INVESTIGATING THE SUITABILITY OF CEMENT STABLIZED MURRAM SOIL AS MORTAR FOR CONSTRUCTION

BY

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Declaration

I declare that this is my original work and that any other persons' work referred to has been properly cited and not plagiarized. I also declare that this work has never been submitted anywhere else for any other certificate, diploma or degree.

Name: .... Signature: ....

Date: ....

Approval

This is to approve that Isaac Siende carried out research on investigating the suitability of cement stabilized murram soil as mortar for construction under my prompt supervision. It is therefore ready for submission to Kabale University for the award of the degree in Civil Engineering.

Supervisor: Mr. Angello Murekye

Signature: ....

Date: ....

Dedication

This report is dedicated to my loving parents, Wanaba Luqman and Nanzala Annet for their continuous support throughout my social and academic life. I also thank my uncle and my supervisor for everything they did for me.

Acknowledgement

My special gratitude for guidance and encouragement in doing this study goes to my supervisor Mr. Angello Murekye. I am especially grateful to my uncle Namukoye Rajab, Tumusiime Sharon and Siende Joseph for support in my studies. Finally, to the laboratory technicians at the Central Materials Laboratory in Kireka Kampala who went out of their way to assist me finish my soil laboratory tests on schedule.

Abstract

Masonry mortar is a homogenous mixture comprising of fine aggregates, binding material and water. The increase in the cost and demand of sand for construction is becoming a problem and making the construction more expensive in some parts of the country. Therefore, the replacement of sand-based mortars with soil-based mortars will be economical in the construction.

This research addresses on an experimental study to understand the suitability of cement stabilized murram soil of G3 as mortar for construction. Critical properties of mortar have been studied i.e., Workability and Plasticity, Flexural and Compressive Strength, the Bond strength, the Initial and Final setting time of the mortars.

The mortar with 0%, 15%, 20%, 25%,50%, 60%, and 75% replacement of sand in murram soil and without varying the percentage of cement was conducted. Their compressive and flexural strength obtained. The compressive strength at the age of 28 days lied within the range of 9.73MPa to 16.42MPa which is acceptable as per the IS code specification, the minimum strength requirement of mortar to be 3 MPa. The initial and final setting time lied in the range of 120 minutes and 150 minutes and the final setting time lied in the range of 270 minutes and 300 minutes for cement and murram mortars respectively. The recommended range of mortar to be used for construction is 30 minutes minimum and 600 minutes maximum for initial and final setting time respectively. The workability of the murram mortar was 82% and the plasticity index of the murram soil was 25%, which lied within the recommended range.

The conclusions of the investigation of murram soil shows that the use of cement stabilized murram mortar can be applied in construction as far as the investigated parameters are concerned.

List of Abbreviations

ASTM	American Standard of Testing and Measurements
AASHTO	American Association of State Highway and Transport Officials
BS	British Standard
IS	International Standard
CBR	California Bearing Ratio
CML	Central Materials Laboratory
FI	Flakiness Index
Gs	Specific gravity
LL	Liquid Limit
LS	Linear Shrinkage
MC	Moisture Content
MDD	Maximum Dry Density
MOWT	Ministry of Works and Transport
OMC	Optimum Moisture Content
PI	Plasticity Index
PL	Plastic Limit
N/mm^2	Newton per millimeter Squared
MPa	Mega Pascal
Kg/m^3	Kilogram per cubic meter
OPC	Ordinary Portland Cement
EN	European standard
UCS	Ultimate Compressive Strength
FM	Fineness Modulus
PSD	Particle Size Distribution
P425	Percentage material passing the 0.425 mm Sieve
DCP	Dynamic Cone Penetrometer
&	And

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CHAPTER ONE: INTRODUCTION

1.1 Background

Mortar is a paste prepared by adding required quantity of water to a mixture of binding material like cement or lime with sand. The binding material and sand are sometimes referred to as matrix and adulterant. The primary function of the mortar is to bind together the individual brick or block units. Mortar is a plastic mixture of water and binding materials used to join concrete blocks, bricks or other masonry units.

Soil has been, and continues to be among the most widely used building material after concrete, and wood throughout most developing countries: it is cheap, available in abundance, and simple to form into building elements (Morris and Booysen 2000).

In the present development, where the supply of sand is declining short of meeting the demand, it becomes imperative to find a different alternative.

Therefore, the replacement of sand-based mortars with soil-based mortars will be economical in some parts of the country.

It is desirable for mortar to hold moisture, be plastic enough to stick to the trowel and the blocks or bricks and finally to develop adequate strength without cracking.

Mortar need not be stronger than the units it joins. In fact, cracks are more likely to appear in the blocks or bricks if the mortar is excessively strong.

1.2 Problem Statement

The increase in the cost, scarcity, and demand of sand for construction is becoming a problem and making the construction more expensive in some parts of the country. In the present development, where the supply of sand is declining short of meeting the demand, it becomes imperative to find a different alternative. Therefore, the replacement of sand-based mortars with soil-based mortars will be economical in the construction.

1.3 Objectives

1.3.1 General Objective

- To investigate the Suitability of Cement Stabilized Murram Soil as Mortar for Construction.

1.3.2 Specific Objectives

- To prepare the different mix ratios of cement stabilized laterite soil;
- To determine the critical properties of cement stabilized laterite soil i.e., workability and plasticity, consistency, flexural and compressive strength;
- To analyze the results and determine their suitability.

1.3 Justification

The appropriate use of earth construction will produce cost-effective buildings thus economically beneficial in the construction in some parts of our country Uganda. Other beneficiaries include people in the tourism and cultural heritage industry who need to stabilize ancient architectural remains using their original materials (Amos, 2014).

Earth construction is economically beneficial. The use of excavated soil means greatly reduced costs in comparison with other building materials. Even if this soil is transported from other construction sites, it is usually much cheaper than industrial building materials.

Earth construction is less durable as a construction material compared to conventional materials and is mostly suitable for in situ construction (Amos, 2014).

CHAPTER TWO: LITERATURE REVIEW

This chapter provides an overview of literature within the proposed research area and this include:-

1. Soil Classification (Atterberg limits and Grading);
2. Workability and Plasticity (flow table test);
3. Consistency (Vicat needle);
4. Flexural and Compressive strength.

2.1 Soil Classification

Soil is a natural body comprised of solids (mineral sand organic matter), liquid, and gases that occurs on the land surface, occupies space, and is characterized by one or both of the following: horizons, or layers, that are distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy and matter or the ability to support rooted plants in a natural environment. The formation of soil happens over a very long period of time. It can take 1000 years or more. Soil is formed from the weathering of rock sand minerals. The surface rocks breakdown into smaller pieces through a process of weathering and is then mixed with moss and organic matter. Soil may be classified differently for Engineering purpose namely: -

(i) Grain Size Classification System for Soils. Grain size classification systems were based on grain size. In this system the terms clay, silt, sand and gravel are used to indicate only particle size and not to signify nature of soil type.

(ii) Textural Classification of Soil. The classification of soil exclusively based on particle size and their percentage distribution is known as textural classification system. This system specifically names the soil depending on the percentage of sand, silt and clay. The triangular charts are used to classify soil by this system. Texture indicates the relative content of particles of various sizes, such as sand, silt and clay in the soil. Texture influences the ease with which soil can be worked, the amount of water and air it holds, and the rate at which water can enter and move through soil.

(iii) AASHTO Classification System of Soil. AASHTO classification was originally developed in 1920 by the U.S. Bureau of Public Roads for the classification of soil for highway subgrade use. This system is developed based on particle size and plasticity characteristics of soil mass. After some revision, this system was adopted by the AASHTO in 1945. In this system the soils are divided into seven major groups. Some of the major groups further divided into subgroups. A soil is classified by proceeding from left to right on the classification chart to find first the group into which the soil test data will fill. Soil having fine fractions are further classified based on their group index. The group index is defined by the following equation.

Group index = (F – 35) [0.2 + 0.005 (LL – 40)] + 0.01(F – 15) (PI – 10)

Where, F – Percentage passing 0.075mm size, LL – Liquid limit, PI – Plasticity index.

(iv) Unified Soil Classification System. Unified soil classification system was originally developed by Casagrande (1948) and was known as airfield classification system. This system is based on both grain size and plasticity characteristics of soil. The same system with minor modification was adopted by IS for general engineering purpose (IS 1498 – 1970). IS system divides soil into three major groups, coarse grained, fine grained and organic soils and other miscellaneous soil materials. Coarse grained soils are those with more than 50% of the material larger than 0.075mm size. Coarse grained soils are further classified into gravels (G) and sands (S). The gravels and sands are further divided into four categories according to gradation, silt or clay content. Fine grained soils are those for which more than 50% of soil finer than 0.075 mm sieve size. They are divided into three sub-divisions as silt (M), clay (C), and organic salts and clays (O) based on their plasticity nature they are added with L, M and H symbol to indicate Low, Medium, and High.

2.2 Soil Characterization

Soils used in mortars are characterized according to the following parameters: -

i. Color;
ii. Atterberg limits (liquid limit, plastic limit and plasticity index);
iii. Particle size distribution (PSD);
iv. Soil density;
v. Air content.

2.2.1 Color

Soil color is measured in accordance with ASTM D1535-97, Standard Practice for Specifying color by the Munsell System. Soil colors are specified according to three criteria: Value, Chroma and hue. The value indicates the lightness of the soil. Chroma is meant to indicate the strength or neutrality of the soil color for its given lightness. The hue notation establishes a soil color in reference to its closeness to the colors red and yellow (Zinn, 2005).

2.2.2 Atterberg Limits

Atterberg limits are a basic measure of the critical water contents of a fine-grained soil, such as its shrinkage limit, plastic limit, and liquid limit. As a dry, clayey soil takes on increasing amounts of water, it undergoes dramatic and distinct changes in behavior and consistency.

- The plastic limit is the moisture content that defines where the soil changes from a semi-solid to a plastic (flexible) state;
- The liquid limit is the moisture content that defines where the soil changes from a plastic to a viscous fluid state.

Objective of the Atterberg limit test

This test is usually performed in the laboratory to determine the plastic and liquid limits of a fine-grained soil. The liquid limit (LL) is arbitrarily defined as the water content, in percent, at which a part of soil in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm when subjected to 25 shocks from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of two shocks per second. The plastic limit (PL) is the water content, in percent, at which a soil can no longer deform by rolling into 3.2 mm diameter threads without crumbling.

Clay Soil

Clay is a type of fine-grained natural soil material that contains hydrous Aluminium phyllosilicates that develops plasticity when wet. Geologic clay deposits are mostly composed of phyllosilicate minerals containing variable amounts of water trapped in the mineral structure. Clays are the main binders of earth and are made up of very small mineral particles (< 2 microns), leached out during erosion of rock. The molecular structure of clays consists of sheets of silicate and aluminate ions. Electrostatic forces set up within such structures produce binding properties. Clay is a product of the erosion of feldspar and other minerals. Feldspar contains Aluminium oxide, a second metal oxide and silicon dioxide. One of the most common types of feldspar has the chemical formula $Al_2O_3 \cdot K_2O \cdot 6SiO_2$.

The presence of clay in moderate amounts in a soil is desirable. Since clay has cohesive nature, it imparts plasticity to the soil when under moist conditions. Plasticity is due to the thin film of absorbed water which adheres strongly to the clay layers thus linking the particles together. Although, due to certain drawbacks are of clay are the facts that it has a high affinity towards water. Clayey soils swell in presence of water and shrinks in the absence of it. If the clay mineral is montmorillonite, this kind of swelling and shrinking is more prominent. Such volume instability is not highly undesirable in mortars. Therefore, soils which have clay content below 30% can be stabilized using cement and soils which have clay content above 30% can be stabilized using lime (K, 2014).

2.2.3 Particle Size Distribution (PSD)

Analysis of soil particle size distribution is performed according to ASTM D422-63, Standard Test method for Particle-Size Analysis of Soils. Also referenced is the ASTM C136-01, Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates. Particle size designations established by ASTM are followed in this characterization.

Table 2.1: Astm Soil Classification

Astm Soil Classification				
Pebbles	**Gravel**	**Sand**	**Silt**	**Clays**
200 to 20 mm	20 to 2 mm	2 to 0.06 mm	0.06 to 0.002 mm	0.002 to 0 mm

(Manette, 2014)

Sand

Sand is a natural product which is obtained as river sand, nalla sand and pit sand. However, sea sand should not be used for the following reasons:

1. It contains salt and hence structure will remain damp. The mortar is affected by efflorescence and blisters appear;

2. It contains shells and other organic matter, which decompose after some time, reducing the life of the mortar.

Sand may be obtained artificially by crushing hard stones. Usually, artificial sand is obtained as a by-product while crushing stones to get jelly (coarse aggregate).

Sand is used in mortar and concrete for the following purpose:

i. It sub-divides the paste of cement into thin films, allows it to adhere and spread;
ii. It fills up the gap between the building blocks and spreads the binding material;
iii. It allows carbon dioxide from the atmosphere to reach some depth and thereby improve setting power.

The properties of good sand are:

i. It should be free from organic or vegetable matter;
ii. It should be well graded;
iii. It should be hard.

Gradation of Fine Aggregates

The gradation of sand is given by sieve analysis. The sieve analysis is done by passing sand through a set of standard sieves and finding out cumulative passing percentage through each sieve. The fineness modulus of sand varies from 2.0 to 4.0; the higher the FM the coarser is the sand.

Table 2.2: Fineness Modulus of Sand

Type of Sand	F M
Fine	2.0 to 2.8
Medium	2.8 to 3.2
Coarse	3.2 and above

(Amos, 2014)

Specific gravity of fine aggregates

This is the ratio of solid density of sand particles to the density of water. Higher the specific gravity, heavier is the sand particles and higher is the density of concrete. Conversely a lower specific gravity of sand will result in lower density of concrete. Specific gravity of sand is found with help of pycnometer bottles. The specific gravity of fine aggregates found in Pune region varies from 2.6 to 2.8.

The figure 1 below shows the ASTM sieve stack and mechanical shaker for grading.

Figure 1: ASTM Sieve stack and Mechanical shaker

2.3 Workability

Is the ease with which mortar can be handled while placing it. Workability of mortar includes two aspects as fluidity and water retention.

2.3.1 Fluidity

The fluidity of mortar, also called "consistency", is defined as the performance of flowing motion created by its self-weight or external force. It is measured with mortar consistometer, taking the sinking depth (mm) as mortar's consistency index. Mortar consistency varies along with these factors: the amount of water consumption, types and the amount of the adopted cementing material and the amount of mortar itself.

2.3.2 Water Retention

The ability of newly-mixed mortar to retain its internal water from leakage loss is called "water retention", which is measured with mortar lamination cone and represented with lamination degree (mm). Bigger lamination degree shows that mortar is easy to delaminate and separate, which has negative influence to construction or cement hardening.

Mortars with good workability usually have the following properties;

- Sticks to the brick, Light, Easy to spread mortar bed, Easy to squeeze mortar bed, Stiffens too fast due to water loss.

2.3.3 Flow Table Test for Cement Mortar

The flow table is the most widely accepted apparatus to measure the consistency of mortar. It consists of a circular plate which is lifted and then dropped over a specified height. The basic principle of slump and flow tests is that a sample is poured or scooped in a conical or cylindrical frustum, which is then carefully lifted, so that the material is allowed to deform under its own weight.

The flow table test of cement mortar is done only to calculate the amount of water required for gauging, conducting strength test of masonry cement and for drying shrinkage test of cement.

2.4 Mortar and Cement Strength

Mortar mix is a combination of cement and sand that is used to hold together construction type blocks. When water is added, it becomes a workable paste that sets hard. It is used with materials like bricks and stones to make walkways and walls. Mortar was originally made of mud or clay. There is evidence of the use of mortar in cultures around the world. Iranian and Babylonian structures used mortar from about 2900 BC on. The earliest Egyptian pyramids used the mud or clay combination, while later buildings used gypsum or lime. This continued on with the ancient Greeks and Romans who perfected the use of concrete and mortar in building their elaborate city schemes. In later cultures, the water-soluble ingredient lime became the primary active ingredient, which was ultimately damaging to the stability of many structures. There are many grades of mortar mixes found at home improvement stores. It is important to recognize that each has its place in construction. Consumers should always purchase the mortar mix that is intended for their project (Batham, 2019).

The figure two (2) below show the mortar time line chart used to differentiate mortar types.

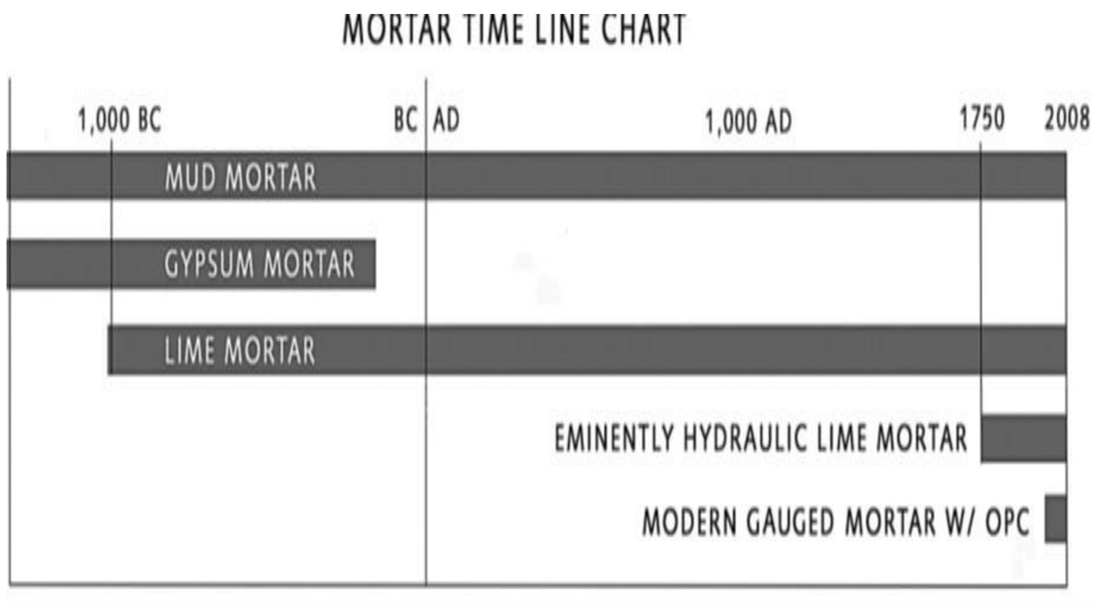

Figure 2: Mortar time line chart

2.4.1 Properties of Mortar

i. It should have good adhesion with bricks, stones;
ii. It should be cheap and durable;
iii. It should easily be workable;
iv. It should be in position to maintain its original appearance for sufficiently long period of time (Duggal, 2008) (M.Vishnukanth, 2006) (Arya, 2009).

However, mortar becomes more susceptible to frost attack in saturated, or near saturated, conditions but this can be offset by adding a plasticizing agent. For most forms of masonry construction, a 1:1:6 cement-lime-sand mortar is suitable. Mortar may account for as little as 7% of the volume of a masonry wall; but the role that it plays and the influence that it has on performance are far greater than the proportion it indicates, selection and use of various mortar ingredients directly affects the performance and bonding characteristics of masonry (Arya, 2009).

2.4.2 Functions of mortars

- To bind the building units such as bricks, stones;
- To carry out painting and plaster works on exposed surfaces of masonry;
- To form an even bedding layer for building units;
- To form joints of pipes;
- To improve the appearance of structure.

2.4.3 Classifications of Mortars

Based on apparent density

According to bulk density of mortar in dry state, the mortars are two types; -

- Heavy mortars: bulk density is more than 1500kg/m3 and prepared from heavy quartz.
- Lightweight mortars: bulk density is less than 1500/mg3 and prepared from light porous sands.

Based on kinds of binding material

The governing factors in deciding a particular type of mortar for a specific structure depends upon the desired strength of masonry, resistance to penetration of rain water, immediate and long-term appearance, hardening temperature, expected working conditions of the building and also cost. The mortars are classified into four categories:

- Lime Mortar, Cement mortar, Gauged Mortar, Gypsum mortar (Bhavikatti, 2010).

Based on strength

Building mortars are subdivided into nine grades on the basis of compressive strength from 0.4 to 30.0 MPa.

Mortar strength classifications according to ASTM C270 - 14a (Standard Specification for Mortar for Unit Masonry) include: -

Type N – All purpose;

Type S – High flexural bond strength;

Type M – High compressive strength but low workability;

Type O – Low strength, usually limited to interior applications.

Bond is an important property of hardened mortar. Bond strength is the ability of the mortar to adhere to the masonry unit. The strength of the mortar depends on the cohesion of the binder, its adhesion to the aggregate particles and to a certain extent on the strength of the aggregate itself. The extent of bond is a measure of the actual contact area at the interface of the mortar and masonry units. The bond strength is a measure of the tensile stress required to break the bond between mortar and masonry units.

Based on nature of application

According to the nature of application, the mortars are classified into two categories namely; -

- Brick laying mortars and Finishing mortars (Duggal, 2008).

2.5 Soil Based Mortars

Soil-based mortars are made of earth thinned with fine-grain and/or fine-fibrous additives. Depending upon their usage they are known as earth masonry mortar, sprayed earth mortar. Earth masonry mortars are used for bricklaying with earth bricks as well as with blocks. This study will mainly focus on earth masonry mortars. Murram is soil of humid tropical or equatorial zones. It is characterized by a deep weathered layer from which silica has been leached. There is no humus, but an accumulation of Aluminium, iron oxides, and hydroxides. The reddish colour of these soils is imparted by the iron compounds. They are generally impervious. Murram is typically an Indian term. The geological equivalent term is Lateritic soil (Manette, 2014).

2.5.1 Nature of the Problem

When building with earth, one is confronted with two basic options;

- The type of soil available on site dictates the building system.
- The building system, having been predetermined, dictates the use of a particular type of soil.

In the first instance, architecture, takes account of the site context and determines the building systems which will ensure the durability of the buildings; architectural choices act as a "stabilizer". This is the first approach to be preferred and used.

In the second instance, it is the manufacturing technique, often alien to the site, which ensures the durability of the materials used, more or less independently of the building systems; the process and the addition of material(s) act as a stabilizer.

In this study, we shall deal with the second instance, i.e., the improvement of the soil by adding stabilizers (materials). Every kind of soil, however, has a corresponding suitable stabilizer.

There are more than a hundred products in use today for stabilization. For this study we shall use the cement stabilizer to stabilize the murram soil.

2.5.2 Objectives of Soil Stabilization

Soil stabilization is the process of elimination of swelling properties of soils to enhance its shear strength and improve its load bearing capacity. Only two characteristics of the soil itself can be treated: its structure and its texture.

There are three ways of treating the structure and the texture of a soil:

- Reducing the volume of voids between the particles, i.e., affecting its porosity;

- Blocking up the voids which can't be eliminated, i.e., affecting its permeability;
- Improving the links binding the particles together, i.e., affecting its mechanical strength.

The main objectives being pursued are:

- Obtaining better mechanical performances: increasing dry and wet compressive strength;
- Reducing porosity and variations in volume: swelling and shrinking with moisture content variations;
- Improving the ability to withstand weathering by wind and rain: reducing surface abrasion and increasing waterproofing (cement stabilization).

2.6 Strength/grade of Cement

Grade of cement e.g. 33 grade, 43 grade or 53 grades can influence the mix design. Grade of cement indicates minimum strength of cement in N/mm2 tested as per standard conditions laid down by IS codes (OPC 43 grade – IS 8112-1989, OPC 53 grade – IS 12269 – 1987 e.g., a 43-grade cement should give minimum strength of 43 N/mm2 at 28 days). The higher the strength of cement, the higher the strength of mortar for the same water/cement ratio. In other words, a higher strength of cement permits the use of higher water/cement ratio to achieve the same strength of mortar.

Standard mix proportions should be chosen from the various mix ratios available depending on purpose of the mortar to be used i.e., (1:1, 1:2, 1:3, 1:4, 1:6, 1:8).

The quantity can be calculated in two ways;

1. Volume method;
2. Weight method.

Much research has been done on the characteristics of mortars. Most of these studies focused on cement mortar, lime mortar, cement-soil mortar, etc. There are no dedicated studies on partial and complete replacement of sand and the optimum binders required. There have been many studies that focus on cement soil mortars which help in deducing what parameters are to be applied in the present study. Results of some earlier researchers on mortars are highlighted below.

1. Walker and Stace studied the properties of some cement stabilized earth blocks and mortars. The effect of soil properties and cement content on the mortar was studied. They found that increase in clay fraction decreased the compressive strength while increase in cement content increased the strength of the mortar (Suraj.M.C, 2016).

2. Reddy and Gupta based one of their research works purely on finding the characteristics of cement-soil mortars. They carried out tests on cement-soil mortar, cement mortars and cement-lime mortars and compared the results. They used red loamy soil which contained 16% clay fraction containing kaolonite clay mineral. Flow values signify the workability of the mortar. A linear relationship exists between water cement ratios and flow value of mortars. As the water-cement ratio increases, flow value increases. Very high flow value of 130% can be achieved for cement soil mortars and cement lime mortars (Suraj.M.C, 2016).
3. Rampezzi and Roberto studied the behavior of brick-and-mortar interface. The samples were taken from the Basilica di San Lorenzo in Milan. They found that thin layer of light colour was formed which was the reason for the pozzolanic reactions. This layer mostly consisted of calcium and silica. Through this study they deducted that the calcium hydroxide in the mortar and the silica in the brick dust reacted to give silicates thus forming a bond between lime and brick dust which strengthens the mortar (Suraj.M.C, 2016).
4. Reddy explored the enhancing bond strength and characteristics of soil-cement block masonry. The masonry was tested with two types of mortar namely cement-soil mortar (CSM) and cement lime mortar (CLM) with flow value of 100% (Gupta 2003). Mortar compressive strength was determined from 7cm cubes. A 28-day compressive strength was 3.45 and 2.93 MPa for CSM and CLM mortars, respectively (Suraj.M.C, 2016).

Some of the areas where mud mortar or earth mortars has been used include the following: -

The use of earthen mortars in the Middle-East, central Asia and the south-western USA is also well documented. In many parts of the world – such as Yemen and Bhutan – there remains a live tradition of use of mud mortars in masonry works. Elsewhere these traditional uses of earth in construction have either been lost to the methods or materials of modern building technology.

From the evident quality of their workmanship, masons in Malton, at least, were highly skilled from the early medieval period onwards, with a deep understanding of their materials. If not from their superior skills, Old Malton Priory, one of the finest early English churches, would not have survived into the modern period. This is together with the many other old structures in Malton. These were commonly used in both high and lower status buildings some of which are still standing to present day e.g., the York House, a late 15th century H-plan house of high status and the gatehouse of Eure mansion.

The figure three (3) below shows the Earth pise mud mortar stone, in Granada Spain.

Figure 3: Earth pise mud mortar stone, in Granada Spain

The figure four (4) below shows the south elevation York house in Malton town.

Figure 4: South elevation, York House, Malton

The fact that some of the buildings built with this technology are standing to date is evidence enough that earth mortars can still be used and also improve its properties by stabilizing it with the cement.

The figure five (5) below shows the use of earthen mortars for construction of a house in Bududa district in Uganda.

Figure 5: Brick work bonded with soil mortar

CHAPTER THREE: METHODOLOGY

3.1 Introduction

The objective of this study was to investigate if the replacement of cement mortar with stabilized murram mortars would result in desirable mortar properties such as; compressive strength, good plastic consistency and workability, bond strength and sufficient setting time. The tests carried out on the sample were those seen to be most crucial to mortars and they are as follows: -

3.2: Preparation of the stabilized earth mortars

Table 3. 1: Mix design of mortar using 40*40*160mm mould

Grade of mortar	Masonry work
Mortar type	N
Cement	450g
Sand	1350g
Water	225 liters

Source EN 196-1:2016 (Standard Cement Test) (Zinn, 2005)

Type N

Type N is of medium strength, which means it is the best choice for projects with bricks that are not load bearing. Also, Garden walls, and Chimneys are common applications for this mix.

Table 3. 2: Mix proportions of the sample by weight method

Percentage ratio of sand and murram soil	Cement	Sand	Murram
100% sand	1	3	0
75% sand & 25% murram	1	2.25	0.75
60% sand & 40% murram	1	1.8	1.2
50% sand & 50% murram	1	1.5	1.5
25% sand & 75% murram	1	0.75	2.25
20% sand & 80% murram	1	0.6	2.4
15% sand & 85% murram	1	0.45	2.55
0% sand & 100% murram	1	0	3

3.3 Atterberg limits

3.3.1 Equipment's used

Casagrande's apparatus, Porcelain (evaporating) dish, Flat grooving tool with gauge, Mortar and pestle, eight moisture tins, Balance, Glass plate, Spatula, Wash bottle filled with distilled water, drying oven set at 105°C.

3.3.2 Test Procedure for Liquid Limit determination

- The sample was first air-dried for a minimum of 24hours on a metallic tray till the soil sample had completely physically lost all the moisture.
- The air-dried soil was crushed using a small mortar and pestle and was passed through a 425µm-sieve.
- The sample that passed through the 425µm-sieve was then mixed with a small amount of distilled water to make a semi-plastic mould and left it to stand for 24 hours in a water/ air proof bag to ensure thorough water penetration into the sample process known as curing.
- The cured sample was then removed from a water proof/ polythene bag and thoroughly mixed the moist sample with a palette knife until a smooth uniform paste was obtained.
- Six of the empty moisture cans were weighed with their lids, and recorded their respective weights and can labels on the data sheet.
- The Casagrande's apparatus was then adjusted by checking the drop height of the cup, the point on the cup brought in contact with the base was raised to a height of 10 mm and the block on the end of the grooving tool 10 mm high was used as the gauge.
- A portion of the previously mixed soil was placed into the cup of the Casagrande's apparatus and spread it into the cup to a depth of about 10 mm at its deepest point.
- The grooving tool was carefully used to cut a clean straight groove down the center of the cup. The tool remained perpendicular to the surface of the cup as the groove was being made.
- The crank of the apparatus was turned at a rate of approximately two bumps per second and counted the number of bumps, required to make the two halves of the soil part come into contact at the bottom of the groove.
- Using the spatula, we took from edge to edge including both sides of the portion of the sample where the groove came in contact. We then placed a small portion of that sample

into two moisture cans, and immediately weighed the moisture cans containing the soil and recorded their masses for average moisture determination.

- The soil remaining was placed in the cup into the porcelain dish. Cleaned and dried the cup on the apparatus and the grooving tool.
- Remixed the entire soil specimen on a glass block, small amount of distilled water was added to increase the water content so that the number of bumps required to join the groove decreased.
- The above procedures were repeated for at least two additional trials producing successively lower numbers of bumps to join the groove. One of the trials for closure requiring 25 to 35 bumps, one for closure between 20 to 30 bumps, and one trial for a closure requiring 10 to 20 bumps.
- The cans were then measured with the moistened sample into the oven and left in the oven for at least 16 hours at temperature of about 105^{o}c to 110^{o}c.
- The water content was determined for each trial.

3.3.3 Plastic Limit determination

a) The remaining empty moisture cans were weighed, recorded their respective weights and can numbers on the data sheet.

b) Take the remaining thoroughly mixed sample of the original soil re-mixed until the soil was at a consistency where it could be rolled without sticking to the hands.

c) Formed the soil into an ellipsoidal mass. Rolled the mass between the palm of the fingers and the glass plate using sufficient pressure to roll the mass into a thread of uniform diameter by using about 90 strokes per minute.

d) When the diameter of the thread reached the correct diameter, the thread was broken into several pieces. Knead and reformed the pieces into ellipsoidal masses and re-rolled them.

e) Continued this alternate rolling, gathering, kneading and re-rolling until the thread crumbled under the pressure required for rolling and could no longer be rolled.

f) Gathered the portions of the crumbled threads together and placed them into a moisture can, immediately weighed the moisture can containing the soil threads, recorded its mass and placed the can into the oven. Left the moisture can in the oven for at least 16 hours.

g) Repeated steps c), d) and e) at least two more times.

h) Determine the water content. Hence, Plasticity Index = Liquid limit – Plastic Limit

3.4 Workability

Apparatus

Balance, Mixer, Flow table, Tamping rod.

Environmental Condition;

Temp 27 ± 2^{0}C; Humidity (Relative) 65 ± 5 %.

Test Procedure

1. Taking 420g of cement & 1440 g of standard sand and a trial percentage of water was done.
2. The ingredients were mixed mechanically with the help of a mixer.
3. The mixing water is placed in the bowl.
4. The masonry cement was added to the water, then the mixer was started at the slow speed (140±5 rev/min) for 30s.
5. The entire quantity of sand was added slowly over a period of 30 s, while mixing at slow speed.
6. The mixer was stopped and changed to medium speed (280±10 rev/min), for 30 s.
7. The mixer was stopped and the mortar was let to stand for one and a half minutes.
8. Upon the completion of mixing, the paddle was shaken to remove excess mortar into the mixing bowl.
10. Carefully, the flow table was wiped to clean the top, and the mould was placed at the Centre.
11. About 25 mm thick layer of mortar was placed in the mould and tamped 20 times with tamping rod.
12. The mould was filled with mortar and tamped as specified for the first layer.
13. The excess mortar was cut off by drawing the straight edge of a trowel with a sawing motion across the top of the mould.
14.The mould was lifted away from the mortar one minute after completion of the mixing operation.
15. Immediately the table was dropped through a height of 12.5 mm, 25 times in 15s. So fresh mortar will spread over the table. The average diameter of the mortar was measured using the Vernier caliper.

Calculation,

Flow = ((average diameter of the mortar- inner base diameter of the mould)/ inner base diameter of the mould) *100

Flow = $[(D_{aveg} – D_0) / D_0]$ *100

Where,

Daveg =Average base diameter of the mortar

D0 =Original base diameter of the mould

Precautions

- The material for moulding each batch of test specimen shall be mixed separately.
- Tamping pressure must be sufficient to ensure uniform filling of the mould.

Figure 6: Flow table Apparatus

The figure below shows the flow of mortar using the flow table apparatus.

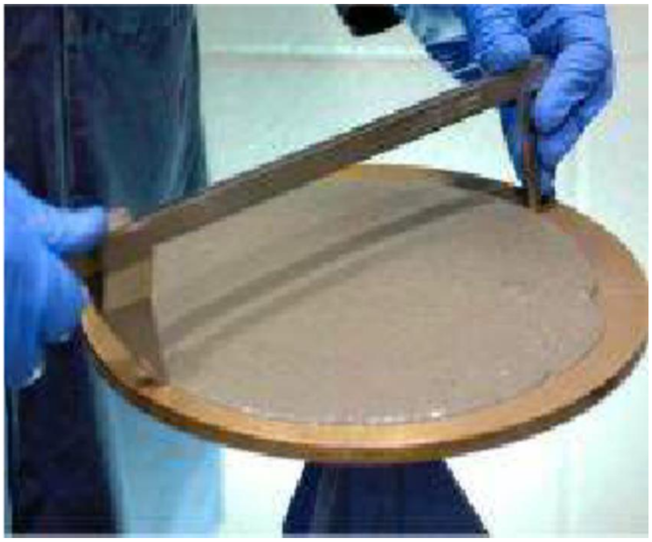

Figure 7: Mortar flow using flow table Apparatus

3.5 Tests on Cement

Tests on cement can be carried out either in the laboratory or in the field but for this report, the tests were carried in the laboratory for example, tests on consistency, final and initial setting time of cement. Consistency is the degree of wetness of mortar.

3.5.1 Setting Time

Setting time is the time required for stiffening of cement paste to a defined consistency. This test is used to determine a nominal time period after which hydraulic cement mixtures can be expected to harden and, in this case, to establish a comparison between the hardening times required by each soil-cement formulation being tested. The determination of the time of setting for the mortars was done according to ASTM C191-99, Standard Test Method for Time of Setting of Hydraulic Cement by Vicat Needle.

Apparatus

Vicat apparatus shall consist of:

- Vicat apparatus with a movable rod of mass 300g, A removable straight steel needle with a diameter of 1mm and a length of not less than 50 mm, Flat trowel, having a sharpened straight-edged steel blade 100 to 150 mm in length, Mixer, bowl and paddle, Stop watch, Conical ring, made of a rigid, non-corroding, non-absorbent material having a height of 40mm and an inside diameter 70mm and an outside diameter of 80mm.

The figure below shows the apparatus of the Vicat needle with all the parts labeled.

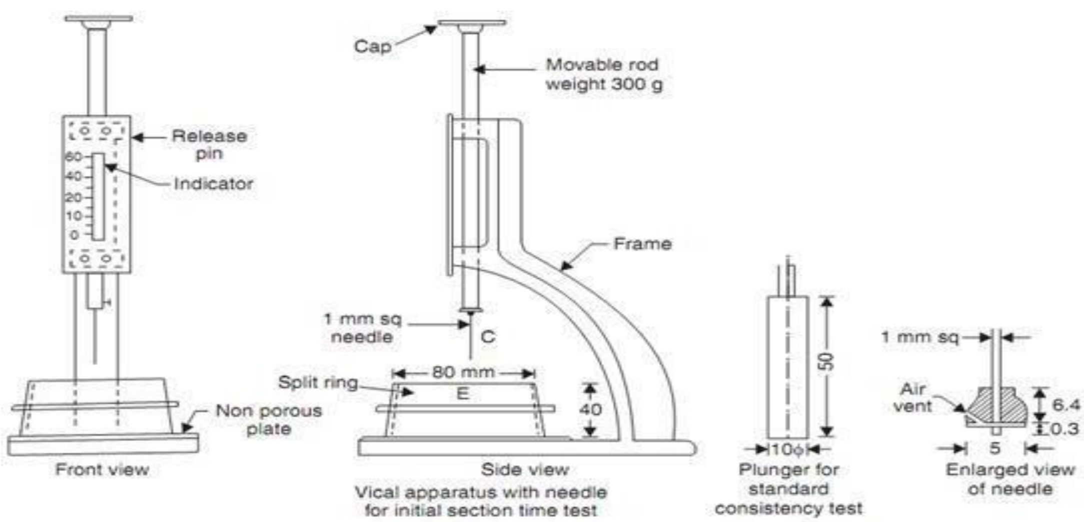

Figure 8: Vicat Apparatus

3.5.2 Standard consistency of cement test

The consistency which will permit Vicat plunger having 10mm diameter and 50mm length to penetrate to a depth of 33-35mm from the top of the mould.

Procedure

- 500g of cement was weighed;
- The cement was put in the mixer and 140ml of standard volume of water added;
- The automatic mixer mixed the sample to form a homogenous paste for 210 seconds;
- The paste was removed from the bowel and then fitted into the mould, trimmed and tested;
- The first value was found to be 40mm and this does not apply since the reading is expected to range between 32 and 36mm;
- So, the above procedures were repeated with an increased volume of water of 150ml;
- The resulting value was found to be 36mm.

Calculation for consistency

$$\text{Consistency} = \frac{\text{volume of water}}{\text{weight of cement}} x100$$

Precautions taken during the test were as follows:

The Vicat apparatus was kept free from vibrations during the penetration tests.

The 1mm needle was kept straight and clean at all times. This was to prevent cement from adhering to the sides of the needle and decreasing penetration, and to prevent cement from adhering to the point therefore increasing penetration.

The figure nine (9) below shows the Vicat Setting time experiment being carried out in the laboratory.

Figure 9: Vicat setting time experiment

3.5.3 Procedure to Find Setting Time of Cement

The setting time of cement gives an indication of how long the cement will remain workable when used in a mortar mixer. If the cement has deteriorated or was originally defective, it may take an excessive time to set. Setting time of cement is done to: -

- To find out the water content required to produce a cement paste of standard consistency.
- To detect the deterioration of cement due storage.

Initial Preparation

Consistency test is to be done before starting the test procedure to find out the water required to give the paste normal consistency (P).

Taking 500 g of cement and preparing a neat cement paste with 0.85P of water by weight of cement.

Gauge time was kept between 3 to 5 minutes. Stop watch was started at the instant when the water was added to the cement. Time (T1) was recorded.

The Vicat mould resting on a glass plate was filled with the cement paste gauged as above.

The mould was filled completely and smoothened off the surface of the paste making it level with the top of the mould. The cement block thus prepared was called test block.

Test for Initial Setting Time

It is the time when cement paste starts hardening. The initial setting time helps to give a time frame for the work. For the initial setting time the needle used should not penetrate the paste beyond 8mm.

The needle penetrated the test block and the reading on the Vicat apparatus graduated scale recorded.

The procedure was repeated until the needle failed to pierce the block by about 5mm measured from bottom of the mould.

- The test block confined in the mould and resting on the non-porous plate was placed under the rod bearing of the needle.
- The needle was lowered gently until it comes in contact with the surface of test block and quick release, allowing it to penetrate into the test block.
- In the beginning the it completely pierces the test block. Procedure was repeated i.e., by quickly releasing the needle after every 2 minutes till the it fails to pierce the block for about 5 mm measured from the bottom of the mould, note (T2).

Test for Final Setting Time

Final setting time is the time when cement paste has hardened sufficiently in such a way that 1mm needle makes an impression on the paste in the mould but 5mm needle does not make any impression. It should not set suddenly but it should have a time limit for hardening so that the work can progress. For the final setting time the needle has to form a mark on the paste and not until the mark has stopped to appear on penetration of the needle.

- For determining the final setting time, the needle of the Vicat's apparatus was replaced by the needle with an annular attachment.
- The cement was considered finally set when upon applying the final setting needle gently to the surface of the test block; the needle makes an impression thereon, while the attachment fails to do so. Time (T3) was recorded.

Calculations,

Initial setting time=T2-T1

Final setting time=T3-T1

Where, T1 =Time at which water is first added to cement;

T2 =Time when needle fails to penetrate 5 mm to 7 mm from bottom of the mould;

T3 =Time when the needle makes an impression but the attachment fails to do so.

3.6 Flexural Strength and Compressive Strength

3.6.1 Flexural Strength

The two standard methods used to test the flexural strength of any material are: ‘Third-point loading’ and/or ‘Center-point loading’. The former test requires application of a set of two equal loads at each 1/3rd point on the entire span of material, while the latter involves application of complete load at the center of the length of the material. The flexural strength of any material or object depicts the maximum stress experienced by it at the instant of its failure.

Third-point loading

The prism was placed in the apparatus with one side face on the supporting rollers and with its longitudinal axis normal to the supports. The load was applied vertically by means of loading roller to the opposite side face of the prism and increased it smoothly at the face rate of 50N/s until fracture. The prism halves covered with a damp cloth until testing in compression.

Calculation of flexural strength

The flexural strength was obtained from;

$$\text{Flexural strength} = \frac{1.5\text{x lengthx force at breaking}}{b\text{^}3}$$

where, b= Side of the prism square section(mm), l= Distance between supports (mm).

The figure ten (10) below shows the broken specimen after placing it in a flexural testing machine.

Figure 10: Broken specimen from the flexural machine

Importance of Flexural Strength

- It helps in designing structural elements like beams, cantilevers;
- Provides a parameter for development of stronger constructional materials;
- Flexural strength helps in judging the quality of structures being used for construction (M. M. Reda Taha, 2005).

3.6.2 Compressive Strength

Compressive strength is the most important property for determining how much load is needed to be applied before the mortar fails.

Procedure for Compressive Strength of Mortar

Taking 450g of cement and 1350g of murram soil passing through a 2mm IS sieve and retained on 90 microns in the mix ratio 1:3 by weight in a pan was done.

The cement and murram soil in dry condition was mixed with a trowel for about 2 minutes and water was added. The time of mixing was between 3 & 4 minutes.

Immediately after mixing the mortar, the mortar was placed in the mould of 40*40*160mm and prod with the help of the rod. The mortar was then vibrated for the period of 2 minutes at the specified speed to ensure elimination of entrained air using a flow table machine. Then, the specimen moulds were placed in dry cool place for 24 hours. After that, the specimens were removed from the moulds and placed in moist oven until the testing time of curing.

Hence, compressive strength (Rc) is calculated from,

Rc = Fc/1600 where Fc is the applied force at fracture.

CHAPTER FOUR: PRESENTATION AND DISCUSSION OF RESULTS

4.1 : Presentation of results

4.1.1 Grading of the murram soil

Table 4. 1: Results of dry sieving of the murram soil

Sieves(mm)	**Mass retained(g)**	**Percentage retained (%)**	**Cumulative percentage retained (%)**	**Percentage passing (%)**
20	-	-	-	-
10	132.70	10.35	10.35	89.65
6.3	132.38	10.33	20.68	79.32
5	70.26	5.48	26.16	73.84
2	234.14	18.26	44.42	55.58
0.600	131.70	10.27	54.69	45.31
0.425	16.23	1.26	55.95	44.05
0.300	15.67	1.22	57.17	42.05
0.212	13.63	1.06	58.23	41.77
0.150	12.61	0.98	59.21	40.79
0.075	30.44	2.37	61.58	38.42

The original mass of the sample was 1282.13g

4.1.2 Atterberg limit tests

Table 4. 2: Results for LL and PL

	LIQUID LIMIT				PLASTIC LIMIT		
TEST NO	1	2	3	4	1	2	AVERAGE
Container no.	KOA	K015	CEQ	A5	TOA		
Mass of wet soil+ container	45.31	36.28	52.19	52.48	25.99		
Mass of dry soil +container	40.92	31.23	42.52	42.10	25.21		
Mass of container	32.13	20.97	23.79	22.09	22.20		
Mass of moisture	4.39	5.05	9.67	10.38			

Mass of dry soil	8.79	10.26	18.73	20.01			
Moisture content (%)	49.94	49.98	51.63	51.87	25.9		
Average		49.9		51.8			

Liquid limit = (49.9+51.8)/2= 50.9%

Plastic limit = 25.9%

Plasticity Index **=** Liquid limit – Plastic Limit

= 50.9 -25.9

=**25%**

4.1.3 Workability

Flow = ((average diameter of the mortar- inner base diameter of the mould)/ inner base diameter of the mould) *100

Average diameter = (180+184)/2

Average diameter = 182 mm

Flow **=** (182-100/100) *100

Flow = **82%**

Calculation for Consistency

$$\text{Consistency} = \frac{\text{Volume of water}}{\text{Weight of cement}}$$

$$= \frac{150\text{ml}}{500\text{g}} \times 100\%$$

$$= \mathbf{30}\%$$

4.1.4 Setting Time

The depth of penetration of Vicat needle in mortars for Initial and Final Setting time.

Table 4. 3: Results of the setting time of the mortars

Time (min)	**Cement mortar(mm)**	**Stabilized Murram mortar(mm)**
0	40	40
15	40	40
30	40	40

45	39	40
60	38	40
75	37.5	39
90	36.5	38.5
105	35.5	37
120	35	36.5
135	33.5	34.5
150	30	33
165	27	28.5
180	25.5	26.5
195	22.5	24
210	20.5	22.5
225	18.5	20
240	16	18.5
255	15.5	17
270	13.5	15.5
285	11.5	14.5
300	10	13
315	9.5	11.5
330	8	10.5
345	7.5	9.5
360	6.5	8
375	6	7.5
390	5	6.5
405	4.5	5.5

The values in red color show the initial setting time for mortars.

The values in green color show the final setting time of the mortars.

Setting Time Calculations

Initial setting time =T2-T1

Final setting time =T3-T1

For cement mortars

T1= 9:00am, T2=11:00am, T3=1:30pm

Initial setting time = T2-T1

= 2hrs

= **120 minutes**

Final setting time = T3-T1

= 4hrs and 30 minutes

= **270 minutes**

For Stabilized Murram mortar

T1= 9:30am, T2=12:00pm, T3=2:30pm

Initial setting time = T2-T1

= 2hrs and 30 minutes

= 150 minutes

Final setting time = T3-T1

= 5hrs

= **300 minutes**

Table 4. 4: Setting time for cement

Setting	**Time**
Initial setting	Minimum 30 minutes
Final setting	Maximum 600 minutes

(Amos, 2014)

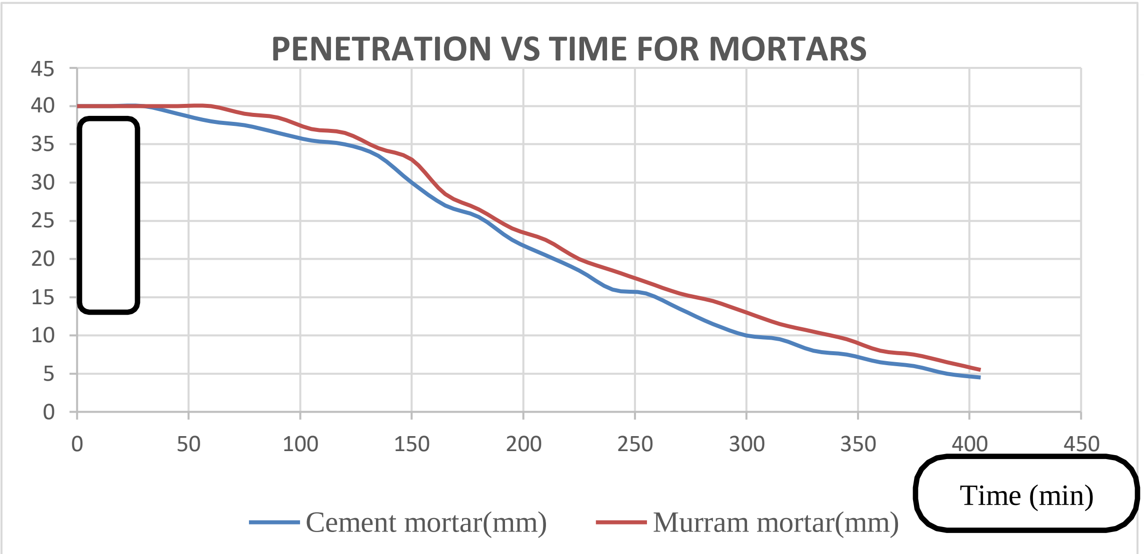

Figure 11: Line graphs of setting time

4.1.5: Flexural and Compressive Strength

Table 4.5: Results of Strength of mortar prisms

% ratio of Sand and Murram	7 days age strength				28 days age strength			
	Flexural S		Compressive S		Flexural S		Compressive S	
	N	MPa	KN	MPa	N	MPa	KN	MPa
100% sand	1750	4.10	34.3	21.4	2150	5.04	54.5	34.1
			35.3	22.1			54.1	33.8
	1700	3.98	35.3	22.3	2200	5.16	55.1	34.4
			36.2	22.6			54.8	34.3
		Av=4.04		**Av=22.12**		**Av=5.10**		**Av=34.20**
75% sand and 25% murram	1200	2.81	15.9	9.94	1600	3.75	24.80	15.50
			17.1	10.69			26.00	16.25
	1200	2.81	17.2	10.75	1600	3.75	25.30	15.81
			17.2	10.75			29.00	18.13
		Av=2.81		**Av=10.53**		**Av=3.75**		**Av=16.42**

60% sand and 40% murram	1100	2.58	13.46 14.78	8.41 9.24	1300	3.05	21.54 23.76	13.46 14.85
	950	2.23	14.72	9.20	1400	3.28	21.95	13.72

			16.05	10.08			24.98	15.61
		Av=2.42		**Av=9.22**		**Av=3.17**		**Av=14.41**
50% sand and 50% murram	900	2.11	12.59 12.90	7.87 8.06	1250	2.99	23.87 20.91	14.92 13.07
	950	2.23	13.39 14.56	8.37 9.10	1100	2.58	18.35 20.58	11.47 12.86
		Av=2.17		**Av=8.35**		**Av=2.79**		**Av=13.08**
25% sand and 75% murram	650	1.52	8.4 10.6	5.25 6.63	750	1.76	14.30 17.60	8.94 11.00
	650	1.52	9.70 10.80	6.06 6.75	800	1.88	11.80 17.70	7.38 11.06
		Av=1.52		**Av=6.17**		**Av=1.82**		**Av=9.73**
20% sand and 80% murram	600	1.40	8.93 11.09	5.58 6.93	750	1.76	15.44 16.19	9.65 10.12
	750	1.76	9.38 11.25	5.86 7.03	850	1.99	14.78 17.01	9.24 10.63
		Av=1.58		**Av=6.35**		**Av=1.85**		**Av=9.91**
15% sand and 85% murram	700	1.64	10.37 12.24	6.48 7.65	850	1.99	16.37 16.88	10.23 10.55
	700	1.64	12.85 13.38	8.03 8.36	750	1.76	15.01 16.26	9.38 10.16
		Av=1.64		**Av=7.63**		**Av=1.89**		**Av=10.08**
100% murram	800	1.88	10.7 11.3	6.69 7.06	850	1.99	16.70 16.90	10.44 10.56
	750	1.76	11.5 11.8	7.19 7.38	850	1.99	17.10 17.20	10.69 10.75
		Av=1 82		**Av=7.08**		**Av=1.99**		**Av=10.61**

Test results of mortar prisms of 40*40*160 mm, multipurpose CEM IV/B(P) 32.5N.

Table 4. 6: Summary of results of strength of mortar prisms

Percentage ratio of sand & murram	**7 days age strength**	**7 days age strength**		**28 days age strength**	**28 days age strength**
	Flexural strength	Compressive strength		Flexural strength	Compressive strength
	MPa	MPa		MPa	MPa
100% sand	4.04	22.12		5.10	34.20
75% sand & 25% murram	2.81	10.53		3.75	16.42
60% sand & 40% murram	2.42	9.22		3.17	14.41
50% sand & 50% murram	2.17	8.35		2.79	13.08
25% sand & 75% murram	1.52	6.17		1.82	9.73
20% sand & 80% murram	1.58	6.35		1.85	9.91
15% sand & 85% murram	1.64	7.63		1.89	10.08
100% murram	1.82	7.08		1.99	10.61

Summary of the average Test results for mortar prisms of 40*40*160 mm using multipurpose CEM IV/B(P) 32.5N (Pozzolanic Cement**)**.

Calculation of flexural strength,

$$Rf = 1.5 * Ff * \frac{l}{b3} \text{ (MPa)}$$

Where, Rf= Flexural strength,

b= Side of the prism square

section(mm), Ff= Applied load at

fracture (N),

l= Distance between supports (mm).

Graph showing test results of Flexural strength of the mortar prism of 40*40*160 mm

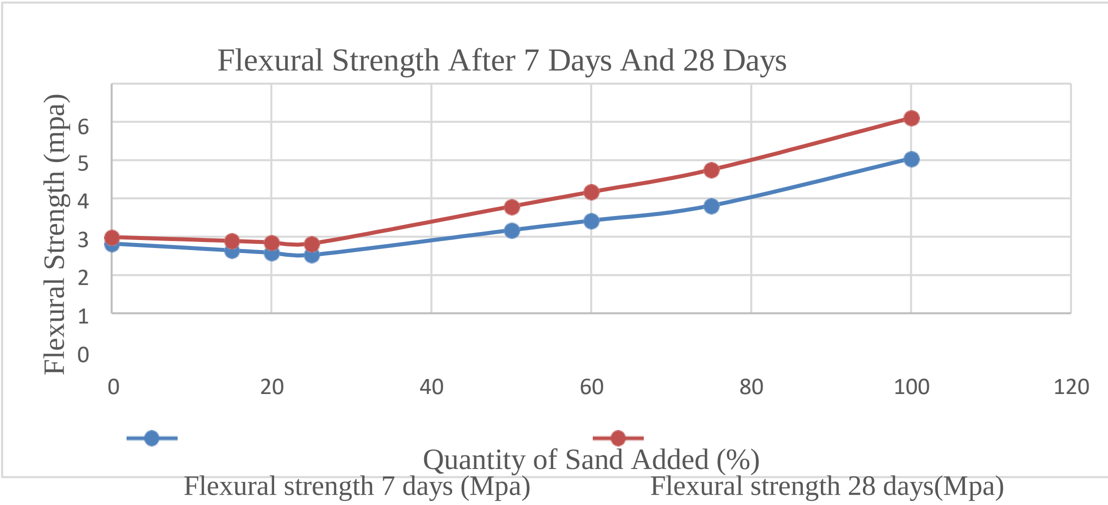

Figure 12: Line graph of Flexural Strength results

Calculation of Compressive strength,

$Rc = Fc / 1600$

Where; Rc = Compressive strength (MPa), Fc = Applied load at fracture(N), 1600 = Area 40*40 (mm^2)

Graph showing test results of the Compressive strength of the mortar prism of 40*40*160 mm

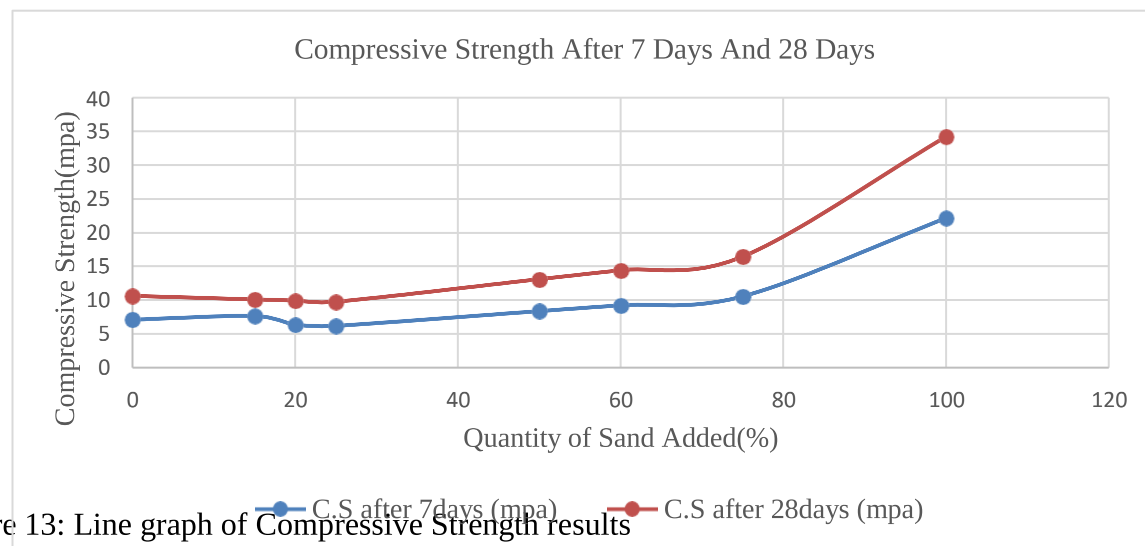

Figure 13: Line graph of Compressive Strength results

4.2 Discussion of results

4.2.1 Introduction

The aim of this project was to investigate the suitability of cement stabilized murram mortars for masonry works in construction industry today. This was done by carrying out different tests on the murram soil. The following section of this chapter is an in-depth discussion of the findings of the tests carried out on the soil mortars.

4.2.2 Setting Time

An ideal mortar should remain workable long enough to enable the workers to set the masonry unit right to line so as to permit the laying of units to proceed smoothly.

From the results indicated in the previous chapter, the initial and final setting time were 120 minutes and 300 minutes respectively. This is within the range according to the general specifications (minimum 30 minutes and maximum 600 minutes).

This could be explained by the fact that cement is actually hygroscopic and requires water in order to set due to its hydrophilic character. In the presence of water, the aluminates and silicates in the cement form products of hydration that are responsible for the stiffening of cement paste.

In the case of soil-cement mixes, the soil competes with the cement for absorption of water needed for the hydration of cement. Therefore, the water available for the hydration of cement is reduced. This leads to an increased time of setting in the soil cement paste. It is however important to note that the murram soil in the soil-cement mix sets by drying and not by hydration. In the long run therefore, the soil will have to lose some of the water that it absorbed during the setting process. This water will then be used in the continual hydration of the cement and aid in its hardening process.

The initial Vicat setting time indicates the approximate time at which the paste begins to stiffen while the final Vicat setting time indicates the time at which the cement paste has hardened and can support some load.

4.2.3 Compressive Strength and Flexural Strength

After the examination of many specifications, it has been noted that compressive strength is the most important property of mortar. However, this may not always be correct as workability and bond strength are also of great significance.

From the results indicated in the previous chapter, Compressive and Flexural strength reduces with the increase in the amount of sand in the murram soil up to 25% by weight and beyond which the strength starts to increase again. This is after 28 days of curing of the specimen. This is due to the fact that as sand is added in murram, its strength reduces because murram soil is still possessing its soil properties due to the presence of much fines present. At this point any sand added to murram soil makes the strength to increase. This is because sand starts to possess its properties but not murram soil until the maximum strength and that's when it's purely sand.

The minimum compressive strength of mortar is 3MPa as established by I.S. 2250 code and the compressive strength results of the murram soil obtained were above the minimum.

4.2.4 Workability

From the results above, it shows that the flow of mortar for cement stabilized murram soil was 82%. However, as the time increases, the mortar starts setting and the flow start reducing due to the fact that the mortar is hardening. There is also a linear relationship between flow and water cement ratio of the mortars. Flow increases with increase in water-cement ratio. Very high flow value of 130% can be achieved for cement soil mortars and cement lime mortars. Reduction in flow value from 100% to 80% leads to increase in strength and modulus of mortars (K, 2014).

4.2.5 Plasticity Index

The soils which have clay content below 30% can be stabilized using cement and soils with clay content above 30% can be stabilized using lime. Therefore, the sample used from the Seguku borrow pit was suitable to be stabilized using Portland cement since it had plasticity index of 25% (K, 2014).

4.2.6 Standard Consistency

Standard consistency or normal consistency test is done to find out water content required to produce a cement paste of standard consistency. It was 30% and the range is from 25% to 35% for ordinary Portland cement.

CHAPTER FIVE: CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

The main objective of the study was to conduct tests on the chosen soil-based mortar with the aim of drawing conclusions from the results that would support or reject the use of stabilized soil-based mortars in construction today.

The murram soil used was of gravel material with the minimum California bearing ratio of three (3), it was passed through the 2mm sieve for fine sand as recommended by ASTM sieve analysis, it was mixed in the ratio of 1:3 for adequate plasticity using EN 196-1:2016 (Standard cement test). Different percentage proportions of lake sand were added in murram soil ranging from 0% to 100% of sand.

The compressive strength values for mortar lied between 9.73Mpa to 34.20Mpa and the flexural strength lied between 1.99Mpa to 5.10Mpa after 28days of curing. The setting time of the mortar lied between 120 minutes and 300 minutes. The plastic index of the soil was 25%. The workability of the soil mortar was 82%. All the values obtained were within the recommended range according to the general specifications.

The conclusion of the investigation confirmed that the use of cement stabilized murram mortar can be applied in construction as far the investigated parameters are concerned.

5.2 Recommendations

The field of stabilized murram mortars is wide and a lot of improvements can be made in its application if well studied. The following are some of the recommendations that can be made with regards to the use of soil-cement mortars in construction:

Further studies and tests on the various properties of ideal mortars can be carried out on soil-based mortars like the water absorption test, air content test, sedimentation test, so as to provide a wider perspective on their suitability during the fresh and hardened states.

Further studies can be conducted to determine which additives can be added in murram mortars to aid in their performance.

Further studies can be done on how other different types of murram soils behave when amended with Portland cement.

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APPENDICES

Appendix A: Sieving and weighing of the sample

Figure 14: Sieving of the soil sample using 2mm sieve

Figure 15: Measuring the ratios using the weighing scale

Appendix B: Mixing and Vibration of specimen

Figure 16: Preparation of the sample for specimens

Figure 17: Vibration of mortar specimen using the flow table

Appendix C: Curing and ready specimen for crushing

Figure 18: Specimen placed in the moist oven for curing

Figure 19: Specimen ready to be tested for strength

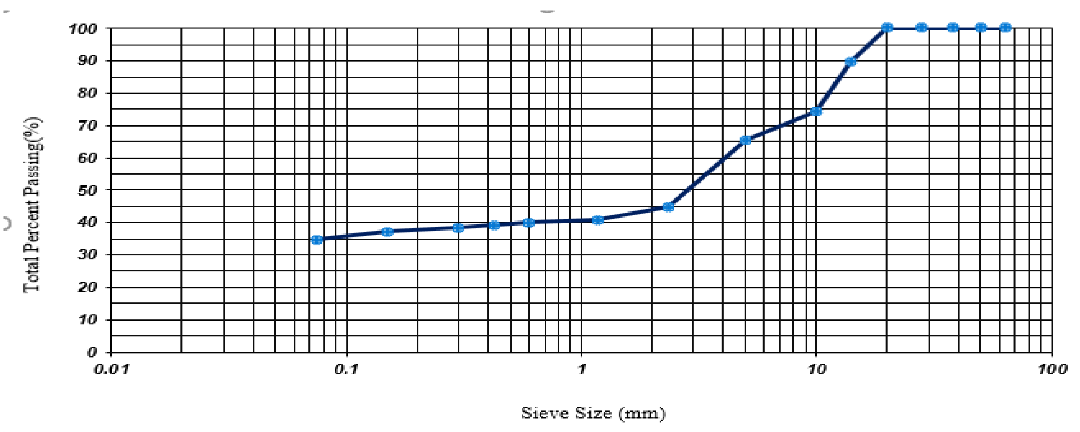
Appendix D: Crushing specimen and Broken specimen

Figure 20: Crushing specimen using flexural strength machine

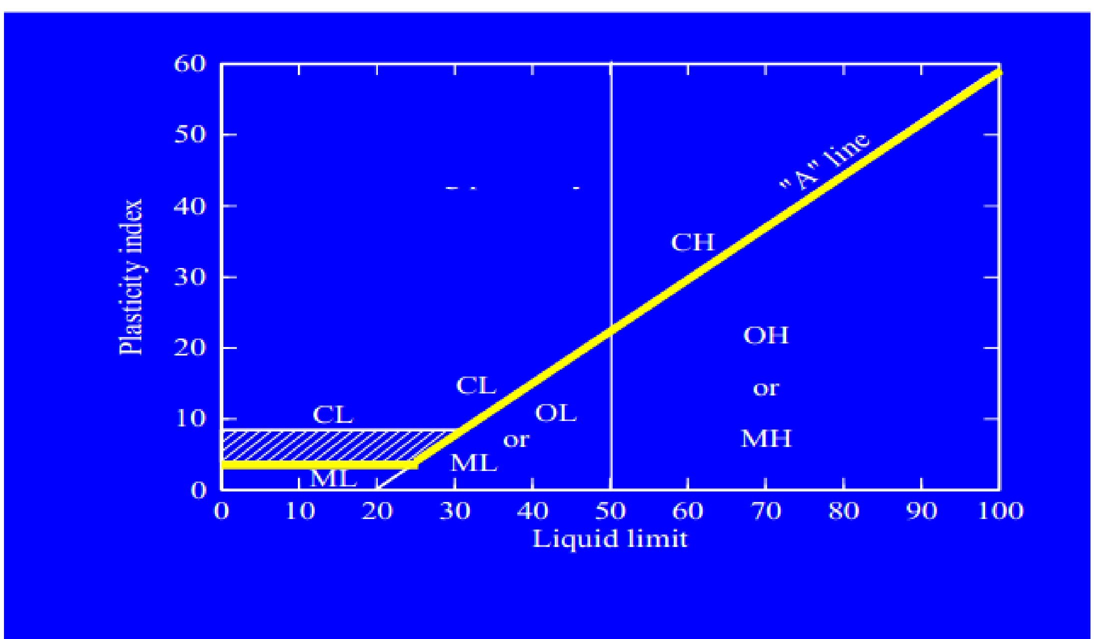
Figure 21: Broken specimen from flexural strength machine

Appendix E: The PSD curve and the chart used to classify soil

A Semi Logarithmic Chart of the Cumulative Percentage Passing of the Soil Sample Against the Test Sieve Size (mm)



The Chart used to classify Soil (Test Standard: ASTM D422**)**



Below A-line use suffix M - Silt

Above A-line use suffix C - Clay