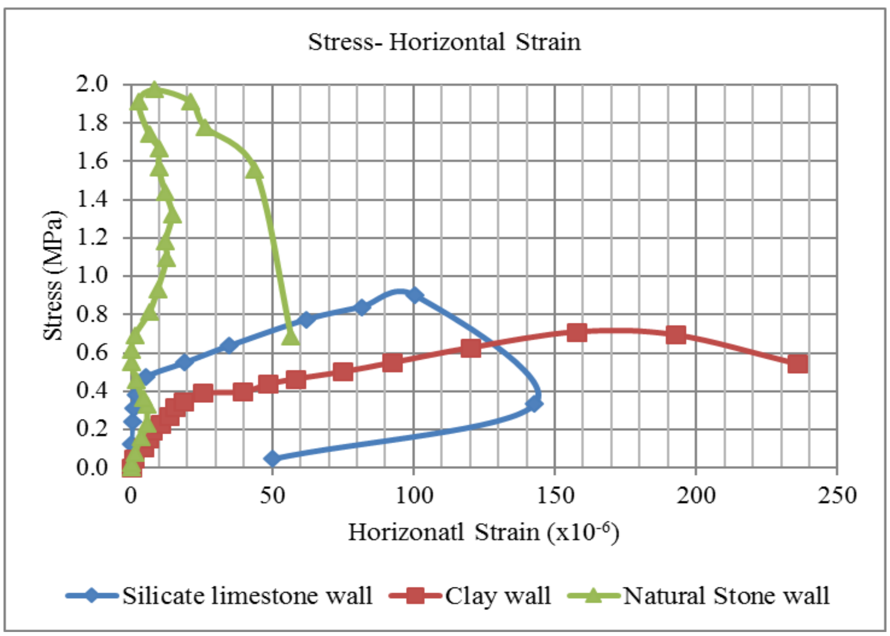


Figure 4-11: Stress-horizontal strain at the center of the wall

Figure 4-11 above shows that:

a) Clay brick wall had higher ductility when under compressive loading while silicate had better ductility during failure as compared to natural stone wall. This is probably due to its good property to bend, it has better flexural strength compared to the others walls.

b) Clay brick wall had highest ductility than the natural stone wall. This is probably due to its good property to bend, it has better flexural strength compared to the others walls.
c) The walls have a better strain in the X direction (horizontal) than Y direction (vertical), probably due the height of wall, which was higher than the length (H=0.8 L=0.6).

4.5.4 Failure patterns of walls

Plate 4-1 below shows some transversal cracks on faces of silicate limestone wall. This failure was predominantly by shear and was due to the combination of tensile cracks parallels to the axis of loading and shear failure along lines of weakness.

Plate 4.1: Failure patterns of silicate limestone wall

Plate 5-2 shows how the clay wall collapsed, it exploded and this kind of failure was due to the voids inside the brick, which could not limit the compressive capacity of the blocks. That is why there was no apparition of preventives cracks before explosion of wall.

Plate 4.2: Failure patterns of Clay bricks wall

Plate 4-3 shows some parallel cracks on faces of natural stone wall; this kind of failure was due by the development of tensile cracks parallels to the axis of loading along lines of weakness which probably corresponded to the lowest bending strength of its unit block.

Plate 4.3: Failure patterns of natural stone wall

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 General

The key objective of this research study was to investigate the properties and structural performance of compressed silicate limestone bricks. To achieve that investigation was done on the effect of varying lime composition on the physical properties of silicate limestone bricks. Afterwards a comparison of strength properties (compression and flexural strength) of these bricks was done with those available in the Kenyan market. Finally, the silicate limestone wall was structurally tested and compared with natural stone and clay bricks walls.

5.2 Conclusions

a) The investigation done in varying lime composition in silicate limestone bricks shows that as the proportion of lime increases, the physical and mechanical properties of bricks become weak.

b) In comparison with the blocks used in the local market, it is found that Silicate Limestone Bricks with 60% of lime content is the optimum replacement as alternative blocks in terms of its strength properties.

c) The walls constructed with stone blocks perform better structurally than those made with limestone bricks with 60% of lime content.

5.3 Recommendations

From this study, it is recommended that:

1) To avert housing collapses in the country, the silicate limestone compressed brick with the mix of 20% cement and 80% of lime should be used for partitioning and unexposed works.
2) To use the silicate limestone bricks as an external wall it is necessary to use a good mortar which has better waterproof properties.
3) Further research work should be carried out to establish the effect of environment (wind, acoustic, thermal) on the compressed silicate limestone bricks.

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APPENDICES

Appendix A: Sieve Analysis of sand

Sieve size	Wtcumul retained	% Retained	% passing
10	5.17	0.52	99.48
5	35.50	3.55	96.45
2.36	79.17	7.92	92.08
1.18	321.67	32.17	67.83
0.6	645.17	64.52	35.48
0.3	804.83	80.48	19.52
0.15	965.33	96.53	3.47
Pan	992.33	99.23	0.77
Total			

Appendix B: Mortar mix

Table B1: Control mixture for each date

Control mixture (Cement: Sand : Water) at 7 days by vibration							
Sample Marking	Casting Date	Testing date	Age (days)	Weight (g)	Load (kN)	Crushing Strength (Mpa)	Cube size (mm^3)
1;3:0.7	6/5/2016	13/5/2016	7	2276.5	172.02	17.202	*100x100x100*
				2284	147.73	14.773	
				2322	175.298	17.53	
1;3:0.8	6/5/2016	13/5/2016	7	2140	112.948	11.295	*100x100x100*
				2093.5	108.913	10.891	
				2248.5	104.652	10.465	
1;3:0.9	6/5/2016	13/5/2016	7	2208.5	102.242	10.224	*100x100x100*
				2195.5	98.767	9.877	
				2181	91.536	9.154	
				2133.5	11.0258	11.026	
1;3:0.6	10/5/2016	16/5/2016	7	2279	171.404	17.17	*100x100x100*
				2335	203.876	20.388	
				2330	175.439	17.544	

1;3:0.5	10/5/2016	16/5/2016	7	2385.5	236.935	23.693	*100x100x100*
				2358.5	229.286	22.929	
				2339.5	165.745	16.575	
1;3:0.4	10/5/2016	16/5/2016	7	2173	241.894	24.189	*100x100x100*
				2232.5	206.565	20.657	
				2239	105.353	10.535	
1;4:0.4	16/5/2016	23/5/2016	7	2279.5	171.6	17.160	*100x100x100*
				2228	175.747	17.575	
				2171	196.787	19.679	
1;4:0.5	16/5/2016	23/5/2016	7	2362.5	128.307	12.831	*100x100x100*
				2376	239.904	23.990	
				2367	197.964	19.796	
1;4:0.6	16/5/2016	23/5/2016	7	2298.5	143.554	14.355	*100x100x100*
				2340	139.974	13.997	
				2361.5	148.374	14.837	
1;4:0.7	16/5/2016	23/5/2016	7	2279	122.814	12.281	*100x100x100*
				2234	124.944	12.494	
				2169	116.928	11.693	
1;4:0.8	16/5/2016	23/5/2016	7	2169	64.882	6.488	*100x100x100*
				2204	78.615	7.862	
				2239	70.628	7.063	
1;5:0.4	**18/5/2016**	**25/5/2016**	**7**	**2259**	**88.705**	**8.871**	***100x100x100***
				2153.5	**95.011**	**9.501**	
				2250.5	**78.615**	**7.862**	
1;5:0.5	18/5/2016	25/5/2016	7	2124	95.908	9.591	*100x100x100*
				2262.5	100.448	10.045	
				2184.5	92.293	9.229	
1;5:0.6	18/5/2016	25/5/2016	7	2266.5	75.084	7.508	*100x100x100*
				2283	82.455	8.246	
				2175	84.165	8.417	
1;5:0.7	18/5/2016	25/5/2016	7	2351.5	99.86	9.986	*100x100x100*
				2304	90.022	9.002	
				2313	91.148	9.115	
1;5:0.8	18/5/2016	25/5/2016	7	2237	54.456	5.446	*100x100x100*
				2202	62.416	6.242	
				2291.5	69.114	6.911	

Table B2: Summarize of control mixture

S/C \ W/C	0.4	0.5	0.6	0.7	0.8
1;3	22.42	21.89	18.37	16.50	10.88
1;4	18.14	21.07	14.40	12.16	7.14
1;5	8.74	9.62	9.37	8.06	6.20

Where, w/c: water cement ratio and, s/c: sand cement ratio

Appendix C: Water absorption

Table C1: Water aborption of bricks at 7 days

Water absorption (Lime:Cement: Sand : Water) at 7 days						
Sample Marking (%perce ntage of lime)	Casting Date	Testing date	Age (days)	Dry Weight Wi (g)	Wet WeightWw(g)	Water absorption (Ww-Wi)*100/Wi %
0%	13/6/2016	23/6/2016	7	10246	11166	9.0
				10365	11289.5	8.9
				10609.5	11565	9.0
				10361	11326.5	9.3
20%	13/6/2016	23/6/2016	7	10013	11090	10.8
				9759.5	10839	11.1
				9994	11121	11.3
				9690	10740.5	10.8
40%	13/6/2016	23/6/2016	7	9214	10294	11.7
				9091	10138.5	11.5
				8870	9926	11.9
				9519	10687.5	12.3
60%	13/6/2016	23/6/2016	7	9942.5	11145	12.1
				8984.5	10023.5	11.6
				9896	11063.5	11.8
				9301	10363	11.4
80%	13/6/2016	23/6/2016	7	8339.5	9589	15.0

				8754.5	10049.5	14.8
				8703	9967	14.5
				8547.5	9899	15.8
100%	13/6/2016	23/6/2016	7	9115	10714	17.5
				9124	10569.5	15.8
				8954.5	10463.5	16.9

Table C2: Water absorption of bricks at 14 days

Water absorption (Lime:Cement: Sand : Water) at 14 days						
Sample Marking(%percentage of lime)	Casting Date	Testing date	Age (days)	Dry Weight Wi (g)	Wet WeightWw(g)	Water absorption (Ww-Wi)*100/Wi %
0%	16/6/2016	30/6/2016	14	10777	11703.5	8.6
				10363	11403.5	10.0
				9950.5	10782.5	8.4
				11276.5	12063.5	7.0
				10067	10944.5	8.7
20%	16/6/2016	30/6/2016	14	10653.5	11553.5	8.4
				9944	11040.5	11.0
				9857	10770	9.3
				10049	10776	7.2
40%	16/6/2016	30/6/2016	14	10490	11416	8.8
				10385	11325.5	9.1
				9451	10469.5	10.8
				1026.5	1137.5	10.8
60%	16/6/2016	30/6/2016	14	10399	11486	10.5
				9818	10890.5	10.9
				10506	11736.5	11.7
80%	16/6/2016	30/6/2016	14	8915	10175.5	14.1
				8237	9445.5	14.7
				9036	10384.5	14.9
				9325	10672	14.4
100%	13/6/2016	23/6/2016	14	10272	11689	13.8
				8941	10334.5	15.6
				9177.5	10612.5	15.6
				9173	10448.5	13.9

Table C3: Water aborption of bricks at 28 days

Water absorption (Lime:Cement: Sand : Water) at 28 days						
Sample Marking(%percentage of lime)	Casting Date	Testing date	Age (days)	Dry Weight Wi (g)	Wet WeightWw(g)	Water absorption (Ww-Wi)*100/Wi %
0%	16/06/2016	27/6/2016	28	10778	11831	9.8
				10175.5	11119	9.3
				10088	10978	8.8
20%	16/06/2016	27/6/2016	28	9592.5	10549	10.0
				10088	11002	9.1
				10362.5	10906.5	5.2
40%	16/06/2016	27/6/2016	28	9412	10367	10.1
				11113	12169.5	9.5
				9682	10643.5	9.9
60%	16/06/2016	27/6/2016	28	9634	10692	11.0
				10080.5	11222	11.3
				9606	10670	11.1
80%	16/06/2016	27/6/2016	28	9992.5	10836	8.4
				9244.5	10522	13.8
				9498.5	10843	14.2
100%	16/06/2016	27/6/2016	28	9194.5	10508.5	14.3
				9230	10550.5	14.3
				9014	10296	14.2

Table C4: Summarize water absorption of bricks at 7,14 and 28 days

Water absorption of Silicate Limestone Brick (SLB in %) at 7,14 and 28 days						
Age of SLB	**% of lime on the composition**					
	0%	20%	40%	60%	80%	100%
7 days	9	11	12	12	15	17
14 days	9	9	10	11	15	15
28 days	9	10	10	11	12	14

Appendix D: Dry density

Table D1: Dry density of bricks at 7 days

Dried Density test at 7 days									
Sample Marking(%percentage of lime)	Casting Date	Testing date	Age (days)	Dry Weight Wi (g)	Size			Volume (cm^3)	Dried Density (kg/m^3)
					X (cm)	Y (cm)	Z (cm)		
0%	13/6/2016	23/6/2016	7	10246	28.7	13.5	14	5424.3	1889
				10365	28.6	13.8	14	5525.52	1876
				10609.5	28.7	14	14	5625.2	1886
				10361	28.7	13.5	14	5424.3	1910
20%	13/6/2016	23/6/2016	7	10013	28.7	14	14	5625.2	1780
				9759.5	28.7	13.3	14	5343.94	1826
				9994	28.9	13.5	14	5462.1	1830
				9690	28.7	13.3	14	5343.94	1813
40%	13/6/2016	23/6/2016	7	9214	28.8	12.5	14	5040	1828
				9091	28.8	12.7	14	5120.64	1775
				8870	28.9	12.5	14	5057.5	1754
				9519	28.9	13	14	5259.8	1810
60%	13/6/2016	23/6/2016	7	9942.5	28.8	13.7	14	5523.84	1800
				8984.5	28.8	12.5	14	5040	1783
				9896	28.9	13.7	14	5543.02	1785
				9301	28.7	12.5	14	5022.5	1852
80%	13/6/2016	23/6/2016	7	8339.5	28.9	12.5	14	5057.5	1649
				8754.5	28.9	12.8	13.9	5141.888	1703
				8703	28.9	13	14	5259.8	1655
				8547.5	28.8	12.5	14	5040	1696
100%	13/6/2016	23/6/2016	7	9115	28.9	14	13.8	5583.48	1632
				9124	28.8	14	14	5644.8	1616
				8954.5	28.9	13.8	14	5583.48	1604

Table D2: Dry density of bricks at 14 days

Dried Density test at14 days									
Sample Marking(%percentage of lime)	Casting Date	Testing date	Age (days)	Dry Weight Wi (g)	Size			Volume (cm^3)	Dried Density (kg/m^3)
					X (cm)	Y (cm)	Z (cm)		
0%	16/6/2016	30/6/2016	14	10777	29	14	14	5684	1896
				10363	29	14	14	5684	1823
				9950.5	29	14	14	5684	1751
				11276.5	29	14	14	5684	1984
				10067	29	14	14	5684	1771
20%	16/6/2016	30/6/2016	14	10653.5	29	14	14	5684	1874
				9944	29	14	14	5684	1749
				9857	29	14	14	5684	1734
				10049	29	14	13	5278	1904
40%	16/6/2016	30/6/2016	14	10490	29	14	14	5684	1846
				10385	29	14	14	5684	1827
				9451	29	14	13	5278	1791
				1026.5	29	14	14	5684	181
60%	16/6/2016	30/6/2016	14	10399	29	14	14	5684	1830
				9818	29	14	13.5	5481	1791
				10506	29	14	14	5684	1848
80%	16/6/2016	30/6/2016	14	8915	29	14	13	5278	1689
				8237	29	14	12	4872	1691
				9036	29	14	14	5684	1590
				9325	29	13.8	13.5	5402.7	1726
100%	13/6/2016	23/6/2016	14	10272	29	14	15	6090	1687
				8941	29	14	13	5278	1694
				9177.5	29	14	13.5	5481	1674
				9173	29	14	13.5	5481	1674

Table D3: Dry density of bricks at 28 days

Dried Density test at28 days									
Sample Marking(%percentage of lime)	Casting Date	Testing date	Age (days)	Dry Weight Wi (g)	Size			Volume (cm^3)	Dried Density (kg/m^3)
					X (cm)	Y (cm)	Z (cm)		
0%	16/6/2016	27/7/2016	28	10778	29	14	14.5	5887	1831
				10175.5	29	14	14	5684	1790
				10088	29	14	14	5684	1775
20%	16/6/2016	30/6/2016	28	9592.5	29	14	13	5278	1817
				10088	29	14	13.8	5602.8	1801
				10362.5	29	14	13.5	5481	1891
40%	16/6/2016	30/6/2016	28	9412	29	14	13	5278	1783
				11113	29	14	14.5	5887	1888
				9682	29	14	13	5278	1834
60%	16/6/2016	30/6/2016	28	9634	29	14	13	5278	1825
				10080.5	29	14	14	5684	1773
				9606	29	14	13	5278	1820
80%	16/6/2016	30/6/2016	28	9992.5	29	14	14	5684	1758
				9244.5	29	14	14	5684	1626
				9498.5	29	14	14	5684	1671
100%	13/6/2016	23/6/2016	28	9194.5	29	14	13.8	5602.8	1641
				9230	29	14	13.6	5521.6	1672
				9014	29	14	13	5278	1708

Table D4: Summarize dry density of bricks at 7, 14 and 28 days

Dry density of SLB (kg/m^3) at 7, 14 and 28 days						
Age of SLB	**% of lime on the composition**					
	0%	20%	40%	60%	80%	100%
7 days	1890	1812	1792	1789	1676	1618
14 days	1845	1815	1821	1823	1674	1682

28 days	1799	1836	1835	1806	1685	1674

Appendix E: Strength of brick

Table E1: Compressive strength of silicate limestone bricks at 7 days

Compressive strength of bricks at 7 days							
Sample Marking(%percentage of lime)	Casting Date	Testing date	Age (days)	Weight (g)	Load (kN)	Crushing strength (MPa)	Size
0%	9/6/2016	16/6/2016	7	10321.5	230	5.665	140x290x140
				10524.5	230	5.665	
				10973.5	240	5.911	
				10518	160	3.941	
0%	10/6/2016	17/6/2016	7	10588	190	4.680	140x290x140
				9777.5	170	4.187	
				10784.5	150	3.695	
20%	9/6/2016	16/6/2016	7	10206.5	270	6.650	140x290x140
				10375	215	5.296	
				10048	270	6.650	
				10471.5	200	4.926	
20%	9/6/2016	16/6/2016	7	10030.5	200	4.926	140x290x140
				10175.5	180	4.433	
				9968	190	4.680	
				9137.5	190	4.680	
40%	9/6/2016	16/6/2016	7	11019.5	100	2.463	140x290x140
				9585.5	110	2.709	
				10633	100	2.463	
				10214	120	2.956	
40%	9/6/2016	16/6/2016	7	11012.5	190	4.680	140x290x140
				10224.5	160	3.941	
				10283	250	6.158	
				10453.5	210	5.172	
				10412.5	180	4.433	
60%	9/6/2016	16/6/2016	7	10274	115	2.833	140x290x140

				10194	170	4.187	
				10042.5	180	4.433	
				9954.5	175	4.310	
60%	9/6/2016	16/6/2016	7	11073	150	3.695	140x290x140
				10711	150	3.695	
				10068.5	140	3.448	
				9862.5	150	3.695	
				9983.5	140	3.448	
80%	9/6/2016	16/6/2016	7	9025.5	120	2.956	140x290x140
				9603	95	2.340	
				9060	110	2.709	
				10242.5	110	2.709	
80%	9/6/2016	16/6/2016	7	9497	60	1.478	140x290x140
				10740	60	1.478	
				10483.5	70	1.724	
				9974.5	65	1.601	
100%	9/6/2016	16/6/2016	7	10941.5	25	0.616	140x290x140
				11284	0	0.000	
				10355	0	0.000	

Table E2: Compressive strength of silicate limestone bricks at 14 days

Compressive strength of bricks at 14 days							
Sample Marking(%percentage of lime)	Casting Date	Testing date	Age (days)	Weight (g)	Load (kN)	Crushing strength (MPa)	Size
/0%	16/6/2016	30/6/2016	14	11294	400	9.852	*140x290x140*
				10261.5	250	6.158	
				11802.5	361	8.892	
				10519.5	308	7.586	
0%	17/6/2016	1/7/2016	14	12035.5	440	10.837	*140x290x140*
				11261.5	310	7.635	
				12182.5	360	8.867	
				11215.5	280	6.897	
20%	16/6/2016	30/6/2016	14	10639.5	270	6.650	*140x290x140*
				10458	265	6.527	
				10176	275	6.773	

				10466	340	8.374	
				10802	225	5.542	
20%	17/6/2016	1/7/2016	14	11882	310	7.635	*140x290x140*
				11361.5	340	8.374	
				11819.5	340	8.374	
				11456	340	8.374	
40%	16/6/2016	30/6/2016	14	11519	340	8.374	*140x290x140*
				10941.5	410	10.099	
				10809.5	250	6.158	
				10413.5	270	6.650	
40%	17/6/2016	1/7/2016	14	11717.5	260	6.404	*140x290x140*
				11106.5	270	6.650	
				11040.5	240	5.911	
				11441.5	200	4.926	
60%	16/6/2016	30/6/2016	14	9887	110	2.709	*140x290x140*
				10637	110	2.709	
				10243	120	2.956	
				10799.5	185	4.557	
				11677	195	4.803	
60%	17/6/2016	1/7/2016	14	11309.5	210	5.172	*140x290x140*
				10510	240	5.911	
				10759	110	2.709	
				11135	160	3.941	
80%	16/6/2016	30/6/2016	14	9766	75	1.847	*140x290x140*
				10940	70	1.724	
				10940	70	1.724	
				10576.5	65	1.601	
80%	17/6/2016	1/7/2016	14	10682.5	50	1.232	*140x290x140*
				11421.5	70	1.724	
				10341.5	60	1.478	
				10525	75	1.847	
				10601.5	60	1.478	
100%	9/6/2016	16/6/2016	14	9028.5	25	0.616	*140x290x140*
				10261.5	20	0.493	
				9203	20	0.493	
				9813	20	0.493	

100%	17/6/2016	1/7/2016	14	10874	20	0.493	*140x290x140*
				10812	17	0.419	
				10050	15	0.369	
				10800	23	0.567	

Table E3: Compressive strength of silicate limestone bricks at 28 days.

Compressive strength of bricks at 14 days							
Sample Marking(%percentage of lime)	Casting Date	Testing date	Age (days)	Weight (g)	Load (kN)	Crushing strength (MPa)	Size
0%	11/6/2016	9/7/2016	28	11528	580	14.286	*140x290x140*
				9802	420	10.345	
				10400	420	10.345	
				10871.5	440	10.837	
20%	11/6/2016	9/7/2016	28	11192	385	9.483	*140x290x140*
				10307.5	455	11.207	
				10754.5	460	11.330	
				10623.5	300	7.389	
40%	11/6/2016	9/7/2016	28	11849	305	7.512	*140x290x140*
				12686	380	9.360	
				11554	330	8.128	
				9853	415	10.222	
60%	11/6/2016	9/7/2016	28	10733.5	180	4.433	*140x290x140*
				11700	270	6.650	
				11339	270	6.650	
				10198	250	6.158	
				10819.5	265	6.527	
80%	11/6/2016	9/7/2016	28	9942	135	3.325	*140x290x140*
				10340.5	130	3.202	
				10529	125	3.079	
				11662.5	110	2.709	
				9050	110	2.709	
100%	11/6/2016	9/7/2016	28	9998	50	1.232	*140x290x140*
				10329.5	55	1.355	

				9512	60	1.478	
				10032	50	1.232	

Table E4: Compressive strength of natural stone

Sample Marking(%percentage of lime)	Weight (g)	Load (kN)	Crushing strength (MPa)	Size
Natural stone	17000	210	3.797	*140x395x200*
	17000	205	3.707	
	17000	220	3.978	
	17000	200	3.617	

Table E5: Compressive strength of concrete block

Sample Marking(%percentage of lime)	Weight (g)	Load (kN)	Crushing strength (MPa)	Size
Concrete block	14700	380	6.960	*140x395x200*
	15400	255	4.670	
	15800	320	5.861	
	15900	380	6.960	
	18 980	705	12.912	

Table E6: Compressive strength of clay brick

Sample Marking(%percentage of lime)	Weight (g)	Load (kN)	Crushing strength (MPa)	Size
CB	6772.5	73.29	1.576	*140x395x200*
	6910	114.322	2.459	
	6918.5	76.317	1.641	
	6960.5	69.283	1.490	
	6725.5	79.709	1.714	
	6547	79.036	1.700	
	6706	93.021	2.000	

Table E7: Flexural strength of silicate limestone bricks at 14 days

Sample Marking(%percentage of lime)	Casting Date	Testing date	Age (days)	Weight (g)	Load (kN)	Crushing Strength (Mpa)	mold size (mm^3)
0%	27/6/2016	12/7/2016	14	556.5	1.98	4.641	*40x40x160*
				507	1.54	3.609	
				531.5	1.94	4.547	
				526	1.9	4.453	
				446.5	1.54	3.609	
				494.5	1.76	4.125	
20%	27/6/2016	12/7/2016	14	577	1.9	4.453	*40x40x160*
				531	2.14	5.016	
				590.5	2.12	4.969	
40%	27/6/2016	12/7/2016	14	517.5	1.48	3.469	*40x40x160*
				505	1.1	2.578	
				490	1.32	3.094	
60%	27/6/2016	12/7/2016	14	492	0.88	2.063	*40x40x160*
				486.5	0.56	1.313	
				551.5	0.92	2.156	
80%	27/6/2016	12/7/2016	14	504.5	0.6	1.406	*40x40x160*
				448	0.5	1.172	
				480	0.5	1.172	
				475.5	0.54	1.266	
100%	27/6/2016	12/7/2016	14	527.5	0	0.000	*40x40x160*
				492	0	0.000	
				499	0.14	0.328	

Table E8: Flexural strength of silicate limestone bricks at 28 days

Sample Marking(%percentage of lime)	Casting Date	Testing date	Age (days)	Weight (g)	Load (kN)	Crushing Strength (Mpa)	mold size (mm^3)
0%	23/6/2016	21/7/2016	28	588	2.7	6.328	*40x40x160*
				568.5	2.08	4.875	
				581.5	2.48	5.813	
				560.5	2.6	6.094	
				582	3.2	7.500	
				582	1.68	3.938	
				546.5	1.7	3.984	
				547.5	2.26	5.297	
20%	23/6/2016	21/7/2016	28	508	1.66	3.891	*40x40x160*
				511	2	4.688	
				539.5	2	4.688	
				565.5	1.8	4.219	
				550.5	2	4.688	
40%	23/6/2016	21/7/2016	28	576.5	1.8	4.219	*40x40x160*
				503.5	1.5	3.516	
				517.5	1.32	3.094	
				540	1.44	3.375	
				549	1.34	3.141	
60%	23/6/2016	21/7/2016	28	547	0.9	2.109	*40x40x160*
				529	0.98	2.297	
				508	0.82	1.922	
80%	23/6/2016	21/7/2016	28	565	1.72	4.031	*40x40x160*
				524	1.64	3.844	
				441	0.54	1.266	
100%	23/6/2016	21/7/2016	28	435	0	0.000	*40x40x160*
				492	0.3	0.703	
				508	0.35	0.820	

Table E9: Flexural strength of natural stone

Sample Marking(%percentage of lime)	Weight (g)	Load (kN)	Crushing strength (MPa)	Size
Natural stone	17000	5.669	0.456	*140x200x395*
	17000	7.637	0.614	
	17000	5.25	0.422	
	17000	5.985	0.481	
	17000	6.004	0.482	

Table E10: Flexural strength of concrete blocks

Sample Marking(%percentage of lime	Load (kN)	Crushing strength (MPa)	Size
Concrete Blocks	9.046	1.483	*140x140x395*
	8.338	1.367	
	12.556	2.059	
	21.33	3.498	
	9.651	1.583	
	20.331	3.334	

Table E11: Flexural strength of clay bricks

Sample Marking(%percentage of lime	Load (kN)	Crushing strength (MPa)	Size
Clay bricks	23.75	3.82	*150x115x300*
	33.25	5.35	
	18.75	3.02	
	23.75	3.82	

Table E12: Summarize of Strength values of silicate limestone brickswith those available in Kenya

Strength performance	**SLB (MPa)**						**block**	**stone**	**Brick**
	0%	**20%**	**40%**	**60%**	**80%**	**100%**			
Compressive	11.45	9.85	8.81	6.08	3.00	1.32	7.47	3.77	1.80

Strength.									
Flexural Strength.	5.48	4.57	3.47	3.05	2.11	0.76	2.22	0.49	4.00

Appendix F: Strength of walls

Table F1: Maximum compressive strength of walls

Designation	**Max Stress (N/mm^2)**
Silicate Limestone Wall (60%)	0.90
Clay Wall	0.64
Natural stone Wall	1.98

Table F2: Load-displacement values

Silicate limestone Wall	Displacement (mm)	0.33	0.81	1.63	2.41	3.00	3.44	3.85	4.63	5.07	5.48	6.33	7.26	
	Load (kN)	10.4	20.32	26.08	31.84	39.68	46.08	53.6	65.12	70.56	75.52	28.16	4	
Clay Wall	Displacement (mm)	0.44	0.93	1.44	1.81	2.37	2.89	3.41	3.89	4.52	5.11	5.37	5.74	6.37
	Load (kN)	4	8.8	13.12	16.48	19.36	22.72	26.4	29.28	32.8	33.44	36.8	39.04	42.24
Stone Wall	Displacement (mm)	0.07	0.56	1.00	1.22	1.59	1.78	2.26	3.22	3.93	4.63	5.22	5.59	6.15
	Load (kN)	1.92	6.56	13.6	19.04	27.68	30.72	38.56	46.24	51.52	58.24	68.32	78.08	92.16

Silicate limestone Wall	Displacement (mm)											
	Load (kN)											
Clay Wall	Displacement (mm)	7.04	7.67	8.26	8.63	8.74						
	Load (kN)	46.24	52.8	59.68	58.4	45.6						
Stone Wall	Displacement (mm)	6.52	7.00	7.41	7.89	8.30	8.70	9.41	9.89	10.37	10.52	10.89
	Load (kN)	99.52	111.2	120.96	131.52	140.16	146.24	160.48	165.92	160.64	149.44	130.88

Table F3: Stress strain vertical

Silicate limestone Wall	Strain (10^{-6})	7.55	18.87	35.38	75.94	101.89	2075.47	2910.38	2263.21	1783.49	1489.62	661.32	53.77
	Stress (MPa)	0.12	0.24	0.31	0.38	0.47	0.55	0.64	0.78	0.84	0.90	0.34	0.05
Clay Wall	Strain (10^{-6})	53.30	113.21	172.17	211.32	237.74	271.70	313.21	352.83	394.81	414.62	445.75	470.28
	Stress (MPa)	0.05	0.10	0.16	0.20	0.23	0.27	0.31	0.35	0.39	0.40	0.44	0.46
Stone Wall	Strain (10^{-6})	0.47	0.47	0.00	0.00	0.47	0.94	0.94	0.94	0.94	0.00	0.00	1.42
	Stress (MPa)	0.02	0.08	0.16	0.23	0.33	0.37	0.46	0.55	0.61	0.69	0.81	0.93

Silicate limestone Wall	Strain (10^{-6})													
	Stress (MPa)													
Clay Wall	Strain (10^{-6})	505.19	547.64	610.85	648.11	579.72	397.17							
	Stress (MPa)	0.50	0.55	0.63	0.71	0.70	0.54							
Stone Wall	Strain (10^{-6})	5.66	10.85	15.57	19.34	23.11	25.47	28.30	15.57	14.62	3.77	183.49	327.36	372.17
	Stress (MPa)	1.10	1.18	1.32	1.44	1.57	1.67	1.74	1.91	1.98	1.91	1.78	1.56	0.69

Table F4:Stress strain Horizontal

Silicate limestone Wall	Strain (10^{-6})	0.00	0.47	0.94	1.89	5.19	18.87	34.91	62.26	81.60	100.47	142.92	50.00
	Stress (MPa)	0.12	0.24	0.31	0.38	0.47	0.55	0.64	0.78	0.84	0.90	0.34	0.05
Clay Wall	Strain (10^{-6})	0.94	4.25	6.13	7.55	10.38	13.21	15.57	18.40	25.47	39.62	48.58	58.02
	Stress (MPa)	0.05	0.10	0.16	0.20	0.23	0.27	0.31	0.35	0.39	0.40	0.44	0.46
Stone Wall	Strain (10^{-6})	0.00	1.42	3.77	5.66	5.66	4.25	1.89	0.00	0.00	1.42	6.60	9.43
	Stress (MPa)	0.02	0.08	0.16	0.23	0.33	0.37	0.46	0.55	0.61	0.69	0.81	0.93

Silicate limestone Wall	Strain (10^{-6})													
	Stress (MPa)													
Clay Wall	Strain (10^{-6})	75.00	92.45	120.28	157.55	192.45	235.85							
	Stress (MPa)	0.50	0.55	0.63	0.71	0.70	0.54							
Stone Wall	Strain (10^{-6})	12.74	12.26	14.62	12.26	9.91	9.91	6.60	2.83	8.49	21.23	26.42	43.87	56.60
	Stress (MPa)	1.10	1.18	1.32	1.44	1.57	1.67	1.74	1.91	1.98	1.91	1.78	1.56	0.69