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MASTER OF SCIENCE IN STRUCTURAL ENGINEERING

RESEARCH TOPIC: ASSESSING THE EFFECT OF DIFFERENT MORTAR MIXES ON STRENGTH OF BURNT CLAY BRICK MASONRY WALL

BY

NAME OF STUDENT: OWINO STEPHEN

BEng.CBE (KYU)

REG.NO: 17/U/14602/GMES/PE

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Certification

The undersigned certify that they have read and hereby recommend for acceptance by Kyambogo University a dissertation report entitled: Assessing the effect of different mortar mixes on strength of burnt clay brick masonry wall in fulfillment of the requirements for the award of a degree of Masters of Structural Engineering of Kyambogo University.

Signature:…………………………………………

Dr. KYAKULA MICHAEL

Date: …………………………………………….

Signature:………………………………………...

DR.MUGUME ROGERS BANGI

Date:………………………………………………

Declaration

I, OWINO STEPHEN, hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree of the university or other institute of higher learning, except where due acknowledgement has been made in the text and reference list.

Signature……………………………………

OWINO STEPHEN.

Date;…………………………………………

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Dedication

I dedicate this research project to my family, my supervisors especially Dr.Kyakula Michael for the time he has offered in ensuring that this research work is completed. To my employer and my family especially my wife thanks for being on my side at all times. To my fellow course mates the sky is not the limit

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Lists of symbols and abbreviations

A1, A2, A3, An……………………………..……………………………………….Sites

ASTM ………………………………………American Standard Test Measurements

BS………………………. …………………………………………..British Standard

f_{kt} ………………………Tested Characteristic compressive strength of burnt clay bricks.

f_{kd} :………………...Designed Characteristic Compressive strength of burnt clay bricks

N_{Rd} ………………………………Design value of vertical resistance of a masonry wall

MoW&T ………………………………………………Ministry of Works and Transport

UBOS…………………………………………………….Uganda Bureau of Statistics

UTM ……………………………………………………...Universal Testing Machine

δ ………………………………………………………………………….Shape factor

Abstract

Following the tremendous increase in population growth rate in Uganda from 12.6 million people in 1980 to 34.6 million people in 2014, there has been an increase in housing units from 2.6 million house in 1980 to 7.34 million houses in 2014. Despite of this increase in housing units, the population has surpassed the demand leading to a deficit of 200, 000 housing units annually. The National Housing and population census of 2014 revealed that the increased housing units is constructed of permanent materials at 43.7% with burnt clay bricks leading at 36.4% followed by mud and poles at 33.6% and these are materials used without the knowledge of their strength and properties. Hence, the need to assess its strength so as to protect the inhabitants against accidents and loss of lives. Research findings indicated that 100% of the structural design firms do not design masonry structures made of burnt clay bricks but instead specify them as infills. 100% survey on 102 sites established that the commonly used mortar mix ratios range between 1:7 to 1:14 far different from the perceived mortar mix ratios of 1:3 to 1:6 as a result of the use of one bag of cement to a number of wheelbarrows and these resulted into a compressive strength of 5.92N/mm^2 to 1.87N/mm^2 respectively far below the intended compressive strength of 17.8N/mm^2 to 6.82N/mm^2. Experimental tests on burnt clay bricks has established varying compressive strength with an average of 7.3N/mm^2 to 2.06N/mm^2 and this was attributed to water absorption, method of manufacture and the soil type. Results on burnt clay masonry walls constructed of most used mortar mix ratios established that , the compressive strength of the wall greatly reduced with increasing value of mortar mix ratios. Conclusively, the wall strength was much influenced by the strength of mortar, indicating that the weaker the strength of mortar the weaker the wall strength and vice versa however strong the brick may be, hence high mix ratios beyond 1:6 should not be used in the construction of masonry clay brick walls to avoid structural failures.

KEY WORDS : **Mortar mixes, Burnt clay Brick strength and Masonry Wall strength**

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Globally, burnt clay bricks is the most used construction material with China leading the production sector at 67% of the total world's production, followed by the three regions of SAR, (Bangledish, Nepal and India) at 21% and the rest of the world at 12%. (Eil Andrew et al.,2020). Globally, the use of cement - sand mortar as a binding material has greatly increased, this is evidenced from the rise in the production and consumption of cement from 3.3 Billion tones in 2010 to around 4.2 Billion tones in 2015 and the forecast shows that this will be 5.9 Billion tones in 2025. This represents a forward expansion of 78% in 2025, (Magazine Article, 2011). And because of this trend of growth in the use of these materials, there has been a tremendous increase in the development of housing units in Uganda from 2.6 million houses in 1980 to 7.34 million houses in 2014 with 75% of the housing units in rural areas and 29% of the houses in urban areas as evidenced in Uganda Bureau of Statistic report, 2014.

This is attributed to the tremendous increase in Uganda's population growth rate from 1.2% in 1980 to 3% in 2014 leading to a population of 34.6 million people in 2014 from 12.6 million people in 1980, (UBOS, 2014, pp.41). The population forecast showed an increase in population to 47 million people in 2025 and 63 million people in 2040 indicating an increase in demand of housing units to cater for the increased population, (UBOS,2014, pp.41). The estimated annual housing demand is 200,000 units per year.

The 2014 housing and population census showed that houses with permanent walling materials constituted 43.7%. It further showed that burnt clay brick walls were the most used walling material at 36.4% followed by mud and poles at 33.6%. The different walling materials are as shown in Table 1.1.

Table 1. 1: Distribution of Household Walling Materials, (Source: Table 6.4 UBOS, 2014)

Walling materials				
Permanent materials	**Percentage contribution**	**Temporary materials**	**Percentage contribution**	**Total**
i. Burnt /stabilized bricks ii. Cement blocks iii. Concrete/stone	36.4 5.3 2.0	i. Mud and pole ii. Unburnt bricks with cement iii. Unburnt bricks with mud iv. Wood v. Tin/iron sheets vi. Others	33.6 2.6 17.2 1.4 0.3 1.2	
	43.7		**56.3**	**100**

Masonry structures are made out of assemblage of masonry units (bricks and blocks) either interlocking or joined together with mortar. The strength of masonry structures depends on the materials used like burnt clay bricks, type of mortar used and the workmanship employed. Masonry structures are made of heterogeneous composite materials like bricks, compressed earth, stones and concrete blocks, held together by mortar. Masonry structures vary from one structure to the other depending on the type of brick units and mortar used. Strength of a masonry structure depends upon the properties and composition of the constituents. According to (Mosalam et al., 2009, pp.8) the interface between mortar and masonry units is the weakest link in the system.

1.2 Problem statement

The need for more housing units to cater for increased population, mostly used construction materials like masonry clay bricks at 36.4% followed by mud and poles at 33.6% are used with out the knowledge of their properties. The strength of masonry structures depends on the type and strength of masonry unit (brick or blocks) and the strength of mortar yet there is no published data concerning these. But from National population and housing census of 2014, 58.1% of the houses in urban areas and 29.4% of the house in rural areas are made of burnt clay bricks. Hence, the need to establish the strength of burnt clay brick wall and derive a relationship that relates it to the varying strength of mortar and bricks, so as to inform the design of masonry walls and also protect the population against accidents and loss of lives due to structural failures of masonry structures..

1.3 Objectives of the research

1.3.1 Main objective

To assess the effect of different mortar mixes on the strength of burnt clay brick masonry wall so as to derive a relationship between the strength of burnt clay brick wall and the varying strength of bricks and mortar

1.3.2 Specific objectives

i. To assess the mortar mix ratios used on construction sites around Kampala;

ii. To assess the mortar strength corresponding to mortar mix ratios commonly used around Kampala;

iii. To assess the strength of bricks used on sites around Kampala;

iv. To assess the strength of the wall in relation to mix ratios, brick strength and mortar strength.

1.4 Research questions

i. What are the mortar mix ratios used on the construction sites around Kampala?

ii. What is the compressive strength of mortar corresponding to the mortar mix ratios used on construction sites?

iii. What is the strength of bricks used on construction sites around Kampala?

iv. What is the relationship of the strength of the wall to the strength of bricks and mortar?

1.5 Justification of the research

Need to provide safe housing units for increased urban population and these should be constructed of materials of known strength to avoid structural failures which can lead to accidents and loss of lives.

1.6 Significance of the research

Establishment of the strength of burnt clay bricks, strength of mortar and the relationship with burnt clay wall strength will help to inform the design. Consequently Engineers will make use of the strength of these important structural materials in design.

1.7 Scope of the study

The scope of the study was considered in terms of content, time and Geographical scope.

1.7.1 Content Scope

This involved the following;

i. Determination of masonry brick strength;

ii. Determination of Mortar strength as per the ratios commonly used;

iii. Determination of Strength of the masonry wall;

iv. Sieve analysis of the fine and coarse sand;

v. Determination of Water absorption capacity of the bricks;

vi. Discussion of test results and derivation of the relationship between wall strength and the varying strength of bricks and mortar.

1.7.2 Geographical scope

The investigation was carried out in Kampala metropolitan area to assess the strength of the housing units due to increased construction of housing units made of masonry clay bricks.

1.7.3 Time Scope

The time was 12 months, from September 2018 to August 2019

1.8 Conceptual frame work

In this research experiment, burnt clay bricks and sand media are dependent variables while ordinary Portland cement of strength 32.5 is an independent variable. Hence, there will be variations in the strength of burnt clay bricks and the quantity of sand media used in the construction of masonry walls while the quantity of ordinary port land cement will remain the constant.

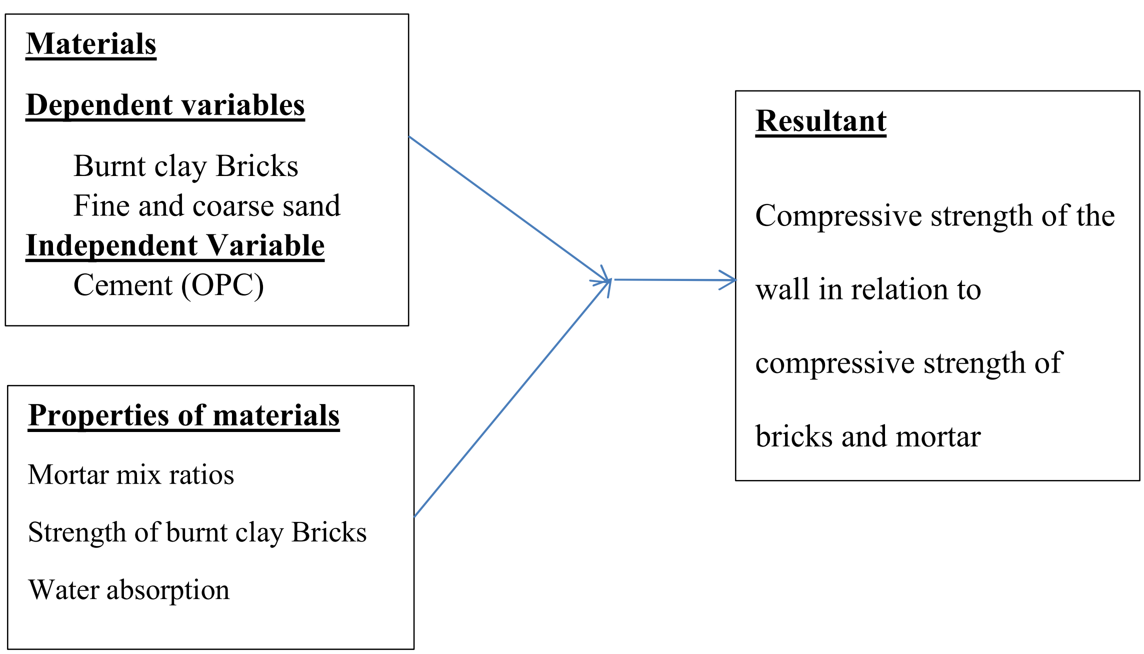

Figure 1. 1: Conceptual frame work of the study

1.9 Summary : Chapter one

In summary, assessing the effect of mortar mixes on the strength of masonry clay brick wall, focus was put on the leading construction materials used in the construction of masonry walls in the world. Research revealed that burnt clay bricks and cement sand mortar are the leading construction materials in the world with China leading at 67% followed by the three regions of SAR (Bangledish, Napal and India). In Uganda, the usage of burnt clay bricks is at 36.4% followed by mud and poles at 33.6%.

In assessing the effect of these materials on masonry walls, the following objectives were listed and followed, among which included assessing the mix ratios commonly used on sites around Kampala metropolitan area, the strength resulting from the commonly used mix ratios, the physical properties of burnt clay bricks used and its resulting strength and the strength of masonry walls built of the commonly used mortar mix ratios in relation to bricks used. These have been used to develop the conceptual framework as guide in assessing its contribution in the construction of masonry walls.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter covers literature review on the materials used in the construction of masonry structures like, the mortar used and masonry units (bricks/blocks. Masonry structures are made out of assemblage of masonry units (blocks/bricks) either interlocking or joined together with mortar. The strength of masonry structures depends on the properties of masonry units, type of mortar used and the workmanship employed.

2.2 Mortar

2.2.1 Introduction to mortar

Mortar is a mixture of cement and sand, cement: lime: sand and water to form a uniform heterogeneous composite material. Ordinary Portland cement is the most used cement on construction sites. The purpose of cement in this mix of cement-lime - sand mortar is to unite coarse grained sand particles together. The use of lime in this mix is to make work easier off the mason's trowel. Setting and hardening of Portland cement is caused due to hydration process. The capacity of the cementitious material is to seal off voids making ordinary Portland cement a good binding material hence its use in construction of masonry units like block/brick walls, (Deichler,C, 1936, pp.2-19).

Mortar is a heterogeneous composite material made of a combination of cement and coarse grained sand, cement and fine grained sand, and a mixture of the two. When these ingredients are mixed together, they form a uniform paste that is easily molded into any shape. The use of cement as a binder has greatly increased from 1.37 billion tons in 1994 to 3.7 billion tons in 2012. Its ability to be used in different forms has made it a special binding material in construction. Zainab, (2017, pp.7-12) studied the effect of partial replacement of sand with waste pistachio shells in cement mortar. Her results indicated that the compressive strength of cement mortar decreased with an increment in the level of pistachio shells and this increases with age. The density of cement: sand mortar decreased with an increase in pistachio shells due to low density of pistachio. In conclusion, replacement of sand with pistachio affected the strength of cement: sand mortar.

Cement-Sand mortar is a cementitious material made of cement and sand mixed with palatable water to attain a required workability to bind together masonry units (block/bricks) into a single integral unit. Sumanth (2015, pp.3-5) used six alternative materials such as granulated blast slag sand, Quarry dust, Granite Powder, Cement - lime soil paste as a total replacement of sand in the process of making mortar. Test results revealed that the use of granite powder and granulated blast furnace slag sand indicated a relatively low compressive strength and this would be easily adapted for use in buildings of low compressive strength.

Among the advantages of cement - sand mortar is that, it is flexible, easy to work with and easy to repair. The evaluation of the mechanical properties of mortar by (Marcos Venicus et.al., 2014) involved addition of natural sisal fibre in the mix of Cement -

sand mortar. Results indicated that normal plain mortar (cement - sand mortar) suffered unstable mode of failure unlike the fibre reinforced mortar. Tests of compressive strength on fibre - reinforced mortar indicated an increase in strength compared to plain mortar.

Investigation on the flexural strength of mortar by (Bonavetti et al.,1994, pp.580-590) indicated that partial replacement of sand with stone dust, Quartz and granite had varying results at 0 and 20% replacement at different ages. The partial replacement of sand with stone dust showed an improvement in the flexural strength of mortar than addition of granite and Quartz. Plain mortar was considered in the experimental research.

Masonry mortar should be classified by their compressive strength, expressed as M followed by the compressive strength in N/mm^{2}. For example, M5 should denote a mix ratio (1:1:5), that cement: Lime: Sand by volume and mortar should be applied as per group purpose and type of mortar, Table 3.3, (EN 1996.1.1.2005, pp.15)

Evaluation of the effect of mix design ratios on the compressive strength of cement - sand mortar ratios by (Eskandari, 2017, pp.396) revealed that the strength of mortar increased with age and depends on the class of cement. The purpose of his research was to determine the strength of wide range of mix designs parameters and this was to evaluate the strength growth depending on age. Findings revealed that strength increased with age between 3 - 7days and 21- 28days. He also evaluated the Cement – Water ratio mix design and concluded that strength depends on the class of cement with a low water content. There was no emphasis put on mix proportions of sand and its influence on the strength of a masonry structure. Technical notes on brick construction 394, (2006) emphasizes that, in testing the strength of masonry structures, proper workmanship must be ensured.

Vermeltfoort (2012,) carried out several tests in investigating the relationship between mortar compressive strength by varying the mortar properties. This was done by addition of more sand to establish a variation in strength of mortar. Results revealed that shear strength of mortar increased with increase in sand to cement ratios while compressive strength reduced. The modulus of rupture and compressive strength decreased with a reduction in amount of cement in mortar. But in this type of research the amount of cement was maintained constant with an increament in the quantity of sand.

2.3 Bricks

2.3.1 Introduction to bricks

A brick is a building material composed of shaped clay, sand and lime or concrete material. It is used to make walls, pavements and other elements in a masonry structure. Burnt Clay bricks are the most durable, cheap, easy to work with and readily available.

Masonry structures are made out of assemblage of masonry units (bricks and blocks) either interlocking or joined together with mortar. The strength of masonry structures depend on the materials used like burnt clay bricks, type of mortar used and the workmanship employed. Mortar is made of different materials like cement- lime, Cement - sand and clay. Classification of bricks was found in Indian Standard. This was considered nearer to the 3rd world countries like Uganda, (IS 1077:1992, pp.1-3)

Table 2. 1: The classification of burnt clay bricks, Source; (Table A.1: IS 1077:1992)

Class designation	Average compressive strength, N/mm^2
35	35
30	30
25	25
20	20
17.5	17.5
15	15
10	10
7.5	7.5
5	5
3.5	3.5

Compressive strength of any individual bricks shall not be less than the minimum compressive strength for the corresponding class of bricks, (IS 1077:1992, pp.3-17)

Khwairakpam,S et.al.,(2017, pp.365) investigated the characteristic strength of machine made bricks, this was based on physical and mechanical properties like abrasion, efflorescence and compressive strength and this was done under controlled conditions. Tests revealed that the compressive strength of the handmade bricks was found to be higher and this is complementary to the compressive strength of masonry structures since results of masonry bricks would contribute highly to the strength of masonry walls. Basing on that conclusion, there was need to assess the strength of masonry walls basing on locally made bricks and the different mortar ratios used on construction sites

Analysis of the production of ancient clay bricks and its properties by (Fernandes, M.F, 2009, pp.7) found out that ordinary clay bricks were difficult to characterize due to the wide diversity of raw materials and the manufacturing process. Tests on water absorption also revealed a varying trend and this greatly affected the strength of burnt clay bricks. These varied in properties where porosity was found to be between (10-40 %), water absorption of (10-20%), hence a scattering compressive strength ranging between 1.5- 30 MPa. With this variation in properties. It is thus important to assess the strength of burnt clay bricks around Kampala.

The investigation on the effect of bond strength and compressive strength of ordinary bricks and standard bricks by (Konthesingha.C, 1985, pp.12) found out that standard bricks gave a higher tensile and shear strength compared to ordinary bricks and hence good bondage is evidenced with use of standard bricks "engineered bricks,'' He also considered the use of three different sand types and their gradation revealed results conforms to standard of BS 812; 1985, however, ordinary bricks vary in properties like manufacturing process and drying procedures, hence the need to assess the performance of burnt clay bricks with varying mortar ratios.

2.4 Masonry wall

2.4.1 Introduction to masonry wall

Masonry wall is an assemblage of masonry units (block/bricks) either interlocking or joined together using mortar. This serves the purpose of shielding inhabitants from lateral loads like wind and effects of rainfall. Masonry structures are made of heterogeneous composite materials like bricks, compressed earth, stones and concrete blocks, held together by mortar. Masonry structures vary from one structure to the other depending on the type of brick units and mortar used. Strength of a masonry structure depend upon the properties and composition of the constituents. According to (Mosalam et.al., 2009, pp.8) the interface between mortar and masonry units is the weakest link in the system.

Masonry wall is controlled by the properties of masonry units, mortar as well as bond between them. (Sarangapani et.al., 2002) compared the characterization and properties of low modulus bricks, table molded bricks, where burnt bricks, mortar and masonry constructed of cement: soil mortar in the ratio of (1 : 6 : 9). Test results indicated a ductile behaviour during compression test and crack development was evidenced between the bricks and the joints but cement - sand mortar was used as a binder in this research.

During the assessment of the crack pattern and compressive strength of masonry prisms constructed of cement mortar, (Nassif, N et.al., 2018, pp.23-38) considered burnt clay bricks and findings revealed that strength of masonry prisms increased with an increase in mortar strength and this was based on brick mortar interface strength hence debonding of mortar brick interface would gradually affect the load transfer through a masonry prism. In this experiment specified mortar ratios were without consideration of the field variations caused as a result of use of different batching equipment, hence the need to assess the effect and strength developed by the variation of mortar strength and the strength of the wall panel as a result of variation of mortar ratios in disguise of standard specified mortar ratios.

The bond between burnt clay bricks and mortar attained is the most important property of a masonry wall. So one to design a masonry structure, knowledge on brick strength and mortar used should be determined and this depends on the selection of mortar for construction of masonry walls. Technical notes on brick construction (2006) revealed that exposure conditions for mortar under which temperatures in the range of 40^0 C was highly applicable for mortar bondage, however, this also depended entirely on specified mortar ratios without considerations of variations on site.

The strength of the masonry wall depends on the thickness of the bed joint, the height to thickness ratio as well as the mortar strength, (Nassif, 2018, pp.23-38). This was assessed by use of different materials and the method used in the production of the bricks. Materials like clay, pressed/stabilized earth bricks, concrete blocks, calcium silicates, stone blocks, perforated blocks and soft mud bricks were used in this experiment. Tests revealed that the compressive strength of masonry unit and mortar is accounted to the volume fractions of masonry units and height to thickness ratio. Results revealed that machine made bricks were much weaker compared to locally burnt clay bricks and the mortar used. According to him, cement used in India is much stiffer than the bricks used this is contrary to findings made by (Khwairakpam Sachidananda, 2017, pp.365) proving variations in strength of even machine made bricks. Hence,the need to assess the performance of locally burnt clay bricks with varying mortar ratios

The compressive strength of a masonry wall depends entirely on the strength of the brick, stronger burnt clay bricks have resulted into higher compressive strength and soft burnt clay bricks revealed low compressive strength as per (Kheiwairakpm et.al., 2009) however there was no consideration of the bond strength between mortar and bricks but masonry wall are constructed of the two materials, hence, the need for the need to establish the strength of the bricks and mortar.

Sawk (1984) presented an analytical approach for the assessment of axial and bending strength of masonry walls by considering parabolic variation of stress-strain curves for masonry in compression based on past experimental studies. The parabolic variation was proposed to continue in the descending part until 1.5 times the peak strain corresponding to prism strength is attained, however, the authors did not suggest any method of estimating the peak strain as well as the effects of different mortar ratios on masonry walls. This research will entirely depend on the experimental data collected.

Masonry structures are made of clay/concrete units joined together using a binding material like cement: sand mortar. (Emeritus, 2001, pp.328-330) reviewed different types of masonry walls among which included those constructed of burnt clay bricks, concrete blocks and calcium silicate bricks. Clay made masonry walls revealed strength of 100 N/mm^2 for commercial buildings and between 20 - 40N/mm^2 for domestic buildings while strength of concrete made masonry varied between 2.8 - 35N/mm^2. Masonry units contribute highly to the resistance of masonry structures under stress but this is not specified anywhere on the drawings with exception of partitioning walls where a breaking strength of 0.05N/mm^2 is required. Hence, the need to investigate whether design firm in Uganda specify wall strength based on locally available clay bricks.

Brick masonry walls revealed varying behavior in its properties when tested in dry and wet condition. The results of the constructed wall also revealed a variation in the strength attained for compressive strength of mortars cubes and cylinders. The young's modulus and stress - strain values of the bricks were found to be varying in relation to the strength of mortar, (Thanikasapradeed et.al., 2014, pp.590). The research was recommended for further study using finite element methods modeling. However, no emphasis was shown on the field derived mortar ratios and their effect on the strength of a masonry walls, hence the need to assess the impact of field derived mortar ratios on strength of a masonry wall.

Mohad et.al.,(2012) investigated the failure mode of walls made of blocks (concrete blocks). It was found out that the vertical component of mortar joints contributed greatly to the failure pattern of the masonry structure. At crushing of the wall vertical/perpendicular mortar joint component was observed to be the possible cause of failure and the friction between the interface of blocks and mortar results into wall failure of the masonry wall. In this research, emphasis has been put of masonry walls constructed of burnt clay bricks and assessment of its performance with varying mortar ratios.

Previous researchers have done numerous investigations on mortar used for construction, this was either done through portion replacement of the sand or total replacement of sand. Addition of other materials like steel filings, stone dust, granulated blast slag sand among others. This resulted into either positive or negative results towards compressive strength of mortar. In this research, emphasis has been put on variation of the volume of sand by maintaining a constant volume of cement.

Masonry walls are constructed of clay bricks, mud, stones and concrete blocks either interlocking of joined together using mortar. In this research study, emphasis has been put on use burnt clay bricks bound together using cement - sand mortar of varying strength and experiments have been carried out to determine the effect of these varying mortar ratios on the strength of brick walls.

2.5 Summary : Chapter two

In this chapter, focus was put on the materials used in the construction of masonry walls and the resultant behaviour of these materials, among which included ; mortar, bricks and masonry walls. Different literature has been used in developing the methodology used in this research. This involved researchers identifying different properties governing the strength of masonry walls among which included, the purpose of cement sand mortar as a binding material by (Zainab, 2017, pp.7-12), compressive strength of alternative materials used in the production of mortar by (Sumanth, 2015, pp.3-5), fluxeral strength of mortar by (Bonavetti et al.,1994, pp.580-590), effect of mix ratio design by (Hamid,E 2017).

Different researchers also presented the physical properties of burnt clay bricks that determine its strength in the construction of masonry walls as classification of burnt clay bricks according to compressive strength by (IS 1077:1992, pp.1-17), characteristic strength of machine made bricks by (Khwairakpam,S et al., 2017, pp.365), diversity in raw materials used in the production of masonry bricks by (Fernandes, F.M, 2009, pp.7) and bond effect of burnt clay bricks by (Konthesingha,C 1985, pp.12).

A masonry wall is an assemblage of of masonry units either interlocking or joined together by mortar to achieve its strength, different researchers have identified the different properties of masonry walls that affect its strength among which included the strength and composition of its constituents, (Mosalam et al., 2009, pp.8), compressive strength of masonry walls depend on the strength of its properties like the bricks and mortar by (Sarangapani et al., 2009), the crack partner through the bricks and mortar joints by (Nassif et al., 2018, pp.23-38), the failure mode of masonry structures dependant on vertical component of mortar joints and the thickness of the bed joint to the height of the wall by (Khwairakpam,S 2017, pp.365). Hence, this literature from previous researchers on mortar, bricks and masonry walls has been used in developing the methodology that has been used in this research by analyzing the properties of the materials used in the construction of masonry walls and the use of cement sand mortar as the main binder in the construction of masonry walls.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter covers the research methods that were used in this study. The research design used involved mixed methods which included qualitative, quantitative, and experimental methods. The research involved survey of the consultants, construction sites, collection of materials (bricks and sand), from sites, making and testing of mortar cubes and walling units.

3.2 Data Collection

3.2.1 Data from consultants

The construction Directory 2019, was used to obtain a list of consultants involved in masonry design (structural engineers). The total number of firms identified from the directory was 24. Since the number was small, the total population (24) was also the target population and sampling was not necessary. A questionnaire given in Appendix 2 was developed and distributed to all of them. 100% of those given returned answers. The aim of the survey was to find if consultants designed masonry structures, the methods used, the brick strength specified, the mortar mixes specified and the batch practices employed in projects supervised.

3.2.2 Data on materials used

The major roads leading to Kampala city were chosen purposively as random representative of the construction sites and these included Jinja road, Entebbe road, Masaka road, Mityana road, Bombo road and Gayaza road. The roads were followed for a distance of 10km and 102 sites along the roads were identified then 35 sites were selected randomly from a population of 102 sites as representative samples. Data and materials were then obtained from selected sites.

Interview guides were used to collect data on different mortar ratios and batch methods used on construction sites around Kampala. Six samples of bricks out of the fifteen bricks that were collected from the representative site randomly were taken and a total of two hundred ten brick (210) were used in the experiments as representative samples for the bricks from each road.

3.2.3 Secondary data collection

The secondary data was collected from different information sources including, text books and published journals on related topics.

3.3 Materials tested

In this research investigation, the following materials were tested in the assessment of the effect of different mortar ratios on the strength of burnt clay masonry walls

- Fine grained sand;
- Course grained sand;

- Mortar cubes;
- Burnt clay bricks and;
- Brick wall 1m long x 1m high x 200mm wide.

3.3.1 Burnt Clay bricks

Burnt clay bricks were sourced from 35 sites along the major roads entering Kampala Capital City. The sourced bricks per road are given in Table 3.1.

Table 3. 1: Samples of burnt clay bricks

Major roads	Number of sites identified	Sites selected by random sampling	Number of bricks per selected site	Average dimensions	Total number of bricks sourced
Entebbe road bricks	15	5	6	200 x 100 x 100	30
Masaka road bricks	15	5	6	219 x 134 x 85	30
Mityana road bricks	15	5	6	210 x 110 x 100	30
Hoima road bricks	14	5	6	208 x 110 x 100	30
Bombo road bricks	14	5	6	210 x 110 x 100	30
Gayaza road bricks	14	5	6	215 x 117 x 100	30
Jinja road bricks	15	5	6	200 x 100 x 100	30
Total	**102**	**35**			**210**

3.3.2 Sand media

The sand media from Rwera and Katosi mining sites were used in this research experiment since it was the most used sand on sites as revealed from the survey of 102 sites.

3.3 Water used in this research

Portable water was used in this research. This was used in the making of mortar cubes and in soaking of burnt clay bricks.

3.4 Tests conducted

The following tests were carried out to ascertain the quality of the materials that were used in the construction of burnt clay brick masonry walls.

- Sieve analysis test on the sand samples;
- Specific gravity and bulk density of the sand samples;
- Water absorption on bricks;
- Compressive strength of the mortar cubes;
- Compressive strength of burnt clay bricks;
- Compressive strength of the masonry wall structures.

3.4.1 Sieve analysis

3.4.2 Test procedure;

i. A representative oven-dried sample that weighs approximately 1000g was taken from the sample of the sand media collected.

ii. Particles were lumped to remove the lumps using the pestle

iii. The mass of sample was accurately measured accurately – Weight (g).

iv. A stack of test sieves was prepared. The sieves were stacked in order with the largest aperture size at the top and the smallest at the bottom. A receiver was placed under all of the sieves to collect samples.

v. All sieves and the pan were weighed separately.

vi. Poured the samples into the top of the stack of sieves with the lid on and shook the stack manually for 10 to 15 minutes

vii. Stopped the process and measured the mass on each sieve retained.

viii. Results were tabled and starting sample weight recorded and compared with the finished total sample weight retained on the sieves after the experiment.

ix. The results were plotted on sieve analysis curves and the grading of the sand samples obtained.

3.4.2 Specific gravity on oven dried samples

The sand samples were oven dried and measured quantities were soaked in water for saturation to remove air voids. The existence of the air bubbles would give inappropriate results. Bulk specific gravity and apparent specific gravity were determined as per AASHTO designated laboratory manual 2002. Using excel sheets and the formulas in Annexes 29 to 30 specific gravity of the sand media was obtained.

a) Water absorption = A-G ………. (Equation 3.1)

Where A – weighted saturated surface dried sand samples

G – dry weight of sample (Oven dried)

b) Percentage water absorption, = $\frac{A-G}{G} x100\%$ ……..…..(Equation 3.2)

All the samples were evaluated from equation (3.2)

c) Bulk dry specific gravity, = $\frac{G}{(A-D)}$ ………(Equation 3.3)

Where, D – weight of immersed materials

d) Apparent specific gravity, = $\frac{G}{(G-E)}$ ………..(Equation 3.4)

E - weight of bottle plus weight of oven dry sample

3.4.3 Water absorption test

One hundred five bricks (105) burnt clay brick samples selected from construction sites along the major roads connecting to Kampala metropolitan were used for water absorption test. Their dimensions were measured, weights at Oven dry temperature were taken and then they were soaked in a bucket full of portable water at room temperature for 24 hours. Bricks were removed and their saturated weights taken and recorded in tables as per the roads selected. The percentage water absorption calculated is given in Annex (1-7).

e) Weight of the dry sample – M_D

f) Weight of saturated sample – M_S

Percentage water absorption = $\frac{Ms - M_D}{M_D} x100\%$ …….. (Equation 3.5)

3.4.5 Testing for compressive strength of mortar cubes, bricks and masonry wall

a) Compression test on mortar cubes

A set of 30 mortar cubes were made and cured for 28 days, this included 10 cubes made of a mixture of cement and fine grained sand only, 10 mortar cubes of cement and coarse grained sand only and 10 were cement : fine grained sand : coarse grained sand using mortar ratios of 1:3 to 1:12. These were tested after 28 days of curing and their results recorded in Annex 32.

b) Thirty six (36) mortar cubes were cast using mix ratios 1:3, 1:4, 1:5, 1:6, 1:7, 1:8, 1:9, 1:10, 1:11, 1:12, 1:13 and 1:14 as given in Annexes 15. These cubes were made per mortar mix ratio and demolded after 3 days and then soaked in water for twenty eight (28) days to attain maximum compressive strength under proper curing conditions. They were then wiped clean and prepared for a compression test. The crushing load at failure was recorded. The compressive strength of mortar for all the different mortar mixes was calculated. A graph of the compressive strength against mortar ratios was drawn and results are presented in chapter four

Figure 3. 1: Compression testing of bricks and mortar

c) Compression test on burnt clay bricks

105 burnt clay bricks were selected from 35 different sites on the major roads in Kampala metropolitan area. Their weights were taken, dimensions measured and recorded in the Tables. The samples were then tested in the compression machine. The compressive strength was determined from equation (3.7)

$$\text{Compressive strength} = \frac{Maximum\ .load\ .at\ .failure}{Contact\ .area} \quad \text{………… (Equation 3.7)}$$

d) Testing for compressive strength of masonry walls (1000mm x 200mm x 1000mm)

Twelve (12) wall structures measuring 1m long x 0.2m wide x 1m high were constructed using mortar ratios 1:7, 1:10, 1:12, and 1:14. These mix ratios were used because from the field survey, they were the most commonly used on sites.The wall units were left to set for 28 days. They were then tested for compressive strength using a steel loading machine at Kireka Central Materials Laboratory.

3.9 Experimental set up and operations of steel loading machine for the wall panel

The wall unit was carefully placed on the compression pads of the Steel Loading machine. The wall unit was kept at the Centre of cross-head so that a uniform compressive loading can be assured on the wall unit as seen from figure 3.2. The loads were increased automatically till failure of the brick wall unit. The steel loading machine stopped as soon as the wall unit failed.

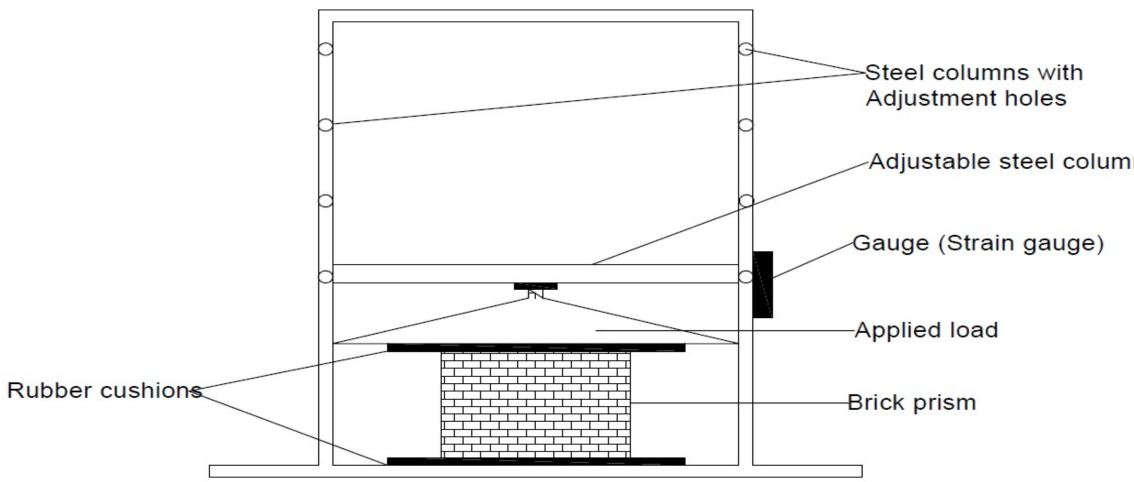

Figure 3. 2: Steel loading frame at central material's laboratory Kireka

3.10 Determination of masonry wall strength

According to EN BS 1996-1-1:2005, the characteristic compressive strength of a wall is calculated using equation (3.2) reproduced below as (3.8)

$$f_k = Kf_b^{0.7} f_m^{0.3}$$ ………………… (Equation 3.8)

Where;

f_k is the characteristic compressive strength of masonry wall in N/mm^2

K is a constant based on the group number and type of mortar,

Table 3.3, EN 1996:-1-1,2005

f_b is normalized mean compressive strength of the masonry units used.

f_m is the compressive strength of mortar in N/mm^2

The normalized mean compressive strength is given by

f_b = [conditioning factor] x [Shape factor] x [Declared mean compressive strength] .... (Equation 3.9)

Declared mean compressive strength was obtained from experimental data

3.11 Determination of the relationship between burnt clay bricks and strength of masonry wall

Twelve (12) masonry wall structures were constructed of cement - sand mortar in varying mortar ratios of 1:7, 1:10, 1:12 and 1:14. Three (3) brick samples were picked from each masonry wall structure constructed and tested for compressive strength of each individual sample. The average strength of bricks was obtained and used to assess the relationship between wall strength and bricks used. The results are presented in chapter four table 4.7.

3.12 Reliability of the test machines

Before final tests were conducted, trial tests were carried out from three laboratories namely; Kireka materials laboratory, Kyambogo university mechanical workshop and Uganda National Roads Authority Laboratory. Results from Kireka materials laboratory and UNRA laboratory revealed consistency in results while Kyambogo laboratory had varying results as shown in Table (5.24). Hence, UNRA laboratory was selected for use in the testing of the final samples for both bricks and mortar cubes.

3.13 Summary : Chapter three

Several methods that were used in this research have been enlisted among which include, research design that involved both qualitative and quantitative methods. Survey on structural design firms, construction sites was also done in investigating the design of masonry walls, materials used on sites among which included bricks, sand and type of cement used in construction. Analysis from the survey of sites revealed the most used coarse sand from the 102 sites and a decision was made basing on this survey to use the same sand media in this research study. Data collection was also done and this involved collecting data from structural design firms, materials collected from that sites included five brick samples from the 102 sites visited, thirty five sites were selected randomly from the 102 visited and six bricks were random picked from the thirty five sites selected, dimension measurements were taken and recorded in tables.

Experiments were conducted to deduce the qualities and strength of these materials. Sieve analysis tests were conducted on the sand media that was collected to ascertain the degree of particle size distribution, specific gravity and its bulk density, thirty six mortar cubes were cast from the most used mortar mix ratios in the field, cure in the bucket full of water for twenty eight days and there later tested for compressive strength.

Water absorption tests were conducted on the selected bricks this was followed by compressive test on randomly selected bricks from the thirty five sites, variability test was also done to ascertain the degree of deviation in compressive strength of these bricks to guide the selective decision of the bricks to be used in the construction of the wall units. Hoima bricks were selected after the variability test to be used in the construction of the twelve wall units using the mostly used mortar ratios in the field. These were cured for twenty eight days at room temperature and thereafter they were test for compressive strength using a steel loading machine at Kireka material's laboratory and results record and discussed as in chapter four.

CHAPTER FOUR

FINDINGS AND DISCUSSION

4.1 Introduction

This chapter covers data presentation, analysis and discussion of results of tests. The materials included bricks from the different sites along road joining Kampala city, sand media used and the different mortar cubes made from different mortar mixes. It also includes data from consultants regarding design of masonry structures, methods used, brick strength and mixes specified. It gives mixes used on 102 sites in Kampala metropolitan and the batch methods employed. It further gives test results on wall units built with local burnt clay bricks and the most commonly used mortar mixes.

4.2 Results from the survey of the consultants

A survey of the 24 consultants revealed that;

i. 100% of the 24 consultants do not design masonry walls constructed of burnt clay bricks instead specify them as infills. Consequently the consultants could not provide information on design methods, brick strength, mortar mixes or batch practices. Engineering is about utilizing materials to their potential to resist the applied loads. Burnt clay bricks are used as infill walls, thus contributing to the load with out being exploited to take part of the load bearing, not even their self-weight. This research provide information for design engineers to begin designing walls made from burnt clay bricks.

4.3 Mortar mixes

Table 4. 1: Mortar mixes used on 102 sites visited

Mortar Ratios (Bag:Wheelbarrows)	**Number of sites**	**Percentage**
1:4	47	46
1:5	32	31
1:6	16	16
1:3	6	6
1:2	1	1
	102	**100**

Table 4.1, shows that 46% of the sampled sites used one bag of cement of 50Kg to four wheel barrows full of sand,(1:4), 31% of the sites uses one bag of cement of 50Kg to five wheelbarrows full of sand, (1:5), 16% uses one bag of cement of 50Kg to six wheel barrows full of sand, (1:6), 6% uses one bag of cement to three wheel arrows full of sand, (1:3) and 1% uses one bag of cement to two wheelbarrows full of sand, (1:2).

ii. Of the 102 sites surveyed, it was found that 76 sites used mortar mix proportions dictated by the site engineer while 24 sites revealed that this is dictated by the client.

iii. All the 102 sites revealed that they use cement: sand for mortar. The mortar ratios used on the 102 sites are given in Table 4.1 above.

iv. The batching methods used on all 102 sites was number of cement bags to number of full wheelbarrows of sand.

v. The volume of a 50Kg bag of sand was found to be $0.036m^3$. And the average volume of different wheelbarrows used on 102 sites was $0.089m^3$ when filled to the top of the wheelbarrow bucket as shown in Figure 4.1.

vi. The level to which a wheel barrow is filled depended on the whims of workforce or the supervisors. There was no site where guidelines on the level of filling the wheel barrow was found. All sites revealed that the sand was heaped above the top of the wheel barrow bowel as shown in Figure 4.1.

vii. The mix proportions used in the field are not appropriate to the strength intended since a wheel barrow of sand media is 2.47 times the volume of a cement bag.

viii. One bag of cement to three wheel barrows of sand is not actually 1:3 as the site engineers assessment but it is 1:7.42 , therefore tests conducted in this work used the commonly used corrected field mix proportion.

ix. 59% of the sites indicated that they mix fine sand and coarse sand to make the sand media in the mortar, 32% of the sites use only coarse sand and 7% use only fine sand. Because 59% of the 102 sites use a combination of fine and coarse sand, the experiments were designed to use the same.

x. Results of compressive strength of trial tests on individual mortar obtained from a mix of a single type of sand revealed that compressive strength of obtained from single sand type mixed with cement varied much with no consistency while results of the mix of the two sand type mixed with cement indicated consistency in the results as shown in Figure: 4.2

Figure 4. 1: Wheel barrow full of sand and wheelbarrow of cement (50 kg bag cement)

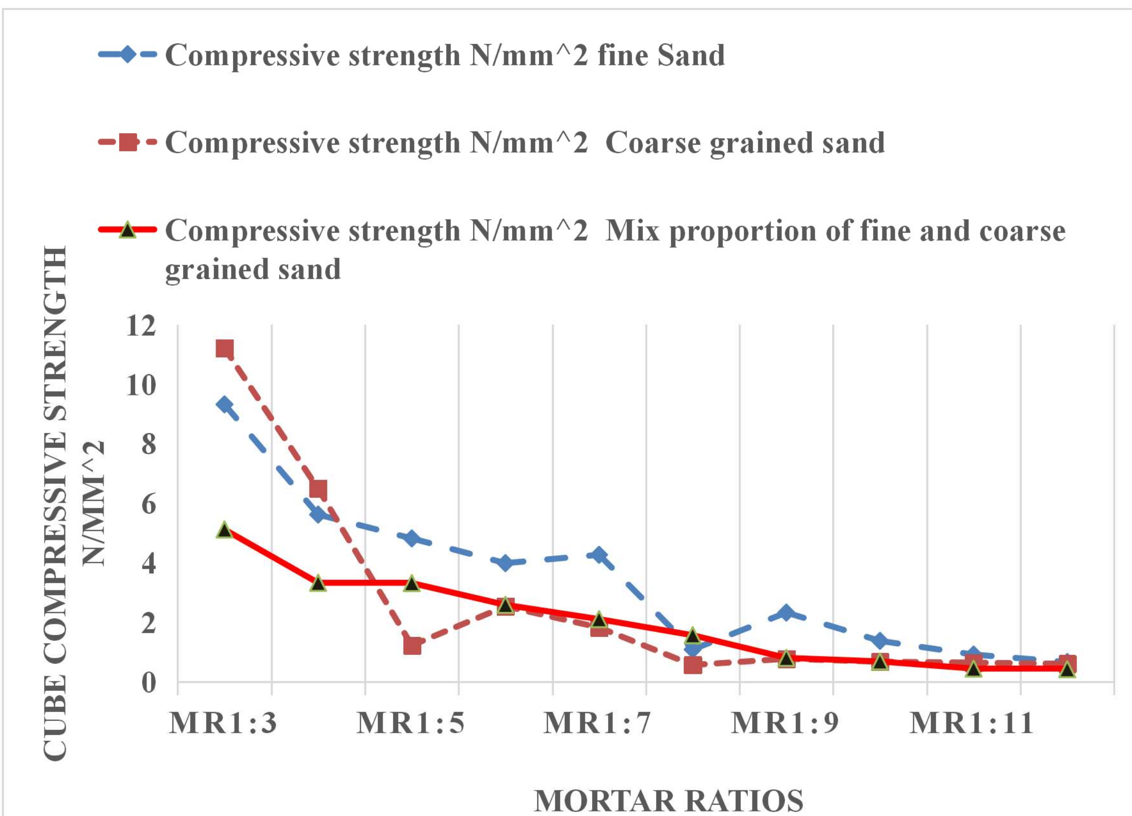

Figure 4. 2: Graph of compressive strength of mortar Vs mix proportions

4.4 Sand media used

On all 102 sites the respondents indicated that the site engineer determines the source of sand based on experience. Research established that 59% of the sites around Kampala used coarse used sand extracted from Rwera mining site along Kampala - Masaka road and this was followed by Buwama sand at 16%, Kapeeka sand at 12% and lastly Lake Victoria and Kamengo at 7%, and this is shown in Figure:4.3

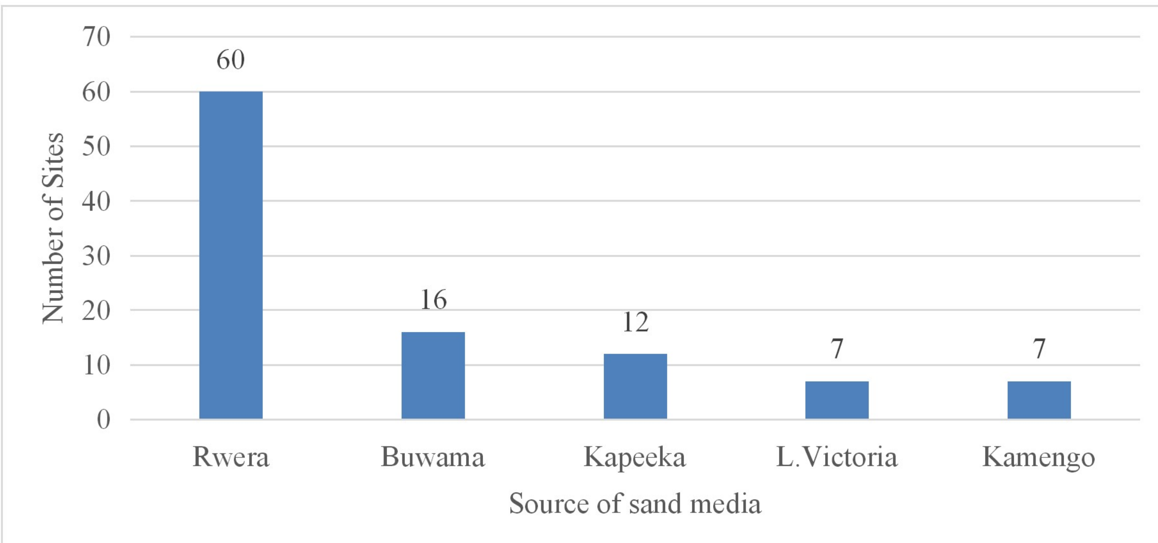

Figure 4. 3: Sources of sand media commonly used

Therefore in this research the source of coarse sand for all tests was Rwera because it is the most commonly used sand source

a) **Sieve analysis test on coarse grained sand**

The uniformity coefficient (C_u) to determine the variety of particle sizes of sand was determined as the ratio of D_{60} to D_{10} (Figure 4.4). The value of D_{60} is the grain diameter at which 60% of sand particles are finer and 40% of sand particles are coarser, while D_{10}

is the grain diameter at which 10% of particles are finer and 90% of the particles are coarser. Therefore, C_u was estimated as below;

$$C_U = \frac{D_{60}}{D_{10}} = \frac{602}{123} = 4.89 > 4.0$$

The sand for use in construction industry should meet the requirements with respect to grading, absence of organic matter and absence of excessive clay. Rwera sand was chosen to be used in the experiment because it is the most used sand. Figure 4.4 shows the results of the sieve analysis tests carried out on sand from Rwera mining site. Results revealed that the sand is well graded since the uniformity of coefficient was found to be more than 4.0.

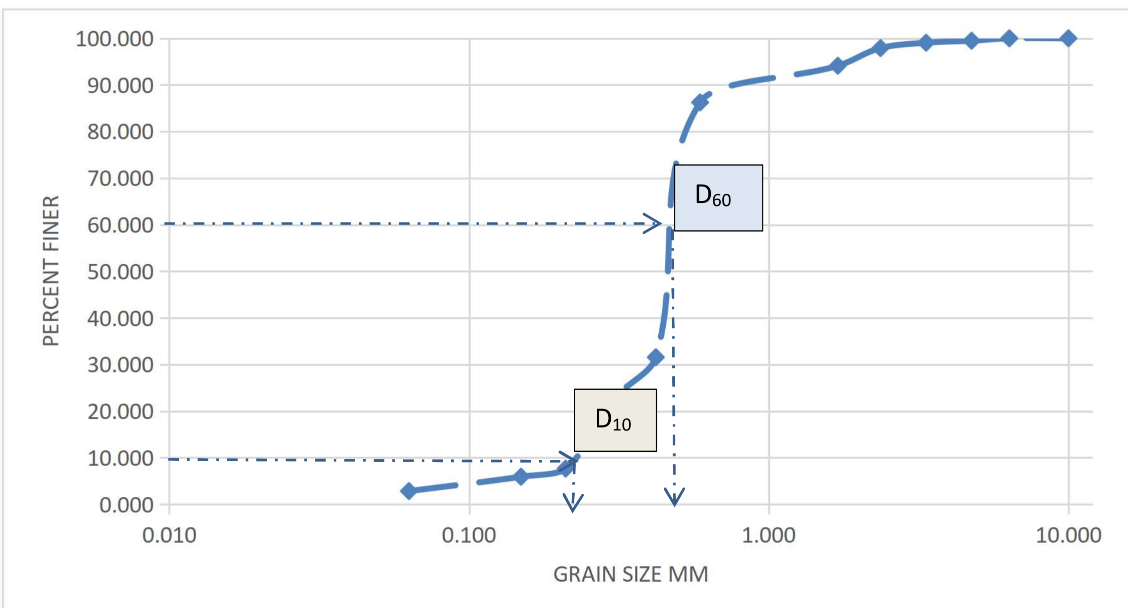

Figure 4. 4: Gradation curve for coarse grained sand

b) Sieve analysis test of fine grained sand

A survey of 102 sites revealed varying sources of fine grained sand (locally called plaster sand) depending on the location of the site. This sand is usually extracted from the nearest valley to the sites. Considering Kampala - Jinja road, 9 sites of the fifteen sample size used fine grained sand from Katosi, hence, its selection for use in this experiment. The results of the sieve analysis are presented in Figure 4.5

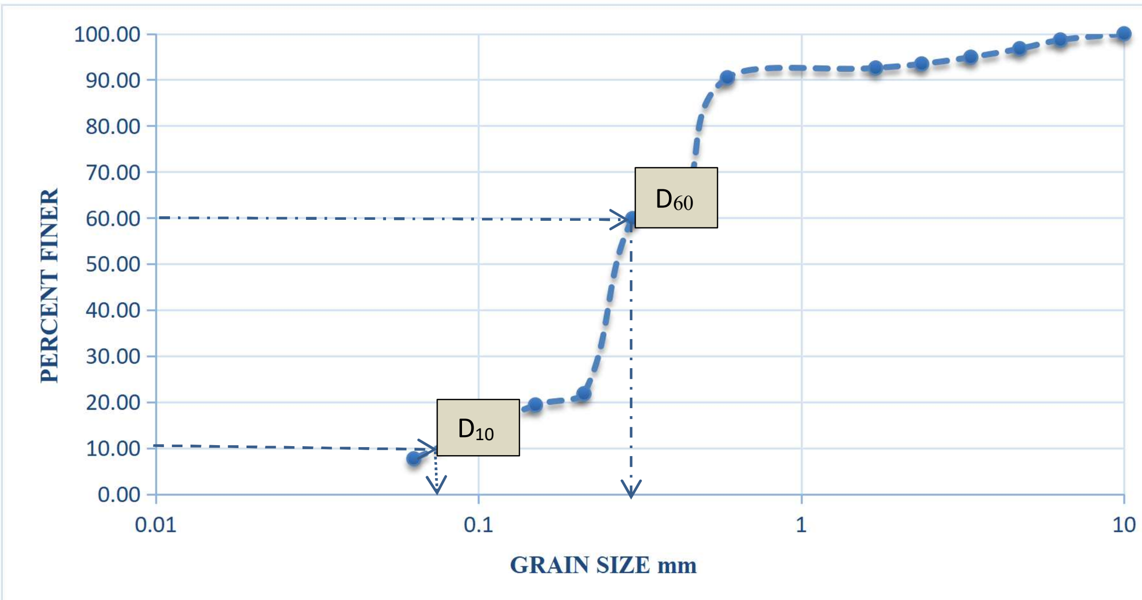

Figure 4. 5: Gradation curve for fine grained sand

4.5 Specific gravity test and bulk density of sand media used

Annexes 29 and 30, show the results for specific gravity of the sand media which was determined using pyconometer method in accordance with ASTM C 127-1993 and the bulk density test which was conducted in accordance to BS 812-2 (1995). It was calculated using the relationship in equations 3.1, 3.2, 3.3 and 3.4. The results from the specific gravity test revealed that specific gravity for coarse grained sand is 2.73 and that of fine grained sand is 2.61. This is within the range of 2.55 to 2.85 specified by IS : 2386 (Part III).

4.6 Cement type commonly used

The type of cement used on sites varied from site to site depending on the availability on the local market; the research found that 56% of the sites use 32.5R and 44% use 32.5N. All site supervisors on 102 sites indicated that they did not know what the symbols R or N meant where R meant rapid hardening cement while N represented normal hardening cement, though the use of any of the mentioned type of cement would not affected the strength of the masonry wall.

4.7 Water used in mixing of mortar

One hundred percent of the sites used portable water for mixing of mortar and this is the recommended water for use in the mix of any concrete.

4.8 Compressive strength of mortar cubes

In accordance to ASTM C109/C109M standard method for testing the compressive strength of cement mortar, a total of 36 mortar cubes were tested. After 28 days of curing and their compressive strength recorded in Table 4.2, these comprised of mortar ratios from 1:3, 1:4, 1:5, 1:6, 1:7, 1:8, 1:9, 1:10, 1:11, 1:12, 1:13 and 1:14, mortar ratios from 1:7 to 1:14 represented the commonly used corrected field mix proportions.

Table 4. 2: Average comprehensive strength for different mortar ratios

MORTAR RATIOS	MIX PROPORTIONS (Cement:Fine Sand: Coarse Sand) C : FS : CS	NUMBER OF CUBES CAST	AVERAGE COMPRESSIVE STRENGTH N/mm^2
MR1:3	1 : 1: 2	3	17.8
MR1:4	1 : 1 : 3	3	14.29
MR1:5	1 : 2 : 3	3	12.33
MR1:6	1 : 2 : 4	3	6.82
MR1:7	1 : 3 : 4	3	5.92
MR1:8	1 : 3 : 5	3	3.78
MR1:9	1 : 4 : 5	3	3.58
MR1:10	1 : 4 : 6	3	3.04
MR1:11	1 : 5 : 6	3	2.57
MR1:12	1 : 5 : 7	3	2.49
MR1:13	1 : 6 : 7	3	1.93
MR1:14	1 : 6 : 8	3	1.87

The results in the Table 4.2, revealed a reduction in compressive strength of mortar cubes as the proportions of cement reduced with increasing numbers of mix proportions

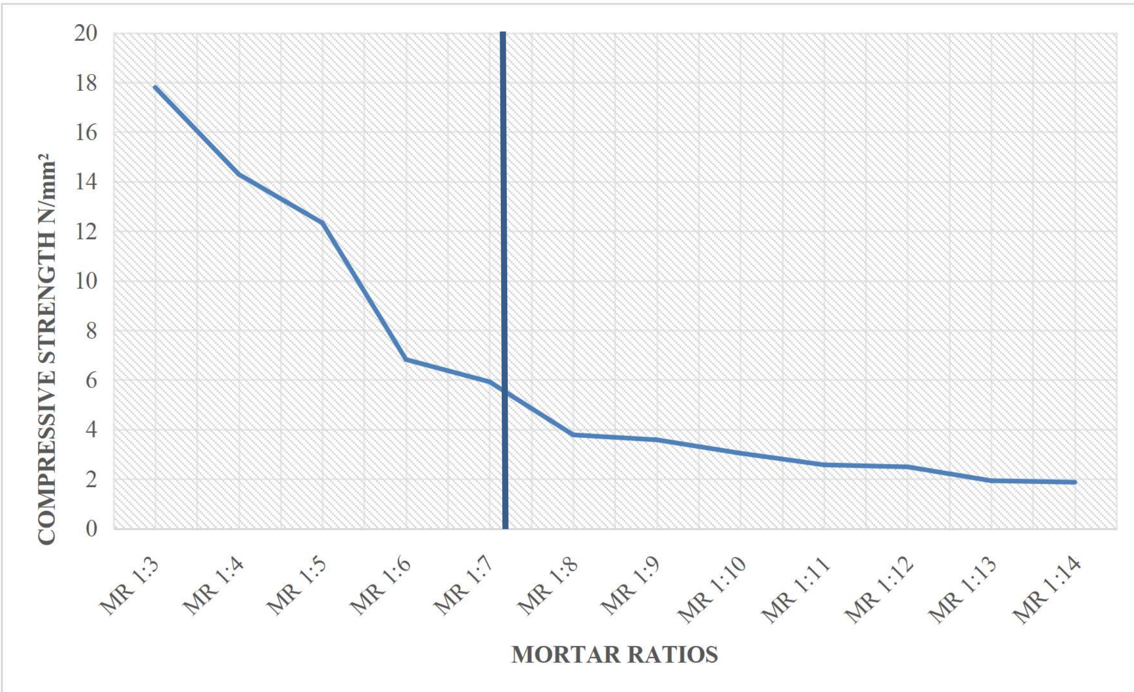

Figure 4. 6: Compressive strength of mortar cubes for different mortar ratios at 28 days

From Figure 4.6, the commonly used field corrected mortar ratios were found to have a maximum strength of 5.92N/mm^2 at mix proportion 1:7 and a minimum strength of 1.87N/mm^2 at a mix proportion of 1:14. From field evaluation of batching methods, mix ratios less than 1:7 were not used, hence the reduction in the strength of mortar cubes by increasing the quantity of sand agrees with (Velmeltfoort, 2012).

4.9 Burnt clay bricks

A survey of 102 construction sites along the major roads entering Kampala city revealed that they used burnt clay bricks from nearby brick production sites. The bricks varied widely in sizes, and their compressive strength. An average dimension of 207mm x 112mm x 98mm was revealed from the measurements carried out on the sample bricks from sites located on all the seven major roads entering Kampala metropolitan. The average sizes are given in the table (4.3.-4.9).

Table 4. 3: Brick size and Compressive strength of bricks from Hoima road

HOIMA ROAD					
SITES	BRICK SAMPLE SIZE (mm)	CONTACT AREA (mm^2)	COMPRESSION LOAD (N)	COMPRESSIVE STRENGTH (N/mm^2)	AVERAGE COMPRESSIVE STRENGTH (N/mm^2)
A1	200 x 105 x 100	21,000	117,900	5.61	
A1	215 x 115 x 90	24,725	201,300	8.14	
A1	205 x 110 x 80	22,550	264,100	11.71	8.49
A2	210 x 105 x 95	22,050	226,200	10.26	
A2	210 x 115 x 95	24,150	197,400	8.17	
A2	200 x 105 x 100	21,000	125,100	5.96	8.13
A3	210 x 115 x 95	24,150	156,100	6.46	
A3	210 x 110 x 90	23,100	201,000	8.70	
A3	210 x 115 x 90	24,150	184,400	7.64	7.60
A4	210 x 115 x 90	24,150	156,200	6.47	
A4	210 x 115 x 90	24,150	113,100	4.68	
A4	195 x 105 x 100	20,475	156,900	7.66	6.27
A5	205 x 115 x 90	23,575	124,600	5.29	
A5	200 x 105 x 100	21,000	97,200	4.63	
A5	210 x 115 x 90	24,150	87,400	3.62	4.51
Average	**207 x 111 x 93**				**7.00**

Table 4. 4: Brick size and Compressive strength of bricks from Mityana road

MITYANA ROAD					
SITES	**BRICK SAMPLE SIZE (mm)**	**CONTACT AREA (mm^2)**	**COMPRESSION LOAD (N)**	**COMPRESSIVE STRENGTH (N/mm^2)**	**AVERAGE COMPRESSIVE STRENGTH (N/mm^2)**
A1	210 x 110 x100	23,100	36,700	1.59	
A1	210 x 110 x 100	23,100	61,300	2.65	
A1	210 x 110 x 110	23,100	21,500	0.93	1.72
A2	210 x 110 x 110	23,100	41,900	1.81	
A2	210 x 110 x 100	23,100	41,100	1.78	
A2	210 x 110 x 95	23,100	61,800	2.68	2.09
A3	210 x 110 x 100	23,100	83,600	3.62	
A3	205 x 110 x 110	22,550	43,200	1.92	
A3	210 x 110 x 100	23,100	30,000	1.30	2.28
A4	210 x 110 x 100	23,100	33,300	1.44	
A4	210 x 110 x 100	23,100	93,600	4.05	
A4	205 x 110 x 95	22,550	41,800	1.85	2.45
A5	215 x 110 x 95	23,650	81,700	3.45	
A5	210 x 110 x 95	23,100	54,200	2.35	
A5	210 x 110 x 95	23,100	84,100	3.64	3.15
Average	**210 x 110 x 107**				**2.34**

Table 4. 5: Brick size and Compressive strength of burnt clay of Gayaza road

GAYAZA ROAD					
SITES	**BRICK SAMPLE SIZE (mm)**	**CONTACT AREA (mm^2)**	**COMPRESSION LOAD (N)**	**COMPRESSIVE STRENGTH (N/mm^2)**	**AVERAGE COMPRESSIVE STRENGTH (N/mm^2)**
A1	210 x 115 x 95	24,150	89,200	3.69	
A1	220 x 120 x 95	26,400	205,400	7.78	
A1	215 x 120 x 100	25,800	187,100	7.25	6.24
A2	215 x 120 x 100	25,800	121,600	4.71	
A2	215 x 115 x 90	24,725	140,500	5.68	
A2	215 x 115 x 95	24,725	26,900	1.09	3.83
A3	215 x 115 x 90	24,725	165,900	6.71	
A3	210 x 120 x 100	25,200	70,400	2.79	
A3	210 x 110 x 100	23,100	26,200	1.13	3.55
A4	215 x 110 x 95	23,650	78,800	3.33	
A4	215 x 115 x 100	24,725	176,600	7.14	
A4	210 x 115 x 100	24,150	76,900	3.18	4.55
A5	215 x 120 x 100	25,800	141,600	5.49	
A5	200 x 100 x 105	20,000	31,300	1.57	
A5	220 x 120 x 95	26,400	179,200	6.79	4.61
Average	**200 x 115 x 97**				**4.56**

Table 4. 6: Brick size and Compressive strength of burnt bricks along Bombo road

BOMBO ROAD					
SITES	**BRICK SAMPLE SIZE (mm)**	**CONTACT AREA (mm^2)**	**COMPRESSION LOAD (N)**	**COMPRESSIVE STRENGTH (N/mm^2)**	**AVERAGE COMPRESSIVE STRENGTH (N/mm^2)**
A1	210 x 110 x 110	23,100	59,100	2.56	
A1	210 x 110 x 100	23,100	94,100	4.07	
A1	210 x 110 x 100	23,100	46,700	2.02	2.88
A2	210 x 110 x 100	23,100	85,100	3.68	
A2	210 x 110 x 100	23,100	60,700	2.63	
A2	210 x 110 x 100	23,100	52,800	2.29	2.87
A3	210 x 110 x 100	23,100	77,300	3.35	
A3	210 x 110 x 100	23,100	84,100	3.64	
A3	215 x 110 x 100	23,650	34,400	1.45	2.81
A4	210 x 110 x 100	23,100	24,900	1.08	
A4	210 x 110 x 100	23,100	35,900	1.55	
A4	210 x 105 x 100	22,050	110,200	5.00	2.54
A5	210 x 110 x 100	23,100	65,400	2.83	
A5	215 x 105 x 100	22,575	84,600	3.75	
A5	210 x 105 x 100	22,050	44,500	2.02	2.87
Average	**210 x 109 x 101**				**2.79**

Table 4. 7: Brick size and Compressive strength of bricks on Masaka road

MASAKA ROAD					
SITES	**BRICK SAMPLE SIZE (mm)**	**CONTACT AREA (mm^2)**	**COMPRESSION LOAD (N)**	**COMPRESSIVE STRENGTH (N/mm^2)**	**AVERAGE COMPRESSIVE STRENGTH (N/mm^2)**
A1	220 x 135 x 80	29,700	194,400	6.55	
A1	220 x 135 x 90	29,700	111,100	3.74	
A1	210 x 130 x 85	27,300	149,700	5.48	5.26
A2	220 x 135 x 80	29,700	398,700	13.42	
A2	225 x 135 x 90	30,375	259,600	8.55	
A2	225 x 135 x 90	30,375	159,400	5.25	9.07
A3	220 x 135 x 85	29,700	305,300	10.28	
A3	225 x 130 x 80	29,250	413,200	14.13	
A3	220 x 130 x 85	28,600	133,900	4.68	9.70
A4	230 x 130 x 80	29,900	120,700	4.04	
A4	220 x 135 x 80	29,700	237,400	7.99	
A4	220 x 135 x 80	29,700	427,200	14.38	8.80
A5	225 x 135 x 80	30,375	130,800	4.31	
A5	220 x 130 x 85	28,600	102,400	3.58	
A5	225 x 130 x 85	29,250	93,400	3.19	3.69
Average	**222 x 133 x 84**				**7.30**

Table 4. 8:Brick size and Compressive strength of bricks on Entebbe road

ENTEBBE ROAD					
SITE	**BRICK SAMPLE SIZE (mm)**	**CONTACT AREA (mm^2)**	**COMPRESSION LOAD (N)**	**COMPRESSIVE STRENGTH (N/mm^2)**	**AVERAGE COMPRESSIVE STRENGTH (N/mm^2)**
A1	200 x 100 x 100	20,000	54,600	2.73	
A1	200 x 100 x 100	20,000	26,700	1.34	
A1	200 x 105 x 100	21,000	56,400	2.69	2.25
A2	200 x 105 x 105	21,000	26,700	1.27	
A2	200 x 100 x 100	20,000	27,200	1.36	
A2	200 x 100 x 100	20,000	40,200	2.01	1.55
A3	200 x 100 x 100	20,000	46,500	2.33	
A3	200 x 100 x 100	20,000	84,200	4.21	
A3	200 x 100 x 100	20,000	28,100	1.41	2.65
A4	200 x 100 x 100	20,000	42,000	2.10	
A4	200 x 100 x 105	20,000	38,000	1.90	
A4	200 x 100 x 105	20,000	53,200	2.66	2.22
A5	200 x 100 x 105	20,000	29,200	1.46	
A5	200 x 100 x 100	20,000	38,000	1.90	
A5	200 x 100 x 100	20,000	29,700	1.49	1.62
Average	**200 x 101 x 101**				**2.06**

Table 4. 9: Brick size and Compressive strength of burnt clay bricks on Jinja road

JINJA ROAD					
SITE	**BRICK SAMPLE SIZE (mm)**	**CONTACT AREA (mm2)**	**COMPRESSION LOAD (N)**	**COMPRESSIVE STRENGTH (N/mm2)**	**AVERAGE COMPRESSIVE STRENGTH (N/mm2)**
A1	200 x 100 x 100	20,000	126,700	6.34	
A1	200 x 100 x 100	20,000	131,900	6.60	
A1	185 x 100 x 100	18,500	59,600	3.22	5.38
A2	200 x 100 x 90	20,000	49,700	2.49	
A2	200 x 100 x 100	20,000	79,000	3.95	
A2	200 x 100 x 100	20,000	92,900	4.65	3.69
A3	200 x 110 x 110	22,000	106,900	4.86	
A3	200 x 100 x 100	20,000	192,200	9.61	
A3	200 x 100 x 90	20,000	79,200	3.96	6.14
A4	190 x 100 x 90	19,000	59,400	3.13	
A4	200 x 100 x 100	20,000	70,600	3.53	
A4	200 x 110 x 110	22,000	41,200	1.87	2.84
A5	200 x 100 x 100	20,000	108,400	5.42	
A5	200 x 110 x 110	22,000	69,200	3.15	
A5	200 x 110 x 110	22,000	91,800	4.17	4.25
Average	**198 x 103 x 101**				**4.46**

4.10 Water absorption test on bricks

The results of water absorption of bricks is given in Tables (5.1-5.7) and figure 4.7. According to IS 1077:1992, for common burnt clay building bricks, water absorption rate should not be more than 20% by weight up to class 12.5 and 15% by weight for higher classes. The average water absorption for the different bricks sourced from different construction sites along the major roads joining Kampala city lie within the 12.5 class with exceptional of bricks from Entebbe road. Bricks from sites on Masaka road had the best water absorption rate with 9.23%, followed by bricks from sites on Mityana road with 11.85%, Jinja road had 12.69%, Hoima road with 14.66%, Bombo road , 14.84%, Gayaza road with 15.32% and Entebbe road with 16.68%. The results obtained conform to the ASTM standards of water absorption for burnt clay bricks. Bricks from Masaka road, Hoima road,Jinja road, Bombo road and Mityana road fall under first class bricks with a water absorption percenatage between 12 - 15% with exceptional of bricks from Entebbe road with 16.68% falling under second class bricks as per IS 1077 (1992) classification. The rate of water absorption affects the strength of masonry walls in this case, the higher the rate of water absorption the lower the compressive strength of a burnt clay brick masonry.

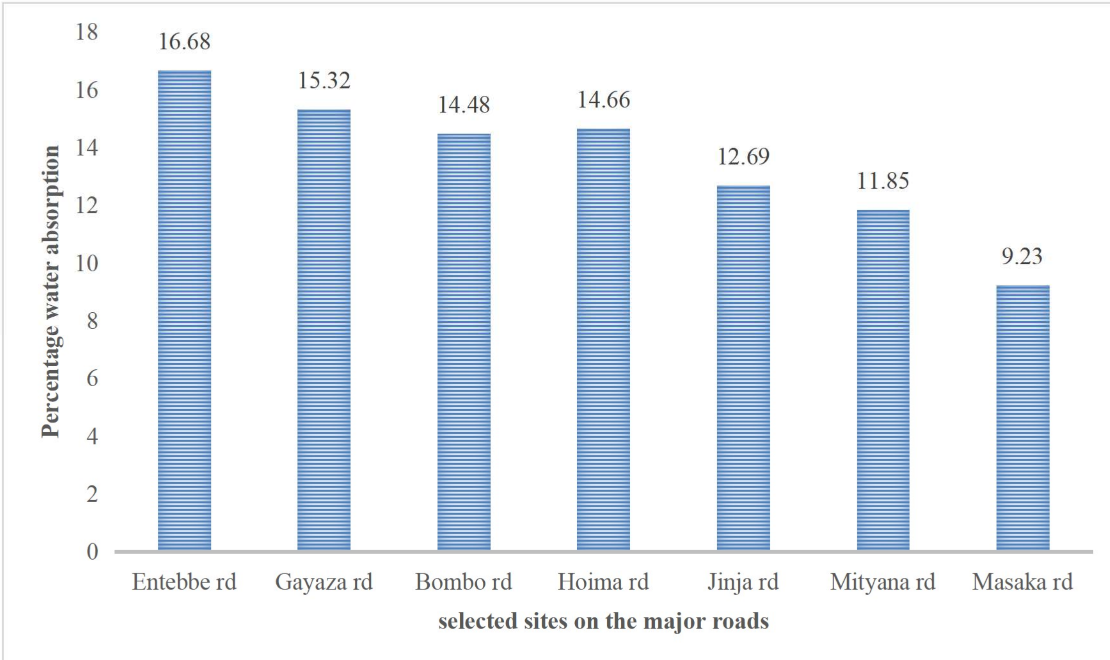

Figure 4. 7: Summary for water absorption for burnt clay bricks

4.11 Compressive strength of burnt clay bricks

Table 4.10, shows results of compressive strength of bricks sourced from 35 construction sites along major roads joining Kampala metropolitan among which included; Hoima road with an average compressive strength of 7N/mm^2, Mityana road with 2.34N/mm^2, Gayaza road with 4.56N/mm^2, Bombo road with 2.79N/mm^2, Masaka road with 7.3N/mm^2, Entebbe road with 2.1N/mm^2 and Jinja road with 4.46N/mm^2. The results revealed wide variation in compressive strength of bricks and this may be as a result of the differences in properties of the soils, production process and the degree of heating of the bricks and these were found to class 7.5 as per the IS 1077:199, pp.3-17.

Table 4. 10: Summary of the average compressive strength of burnt clay bricks from the major selected bricks

MAJOR ROADS	A1	A2	A3	A4	A5
Hoima road	8.49	8.13	7.6	6.27	4.51
Mityana road	1.72	2.09	2.28	2.45	3.15
Gayaza road	6.24	3.83	3.55	4.55	4.61
Bombo road	2.88	2.87	2.81	2.54	2.87
Masaka road	5.26	9.07	9.7	8.8	3.69
Entebbe road	2.25	1.55	2.65	2.22	1.62
Jinja road	5.38	3.69	6.14	2.84	4.25

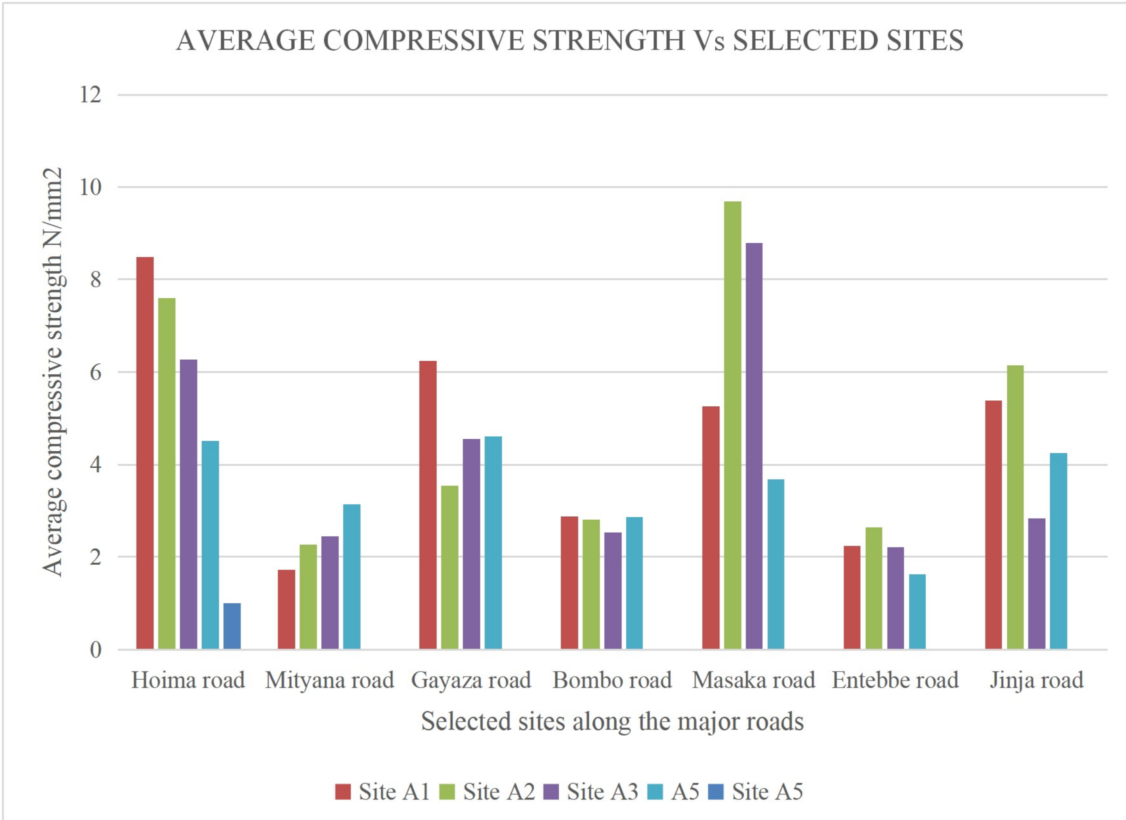

Figure 4. 8: Summary of compressive strength of burnt clay bricks on sites along the major selected roads

From Figure 4.8, burnt clay bricks can be grouped as follows, Masaka road and Hoima road bricks fall under second class bricks with a crushing strength between 10N/mm^2 and 7.5N/mm^2, while bricks from Jinja road and Gayaza road fall under third class bricks with a crushing strength of 7.5N/mm^2 to 5N/mm^2 and bricks from Mityana road, Bombo road fall under the fourth class of bricks with a crushing strength between 5N/mm^2 to 3.5N/mm^2 while bricks from Entebbe road were not grouped since its strength did not conform to the specification as per IS 1077(1992).

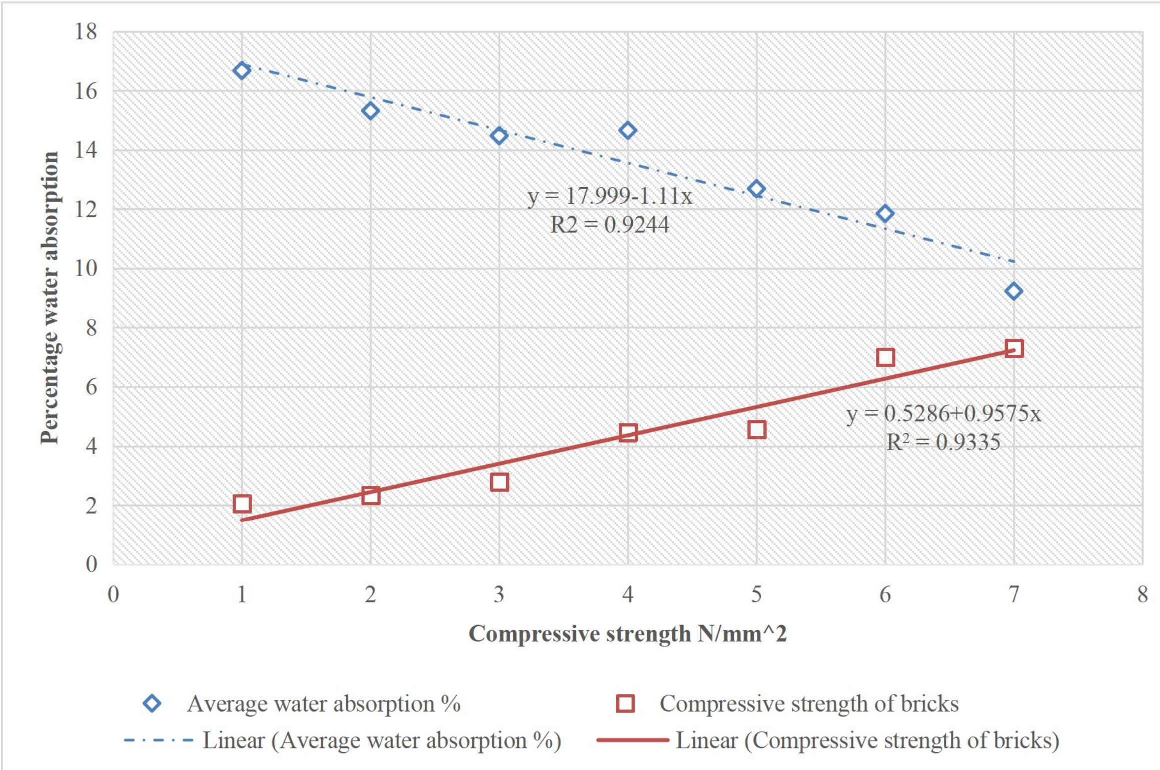

Figure 4. 9: Relationship between water absorption and Compressive strength of burnt clay bricks

From Figure 4.9, test results revealed that there is a relationship between water absorption and compressive strength of burnt clay bricks. The test results indicate that a higher percentage water absorption results into low compressive strength and as the percentage water absorption reduces, there is a gradual increase in compressive strength of burnt clay bricks

4.12 Variability of compressive strength of burnt clay bricks

Using the statistical method of validating the variability of materials, it was found out that materials used around Kampala vary widely in compressive strength. Masaka road bricks had the highest deviation of 3.21N/mm^2, followed by Gayaza road with 2.49N/mm^2, Hoima road with 1.73N/mm^2, Jinja road with 1.60N/mm^2, Bombo road with 1.20N/mm^2, Mityana road with 0.93N/mm^2 and finally Entebbe road with 0.65N/mm^{2,} this is clearly indicated in Figure 4.10. This was calculated using the statistical method of calculating the Standard deviation of materials as given in the Tables (5.9-5.15). Bricks from Entebbe road, Mityana road and Bombo road had the lowest deviation though their strength could have been affected due to the presence of sand media into the materials that were observed at the time of testing.

Variance (S^2) = $\left[\frac{\sum (X - \overline{X})^2}{(N - 1)} \right]$ …………………… (Equation 4.1)

Standard Deviation, S = $S = \sqrt{\frac{\Sigma\left(x_i - \bar{x}\right)^2}{(N-1)}}$ …………………. (Equation 4.2)

Where , X - sample material

$\overline{X}$ - mean sample space

N - Total number of sample material

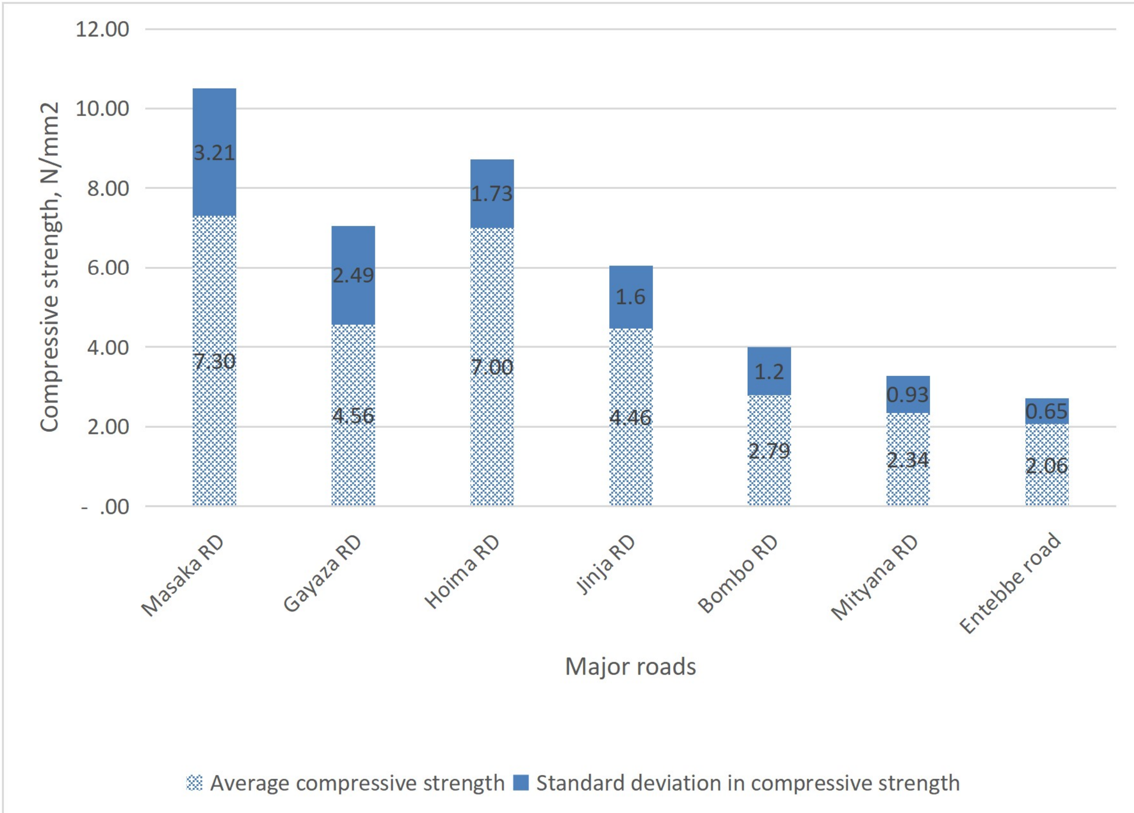

Figure 4. 10: Summary of availability of compressive strength of bricks around Kampala

4.13 Determination of masonry wall strength using the test results obtained from the Laboratory

According to EN BS 1996-1-1:2005, the compressive strength of a wall is given by

$$f_k = K f_b^{0.7} f_m^{0.3} \qquad \text{………………} \quad \text{(Equation 4.3)}$$

Where;

f_k is the characteristic compressive strength of masonry wall in N/mm^2

K is a constant based on the group number and type of mortar,Table3.3,EN1996.1.1:2005

f_b is normalized mean compressive strength of the masonry units used.

f_m is the compressive strength of mortar in N/mm^2

The normalized mean compressive strength is given by

f_b = [conditioning factor] x [Shape factor] x [Declared mean compressive strength]

Declared mean compressive strength is obtained from experimental data

For air dried bricks, conditioning factor is 1.0

From EN772-1:2000, Table A1, the shape factor is 1.25 for wall panels with width 200mm and height greater than 250mm, hence its use in this research where the wall panels were 1000mm long x 200mm wide x 1000mm high.

Table 4. 11: Summary of computed compressive strength of burnt clay brick walls

MORTAR RATIOS AND STRENGTH	Hoima RD Average strength 7.0, N/mm^2	Mityana RD Average strength 2.34 N/mm^2	Gayaza RD Average strength 4.56N/mm^2	Bombo RD Average strength 2.79N/mm^2	Masaka RD Average strength 7.30N/mm^2	Entebbe RD Average strength 2.06N/mm^2	Jinja RD Average strength 4.46N/mm^2
MR1:3, (17.8 N/mm^2)	3.79	1.76	2.81	1.99	3.9	1.61	2.76
MR1:4, (14.8 N/mm^2)	3.55	1.65	2.63	1.86	3.65	1.51	2.59
MR1:5, (12.33 N/mm^2)	3.39	1.58	2.51	1.78	3.5	1.44	2.48
MR1:6, (6.82 N/mm^2)	2.84	1.32	2.11	1.49	2.93	1.21	2.07
MR1:7, (5.92 N/mm^2)	2.72	1.26	2.02	1.43	2.8	1.16	1.99
MR1:8, (3.78 N/mm^2)	2.38	1.11	1.76	1.25	2.45	1.01	1.71
MR1:9, (3.58N/mm^2)	2.34	1.09	1.74	1.23	2.4	1	1.71
MR1:10, (3.04N/mm^2)	2.23	1.04	1.65	1.17	2.3	0.95	1.63
MR1:11, (2.57 N/mm^2)	2.12	0.98	1.57	1.11	2.18	0.9	1.55
MR1:12, (2.49N/mm^2)	2.1	0.98	1.56	1.1	2.18	0.9	1.55
MR1:13, (1.93 N/mm^2)	1.95	0.9	1.44	1.02	2	0.83	1.42
MR1:14, (1.87 N/mm^2)	1.93	0.9	1.43	1.01	1.99	0.82	1.41

Table 4.11 and Figure 4.11, it is seen that when weak bricks are used with high strength mortar, the strength of the wall is found to be influenced more by the weak bricks strength. Whereas from from Table 4.4, the mortar strength varies from 17.8N/mm^2 for 1:3 mix ratio to 1.87N/mm^2 for 1:14N/mm^2 mortar ratio. The strength of the wall is considerably reduced to vary from 3.9N/mm^2 for 1:3 mix ratios to 0.82N/mm^2 at 1:14 mix ratio.

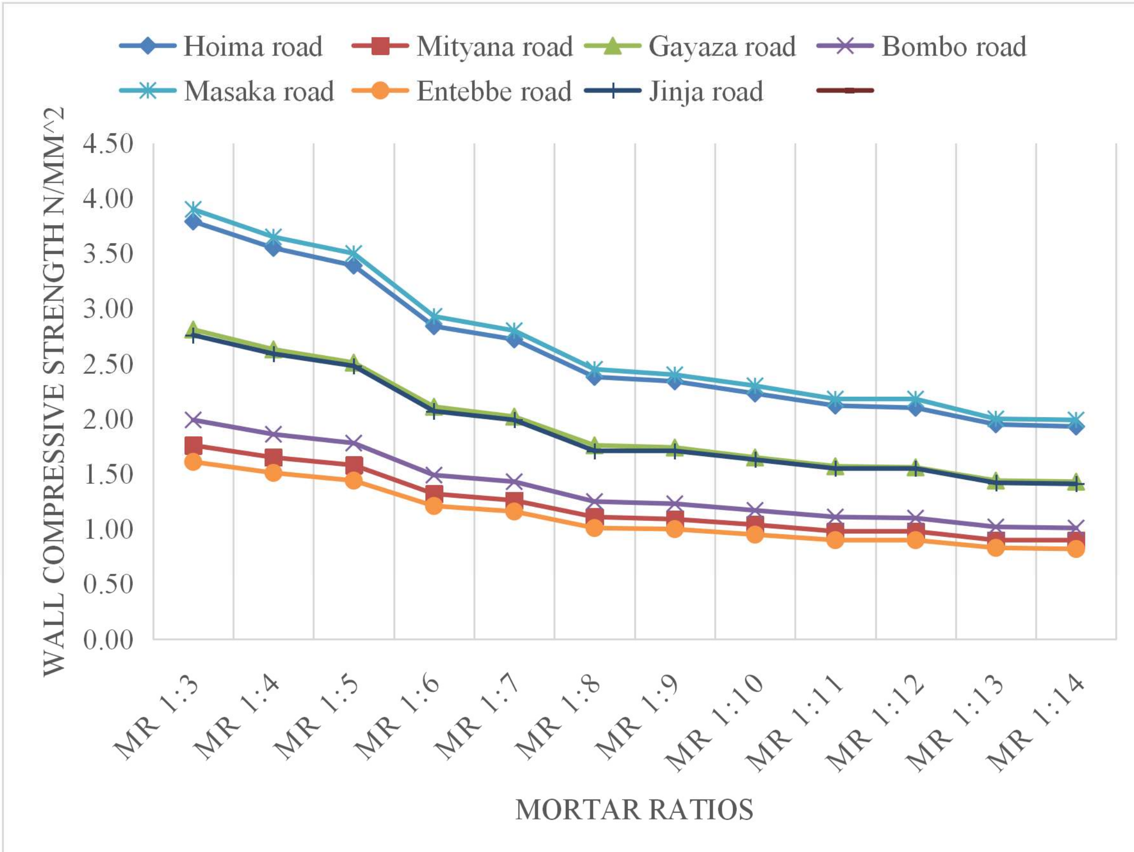

Figure 4. 11: The compressive strength of masonry walls

4.15 Determination of wall compressive strength constructed of field derived mortar ratios

A set of twelve walls were constructed using mortar mixes 1:7, 1:10, 1:12 and 1:14 for each of the tests. The ratios were obtained after a field survey that revealed an average volume of a wheel barrow to be $0.089m^3$ and the volume of a cement bag of $0.036m^3$ thus these ratios were the most applicable in the field. These were tested after 28 days using a steel loading machine at Kireka materials laboratory shown in Figure 4.12 and the results shown in Table 4.12

Figure 4. 12: Wall structure (1000 x 1000) mm tested and failure of the walls)

100% of the tested walls failed due to the effect of a weaker bond strength between bricks and mortar this was evidenced by the crack patterns that followed the mortar joints with less cracks through the bricks as shown in Figure 4.12 indicating a failure due to bond effect and this was found to compatible with (Konthesingha,C, 1985, pp.12).

Table 4. 12: Relationship between field derived mortar constructed walls vs designed wall strength

Wall size (1000 x 200)mm Ratios (FA)	Compression load KN	Compressive strength N/mm^2	Tested Average Strength N/mm^2 (f_{kt})	Designed wall strength N/mm^2 (f_{kd})	Percentage Wall compressive strength of tested walls $\frac{f_{kt}}{f_{kd}} x100\%$
MR1:7	299	1.50			
	429	2.15			
	385	1.92	1.85	2.72	68%
MR1:10	293	1.46			
	359	1.79			
	386	1.93	1.73	2.23	77.5%
MR1:12	275	1.38			
	321	1.61			
	301	1.51	1.50	2.10	71%
MR1:14	315	1.58			
	286	1.43			
	291	1.46	1.49	1.93	77%

From the Table 4.12, its observed that the compressive strength of field most used mortar ratios constructed walls reduced with increasing value of mix ratios as was expected. Tested results varied from 68% to 77% of the calculated designed strength of the wall.

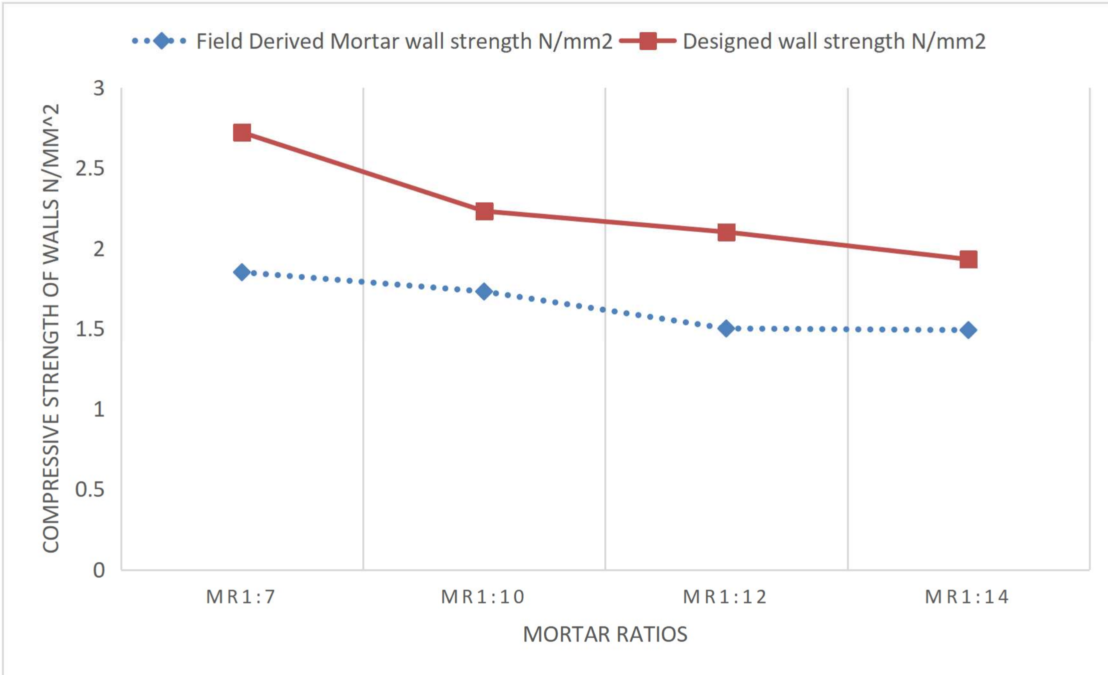

Figure 4. 13: Field derived mortar strength vs designed wall strength

From Figure 4.13, the designed wall strength is higher than the field derived mortar ratio constructed walls . Hence, capacity reduction factor can be calculated from,

$$\phi_k = \frac{\text{Experimental wall strength, N/mm}^2}{\text{Design wall strength, N/mm}^2} \qquad \text{………………..(Equation 4.3)}$$

And the lowest capacity reduction factor from Table 4.7 is 0.68, hence;

$$N_{Rd} = \phi f_d t \qquad \text{…………………..(Equation 4.4)}$$

Where,

ϕ is Capacity reduction factor

f_d is design compressive strength

t is the thickness of the wall

4.16 Relationship between wall strength and brick strength

Table 4. 13, Results of wall strength Vs Brick strength (From Hoima road)

MR1:7		MR1:10		MR1:12		MR1:14	
Wall strength, N/mm^2	Brick strength, N/mm^2	Wall strength, N/mm^2	Brick strength, N/mm^2	Wall strength, N/mm^2	Brick strength, N/mm^2	Wall strength, N/mm^2	Brick strength, N/mm^2
1.50	5.63	1.46	5.99	1.38	6.5	1.43	4.7
1.90	8.17	1.79	8.2	1.51	7.69	1.46	6.5
2.15	11.73	1.93	10.29	1.61	8.9	1.56	7.71

Table 4.13, shows the different wall strength obtained from wall units constructed of different mortar ratios using bricks of varying compressive strength, 3 samples of bricks were picked from the materials for each walling unit before construction of the unit. They were tested for compressive strength and the average found.

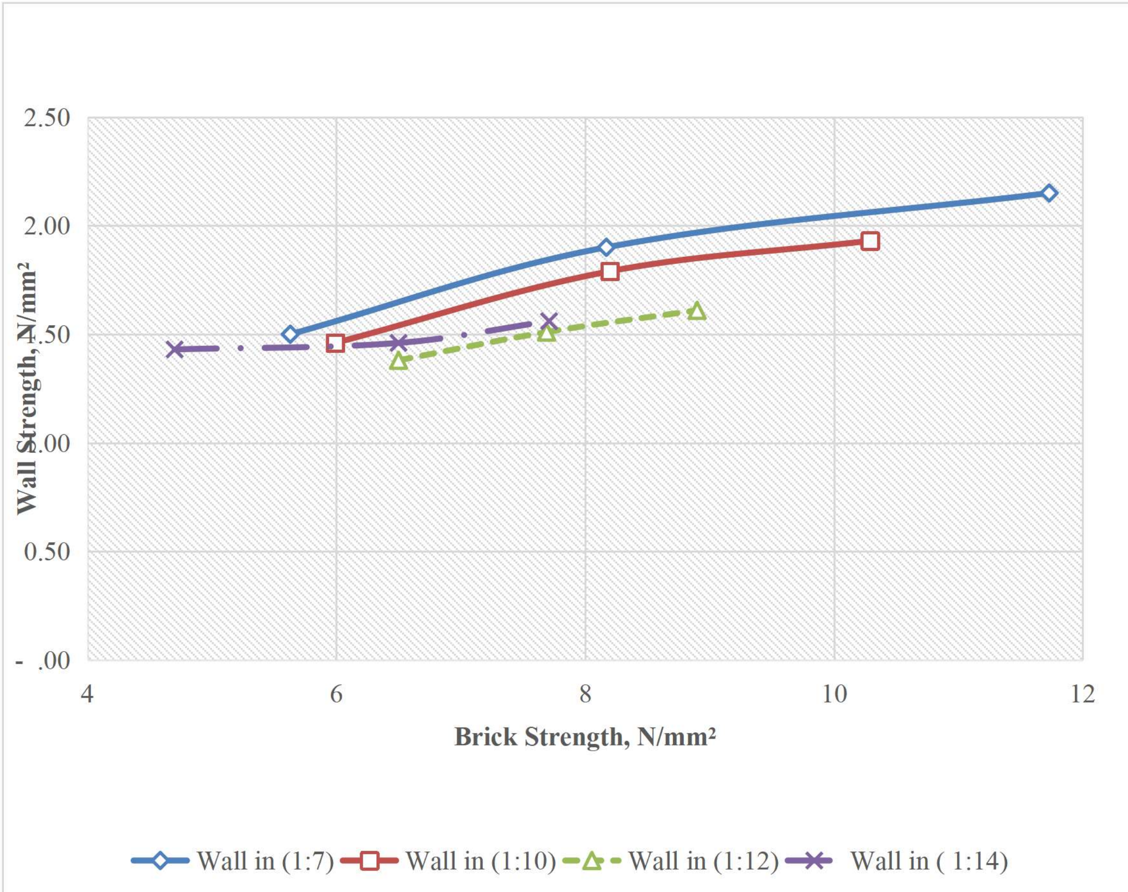

Figure 4. 14: Comparative relationship between wall strength and burnt clay bricks strength

From Figure 4.14, walls units constructed of field derived mortar ratios 1:7, 1:10, 1:12 and 1:14 have a positive correlation with the brick strength, where higher brick strength results into higher values of wall strength. The results also indicate that, wall strength is dependent on brick strength.

From Figure 4.14, it is seen that the lowest average brick strength of 4.7N/mm^2, resulted into wall strength of 1.43N/mm^2 and the highest brick strength of 11.73N/mm^2 resulting into a wall strength of 2.15N/mm^2.

Increase in brick strength $= \frac{(11.73 - 4.7)}{4.7} x100\% = 150\%$

Wall strength $= \left(\frac{(2.15 - 1.43)}{1.43} \right) x100\% = 50\%$

Thus an increase in brick strength of 150% resulted into only 50% effect of brick strength and the wall strength is not so much pronounced.

4.17 Load capacity for walls and implication factor for design

For a wall (200mm wide x 4000mm long) of mortar mix (1:14) and average brick strength of 7.0N/mm^2. This would be able to support 1,192 KN.

Compressive strength (Wall strength) = $\frac{LoadKN}{Contactare}$ ………………(Equation 4.5)

The load capacity is (4000 x 200 x 1.49) x 10^{-3} = 1.192KN

It would be wrong for an engineer to ignore this load carrying capacity and instead use bricks as infill. Exploiting the load capacity of the wall would serve as a factor of safety against differential settlements due to disturbed soils. It would ensure that the wall serves as a fuse during seismic loading.

4.18 Summary : Chapter four

This chapter covers, data presentation analysis of results and discussions. This includes results from data collection, survey of structural firms and construction sites, materials used among which includes sand media, bricks and wall units.

100% of the design firms did not design masonry walls made of burnt clay bricks but rather specify it as infills, 100% of the 102 sites use volume batching as means of batching where one bag cement is mixed to a number of wheelbarrows.

The most used coarse sand was found to be sand from Rwera mining site. Results from sieve analysis revealed that the uniformity of coefficient was found to be more than 4, hence, this indicated that sand was well graded

The specific gravity of sand media was found to be 2.73 and 2.61 for coarse grained sand and fine grained sand respectively and this was found to be with in the standard between 2.55 -2.85 as per IS:2386(Part III), 32.5 type of cement was the most used cement on all the 102 sites used and portable water was used in the mix of mortar. In accordance to ASTM C109/C109M, compressive strength from the 36 mortar cubes after 28 days varied widely with reducing strength with increase in value of mix ratios that's from 17.8N/mm2 to 1.78N/mm2 for mix ratios 1:3 to 1:14 cement sand mortar.

Bricks used on construction sites were collected from the nearby production sites and it's dimensions varied from site to site with an average of 208mm x 112mm x 98mm The water absorption test revealed varied between 16.68% to 9.23% respective of the production site. Compressive strength of bricks varied from site to site with an average strength of 7.3N/mm2 to 2.06N/mm2 as per IS 1077:1992. Bricks collected from sites along Masaka road had the highest deviation in compressive strength despite it having the highest compressive strength.

Design of wall units using compressive test results from the lab revealed a reduction in strength of wall units with increasing value of mix ratios as this was proved right from the practical test of the twelve wall units built of most used mortar ratios.

100% of the constructed walls failed due to bond effect between the bricks and mortar joints and the crack partner followed through the mortar joints.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

From the analysis and results presented in Chapter four, conclusions and recommendations have been drawn as its highlighted below.

5.2 Conclusions drawn from study findings

The need for more housing units to cater for increased population, mostly used construction materials like masonry clay bricks at 36.4% followed by mud and poles at 33.6% are used with out the knowledge of their properties. Research established that one hundred percent of the housing units use cement - sand mortar in the construction of masonry walls .

Research further established that the mostly used batching method is volume batching with the application of one bag of cement to a number of wheelbarrows full of sand media with an average volume of a wheelbarrow is 2.47 times the volume of one bag of cement. This resulted into varying strength of mortar ranging between 5.92N/mm^2 for 1:7 and 1.87 N/mm^2 for 1:14 for the mostly used mortar mix ratios and this was characterized with a reduction in compressive strength with increasing value of mix ratios. Hence, in the construction of masonry walls mortar mix ratios beyond 1:6 should not be used**.**

Research also established that the compressive strength of burnt clay bricks varied widely between 7.3N/mm^2 and 2.06N/mm^2 and this was entirely depended of the rate of water absorption, method of manufacture and soil type.

Experimental tests on burnt clay masonry walls constructed of mostly used mortar mix ratios established that the compressive strength of the walls reduced greatly with increasing value of mix ratios, and this was entirely depended of the mortar compressive strength however strong the bricks may be.

Survey on Structural design firms revealed that 100% of the firms do not design masonry walls but rather specify them as infills yet the design of these walls would reduce on the impact failure and cost of construction by reduction in number of columns used.

5.3 Recommendations

From the test data observations, the following recommendations have been made to support both academic and construction industry in Uganda.

a) Research established a variation in the compressive strength of mortar cubes with a reduction in strength with increasing values of mix ratios and this was majorly attributed to the use of volume batching where a bag of cement to a number of wheelbarrows is used, hence, construction sites should enforce the use of batch boxes as away of attaining the perceived mix ratios and the strength intended.

b) Construction sites should enforce testing of the masonry units used such as bricks for both water absorption and compressive strength as away of using right materials of known strength to protect inhabitants from accidents and loss of lives since these properties affect the strength of a masonry wall.

c) Structural design firms should always design masonry walls made of burnt clay bricks as load bearing walls other than providing them as infills to reduce on cost of construction, and to utilize all materials in carrying loads.

d) Further research should be conducted to assess the cause of variations in the strength of burnt clay bricks as factor affecting the strength of masonry walls. A case study of bricks collected along Entebbe road can be used.

e) I strongly recommend that mix ratios beyond 1:6 should not be used in the construction of masonry walls since research has established that the wall strength is highly determined by the strength of mortar and greatly reduces with increasing valve of mix ratios.

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5.4 Appendices

Appendix 1: Interview guide used in data collection

a) What is the mortar mix ratio used for this site?

....

b) What is the method of mortar mixing used on site?

   - ❖ Hands or Mixer

c) What are the methods used in batching

   - ❖ Weight or Volume

d) If not weight, why and if volume why?

....

e) If volume, is batch box available?

   - ❖ Yes or NO

f) If Yes, what is the volume of the batch box?

………………………………………………………………………………………

g) Are they equivalent to a cement bag?

   - ❖ Yes or NO

h) If NO batch boxes, what do they use

   1) Wheelbarrows
   2) Others

i) If wheel barrow, what is the volume of the wheel barrows used or its equivalent to the bag of cement? 1bag: how many wheel barrows

………………………………………………………………………………………

j) What is the type of cement used?

- ❖ 32.5R or 32.5N
- ❖ 42.5R or 42.5N

k) What is source of coarse sand used?

…..…………………………………………………………………………………..

l) What is the source of fine sand?

…………………………………………………………………………………..

m) What is the amount water used in the mixing of sand?

…………………………………………………………………………………..

n) Which type of bricks is used?

…………………………………………………………………………………………

o) What is the source of the bricks?

…..……………………………………………………………………………………

….

p) Do you mix fine and coarse sand in making mortar

YES or NO

q) Do you use;

coarse sand only ☐

Fine sand only ☐

Mixture (50/50) coarse/fine sand ☐

Appendix 2: Information from consultants

Questionnaires

Qn1. Do you design Masonry structures in multi storey buildings

YES ☐ NO ☐

Qn2. If yes, what code do you use?, if NO go to question 3.

Qn3. What brick strength of burnt clay bricks do you commonly specify?

1 - 3 N/mm^2 ☐	3.1 - 6N/mm^2 ☐
6.1 - 10N/mm^2 ☐	> 10N/mm^2 ☐

Qn4. What mortar mixes do you specify?

1:3 ☐	1:4 ☐	1:5 ☐	1:6 ☐	1:7 ☐
1:8 ☐	1:9 ☐	1:10 ☐	1:11 ☐	1: 12 ☐
1:13 ☐	1:14 ☐			

5.5 Data Tables

Table 5. 1: Water absorption for bricks on JINJA ROAD

JINJA ROAD				
SITES	**BRICK SAMPLE SIZE (mm)**	**DRY WEIGHT (g)**	**SATURATED WEIGHT (g)**	**PERCENTAGE WATER ABSORPTION**
A1	200 x 100 x 100	4045	4332	7.10
A1	200 x 100 x 100	3830	4359	13.81
A1	185 x 100 x 100	3326	3746	12.63
A2	200 x 100 x 90	2904	3135	7.95
A2	200 x 100 x 100	4103	4381	6.78
A2	200 x 100 x 100	3567	4032	13.04
A3	200 x 110 x 110	3880	4478	15.41
A3	200 x 100 x 100	3968	4309	8.59
A3	200 x 100 x 90	3045	3615	18.72
A4	190 x 100 x 90	2720	3460	27.21
A4	200 x 100 x 100	4010	4251	6.01
A4	200 x 110 x 110	4025	4589	14.01
A5	200 x 100 x 100	3989	4460	11.81
A5	200 x 110 x 110	3880	4476	15.36
A5	200 x 110 x 110	3869	4330	11.92
	Average water absorption			**12.69**

Table 5. 2: Water absorption for bricks from GAYAZA road

GAYAZA ROAD					
SITES	**BRICK SAMPLE SIZE (mm)**	**DRY WEIGHT (g)**	**SATURATED WEIGHT (g)**	**DIFFERENCE IN WEIGHT (g)**	**PERCENTAGE WATER ABSORPTION**
A1	210 x 115 x 95	4137	4703	566	13.68
A1	220 x 120 x 95	4360	5085	725	16.63
A1	215 x 120 x 100	4479	5238	759	16.95
A2	215 x 120 x 100	4548	5321	773	17.00
A2	215 x 115 x 90	3751	4397	646	17.22
A2	215 x 115 x 95	4268	4780	512	12.00
A3	215 x 115 x 90	4224	4747	523	12.38
A3	210 x 120 x 100	4174	4743	569	13.63
A3	210 x 110 x 100	3571	4310	739	20.69
A4	215 x 110 x 95	4192	4669	477	11.38
A4	215 x 115 x 100	4012	4703	691	17.22
A4	210 x 115 x 100	4249	4776	527	12.40
A5	215 x 120 x 100	4373	5137	764	17.47
A5	200 x 100 x 105	3749	4357	608	16.22
A5	220 x 120 x 95	4361	5010	649	14.88
	Average water absorption				**15.32**

Table 5. 3: Water absorption from Hoima road

HOIMA ROAD					
SITES	**BRICK SAMPLE SIZE (mm)**	**DRY WEIGHT (g)**	**SATURATED WEIGHT (g)**	**DIFFERENCE IN WEIGHT (g)**	**PERCENTAGE WATER ABSORPTION**
A1	200 x 105 x 100	3806	4331	525	13.79
A1	215 x 115 x 90	3544	4065	521	14.70
A1	205 x 110 x 80	3510	4026	516	14.70
A2	210 x 105 x 95	3824	4406	582	15.22
A2	210 x 115 x 95	3742	4309	567	15.15
A2	200 x 105 x 100	3743	4294	551	14.72
A3	210 x 115 x 95	3856	4466	610	15.82
A3	210 x 110 x 90	3499	4022	523	14.95
A3	210 x 115 x 90	3545	4096	551	15.54
A4	210 x 115 x 90	3796	4390	594	15.65
A4	210 x 115 x 90	3624	4062	438	12.09
A4	195 x 105 x 100	3617	4154	537	14.85
A5	205 x 115 x 90	3900	4498	598	15.33
A5	200 x 105 x 100	3812	4308	496	13.01
A5	210 x 115 x 90	3800	4345	545	14.34
	Average water absorption				**14.66**

Table 5. 4: Water absorption of bricks from Bombo road

BOMBO ROAD					
SITES	**BRICK SAMPLE SIZE (mm)**	**DRY WEIGHT (g)**	**SATURATED WEIGHT (g)**	**DIFFERENCE IN WEIGHT (g)**	**PERCENTAGE WATER ABSORPTION**
A1	210 x 110 x 110	4491	5163	672	14.96
A1	210 x 110 x 100	4062	4663	601	14.80
A1	210 x 110 x 100	4390	5082	692	15.76
A2	210 x 110 x 100	4449	5131	682	15.33
A2	210 x 110 x 100	4543	5219	676	14.88
A2	210 x 110 x 100	4451	5112	661	14.85
A3	210 x 110 x 100	4418	5099	681	15.41
A3	210 x 110 x 100	4029	4636	607	15.07
A3	215 x 110 x 100	4476	5148	672	15.01
A4	210 x 110 x 100	4225	4805	580	13.73
A4	210 x 110 x 100	4123	4676	553	13.41
A4	210 x 105 x 100	4039	4651	612	15.15
A5	210 x 110 x 100	4561	5203	642	14.08
A5	215 x 105 x 100	4112	4751	639	15.54
A5	210 x 105 x 100	3930	4506	576	14.66
	Average water absorption				**14.84**

Table 5. 5: Water absorption for bricks from Mityana road

MITYANA ROAD					
SITES	**BRICK SAMPLE SIZE (mm)**	**DRY WEIGHT (g)**	**SATURATED WEIGHT (g)**	**DIFFERENCE IN WEIGHT (g)**	**PERCENTAGE WATER ABSORPTION**
A1	210 X 110 X 100	4341	4999	658	15.16
A1	210 x 110 x 100	4140	4670	530	12.80
A1	210 x 110 x 110	4523	5124	601	13.29
A2	210 x 110 x 110	4623	4817	194	4.20
A2	210 x 110 x 100	4281	4457	176	4.11
A2	210 x 110 x 95	4092	4630	538	13.15
A3	210 x 110 x 100	3891	4681	790	20.30
A3	205 x 110 x 110	4332	4812	480	11.08
A3	210 x 110 x 100	4140	4586	446	10.77
A4	210 x 110 x 100	4360	4867	507	11.63
A4	210 x 110 x 100	4234	4799	565	13.34
A4	205 x 110 x 95	3961	4390	429	10.83
A5	215 x 110 x 95	4180	4726	546	13.06
A5	210 x 110 x 95	4260	4442	182	4.27
A5	210 x 110 x 95	3930	4709	779	19.82
	Average water absorption				**11.85**

Table 5. 6: Water absorption for bricks Entebbe road

ENTEBBE ROAD					
SITES	**BRICK SAMPLE SIZE (mm)**	**DRY WEIGHT (g)**	**SATURATED WEIGHT (g)**	**DIFFERENCE IN WEIGHT (g)**	**PERCENTAGE WATER ABSORPTION**
A1	200 x 100 x 100	3721	4268	547	14.70
A1	200 x 100 x 100	3744	4309	565	15.09
A1	200 x 105 x 100	3833	4340	507	13.23
A2	200 x 105 x 105	3734	4335	601	16.10
A2	200 x 100 x 100	3712	4345	633	17.05
A2	200 x 100 x 100	3632	4487	855	23.54
A3	200 x 100 x 100	3771	4356	585	15.51
A3	200 x 100 x 100	3601	4286	685	19.02
A3	200 x 100 x 100	3732	4340	608	16.29
A4	200 x 100 x 100	3804	4251	447	11.75
A4	200 x 100 x 105	3701	4312	611	16.51
A4	200 x 100 x 105	3621	4433	812	22.42
A5	200 x 100 x 105	3762	4401	639	16.99
A5	200 x 100 x 100	3691	4332	641	17.37
A5	200 x 100 x 100	3683	4221	538	14.61
	Average water absorption				**16.68**

Table 5. 7: Water absorption for bricks from Masaka road

MASAKA ROAD					
SITES	**BRICK SAMPLE SIZE (mm)**	**DRY WEIGHT (g)**	**SATURATED WEIGHT (g)**	**DIFFERENCE IN WEIGHT (g)**	**PERCENTAGE WATER ABSORPTION**
A1	220 x 135 x 80	4071	4672	601	14.76
A1	220 x 135 x 90	4615	5016	401	8.69
A1	210 x 130 x 85	4346	4780	434	9.99
A2	220 x 135 x 80	4530	4816	286	6.31
A2	225 x 135 x 90	4526	4967	441	9.74
A2	225 x 135 x 90	4467	4840	373	8.35
A3	220 x 135 x 85	4415	5036	621	14.07
A3	225 x 130 x 80	4330	4519	189	4.36
A3	220 x 130 x 85	4710	4850	140	2.97
A4	230 x 130 x 80	4645	4956	311	6.70
A4	220 x 135 x 80	4140	4556	416	10.05
A4	220 x 135 x 80	4072	4540	468	11.49
A5	225 x 135 x 80	4541	4967	426	9.38
A5	220 x 130 x 85	4556	5123	567	12.45
A5	225 x 130 x 85	4631	5052	421	9.09
	Average water absorption				**9.23**

Table 5. 8: A compressive strength of mortar cubes

MORTAR RATIOS	MORTAR CUBE SIZE (mm)	CONTACT AREA (mm2)	COMPRESSION LOAD (N)	COMPRESSIVE STRENGTH (N/mm2)	AVERAGE COMPRESSIVE STRENGTH (N/mm2)
MR1:3	100 x 100 x 100	10,000	162,300	16.23	
MR1:3	100 x 100 x 100	10,000	204,700	20.47	
MR1:3	100 x 100 x 100	10,000	166,900	16.69	17.80
MR1:4	100 x 100 x 100	10,000	139,400	13.94	
MR1:4	100 x 100 x 100	10,000	143,100	14.31	
MR1:4	100 x 100 x 100	10,000	146,200	14.62	14.29
MR1:5	100 x 100 x 100	10,000	123,500	12.35	
MR1:5	100 x 100 x 100	10,000	122,600	12.26	
MR1:5	100 x 100 x 100	10,000	123,900	12.39	12.33
MR1:6	100 x 100 x 100	10,000	67,000	6.70	
MR1:6	100 x 100 x 100	10,000	62,900	6.29	
MR1:6	100 x 100 x 100	10,000	74,800	7.48	6.82
MR1:7	100 x 100 x 100	10,000	53,500	5.35	
MR1:7	100 x 100 x 100	10,000	60,700	6.07	
MR1:7	100 x 100 x 100	10,000	63,400	6.34	5.92
MR1:8	100 x 100 x 100	10,000	47,000	4.70	
MR1:8	100 x 100 x 100	10,000	31,300	3.13	
MR1:8	100 x 100 x 100	10,000	35,200	3.52	3.78
MR1:9	100 x 100 x 100	10,000	40,300	4.03	
MR1:9	100 x 100 x 100	10,000	33,500	3.35	
MR1:9	100 x 100 x 100	10,000	33,700	3.37	3.58

MR1:10	100 x 100 x 100	10,000	29,400	2.94	
MR1:10	100 x 100 x 100	10,000	33,200	3.32	
MR1:10	100 x 100 x 100	10,000	28,500	2.85	3.04
MR1:11	100 x 100 x 100	10,000	23,900	2.39	
MR1:11	100 x 100 x 100	10,000	21,400	2.14	
MR1:11	100 x 100 x 100	10,000	31,800	3.18	2.57
MR1:12	100 x 100 x 100	10,000	29,200	2.92	
MR1:12	100 x 100 x 100	10,000	26,600	2.66	
MR1:12	100 x 100 x 100	10,000	18,800	1.88	2.49
MR1:13	100 x 100 x 100	10,000	20,400	2.04	
MR1:13	100 x 100 x 100	10,000	17,900	1.79	
MR1:13	100 x 100 x 100	10,000	19,600	1.96	1.93
MR1:14	100 x 100 x 100	10,000	18,000	1.80	
MR1:14	100 x 100 x 100	10,000	18,300	1.83	
MR1:14	100 x 100 x 100	10,000	19,900	1.99	1.87

Table 5. 9: Standard deviation of strength of bricks from Hoima road

HOIMA ROAD			
SITES	**COMPRESSIVE STRENGTH (N/mm²)** (x_i)	**VARIANCE IN COMPRESSIVE STRENGTH (N/mm²)** $s^2 = \Sigma \frac{\left(x - \bar{x}\right)^2}{(N-1)}$	$S = \sqrt{\frac{\left(x_i - \bar{x}\right)^2}{(N-1)}}$
A1	5.61		
A1	8.14		
A1	11.71	9.39	3.06
A2	10.26		
A2	8.17		
A2	5.96	4.63	2.15
A3	6.46		
A3	8.70		
A3	7.64	1.25	1.12
A4	6.47		
A4	4.68		
A4	7.66	2.25	1.50
A5	5.29		
A5	4.63		
A5	3.62	0.70	0.84
N=15	**105.00**	**3.64**	**1.73**
Ẍ	**7.00**		

Table 5. 10: Standard deviation of compressive strength of bricks from Mityana road

Mityana road			
SITES	**COMPRESSIVE STRENGTH (N/mm²)** (x_i)	**VARIANCE IN COMPRESSIVE STRENGTH (N/mm²)** $s^2 = \Sigma \frac{\left(x - \bar{x}\right)^2}{(N-1)}$	$S = \sqrt{\frac{\left(x_i - \bar{x}\right)^2}{(N-1)}}$
A1	1.59		
A1	2.65		
A1	0.93	0.76	0.87
A2	1.81		
A2	1.78		
A2	2.68	0.26	0.51
A3	3.62		
A3	1.92		
A3	1.30	1.44	1.20
A4	1.44		
A4	4.05		
A4	1.85	1.97	1.40
A5	3.45		
A5	2.35		
A5	3.64	0.49	0.70
N=15	**35.06**	**0.98**	**0.94**
Ẍ	**2.34**		

Table 5. 11: Standard deviation of strength of brick samples from Gayaza road

Gayaza road			
SITES	**COMPRESSIVE STRENGTH (N/mm²)** (x_i)	**VARIANCE IN COMPRESSIVE STRENGTH (N/mm²)** $s^2 = \Sigma \frac{\left(x - \bar{x}\right)^2}{(N-1)}$	$S = \sqrt{\frac{\left(x_i - \bar{x}\right)^2}{(N-1)}}$
A1	3.69		
A1	7.78		
A1	7.25	4.94	2.22
A2	4.71		
A2	5.68		
A2	1.09	5.87	2.42
A3	6.71		
A3	2.79		
A3	1.13	8.20	2.86
A4	3.33		
A4	7.14		
A4	3.18	5.04	2.24
A5	5.49		
A5	1.57		
A5	6.79	7.39	2.72
N=15	**68.35**	**6.29**	**2.49**
Ẍ	**4.56**	**Variance**	

Table 5. 12: Standard deviation of compressive strength of bricks on Bombo road

Bombo road			
SITES	**COMPRESSIVE STRENGTH (N/mm²)** (x_i)	**VARIANCE IN COMPRESSIVE STRENGTH (N/mm²)** $s^2 = \Sigma \frac{\left(x - \bar{x}\right)^2}{(N-1)}$	$S = \sqrt{\frac{\left(x_i - \bar{x}\right)^2}{(N-1)}}$
A1	2.56		
A1	4.07		
A1	2.02	1.13	1.06
A2	3.68		
A2	2.63		
A2	2.29	0.53	0.73
A3	3.35		
A3	3.64		
A3	1.45	1.41	1.19
A4	1.08		
A4	1.55		
A4	5.00	4.58	2.14
A5	2.83		
A5	3.75		
A5	2.02	0.75	0.87
N=15	**41.92**	**1.68**	**1.20**
Ẍ	**2.79**		

Table 5. 13:Standard deviation of compressive strength of bricks from Masaka road

Masaka road			
SITES	**COMPRESSIVE STRENGTH (N/mm²)** (x_i)	**VARIANCE IN COMPRESSIVE STRENGTH (N/mm²)** $s^2 = \Sigma \frac{\left(x - \bar{x}\right)^2}{(N-1)}$	$S = \sqrt{\frac{\left(x_i - \bar{x}\right)^2}{(N-1)}}$
A1	6.55		
A1	3.74		
A1	5.48	2.01	1.42
A2	13.42		
A2	8.55		
A2	5.25	16.92	4.11
A3	10.28		
A3	14.13		
A3	4.68	22.56	4.75
A4	4.04		
A4	7.99		
A4	14.38	27.26	5.22
A5	4.31		
A5	3.58		
A5	3.19	0.32	0.57
N=15	**109.57**	**13.81**	**3.21**
Ẍ	**7.30**		

Table 5. 14: Standard deviation of compressive strength of bricks from Entebbe road

Entebbe road			
SITES	**COMPRESSIVE STRENGTH (N/mm²)** (x_i)	**VARIANCE IN COMPRESSIVE STRENGTH (N/mm²)** $s^2 = \Sigma \frac{\left(x - \bar{x}\right)^2}{(N-1)}$	$S = \sqrt{\frac{\left(x_i - \bar{x}\right)^2}{(N-1)}}$
A1	2.73		
A1	1.34		
A1	2.69	0.63	0.79
A2	1.27		
A2	1.36		
A2	2.01	0.16	0.40
A3	2.33		
A3	4.21		
A3	1.41	2.04	1.43
A4	2.10		
A4	1.90		
A4	2.66	0.16	0.39
A5	1.46		
A5	1.90		
A5	1.49	0.06	0.25
N=15	**30.84**	**0.61**	0.65
Ẍ	**2.06**		

Table 5. 15: Standard deviation of compressive strength in bricks from Jinja road

Jinja road			
SITES	**COMPRESSIVE STRENGTH (N/mm²)** (x_i)	**VARIANCE IN COMPRESSIVE STRENGTH (N/mm²)** $s^2 = \Sigma \frac{\left(x - \bar{x}\right)^2}{(N-1)}$	$S = \sqrt{\frac{\left(x_i - \bar{x}\right)^2}{(N-1)}}$
A1	6.34		
A1	6.60		
A1	3.22	3.52	1.88
A2	2.49		
A2	3.95		
A2	4.65	1.22	1.10
A3	4.86		
A3	9.61		
A3	3.96	9.22	3.04
A4	3.13		
A4	3.53		
A4	1.87	0.75	0.86
A5	5.42		
A5	3.15		
A5	4.17	1.30	1.14
N=15	**66.93**	**3.20**	1.60
Ẍ	**4.46**	**Variance**	

Table 5. 16: Design compressive strength of masonry walls based on Eurocode 6

DESIGN OF WALL STRENGTH TO EUROCODE 6 USING TEST RESULTS				
MAJOR ROADS	**BRICK STRENGTH N/mm²** **(declared mean compressive strength),** f_{kt}	**Normalised compressive strength,** $f_b = \delta f_{kt}$ **(N/mm²)**	**MORTAR RATIO (1:3),** f_m	**DESIGN TO EUROCODE 6,** $k = 0.35$ $f_k = k\left(f_b^{0.7}\right)\left(f_m^{0.3}\right)$
Hoima road	7	8.75	17.8	3.79
Mityana road	2.34	2.93		1.76
Gayaza road	4.56	5.70		2.81
Bombo road	2.79	3.49		1.99
Masaka road	7.3	9.13		3.90
Entebbe road	2.06	2.58		1.61
Jinja road	4.46	5.58		2.76
DESIGN OF WALL STRENGTH TO EUROCODE 6 USING TEST RESULTS				
MAJOR ROADS	**BRICK STRENGTH N/mm²** **(declared mean compressive strength),** f_{kt}	**Normalised compressive strength,** $f_b = \delta f_{kt}$ **(N/mm²)**	**MORTAR RATIO (1:4),** f_m	**DESIGN TO EUROCODE 6,** $k = 0.35$ $f_k = k\left(f_b^{0.7}\right)\left(f_m^{0.3}\right)$
Hoima road	7	8.75	14.29	3.55
Mityana road	2.34	2.93		1.65
Gayaza	4.56	5.70		2.63

road				
Bombo road	2.79	3.49		1.86
Masaka road	7.3	9.13		3.65
Entebbe road	2.06	2.58		1.51
Jinja road	4.46	5.58		2.59
DESIGN OF WALL STRENGTH TO EUROCODE 6 USING TEST RESULTS				
MAJOR ROADS	**BRICK STRENGTH N/mm²** **(declared mean compressive strength),** f_{kt}	**Normalised compressive strength,** $f_b = \delta f_{kt}$ **(N/mm²)**	**MORTAR RATIO (1:5),** f_m	**DESIGN TO EUROCODE 6,** $k = 0.35$ $f_k = k\left(f_b^{\ 0.7}\right)\left(f_m^{\ 0.3}\right)$
Hoima road	7	8.75	12.33	3.39
Mityana road	2.34	2.93		1.58
Gayaza road	4.56	5.70		2.51
Bombo road	2.79	3.49		1.78
Masaka road	7.3	9.13		3.50
Entebbe road	2.06	2.58		1.44
Jinja road	4.46	5.58		2.48

Table 5. 17: Design compressive strength of masonry walls based on Eurocode 6

DESIGN OF WALL STRENGTH TO EUROCODE 6 USING TEST RESULTS				
MAJOR ROADS	**BRICK STRENGTH N/mm²** **(declared mean compressive strength),** f_{kt}	**Normalised compressive strength,** $f_b = \delta f_{kt}$ **(N/mm²)**	**MORTAR RATIO (1:6),** f_m	**DESIGN TO EUROCODE 6,** $k = 0.35$ $f_k = k(f_b^{0.7})(f_m^{0.3})$
Hoima road	7	8.75	6.82	2.84
Mityana road	2.34	2.93		1.32
Gayaza road	4.56	5.70		2.11
Bombo road	2.79	3.49		1.49
Masaka road	7.3	9.13		2.93
Entebbe road	2.06	2.58		1.21
Jinja road	4.46	5.58		2.07
DESIGN OF WALL STRENGTH TO EUROCODE 6 USING TEST RESULTS				
MAJOR ROADS	**BRICK STRENGTH N/mm²** **(declared mean compressive strength),** f_{kt}	**Normalised compressive strength,** $f_b = \delta f_{kt}$ **(N/mm²)**	**MORTAR RATIO (1:7),** f_m	**DESIGN TO EUROCODE 6,** $k = 0.35$ $f_k = k(f_b^{0.7})(f_m^{0.3})$
Hoima road	7	8.75	5.92	2.72
Mityana road	2.34	2.93		1.26
Gayaza	4.56	5.70		2.02

road				
Bombo road	2.79	3.49		1.43
Masaka road	7.3	9.13		2.80
Entebbe road	2.06	2.58		1.16
Jinja road	4.46	5.58		1.99
DESIGN OF WALL STRENGTH TO EUROCODE 6 USING TEST RESULTS				
MAJOR ROADS	**BRICK STRENGTH N/mm²** **(declared mean compressive strength),** f_{kt}	**Normalized compressive strength,** $f_b = \delta f_{kt}$ **(N/mm²)**	**MORTAR RATIO (1:8),** f_m	**DESIGN TO EUROCODE 6,** $k = 0.35$ $f_k = k\left(f_b^{0.7}\right)\left(f_m^{0.3}\right)$
Hoima road	7	8.75	3.78	2.38
Mityana road	2.34	2.93		1.11
Gayaza road	4.56	5.70		1.76
Bombo road	2.79	3.49		1.25
Masaka road	7.3	9.13		2.45
Entebbe road	2.06	2.58		1.01
aJinja road	4.46	5.58		1.74

Table 5. 18: Design compressive strength of masonry walls based on Eurocode 6

DESIGN OF WALL STRENGTH TO EUROCODE 6 USING TEST RESULTS				
MAJOR ROADS	**BRICK STRENGTH N/mm²** **(declared mean compressive strength),** f_{kt}	**Normalized compressive strength,** $f_b = \delta f_{kt}$ **(N/mm²)**	**MORTAR RATIO (1:9),** f_m	**DESIGN TO EUROCODE 6,** $k = 0.35$ $f_k = k\left(f_b^{0.7}\right)\left(f_m^{0.3}\right)$
Hoima road	7	8.75	3.58	2.342
Mityana road	2.34	2.93		1.088
Gayaza road	4.56	5.70		1.735
Bombo road	2.79	3.49		1.230
Masaka road	7.3	9.13		2.412
Entebbe road	2.06	2.58		0.995
Jinja road	4.46	5.58		1.708
DESIGN OF WALL STRENGTH TO EUROCODE 6 USING TEST RESULTS				
MAJOR ROADS	**BRICK STRENGTH N/mm²** **(declared mean compressive strength),** f_{kt}	**Normalised compressive strength,** $f_b = \delta f_{kt}$ **(N/mm²)**	**MORTAR RATIO (1:10),** f_m	**DESIGN TO EUROCODE 6,** $k = 0.35$ $f_k = k\left(f_b^{0.7}\right)\left(f_m^{0.3}\right)$
Hoima road	7	8.75	3.04	2.23
Mityana road	2.34	2.93		1.04

Gayaza road	4.56	5.70		1.65
Bombo road	2.79	3.49		1.17
Masaka road	7.3	9.13		2.30
Entebbe road	2.06	2.58		0.95
Jinja road	4.46	5.58		1.63

DESIGN OF WALL STRENGTH TO EUROCODE 6 USING TEST RESULTS

MAJOR ROADS	**BRICK STRENGTH N/mm²** **(declared mean compressive strength),** f_{kt}	**Normalised compressive strength,** $f_b = \delta f_{kt}$ **(N/mm²)**	**MORTAR RATIO (1:11),** f_m	**DESIGN TO EUROCODE 6,** $k = 0.35$ $f_k = k\left(f_b^{0.7}\right)\left(f_m^{0.3}\right)$
Hoima road	7	8.75	2.57	2.12
Mityana road	2.34	2.93		0.98
Gayaza road	4.56	5.70		1.57
Bombo road	2.79	3.49		1.11
Masaka road	7.3	9.13		2.18
Entebbe road	2.06	2.58		0.90
Jinja road	4.46	5.58		1.55

Table 5. 19: Design compressive strength of masonry walls based on Eurocode 6

DESIGN OF WALL STRENGTH TO EUROCODE 6 USING TEST RESULTS				
MAJOR ROADS	**BRICK STRENGTH N/mm²** **(declared mean compressive strength),** f_{kt}	**Normalised compressive strength,** $f_b = \delta f_{kt}$ **(N/mm²)**	**MORTAR RATIO (1:12),** f_m	**DESIGN TO EUROCODE 6,** $k = 0.35$ $f_k = k\left(f_b^{0.7}\right)\left(f_m^{0.3}\right)$
Hoima road	7	8.75	2.49	2.10
Mityana road	2.34	2.93		0.98
Gayaza road	4.56	5.70		1.56
Bombo road	2.79	3.49		1.10
Masaka road	7.3	9.13		2.16
Entebbe road	2.06	2.58		0.89
Jinja road	4.46	5.58		1.53
DESIGN OF WALL STRENGTH TO EUROCODE 6 USING TEST RESULTS				
MAJOR ROADS	**BRICK STRENGTH N/mm²** **(declared mean compressive strength),** f_{kt}	**Normalised compressive strength,** $f_b = \delta f_{kt}$ **(N/mm²)**	**MORTAR RATIO (1:13),** f_m	**DESIGN TO EUROCODE 6,** $k = 0.35$ $f_k = k\left(f_b^{0.7}\right)\left(f_m^{0.3}\right)$
Hoima road	7	8.75	1.93	1.95
Mityana road	2.34	2.93		0.90
Gayaza	4.56	5.70		1.44

road				
Bombo road	2.79	3.49		1.02
Masaka road	7.3	9.13		2.00
Entebbe road	2.06	2.58		0.83
Jinja road	4.46	5.58		1.42
DESIGN OF WALL STRENGTH TO EUROCODE 6 USING TEST RESULTS				
MAJOR ROADS	**BRICK STRENGTH N/mm^2 (declared mean compressive strength),** f_{kt}	**Normalised compressive strength,** $f_b = \delta f_{kt}$ **(N/mm^2)**	**MORTAR RATIO (1:3),** f_m	**DESIGN TO EUROCODE 6,** $k = 0.35$ $f_k = k\left(f_b^{0.7}\right)\left(f_m^{0.3}\right)$
Hoima road	7	8.75	1.87	1.93
Mityana road	2.34	2.93		0.90
Gayaza road	4.56	5.70		1.43
Bombo road	2.79	3.49		1.01
Masaka road	7.3	9.13		1.99
Entebbe road	2.06	2.58		0.82
Jinja road	4.46	5.58		1.41

Table 5. 20: Sieve analysis test of coarse grained sand

SIEVE ANALYSIS RESULTS FOR COARSE GRAINED SAND FROM RWERA SAND						
Sieve size	**Sieve numbers**	**Sieve opening, mm**	**Mass retained ,g**	**% mass retained**	**Cumulative weight passing, g**	**Cumulative % passing**
10mm		2.0	0	-	1000.0	100.00
6.3mm	.25"	6.35	5.2	1	1000.0	100.00
4.75mm	4	4.75	4.2	0	994.8	99.48
3.35mm	6	3.35	11.6	1	990.6	99.06
2.36mm	8	2.36	37.9	4	979.0	97.90
1.70mm	12	1.7	78.7	8	941.1	94.11
600um	30	0.59	546.8	55	862.4	86.24
425um	40	0.42	92	9	315.6	31.56
300um	50	0.3	147.1	15	223.6	22.36
212um	70	0.21	17.4	2	76.5	7.65
150um		0.149	30.8	3	59.1	5.91
0.063um			25.3	3	28.3	2.83
Pan			3	0	3.0	0.30
Total			**1000**	100		

Table 5. 21:Sieve analysis test for fine grained sand

SIEVE ANALYSIS RESULTS FOR FINE GRAINED SAND FROM KATOSI						
Sieve size	**Sieve numbers**	**Sieve opening, mm**	**Mass retained ,g**	**% mass retained**	**Cumulative weight passing, g**	**Cumulative % passing**
10mm		2.0	13.2	1	985.5	100.00
6.3mm	.25"	6.35	18.7	2	972.3	98.66
4.75mm	4	4.75	18.2	2	953.6	96.76
3.35mm	6	3.35	14.4	1	935.4	94.92
2.36mm	8	2.36	8.7	1	921.0	93.46
1.70mm	12	1.7	20.9	2	912.3	92.57
600um	30	0.59	276.3	28	891.4	90.45
425um	40	0.42	25.3	3	615.1	62.42
300um	50	0.3	374.9	38	589.8	59.85
212um	70	0.21	24	2	214.9	21.81
150um		0.149	115.2	12	190.9	19.37
0.063um			48.1	5	75.7	7.68
Pan			27.6	3	27.6	2.80
Total			**985.5**	100		

Table 5. 22: Specific gravity for coarse grained sand

	SPECIFIC GRAVITY AND WATER ABSORPTION RESULTS FOR COARSE GRAINED SAND FROM RWERA			
		Bottle 1	**Bottle 2**	**Average values**
A	Weight for saturated surface dried samples	528	525.2	526.6
B	Weight of bottle + water + Materials	1,047	1034.7	1040.85
B	Weight of bottle + water	724	725.3	724.7
D	Weight of immersed sand	323	309.4	316.2
E	Weight of bottle + oven dry sample	872	871.3	871.65
F	Weight of bottle alone	372	371.3	371.65
G	Weight of oven dry sample alone	500	500.0	500
	Calculations			
	Absorption (A-G)	27	25.2	26.25
	Percentage absorption [(A-G)/G]*100	5	5.0	5.25
	Bulk (Dry) Specific gravity	2	2.3	2.38
	Apparent Specific gravity	3	2.6	2.73

Table 5. 23: Specific gravity of fine grained

SPECIFIC GRAVITY AND WATER ABSORPTION RESULTS FOR FOR FINE GRAINED SAND FROM KATOSI				
		Bottle 1	**Bottle 2**	**Average values**
A	Weight for saturated surface dried samples	501.8	515.1	508.45
B	Weight of bottle + water + Materials	1,032.8	1033.4	1033.1
C	Weight of bottle + water	723.8	725.3	724.55
D	Weight of immersed sand	309.0	308.1	308.55
E	Weight of bottle + oven dry sample	871.2	871.4	871.3
F	Weight of bottle alone	372.0	371.3	371.65
G	Weight of oven dry sample alone	499.2	500.1	499.65
	Calculations			
	Absorption (A-G)	2.6	15.0	8.80
	Percentage absorption [(A-G)/G]*100	0.5	3.0	1.76
	Bulk (Dry) Specific gravity	2.6	2.4	2.50
	Apparent Specific gravity	2.6	2.6	2.61

Table 5. 24: Trial test results compressive strength of mortar cubes for testing reliability of compressive test machine

Laboratory	Number of mortar cubes(100mm x 100mm x 100mm)(1:4)	Compressive strength N/mm^2	Average compressive strength N/mm^2
Kireka M L	1	9.36	9.5
	2	9.17	
	3	9.93	
Kyambogo ML	1	6.75	6.5
	2	7.5	
	3	6.3	
UNRA Laboratory	1	9.1	9.3
	2	9.18	
	3	9.67	

Table 5. 25: Compressive strength of mortar cubes, fine grained sand only

Fine grained sand only at 28 days			
mortar ratio	**contact area (100 mm x 100mm)**	**Compression load N**	**Compressive strength N/mm^2**
MR1:3	10000	93200	9.32
MR1:4	10000	56200	5.62
MR1:5	10000	48200	4.82
MR1:6	10000	39900	3.99
MR1:7	10000	42700	4.27
MR1:8	10000	10900	1.09
MR1:9	10000	23300	2.33
MR1:10	10000	13800	1.38
MR1:11	10000	9200	0.92
MR1:12	10000	6700	0.67

Table 5. 26: Compressive strength of mortar cubes, Coarse grained sand only

Coarse grained sand only at 28 days			
mortar ratio	**contact area (100 mm x 100mm)**	**Compression load N**	**Compressive strength N/mm^2**
MR1:3	10000	112100	11.21
MR1:4	10000	64900	6.49
MR1:5	10000	12300	1.23
MR1:6	10000	25400	2.54
MR1:7	10000	18300	1.83
MR1:8	10000	5700	0.57
MR1:9	10000	7800	0.78
MR1:10	10000	6800	0.68
MR1:11	10000	6500	0.65
MR1:12	10000	6100	0.61

Table 5. 27: Compressive strength of mortar cubes made of mix proportions of Cement : Fine sand : Coarse sand

Mix proportions of Fine grained and Coarse grained sand only at 28 days			
mortar ratio	**contact area (100 mm x 100mm)**	**Compression load N/mm^2**	**Compressive strength N/mm^2**
MR1:3	10000	51200	5.12
MR1:4	10000	33300	3.33
MR1:5	10000	33200	3.32
MR1:6	10000	25900	2.59
MR1:7	10000	21100	2.11
MR1:8	10000	15700	1.57
MR1:9	10000	8100	0.81
MR1:10	10000	6900	0.69
MR1:11	10000	4500	0.45
MR1:12	10000	4300	0.43