KYAMBOGO UNIVERSITY

FACULTY OF ENGINEERING

DEPARTMENT OF CIVIL AND BUILDING ENGINEERING

PERFORMANCE OF BURNT CLAY HOLLOW BLOCK SLAB UNDER SEISMIC ACTION IN UGANDA

BY

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SEPTEMBER, 2018

DECLARATION

I hereby declare that the information contained herein, is a true representative of my physical work carried out during preparation of the dissertation. I therefore wish to be corrected for any error(s), mistakes and omissions made during this preparation as it's not the author's intention.

Signed: .... Date: 4th/12/2018..

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APPROVAL

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EC	Euro Code
USGS	United States Geological Survey

ABSTRACT

A storeyed building has different structural elements each working to complement the other in resisting seismic actions. Since most of the building mass is present at floor levels, earthquake-induced inertia forces primarily develop at the floor levels due to ground vibrations from which they travel horizontally through the slabs and beams to columns and walls, and then to the foundations where they are dispersed to the ground.

Ninety five percent (95%) of storeyed buildings in Kampala the capital city of Uganda have their slabs constructed with burnt clay hollow block reinforced concrete slabs. Slabs containing hollow blocks are constructed with the hollow side of blocks end to end running in one direction, with a rib between rows of blocks in which steel reinforcement is laid. This constrains the slab to act as one-way spanning.

For a structure subjected to seismic loading, the requirement for a diaphragm is that the slab should have equal strength in both horizontal directions. This is because horizontal seismic action is described by two orthogonal components considered as independent and represented by the same response spectrum. According to EN 1998, (Euro Code 8), one of the guiding principles governing conceptual design against seismic hazard is the bi-directional resistance and stiffness at storey level. Seismic load is applied to the slab as a compressive load in the plane of the slab. This study determined the load capacity of hollow blocks parallel and perpendicular to the holes in the plane of the slab.

Hollow block slabs measuring 750 x 800mm were produced. These were cured for 28days and loaded parallel and perpendicular to the direction of hollow blocks and ribs. Also, the hollow blocks were loaded parallel and perpendicular to the direction of holes. It was found that the load capacity of burnt clay hollow blocks when loaded parallel to holes varied from 103.35kN – 123.93kN giving a compressive stress of 2.3N/mm^2 – 2.8N/mm^2, whereas the load capacity, perpendicular to the direction of holes ranged from 45.6kN – 47.4kN giving a compressive strength of 1.0N/mm^2 – 1.05N/mm^2.

For the slab, the failure load varied from 315kN – 375kN when loaded parallel to the rib, giving a stress of 1.97N/mm^2 – 2.34N/mm^2 and the failure stress perpendicular to ribs varied from 1.04N/mm^2 – 1.2N/mm^2.

A computer model was developed to model the behaviour of the slabs. The hollow block slab computer model revealed that the stress in the hollow block slab model when loaded parallel to ribs was a maximum of $2.151 \times 10^6 N/m^2$ ($2.151 N/mm^2$) in the plane of application of load and the stress when loaded perpendicular to the rib the stress was a maximum of $1.074 \times 10^6 N/m^2$ ($1.074 N/mm^2$) in the plane of application of load respectively.

This study concluded that the compressive strength of burnt clay hollow blocks, has a great influence on the horizontal load capacity of the slab. Also, the strength parallel to the rib is about twice that perpendicular to the rib. This does not satisfy the requirement of equal strength in both directions.

From the computer model, the results revealed that the compressive strength of the hollow block slab had a great influence on horizontal capacity of the slab and the compressive strength parallel to the ribs is twice that perpendicular to the ribs. The study further showed that the hollow block slab is weaker when lateral loads are applied in the direction perpendicular to the ribs. Therefore, the results of the computer model and the laboratory tests revealed that the hollow block slab does not have the same resistance to seismic lateral load in the direction perpendicular and parallel to the rib.

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND

The onset of the 21st century brought with it a new public consciousness of seismic activities / earthquakes. Past calamities like the 2004 tsunami in Asia that was triggered a magnitude 9.3 earthquake on the Richter Scale (Fehr *et al.*, 2004), caused waves of up to 20m high, spread devastation and brought seismic design considerations to the fore front.

The African Continent is divided into three (3) major zones of Maghreb, Southern, and Sub Saharan part. Sub – Saharan Africa comprises two (2) tectonically varying regions, the West Africa Craton and the active East African Rift Valley where the highest seismicity of the continent is concentrated as shown in Figure 1.1.

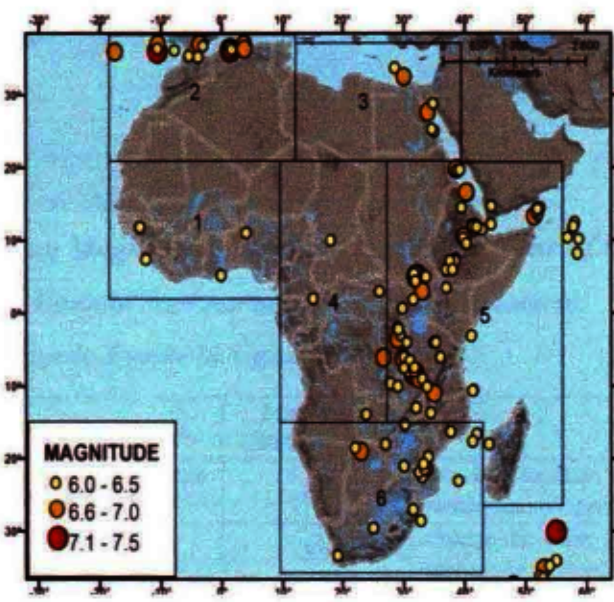


Figure 1.1: Seismic-tectonic Provinces (1 to 6) and major recent Earthquakes of the African Continent

Before the 20th century, the East African Rift Valley was dormant, however recent seismic events show that the East African Rift is prone to large earthquakes. The most recent large quake was the M 5.9 near the west shore of Lake Victoria in northern Tanzania on 10th September, 2016 as recorded by the United States Geological Survey (USGS, 2016). However, the largest quake on record in the region was in the 20th century on 13 December 1910 in Rukwa, Tanzania that exceeded M 7 (Albini et al. 2013).

Uganda has experienced several medium sized earth quakes and these are shown in Figure 1.2. During Seismic activity, buildings are exposed to a relatively high risk of damage from mostly the main shock and the aftershocks. Table 1.1 shows a summary of seismic events that have occurred in Uganda with the effects they have had on both life and property.

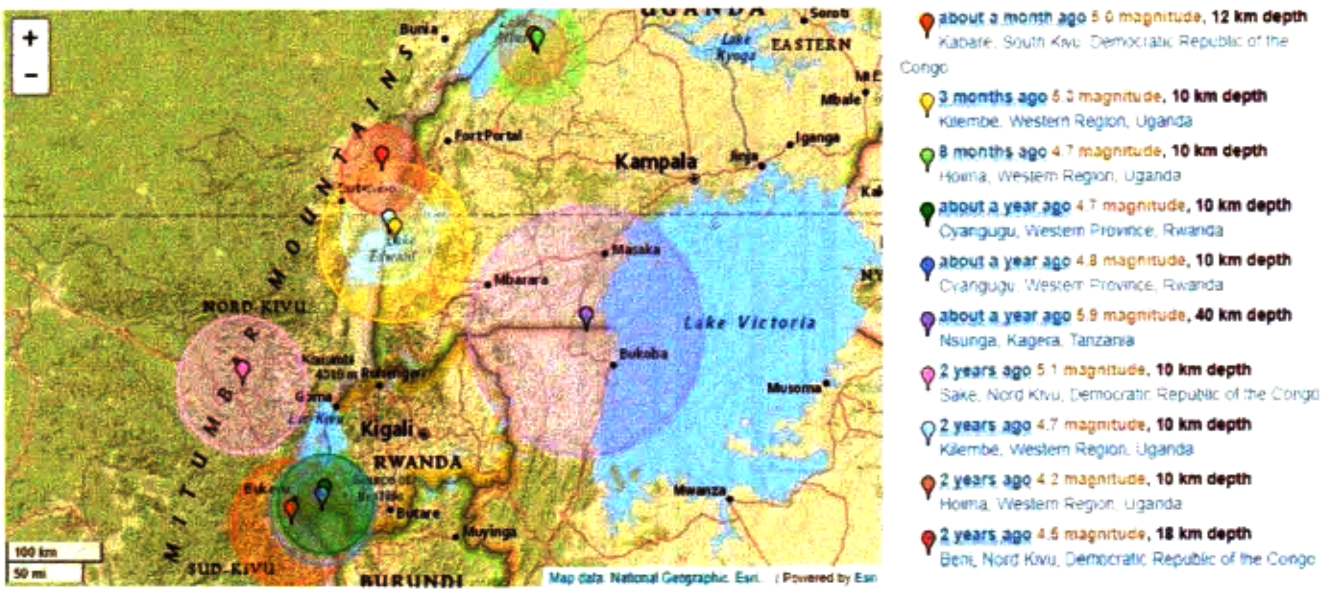


***Figure 1.2: Map showing Magnitude, Location, Depth and Time of recent Earthquake in Uganda** (https://earthquaketrack.com/p/uganda/recent)*

Table 1.1: Summary of Seismic Events in Uganda

Date	Epicentre Location	Magnitude (Richter Scale)	Effects
9th July 1912	Kitgum close to Aswa Shear Zone.	6.0	Partial destruction of buildings in Northern and Northwestern Uganda.
2nd October 1929	Toro, Western Uganda.	5.9	Change of water color in the hot springs and earthquake induced landslides (Simmons 1930)
18th March 1945	Sembabule (40 km North of Masaka Town).	6.0	Entebbe seismograph put out of order, 5 people dead and destruction of some buildings (Bisset 1945; Gutenberg and Richter, 1949)
29th March 1966	Toro, Western Uganda.	6.6	150 people dead and over 1,300 injured as well as property loss worth millions of dollars. (Loupekine 1966; Sykes 1967)
7th September 1990	Lake Victoria close to Kampala	5.0	Destroyed semi-permanent buildings around Kampala.
9th October 1991	Butiaba on Lake Albert.	5.3	Destroyed semi-permanent buildings.
5th February 1994	Kisomoro, Western Uganda.	6.2	8 people dead and destruction of property worth US dollars 61 million in the Western Districts of Kasese, Bundibugyo and Kabarole. The hottest hot spring in Buranga (Sempaya) geothermal field (98°C) emerged.

(Source: Joseph, 2012)

Generally, a storeyed building has different structural elements each working to complement the other in resisting seismic actions. Since most of the building mass is present at floor levels, earthquake-induced inertia forces primarily develop at the floor levels due to ground vibrations from which they travel horizontally through the slabs and beams to columns and walls, and then to the foundations where they are dispersed to the ground.

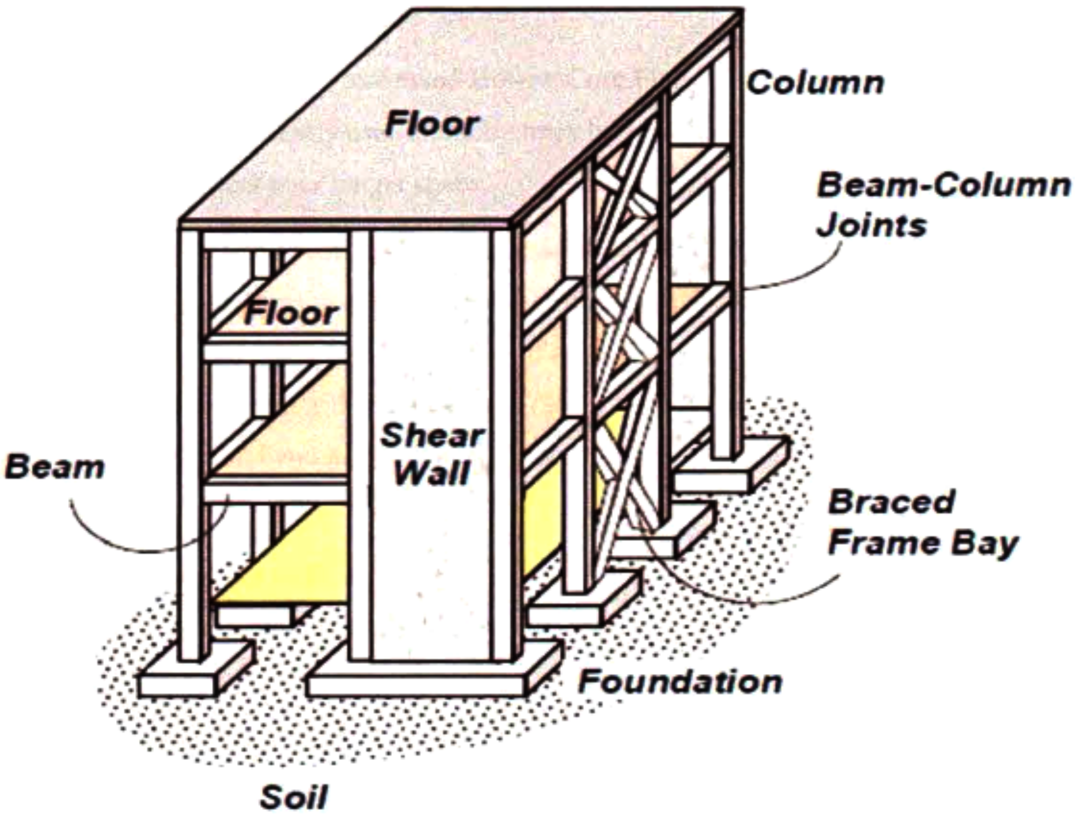


Figure 1.3: Typical Elements of a Storeyed Building

(Source: Murty, 2016).

Slabs may be classified based on distribution of loads as one way transmitting loads to the supporting beams along the shorter ends of the slab or two way transmitting loads to the supporting beams along the four ends of the slab. (Bungey & Mosley, 2007).

They may also be classified based on support conditions as supported by beams or flat slabs supported on column heads. Flat slabs are reinforced in two directions and usually with no beams or girders hence transferring loads directly to the supporting columns.

Furthermore, slabs may be classified based on cross-section as solid or hollow. Hollow slabs may have hollow blocks (Burnt clay hollow block) made of either clay or light weight aggregates and spanning one way or they may not have hollow blocks but are spanning in one or both directions. When they span in both directions, permanent shuttering is used forming waffle slab spanning two way (Nadim, Hassoun, Akthem, 2012).

Hollow slabs including Precast, Prestressed Hollow Core Flooring and Hollow Block (Burnt clay hollow block) slabs are frequently used in multi-storey buildings as they usually result in use of less concrete and reinforcement over longer spans.

There are two major types of slabs in Uganda, the solid slab and the hollow block slab. Kyakula et. al (2006) note that Ninety-nine percentage (99%) of multi storey structures in Uganda are made of reinforced concrete framing. Also, from a survey of one hundred (100) buildings under construction in Kampala revealed that ninety five percentage (95%) were made purely of hollow block slabs, three percentage (3%) solid and hollow block slabs on different floors while two percentage (2%) had solid slabs.

Hollow reinforced concrete slabs are made of hollow clay blocks of light weight permanently fixed in the floor. The hollow blocks are laid in way that the side with holes laid end to end running along the shortest span of the slab and leaving space (rib) between them with in which the reinforcements are laid and concrete placed. Below the Burnt clay hollow block, no concrete cover is provided however on top there is a concrete topping containing a weld mesh provided as shown in Figure 1.4.

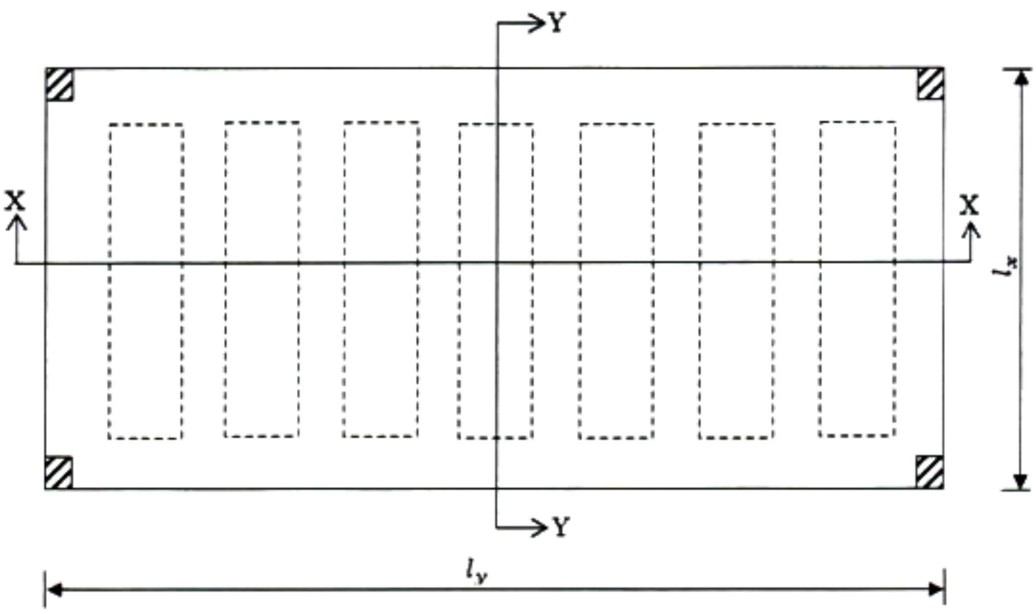


Figure 1.4: Plan of Burnt Clay Hollow Block Slab showing the layout of the Hollow Blocks

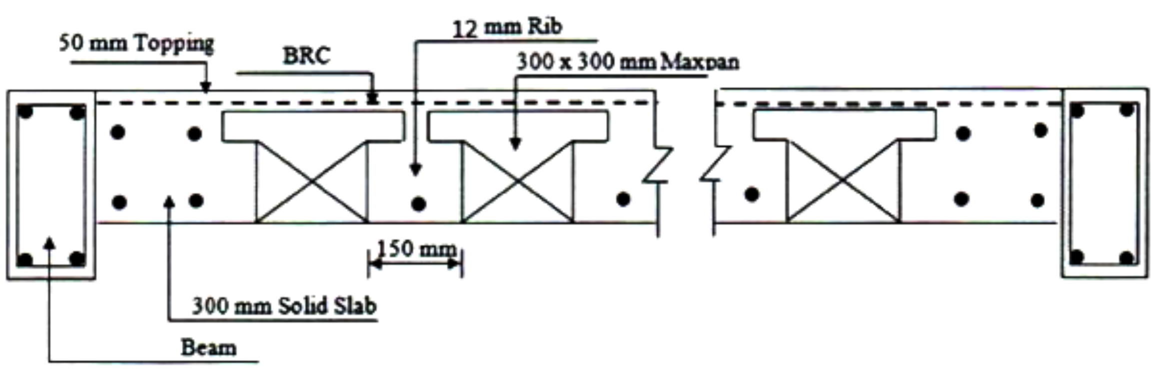


Figure 1.5: Section through Burnt Clay Hollow Block Slab (X-X)

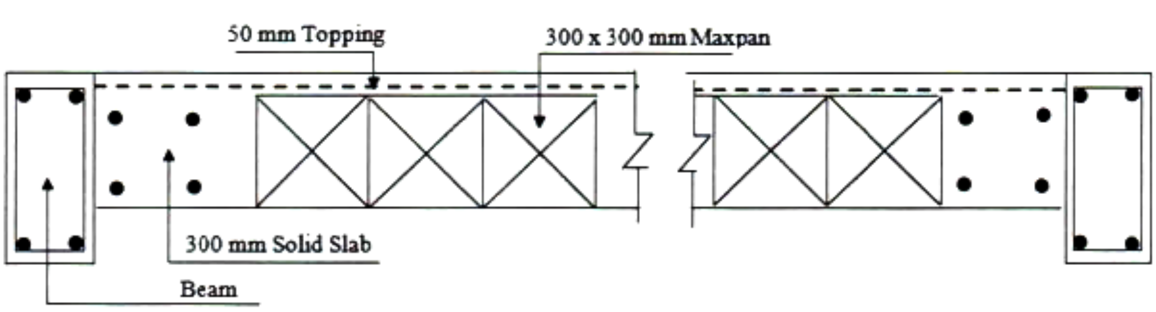


Figure 1.6: Section through Burnt Clay Hollow Block Slab (Y-Y)

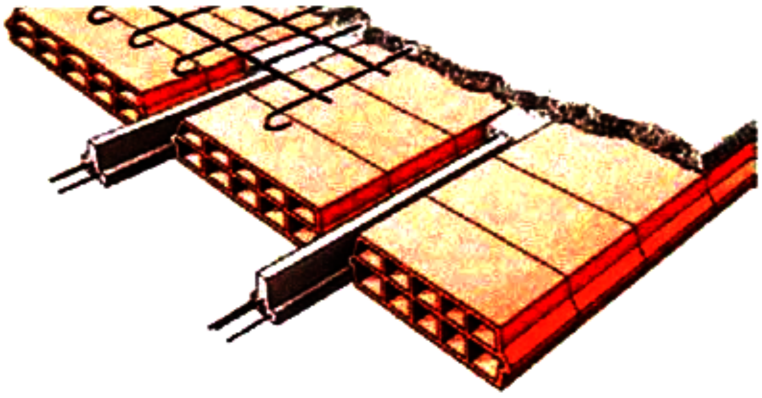


Figure 1.7: Composition of Burnt Clay Hollow Block Slab

Slabs play an important role in collapse prevention as they hold the collapsing regions and core walls together which prevent a larger collapse (Varadharajan, 2014). Therefore, care needs to be given to their performance during seismic activity.

Usually, beams and slabs at one storey level are cast together. When beams bend in the vertical direction during earthquakes, these thin slabs bend along with them. And, when beams move with columns in the horizontal direction, the slab usually forces the beams to move together with it. In most buildings, the geometric distortion of the slab is negligible in the plane of a slab, a behavior known as the Rigid Diaphragm Action (Murty, 2016).

Generally, earthquake forces have three components; a horizontal force in the East - West direction, and a horizontal force in the North-South direction and a vertical force. The vertical force does not cause significant stress in superstructure because it is cancelled by the weight of the structure.

Figure 1.8 shows that the horizontal components of seismic forces are represented as horizontal forces acting at floor level in the direction of the diaphragm.

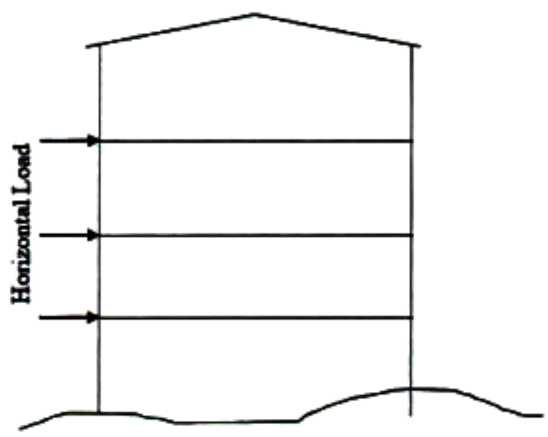


Figure 1.8: Horizontal Load for Seismic Waves

Studies carried out on precast, prestressed hollow slabs have shown that there is potential for brittle failure mechanisms due to the non-ductile characteristics of hollow-core flooring. This could lead to floor collapse due to sway of the building, due to wind or seismic actions, which induces relative rotation between the support and hollow-core units (Woods, Bull and Fenwick, 2008). This behavior can be related to burnt clay hollow block slab given that they are a product of fired clay that is a brittle material itself.

The increased seismic activity in the region calls for an evaluation of the effects of seismic action on structures to establish the suitability of burnt clay hollow block usage in ribbed slabs. Furthermore, a clear understanding of the failure of the burnt clay hollow block slab due to earth quake needs to be established. However, unlike their precast, prestressed hollow and waffle counterparts, there is limited research and knowledge on the effect of seismic action on burnt clay hollow block slabs and their failure mode. Establishing the above will provide some practical reference and guide in use of burnt clay hollow block slabs with regards to seismic design resulting in safer structural practices.

1.2 PROBLEM STATEMENT

Kyakula et. al (2006) note that Ninety-nine percentage (99%) of multi storey structures in Uganda are made of reinforced concrete framing. Also, from a survey of one hundred (100) buildings under construction in Kampala revealed that ninety five percentage (95%) were made purely of hollow block slabs, three percentage (3%) solid and hollow block slabs on different floors while two percentage (2%) had solid slabs. Slabs containing hollow blocks are constructed with the holes of the blocks placed end to end and blocks are running in one direction, with a rib between rows of blocks in which steel reinforcement is laid, which constrains the slab to act as one-way spanning.

East Africa is one of the most seismically active regions in Africa. For a structure subject to seismic loading, the requirement for a diaphragm is that the slab should have equal strength in both horizontal directions. This is because horizontal seismic action is described by two orthogonal components considered as independent and represented by the same response spectrum. According to EN 1998, (Euro Code 8), the guiding principles governing conceptual design against seismic hazard include among others: uniformity, symmetry and redundancy; bi-directional resistance and stiffness and diaphragmatic behaviour at storey level. It is therefore prudent to carry out a research on the behavior of hollow blocks reinforced concrete slabs under horizontal loads, in order to predict their behaviour under seismic loading.

1.3 OBJECTIVES

1.3.1 Main Objective

The aim of the study is to investigate the performance of burnt clay hollow blocks reinforced concrete slabs under action of horizontal load in the plane of the diaphragm.

1.3.2 Specific Objectives

The specific objectives of the study are;

i. To determine the compressive strength of burnt clay hollow blocks in two perpendicular directions.
ii. To produce physical models of hollow slab and subject them to compressive loads on the two perpendicular planes of the slab.
iii. To determine the behavior of a hollow block slab using a computer software.
iv. To determine the failure mode and limitations of hollow slabs.

1.4 PROJECT JUSTIFICATION

The recent increase in seismic activity in the East African Rift Valley coupled with the population increase and urbanization have resulted into the construction of storeyed structures. Ninety-five percent (95%) of multi storeyed structures use burnt clay hollow block slabs in Kampala. This calls for engineers to fully understand the limitations of burnt clay hollow block slabs for use with respect to seismic design.

1.5 PROJECT SIGNIFICANCE

Results from this research shall inform the safe usage of hollow slabs without the fear of failure given that the limitation of the hollow slab will not be exceeded.

The research could also open a window to modifications in detailing of the slabs to improve on resistance to seismic actions.

There is a lot of literature on the performance of clay hollow block slab under seismic action and little information is available on their use practically in developing countries. This study provides scientific facts on the performance of clay hollow block slab under seismic action. Therefore, it can be used for future academic reference and hopefully encourage more research.

1.6 PROJECT SCOPE

1.6.1 Time Scope

The project was run from October 2017 to October 2018 (12 months)

1.6.2 Content Scope

The project was limited to establishing compressive strength of burnt clay hollow blocks; compressive strength of physical models of the hollow slabs in two perpendicular directions and using of a computer software to model behavior of a hollow slab and test results. The study was also aimed at identifying the failure mechanism for hollow slabs and thus improving on their seismic design methods.

1.6.3 Geographical Scope

The project was limited to Kampala Metropolitan

1.7 CONCEPTUAL FRAMEWORK

This outline the steps involved in the research of the project carried out.

The frame in Figure 1.9 describes the process of evaluating the performance of burnt clay hollow blocks under seismic action

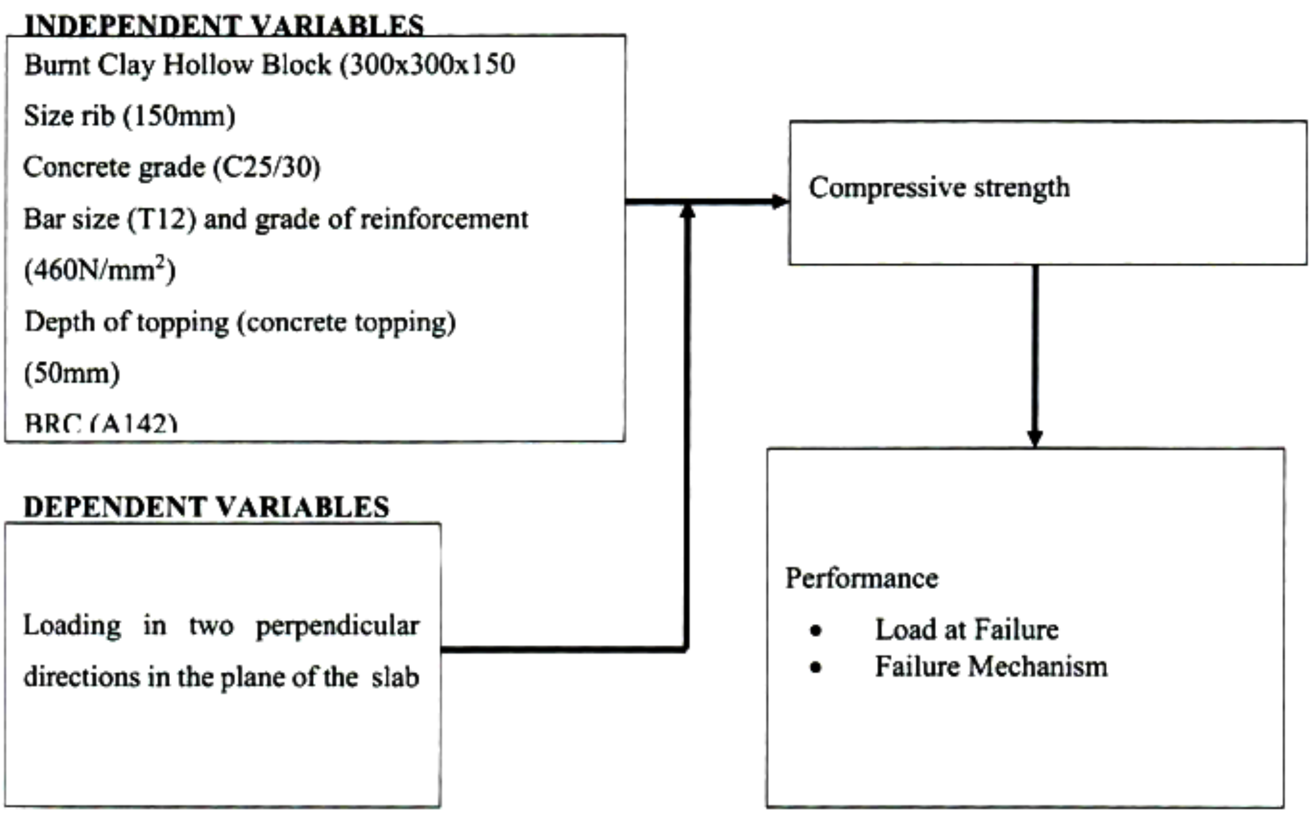


Figure 1.9: Conceptual Framework

CHAPTER TWO: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents findings by previous researchers and relevant information pertaining to performance of buildings during earthquakes.

2.2 RIBBED SLABS

Ribbed floors are made of equally spaced ribs usually supported on beams or supported directly by columns. They are either one-way spanning systems known as ribbed slab or a two-way ribbed system known as a waffle slab (Civil Digital, 2017). The commonest slab in Uganda is the ribbed slab supported on a network of beams and columns. The loads applied to supporting members by the reactions from one-way spanning slabs, ribbed slabs and beams may be calculated on the assumption that the members supported are simply supported (BSI, 1992). Continuity should, however, be considered at the first internal support and at other internal supports if the spans on either side of the support differ by more than 30%.

Relative to solid slabs, ribbed slabs have longer span and live loads varying between light to moderate in magnitude (Rana *et al.*, 2012). They are considered more economical due to less concrete, reinforcement and to some extent formwork used. Hence the exponential growth in popularity in the 21^{st} century.

2.3 SEISMIC WAVES

According to Brown (2007), a seismic event occurs when built up energy is released in a sudden slippage of a fault inducing seismic waves. Faults, or cracks in the earth's surface, occur primarily at the edges of tectonic plates. The seismic waves can be categorized into two groups, body waves and surface waves. The body waves travel inside the earth and are of two types. One type of a body wave is the pressure wave (P wave) which is a longitudinal wave that causes tension and compression of the body it travels through. The P waves have the greatest travel velocity and are the first waves to reach any place and are therefore often referred to as primary waves. The other type of body waves is a shear wave (S wave) which occurs perpendicular to a P wave, causing a up and down and side to side motion of the structure. The S waves have less travel velocity than the P waves and arrive later at a given location. They are therefore often referred to as secondary waves (Kramer, 1996). The sequence of events is such that the high-speed P-waves are felt first with rattling of windows and at times sounding like a sonic boom followed by the S-waves characterized by the vertical and horizontal displacement and the most likely to scathe buildings, compromising their structural integrity (Brown, 2007).

Surface waves are of two types and they are propagated along the ground surface. They include Love waves which cause horizontal shifting of the earth and Rayleigh waves which move both vertically and horizontally in a vertical plane pointed in the direction in which the waves are travelling. The earthquake cause collapse of the building with injuries, loss of life and property; structural damage making the structure unsafe for occupation, and non-structural damage to water pipes, doors, walls among other fittings. (Brown, 2007).

A building, or other structure, excited by seismic waves is assumed to move with the surface of the ground and the dynamic forcing is therefore created by the interaction of the structural mass and the acceleration of the ground. The equation of motion for a SDOF system subjected to seismic induced ground acceleration is given by:

$$m\ddot{x} + c\dot{x}(t) + kx(t) = -m\ddot{x}_g(t) \qquad \textit{Equation 2.1}$$

Where "$m\ddot{x}(t)$: is the product of mass and acceleration; $c\dot{x}(t)$ is the dumping term and equals to zero for undamped motion; $kx(t)$ is the product of displacement and stiffness, (El-Shaer, 2014). The forces acting on a system therefore due to the relative displacement of the mass to the ground caused by the ground acceleration and although it is not an actual external force it can be thought of as an external force, equal to $-m\ddot{x}_g(t)$, acting on a stationary system in the opposite direction to the ground acceleration (Chopra, 2006). It is then seen that an increased mass of a system leads to an increase in the dynamic loading.

2.4 MATERIAL AND MATERIAL TESTING

2.4.1 Aggregate

This is a granular material obtained by processing natural materials.

CLASSIFICATION OF AGGREGATES

Aggregated can be divided into several categories according to different criteria:

a) In accordance with Size

Coarse aggregated: Particles of course aggregates passing through 37.5mm sieve and are entirely retained on 5mm sieve are termed as coarse aggregates. For mass concrete, the maximum size can be as large as 40mm. (Surendra , 1979)

Fine aggregate (sand): Particles of fine aggregates pass through 5mm sieve and are entirely retained on 150μm sieve. Most commonly used fine aggregates are sand, crushed stone, ash.

b) In accordance with source

Natural aggregates: This kind of aggregate is taken from natural deposits without changing their nature during the process of production such as crushing and grinding. Some examples in this category are sand, crushed limestone, and gravel. (Surendra , 1979)

Manufactured (synthetic) aggregates:

This is a kind of man-made materials produced as a main product or an industrial by-product. Some examples are blast furnace slag, lightweight aggregate (e.g. expanded perlite), and heavy weight aggregates (e.g. iron ore or crushed steel). (Surendra , 1979)

c) In accordance with unit weight

Light weight aggregate: The unit weight of aggregate is less than 800.9 kg/m^3, examples are Cinder, blast-furnace slag, volcanic pumice aggregates

Normal weight aggregate: The aggregate has unit weight of 1282- 1602kg/m^3. The concrete made with this type of aggregate has a bulk density of 2300-2400 kg/m^3.

Heavy weight aggregate: The unit weight is greater than 2243 kg/m^3. The bulk density of the corresponding concrete is greater than 3200 kg/m3. A typical example is magnetite limonite, a heavy iron ore. Heavy weight concrete is used in special structures such as radiation shields. (BS 648; 1964)

2.4.2 Sieve Analysis of Aggregates

The preparation of samples for sieving and the sieve test procedures are described in BS1377; 1990 and BS 882; 1992

This is the name given to the operation of dividing a sample of aggregate into various fractions each consisting of particles of the same size. The sieve analysis is conducted to determine the particle size distribution in a sample of aggregate, which is termed as gradation. A convenient system of expressing the gradation of aggregate is one which the consecutive sieve openings are constantly doubled, such as 10 mm, 20 mm, 40 mm etc. Under such a system, employing a logarithmic scale, lines can be spaced at equal intervals to represent the successive sizes.

The aggregates used for making concrete are normally of the maximum size 80 mm, 40 mm, 20 mm, 10 mm, 4.75 mm, 2.36 mm, 600-micron, 300 micron and 150 microns. The aggregate fraction from 80 mm to 4.75 mm are termed as coarse aggregate and those fraction from 4.75 mm to 150 microns are termed as fine aggregate. The size 4.75 mm is a common fraction appearing both in coarse aggregate and fine aggregate (Scott, 1990).

Grading pattern of a sample of C.A. or F.A. is assessed by sieving a sample successively through all the sieves mounted one over the other in order of size, with larger sieve on the top. The material retained on each sieve after shaking, represents the fraction of aggregate coarser than the sieve in question and finer than the sieve above. Sieving can be done either manually or mechanically. In the manual operation the sieve is shaken giving movements in all possible direction to give chance to all particles for passing through the sieve. Operation should be continued till such time that almost no particle is passing through. Mechanical devices are actually designed to give motion in all possible direction, and as such, it is more systematic and efficient than hand sieving. For assessing the gradation by sieve analysis, the quantity of materials to be taken on the sieve (Gambhir, 2005).

The most common form of plot is the cumulative graph displaying the percentage by weight of the material. The sieve sizes and percentage mass passing are represented on a logarithmic scale. From the graph the particle size distribution of the silt fraction are obtained

The value of D10, D30 and D60 are obtained from the graph to calculate the uniformity coefficient (C_u) and coefficient of curvature (C_c). These are used to classify sand (Jackson and DHIR; 1988).

Formulae used to calculate the C_u and C_c are as follows:

$C_u = \frac{D_{60}}{D_{10}}$ and $C_c = \frac{(D_{30})^2}{D_{60} x D_{10}}$ .... ***Equation 2.2***

For well graded sand the coefficient uniformity should be greater than 6 or more and the coefficient of curvature should be between 1 and 3 (Arora, 2004)

Quality requirement for sand

The silt content in the sand should not exceed 4% of mass passing the 75μm sieve as in the table 2.1. The silt content in the sand which is greater than 4%, sand should be washed before used in concrete.

Table 2.1: Quality requirements for sand

Fines	
Aggregate type	Percentage by mass passing 75μm sieve (max)
Uncrushed, partially crushed, or crushed gravel coarse aggregates Crushed rock aggregate	2 4
Uncrushed, partially crushed or crushed gravel sand Crushed rock sand Gravel all in aggregate Crushed rock all in aggregate	4 16(9 for use in heavy duty floor finishes 3 11

(**Source**: BS 882, 1992)

2.4.3 Flakiness Index Test

Flaky material is described as material which is usually angular and its thickness is smallest relative to the width and length. The flakiness index is determined by separating the flaky particles and expressing their mass as a proportion of the total sample. The test must be carried out on all particle sizes in the sample.

Aggregate particles are deemed flaky when they have a thickness less than 0.6 of the mean sieve size. This shape is taken as the means of limiting sieve sizes used for determining the size fraction in which the particle occurs. The test is not applicable to material passing a 6.3 mm test sieve, the flakiness index is reported as the sieve of masses of aggregates passing through the various thickness gauges expressed as a percentage of the total mass of the sample that is being gauged. The lower the index the more cubicle the aggregates will be. The flakiness index should not exceed thirty five percentage (35%) (BS 812, 1990) and forty five percentage (45%) (TRL, 1993), for quality concrete

2.4.4 Compressive Strength of Concrete Cube Test

It provides an idea about all the characteristics of concrete. By this single test one judge that whether Concreting has been done properly or not. Concrete compressive strength for general construction varies from 15 MPa to 30 MPa and higher in commercial and industrial structures.

Compressive strength of concrete depends on many factors such as water-cement ratio, cement strength, quality of concrete material, and quality control during production of concrete etc. Test for compressive strength is carried out either on cube or cylinder. Various standard codes recommend concrete cylinder or concrete cube as the standard specimen for the test.

Compressive strength is the ability of material or structure to carry the loads on its surface without any crack or deflection. A material under compression tends to reduce the size, while in tension, size elongates. For cube test two types of specimens either cubes of 150mm X 150mm X 150mm or 100mm X 100mm x 100mm depending upon the size of aggregate are used. For most of the works cubical moulds of size 150mm x 150mm x 150mm are commonly used.

This concrete is poured in the mould and tempered properly so as not to have any voids. After 24 hours these moulds are removed and test specimens are put in water for curing. The top surface of these specimen should be made even and smooth. This is done by putting cement paste and spreading smoothly on whole area of specimen.

These specimens are tested by compression testing machine after 7 days curing or 28 days curing. Load should be applied gradually at the rate of 140×10^{-4} kg/m^2 per minute till the Specimens fails. Load at the failure divided by area of specimen gives the compressive strength of concrete.

Compressive strength formula for any material is the load applied at the point of failure to the cross-section area of the face on which load was applied.

Compressive Strength = Load / Cross-sectional Area..................................*Equation 2.3*

Average Compressive Strength (Central Value)

The central value of the compressive stress is the average of the compressive stress results obtained in the laboratory (Stroud, 1982)

Standard Deviation

The standard deviation from the mean was used in statistic to indicate the degree of dispersion. It considers deviation if every compressive stress from test from the mean.

2.4.5 Clay Bricks and Hollow Clay Bricks

Clay Burnt hollow clay brick are made by shaping suitable clays and shale to units of standard size, which are then fired to a temperature in the range 900°C to 1200°C. The fired product is a ceramic composed is a ceramic composed predominantly of silica SiO_2 (generally between 55% to 65% by weight) and Alumina Al_2O_2 (10% to 25%) combined with as much as 25% of other constituents. Burnt hollow clay brick are perforated to reduce weight (Jackson and Dhir, 1988).

The properties are mechanical behaviour, water absorption and permeability and durability. These properties are controlled in some measure by the porous nature of brick ceramics.

Density

The solid density of clay brick or burnt hollow clay brick depends on the clay composition and varies from about 2250kg/m^3 to about 2800kg/m^3 as shown in table 2.2 The bulky density of bricks $\rho = \rho_s(1 - n)$ where n is the porosity. Porosity (n) varies widely amongst burnt hollow clay brick of different kinds and perforation present. (Gambhir, 2005)

Table 2.2: Characteristics of hollow Burnt Clay Bricks

Size (in.)	Kg/Unit	Length (mm)	Width (mm)	Height (mm)	Number/ m^2
4"	7.7	300	300	100	8
5"	8.70	300	300	125	8
6"	9.00	300	300	150	8
7"	10.6	300	300	175	8
8"	12.2	300	300	200	8
9"	13.6	300	300	230	8

(**Source:** Uganda Clays Limited)

Compressive Strength of Burnt Hollow Clay Brick

The compressive strength is the only mechanical property used in brick specification, it's the failure stress measured normal to the bed face. Bricks are tested wet, normally with peroration filled with hardened mortar.

A considerable variation is found between individual brick and a batch of ten is tested to obtain a mean strength.

The compressive strength decreases with increasing porosity, but strength is also influenced by clay composition and firing. The compressive strength is limited by brittle fracture and is sensitive to individual flaws in the sample under test, including those associated with large particles, fissures formed during shaping and shrinkage cracking.

The young's modulus of elasticity of bricks ceramic lies usually in the range 5 to 30 kN/mm^2 (Jackson and Dhir, 1988)

2.5 SEISMIC ANALYSIS

2.5.1 Static Lateral Force Method

The static lateral force method was developed to simplify both dynamic and inelastic considerations. The method relies on the fact that the maximum response of a dynamic system is dependent on the natural period, degree of damping and utilization of inelastic deformations to absorb large levels of energy leading to a reduction in the design forces. After yielding, the member forces remain below the level they would have reached had the structure remained elastic. For structures with an initial period greater than or equal to the period for maximum spectral acceleration and also greater than the predominant period of the earthquake, lengthening of the structural period caused by yielding of members helps to reduce the response. This method uses response modification factors to reduce the design forces such that during minor earthquakes, no damage is suffered, but during a major earthquake, structures may deform into the inelastic range without collapse (Euro code 8, 2003).

The static lateral force method computes the peak earthquake load as a function of;

a) The Geographical Location; (Zone Factor)
b) Foundation Soil; (Soil Factor)
c) Intended Use of The Structure; (Importance Factor)
d) The Weight of The Structure
e) The Fundamental Period, T1 of the Structure
f) The Ductility Expected (Response Modification Factor R)

2.5.2 Horizontal Elastic Response Spectrum

The elastic response spectrum Se(T) for horizontal component of the seismic action is calculated using formulae from the euro code 8 clause 3.2.2.2 it depends on the ground type, ground acceleration, soil factor and spectra type. There are two types of spectra namely; Type 1 and Type 2. The selection of the type of the spectrum depends on the magnitude when it is greater than 5.5, the spectrum type 1 is selected. In case the magnitude is less than 5.5, the spectrum type 2 is selected. In this case the magnitude of 5.9 of earth quake occurred a year ago around Nsungu, Kagera Tanzania in the zone 3.

Formulae for calculating the Elastic Response Spectrum.

Se(T) For the horizontal component of the seismic action, is defined by the following expressions;

$0 \leq T \leq T_B;\ S_e(T) = a_g.S.\left[1 + \frac{T}{T_B}(\eta.2,5 - 1)\right]$ .... ***(Equation 2.3)***

$T_B < T < T_C;\ S_e(T) = a_g.S.[(\eta.2,5)]$ .... ***(Equation 2.4)***

$T_C < T < T_D;\ S_e(T) = a_g.S.\eta.2,5\left(\frac{T_C}{T}\right)$ .... ***(Equation 2.5)***

T_D<T<4s; $S_e(T) = a_g . S . \eta . 2{,}5\left(\frac{T_C T_D}{T^2}\right)$ .... *(Equation 2.6)*

US 319:2003 (Uganda Standard code), doesn't give the elastic response spectrum and design response spectrum for horizontal component of seismic action. Here one value of acceleration and period is obtained when the sub soil type is considered, even the soil factor is not considered. In case of a euro code, different values of periods and accelerations are obtained because the seismic action does not apply at a particular time and particular acceleration, that's why the euro code 8 mainly used with Uganda standard code US 319: 2003 in this research.

The ground type C, the seismic zone as Zone 3, soil factor and the spectrum type 1(Earth quake magnitude $|M|$ is greater than 5.5) is considered

The values of periods depend on the soil factor and the damping correction factors are used in the formulae to calculate the ground acceleration The value of soil factor for ground type C and for the spectrum Type 1 which is 1.15

2.5.3 Design Spectrum

Design spectrum Sd(T) for the frame structure depends on the following factors

i. Behaviour factors q

$q = q_o k_w > 1.5$ .... *(Equation 2.7)*

Assume a four storied building with multi bay frames.

Assumed medium ductility (DCM)and structural type because it applies to the composite structures.

ii. Frame system

$q_0 = 4.5\frac{\alpha_u}{\alpha_1}$ .... *(Equation 2.8)*

Assumed multi – storeyed and multi-bay frame,

$\frac{\alpha_u}{\alpha_1} = 1.3$ .... *(Equation 2.9)*

Prevailing failure mode in structural system with wall $k_w = 1.0$

The formulae used to calculate the design spectrum $S_d(T)$, were as follows (Euro Code 8, 2003)

0<T<T_B: $S_d(T) = a_g . s . \left[\frac{2}{3} + \frac{T}{T_B}\left(\frac{2.5}{q} - \frac{2}{3}\right)\right]$ ....*(Equation 2.10)*

$T_B<T<T_C \quad S_d(T) = a_g.s.\left[\left(\frac{2.5}{q}\right)\right]$ .... *(Equation 2.11)*

$T_C<T<T_D: \quad S_e(T) = \begin{cases} a_g.S.\frac{2.5}{q}\left[\frac{T_C}{T}\right] \\ \geq \beta a_g \end{cases}$ ....*(Equation 2.12)*

2.5 DESIGN PROCESS

According to clause 3.2.2.1 (3) P, EN 1998, (Eurocode 8) The horizontal seismic action is described by two orthogonal components considered as independent and represented by the same response spectrum.

The shape of the elastic response spectrum is taken the same for the two levels of seismic action introduced for the no-collapse requirement (Ultimate limit state – design seismic action) and for the damage limitation requirement.

The guiding principles governing this conceptual design against seismic hazard are: structural simplicity; uniformity, symmetry and redundancy; bi-directional resistance and stiffness; torsional resistance and stiffness; diaphragmatic behaviour at storey level; and adequate foundation. EN 1998,

The bi-directional resistance and stiffness is not conformed to by Burnt clay hollow block slabs yet According to clause 4.2.1.3 (1) P EN 1998, "Horizontal seismic motion is a bi-directional phenomenon and thus the building structure shall be able to resist horizontal actions in any direction."

"To satisfy (1)P, the structural elements should be arranged in an orthogonal in-plan structural pattern, ensuring similar resistance and stiffness characteristics in both main directions.

The rules that govern the Diaphragmatic behaviour at storey level during seismic response are set out in clause 4.2.1.5 of EN1998 as follows:

(1) "In buildings, floors (including the roof) play a very important role in the overall seismic behaviour of the structure. They act as horizontal diaphragms that collect and transmit the inertia forces to the vertical structural systems and ensure that those systems act together in resisting the horizontal seismic action. The action of floors as diaphragms is especially relevant in cases of complex and non-uniform layouts of the vertical structural systems, or where systems with different horizontal deformability characteristics are used together (e.g. in dual or mixed systems)."

(2) "Floor systems and the roof should be provided with in-plane stiffness and resistance and with effective connection to the vertical structural systems. Particular care should be taken in cases of non-compact or very elongated in-plan shapes and in cases of large floor openings, especially if the latter are located in the vicinity of the main vertical structural elements, thus hindering such effective connection. Diaphragms should have sufficient in-plane stiffness for the distribution of horizontal and inertia forces to the vertical structural systems in accordance with the assumptions of the analysis; that is rigidity of the diaphragm (slab).

2.5.3 Procedure for carrying out the Lateral Static Force Analysis

Define the design earthquake in terms of an acceleration response spectrum, this was picked from the Uganda standard code clause 9.1.4. Carry out the preliminary sizing of the structural members, the size of column, beams, slabs and wall thickness were obtained by use of codes and experience. Determine the response modification factor (Behaviour factor) from Eurocode 8, then define structural model and determine the properties of the model; total weight, W and fundamental period, T1 these were used to determine the minimum design base shear, V by dividing the. Total base shear by the response modification factor which was later used to distribute the design base shear over the height of the structure following the first mode response. Perform elastic analysis under the action of earthquake and gravity loads (Euro code 8, 2003).

2.6 ABAQUS

2.6.1 General

Abaqus is a suite of powerful engineering simulation programs, based on the finite element method that can solve problems ranging from relatively simple linear analyses to the most challenging nonlinear simulations. Abaqus contains an extensive library of elements that can model virtually any geometry. It has an equally extensive list of material models that can simulate the behavior of most typical engineering materials including metals, rubber, polymers, composites, reinforced concrete, crushable and resilient foams, and geotechnical materials such as soils and rock. Designed as a general-purpose simulation tool, Abaqus can be used to study more than just structural (stress/displacement) problems.

It can simulate problems in such diverse areas as heat transfer, mass diffusion, thermal management of electrical components (coupled thermal-electrical analyses), acoustics, soil mechanics (coupled pore fluid-stress analyses), and piezoelectric analysis. Abaqus offers a wide range of capabilities for simulation of linear and nonlinear applications.

Problems with multiple components are modeled by associating the geometry defining each component with the appropriate material models and specifying component interactions. In a nonlinear analysis Abaqus automatically chooses appropriate load increments and convergence tolerances, and continually adjusts them during the analysis to ensure that an accurate solution is obtained efficiently (Abaqus Manual, Version 6.8, 2008).

2.6.2 Abaqus Basics

A complete Abaqus analysis usually consists of three distinct stages: preprocessing, simulation, and postprocessing. These three stages are linked together by files as shown in figure:

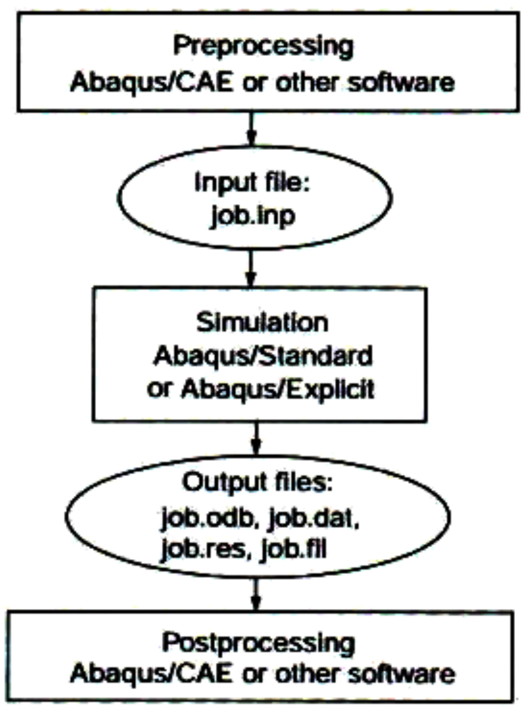


Figure 2.1: Systematic flow of the Abaqus Modeling and Analysis

(SOURCE: (Abaqus Manual, Version 6.8, 2008)

2.6.3 Preprocessing (Abaqus/CAE)

In this stage the model of the physical problem is defined and an Abaqus input file is created. The model is usually created graphically using Abaqus/CAE or another preprocessor, although the Abaqus input file for a simple analysis can be created directly using a text editor (Abaqus Manual, Version 6.8, 2008).

2.6.4 Simulation (Abaqus/Standard or Abaqus/Explicit)

The simulation, which normally is run as a background process, is the stage in which Abaqus/Standard or Abaqus/Explicit solves the numerical problem defined in the model. Examples of output from a stress analysis include displacements and stresses that are stored in binary files ready for post-processing. Depending on the complexity of the problem being analyzed and the power of the computer being used, it may take anywhere from seconds to days to complete an analysis run (Abaqus Manual, Version 6.8, 2008).

2.6.5 Postprocessing (Abaqus/CAE)

the results are evaluated once the simulation has been completed and the displacements, stresses, or other fundamental variables have been calculated. The evaluation is generally done interactively using the Visualization module of Abaqus/CAE or another postprocessor. The Visualization module, which reads the neutral binary output database file, has a variety of options for displaying the results, including color contour plots, animations, deformed shape plots, and *X–Y* plots (Abaqus Manual, Version 6.8, 2008).

2.6.6 Components of an Abaqus Analysis Model

An Abaqus model is composed of several different components that together describe the physical problem to be analyzed and the results to be obtained. At a minimum the analysis model consists of the following information: discretized geometry, element section properties, material data, loads and boundary conditions, analysis type, and output requests (Abaqus Manual, Version 6.8, 2008).

2.6.6.1 Discretized Geometry

Finite elements and nodes define the basic geometry of the physical structure being modeled in Abaqus. Each element in the model represents a discrete portion of the physical structure, which is, in turn, represented by many interconnected elements. Elements are connected to one another by shared nodes. The coordinates of the nodes and the connectivity of the elements—that is, which nodes belong to which elements—comprise the model geometry. The collection of all the elements and nodes in a model is called the mesh. Generally, the mesh will be only an approximation of the actual geometry of the structure.

The element type, shape, and location, as well as the overall number of elements used in the mesh, affect the results obtained from a simulation. The greater the mesh density (i.e., the greater the number of elements in the mesh), the more accurate the results. As the mesh density increases, the analysis results converge to a unique solution, and the computer time required for the analysis increases. The solution obtained from the numerical model is generally an approximation to the solution of the physical problem being simulated. The extent of the approximations made in the model's geometry, material behavior, boundary conditions, and loading determines how well the numerical simulation matches the physical problem (Abaqus Manual, Version 6.8, 2008).

2.6.6.2 Element Section Properties

Abaqus has a wide range of elements, many of which have geometry not defined completely by the coordinates of their nodes. For example, the layers of a composite shell or the dimensions of an I-beam section are not defined by the nodes of the element. Such additional geometric data are defined as physical properties of the element and are necessary to define the model geometry completely (Abaqus Manual, Version 6.8, 2008).

2.6.6.3 Material Data

Material properties for all elements must be specified. While high-quality material data are often difficult to obtain, particularly for the more complex material models, the validity of the Abaqus results is limited by the accuracy and extent of the material data (Abaqus Manual, Version 6.8, 2008).

2.6.7 Loads and Boundary Conditions

Loads distort the physical structure and, thus, create stress in it. The most common forms of loading include:

- Point Loads;
- Pressure Loads on Surfaces;
- Distributed Tractions on Surfaces;
- Distributed Edge Loads and Moments on Shell Edges;
- Body Forces, Such as the Force of Gravity; and
- Thermal Loads.

Boundary conditions are used to constrain portions of the model to remain fixed (zero displacements) or to move by a prescribed amount (nonzero displacements).

In a static analysis enough, boundary conditions must be used to prevent the model from moving as a rigid body in any direction; otherwise, unrestrained rigid body motion causes the stiffness matrix to be singular. A solver problem will occur during the solution stage and may cause the simulation to stop prematurely. Abaqus/Standard will issue a warning message if it detects a solver problem during a simulation. It is important that you learn to interpret such error messages. If you see a "numerical singularity" or "zero pivot" warning message during a static stress analysis, you should check whether all or part of your model lacks constraints against rigid body translations or rotations. Rigid body motions can consist of both translations and rotations of the components. The potential rigid body motions depend on the dimensionality of the model. (Abaqus Manual, Version 6.8, 2008)

Table 2.3: Dimensionality and respective possible Rigid Body Motion

Dimensionality	Possible Rigid Body Motion
Three- dimensional	Translation in the 1-, 2-, and 3-directions. Rotation about the 1-, 2-, and 3-axes
Axisymmetric	Translation in the 2-direction Rotation about the 3-axis (axisymmetric rigid bodies only)
Plane stress Plane strain	Translation in the 1- and 2-directions Rotation about the 3-axis

By default, the 1-, 2-, and 3-directions are aligned with the axes of a global Cartesian coordinate system.

In a dynamic analysis, inertia forces prevent the model from undergoing infinite motion instantaneously as long as all separate parts in the model have some mass; therefore, solver problem warnings in a dynamic analysis usually indicate some other modeling problem, such as excessive plasticity.

2.6.8 Analysis Type

Abaqus can carry out many different types of simulations, but this guide only covers the two most common: static and dynamic stress analyses.

In a static analysis the long-term response of the structure to the applied loads is obtained. In other cases, the dynamic response of a structure to the loads may be of interest: for example, the effect of a sudden load on a component, such as occurs during an impact, or the response of a building in an earthquake. (Abaqus Manual, Version 6.8, 2008)

2.6.9 Output Requests

An Abaqus simulation can generate a large amount of output. To avoid using excessive disk space, you can limit the output to that required for interpreting the results. Generally, a preprocessor such as Abaqus/CAE is used to define the necessary components of the model. (Abaqus Manual, Version 6.8, 2008)

CHAPTER THREE: METHODOLOGY

3.1 INTRODUCTION

This chapter presents the research design and methodology that was used in conducting the research and is delineated in the subsequent narrative. It includes experimental setup and testing, modelling with Abaqus software, experimental data analysis and comparison with data generated from computer model.

3.2 RESEARCH DESIGN

Experimental design was adopted for this research and was comparative in nature. The relationship between the internal slab configuration and axial loads in the plane of the slab was established and used to explain the failure mode. In seismic analysis an earthquake load is represented as a horizontal load applied at slab level in the plane of the slab.

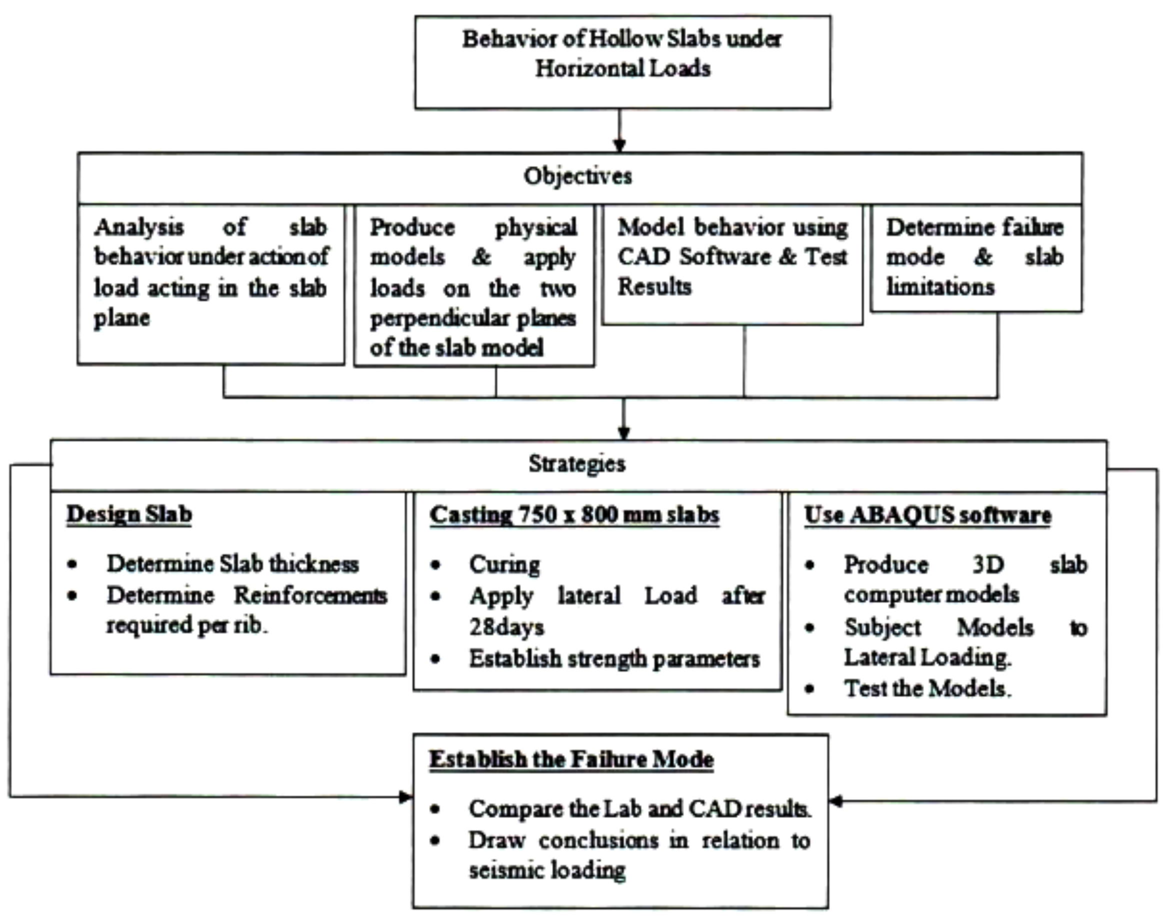


Figure 3.1: Systematic Flow chart of the Research Design

3.3 RESEARCH APPROACH

The research was experimental exploring the relationship between behavior of hollow block slab with increasing magnitude of seismic action (represented by horizontal loads), the deformation and ultimate load at failure of the slab. The first stage involved development of ribbed slab prototypes on which a load was applied in the plane of the slab.

The second stage was computer modelling of the slab and experimental load in ABAQUS computer software to simulate the performance of the slab.

3.3.1 Material Testing

3.3.1.1 Grading of Fine Aggregates

The sieve analysis was carried using a set of sieves 10, 5, 2.36, 1.18, 600μ, 300μ and 150μ mm. The sample of 1000.29g of sand was selected and weighed on a weighing machine.

After weighing the sample, it was put on the set of sieves. The sieving was started, and mass retained on the sieve was recorded on each sieve. The percentage of mass retained was obtained for each sample retained and percentage accumulation was obtained by adding percentage retained.

Percentage mass passing was obtained by subtracting accumulation percentage from 100%. The results were tabulated in table 3.1.

Table 3.1: Grading Results

Sieve Size	Mass Retained	% Mass Retained	% Mass Accumulation	% Mass Passing

The graph of sieve size was plotted against mass passing.

3.3.1.2 Grading of Coarse Aggregates

The grading of aggregates was carried out on a batch of aggregates to be used in concrete the specimen. The sample was taken and weighed on weighing machine.

The weight of sample was recorded as 3612.12g. The sample was put on the set of sieves, 37, 20, 14, 10, and 5 mm. The mass retained on each sieve was put onto pan and weighed again. The mass retained was recorded and retained was recorded and then the percentage obtained. Also, percentage mass passing was obtained in similar manner as for sand.

The sample retained on the 6.3 mm sieve was tested again using the following sieves: 28-20, 20-14, 14-10, and 10-6.3mm. The mass retained on each sieve was recorded, total mass retained on each sieve was obtained and expressed as percentage of total mass of sample.

$$Percentage\ mass\ passing = \frac{mass\ passing}{total\ mass\ of\ the\ sample} \times 100 \quad \text{......................} \textbf{\textit{(Equation 3.1)}}$$

3.3.1.3 Determination of weight of concrete cubes.

The concrete cubes were measured on a weighing machine and the weight of each cube was recorded. The whole processes repeated.

3.3.1.4 Determination of Compressive Stress of Concrete Cube

The cube is placed compressive machine to obtain a compressive force and stress. The procedure was repeated for other cubes, the results were tabulated in Table 3.2

Table 3.2: Concrete Cube Crushing Results

Sample	Weight	Area	Compressive Force	Compressive Stress
1				
2				
3				

3.3.1.5 Determination of Mean and Standard Deviation

The mean of the compressive stress was obtained by dividing the total compressive stress results by the number of samples tested.

Mean, $\bar{x} = \frac{\Sigma f(x)}{n}$ .... ***(Equation 3.2)***

The standard deviation of compressive stress was obtained by subtracting the average compressive stress from the compressive stress. The value was squared, adding them to give the total which was later divided by number of samples. The square roots of the resulting value were the standard deviation of the compressive stress of results from laboratory.

The standard deviation was obtained using the formula

$$\delta = \sqrt{\frac{(x-\bar{x})^2}{n}} \text{.. (Equation 3.3)}$$

The characteristic strength of concrete was obtained using the formula

$$f_k = f_n - 1.64\delta \text{.. (Equation 3.4)}$$

3.3.1.6 Burnt clay hollow blocks

Burnt clay hollow bricks were measured on a weighing machine and the weight of each block was recorded. The whole processes repeated.

Sample	Weight	Area	Compressive Force	Compressive Stress
1				
2				
3				

3.3.1.7 Test of burnt clay hollow block specimens

General

300 x 300 x 150mm burnt clay hollow blocks manufactured by Uganda Clays Limited were used and these were tested in compression in the two perpendicular planes. The respective perpendicular cross-sectional areas of 45000mm^2 side parallel to the Burnt clay hollow block holes and 45000mm^2 perpendicular to the Burnt clay hollow block holes as shown in Figure 3.2.

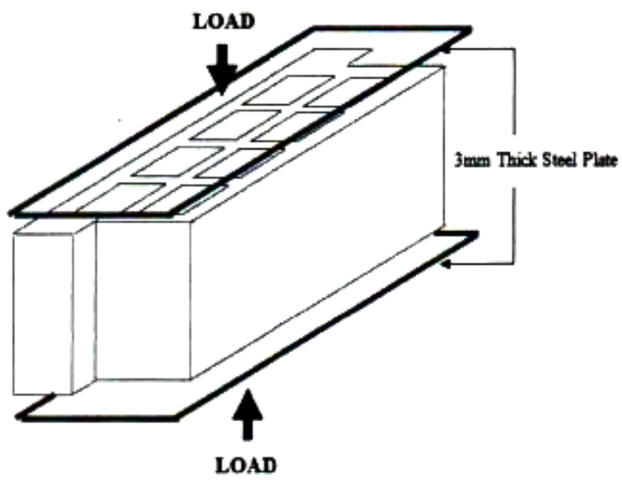


Figure 3.2: Loading arrangement for burnt clay hollow block parallel to the holes

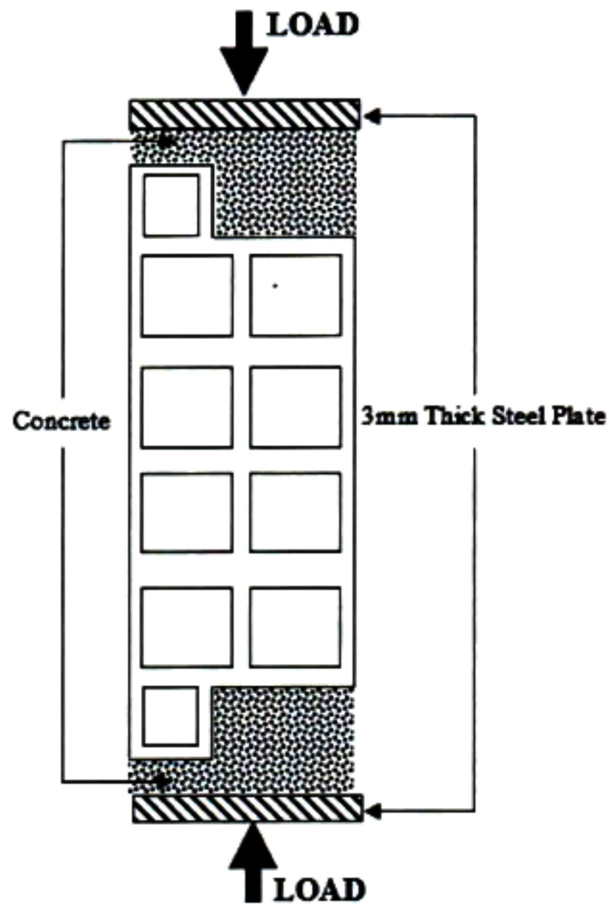


Figure 3.3 Loading arrangement of burnt clay hollow blocks loaded perpendicular to the holes

3.3.1.8 Determination of weight of burnt clay hollow block

Burnt clay hollow blocks were measured on a weighing machine as shown in the figure below. And the weight of each block was recorded. The whole processes repeated

3.3.1.9 Determination of Compressive Strength of Burnt Clay Hollow Block

The burnt clay hollow block was put into a compressive machine test to obtain a compressive force, it was recorded together with the cross-section area parallel to the holes. The procedure was repeated for other burnt clay hollow blocks, in the direction perpendicular to the holes.

Table 3.3: Hollow Block Crushing Results

Sample	Weight	Area	Compressive Force	Compressive Stress
1				
2				

The compressive stress was obtained by dividing the compressive force by cross sectional area in the direction the force was applied.

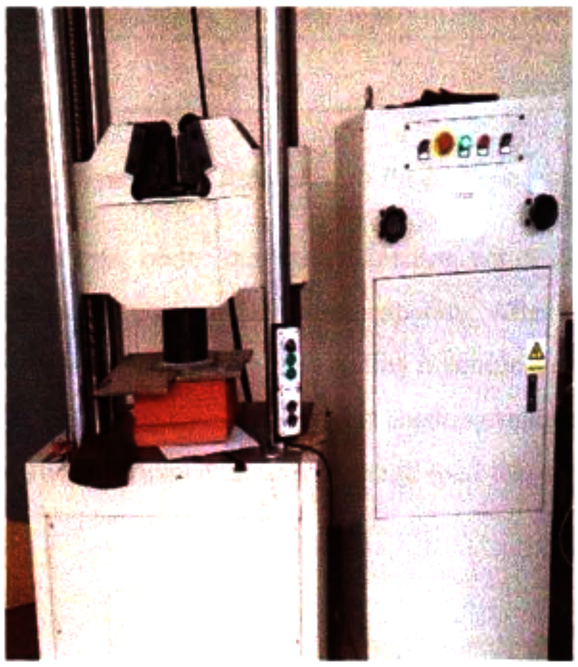


Plate 3.1: Crushing of Hollow Block Perpendicular to Holes

3.3.2 Slab Specimens

Four (4) specimens with simple support boundary conditions were prepared and tested to failure under sequential high-mass, low-velocity loading conditions.

Concrete was mixed in a concrete mixer in the Laboratory, to ensure consistence and good quality. A mix of 1:2:4 batching by weight and water cement ratio of 0.45 was used. The concrete cubes were cast, cured for 28 days and tested for compressive strength.

The resulting geometries of the constructed hollow slab four specimens were 750 x 800mm. With thickness of 200mm. The target 28-day compressive strength for the concrete was 25 MPa and the maximum nominal aggregate size were 20 mm. Two T12 reinforcement bars were provided in the ribs and an A 142 BRC mesh provided in the concrete topping of 50mm. Typical section through the specimens are shown in Figure 3.3.

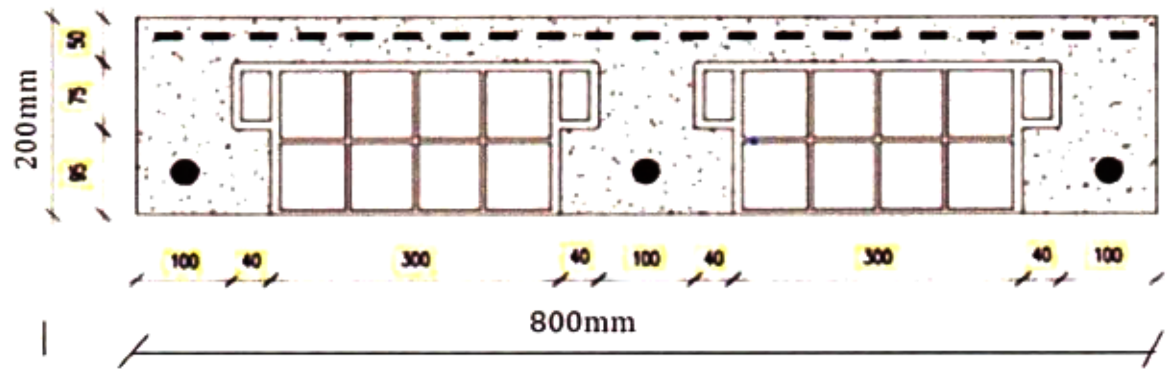


Figure 3.3: Ribbed Slab Proto Type

The slabs were designed such that, under monotonic loading conditions, a ductile failure mode consisting of tension steel yielding governed ultimate capacity. After curing for 28days, the slab samples were subjected to loading using the culvert testing machine modified by introducing Steel Beams. The experimental set up of the modified culvert crushing machine is shown in Figures 3.4 and 3.5. The slab specimens were crushed and the average load taken as the crushing load of the slab.

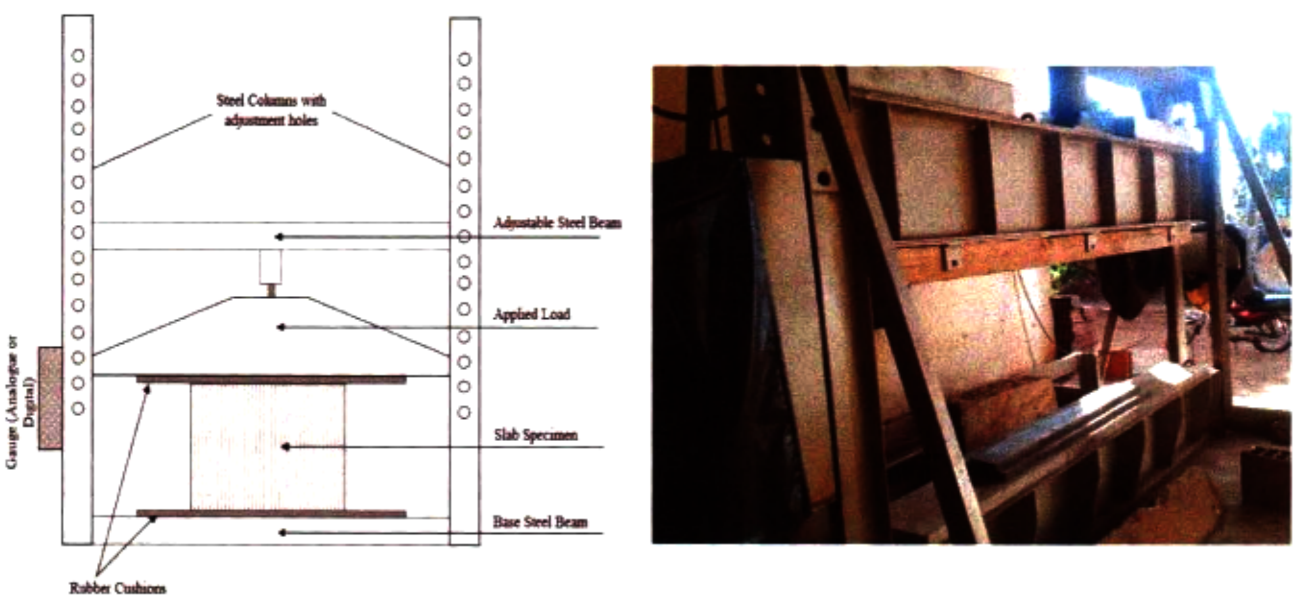


Figure 3.4: Modified Culvert Testing Machine

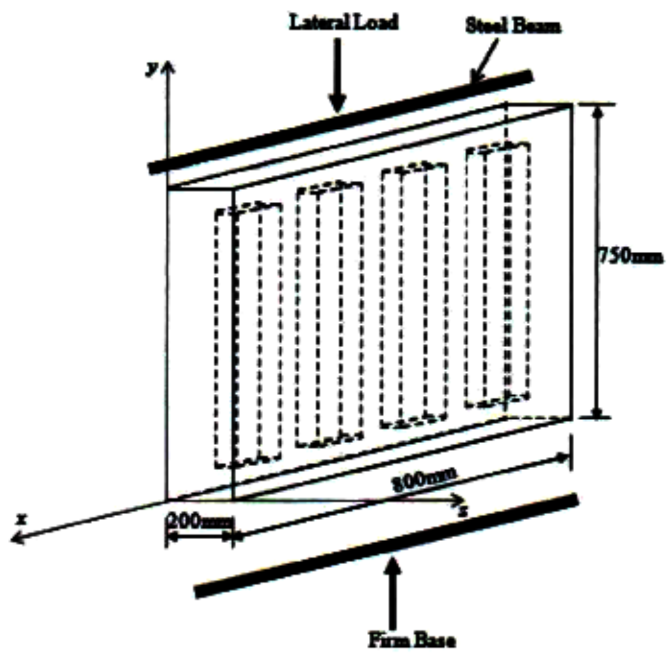


Figure 3.5: Load applied parallel to the Ribs

When hollow slab physical model gained enough strength after 28 days. The models were taken to the culvert testing machine for crushing. The model was placed perpendicular to the rib and the results were recorded at failure, this was repeated for the second model.

The third model was placed parallel to the rib and the reading was recorded at failure. This was repeated on the fourth model. The compressive strength of the model parallel to the rib was obtained by dividing the compressive force by cross section area.

$$Compressive\ stress = \frac{Compressive\ force}{Surface\ Area}$$

The results were tabulated in the Table 3.4

Table 3.4: Results for Compressive Force and Stress of Slab Specimen

Model	Compressive Force	Cross Section Area	Compressive Stress
Parallel to the Rib			
Perpendicular to the Rib			

3.3.3 Video Camera

A standard imaging hand-held and video camera was used to capture additional details regarding the loading and failure mechanism. The camera was positioned so as to capture the test slab and the load guide rail suspended above the slab. The camera was used to verify the loading and failure mechanism.

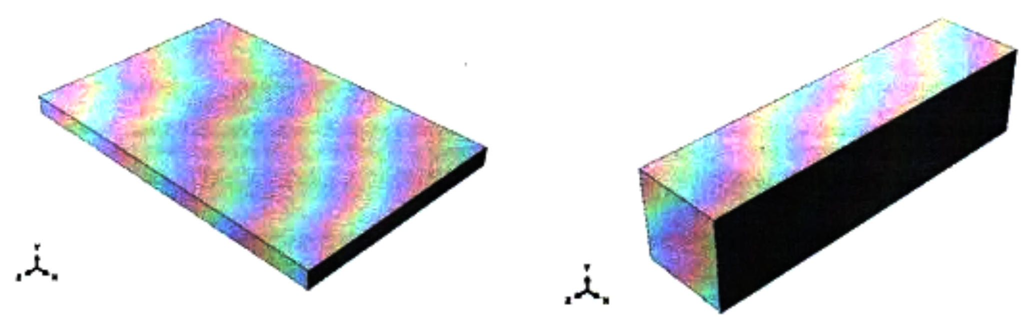
3.4 ABAQUS

3.4.1 General

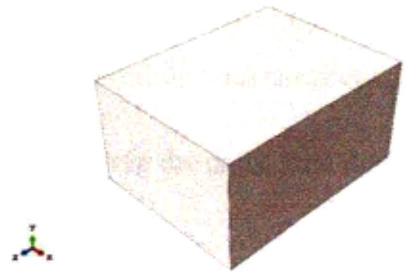
The model was assembled in five (5) parts, the equivalent solid clay block, the rib, the concrete topping, the rib reinforcement, the weld mesh and 3mm thick steel plate. Since the model was mainly composed of three materials, the respective material properties were allocated to the different parts accordingly as explained in section 3.4.3.

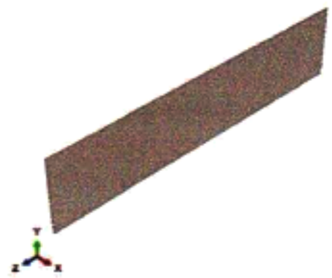
3.4.2 Part Geometry

All parts were created entirely from Abaqus/CAE, and this started by creating a three-dimensional, deformable solid bodies for the hollow block and wires for the mesh and the reinforcements respectively by sketching the two-dimensional profile of a rectangle and extruding it.



(a) (b)





(c) **(d)**

Figure 3.6: Different parts of the model (a) Top Slab, (b) Rib, (c) Equivalent Burnt Clay Solid Block, and (d) 3 mm Thick Plate

3.4.3 Material Data

Material properties for all elements were specified. The material properties input into Abaqus/CAE included the respective densities, young's modulus and Poisson's ratio.

3.4.4 Assembling of the Model

The parts were assembled to form the model slab specimen. Instances of the parts were created representing the original parts making up the model. Ribs were placed and patterned between which equivalent burnt clay solid blocks were placed. A concrete topping was the place on top of the ribs and reinforcement embed in the respective parts.

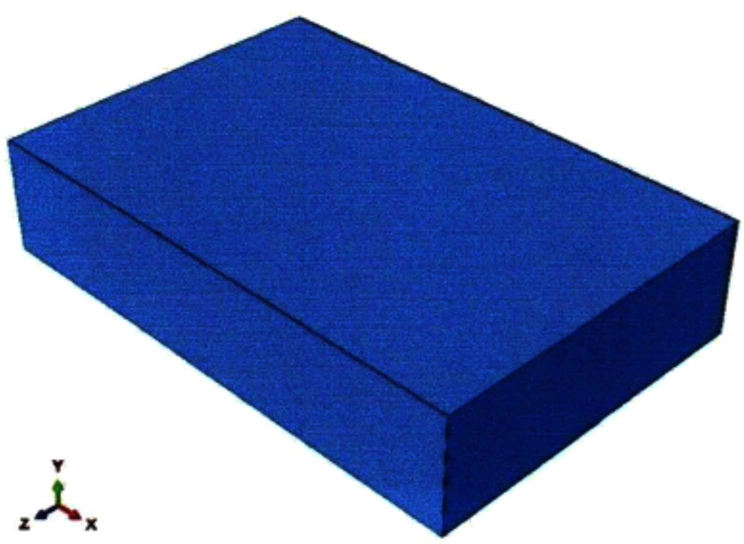


Figure 3.7: Assembled Burnt Clay Hollow Slab

3.4.5 Defining Analysis Steps

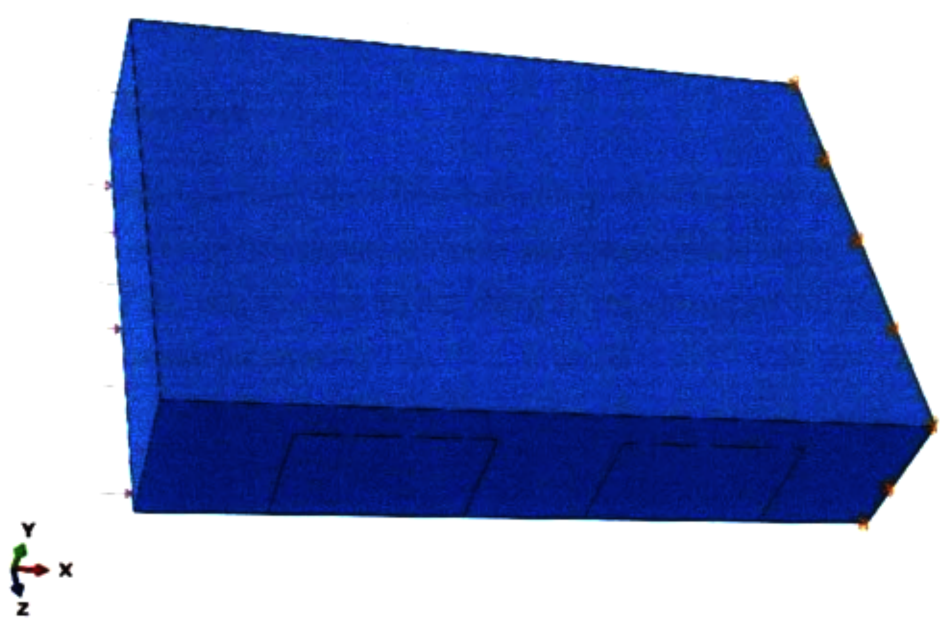
After creating the parts, then the analysis steps were defined which consisted of the following two steps:

- An initial step, was used to apply boundary conditions that constrains one end of the slab model depending on the direction of load.
- A general, static analysis step, in which was used to apply a pressure load to the opposite face of the slab model to that of the applied load.

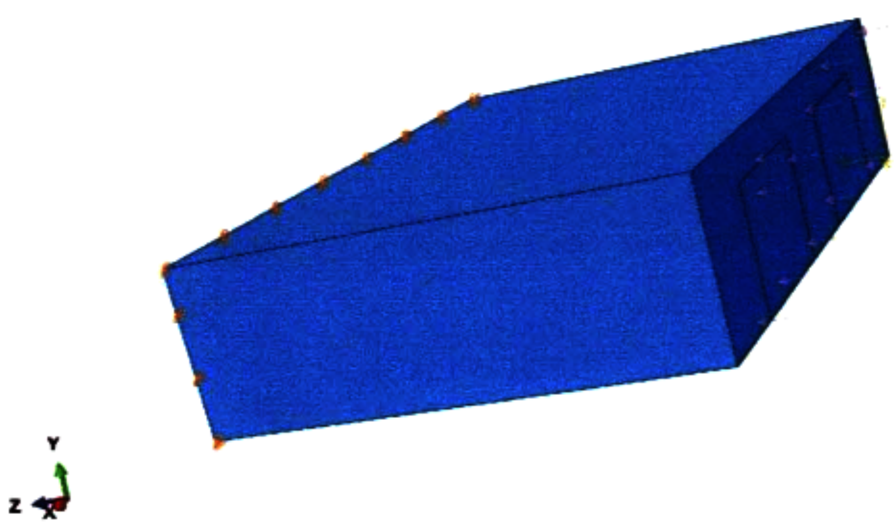
3.4.6 Model Boundary Condition and Loading

Prescribed conditions, such as loads and boundary conditions, are step-dependent, which means that one must specify the step or steps in which they become active. After defining the steps in the analysis, the following prescribed conditions were also defined:

- A boundary condition that constrains one end of the cantilever beam in the X-, Y-, and Z-directions; the boundary condition is applied during the initial step.
- A load was applied to the top face of the beam during the general analysis step.



(a)



(b)

Figure 3.8: Horizontal Load applied to the Slab (a) perpendicular to Rib and (b) parallel to Rib

3.4.7 Model Meshing and Assigning Mesh Controls

A meshing technique was selected to be used by Abaqus/CAE to create the finite element mesh. The default meshing technique assigned to the model is indicated by the color of the model when the Mesh module is entered.

3.4.8 Creating the Mesh

This was a two-stage operation which included seeding of the edges of the part instance, and then meshing the part instance. The number of seeds was selected based on the desired element size or on the number of elements that was needed along an edge. Abaqus/CAE places the nodes of the mesh at the seeds whenever possible.

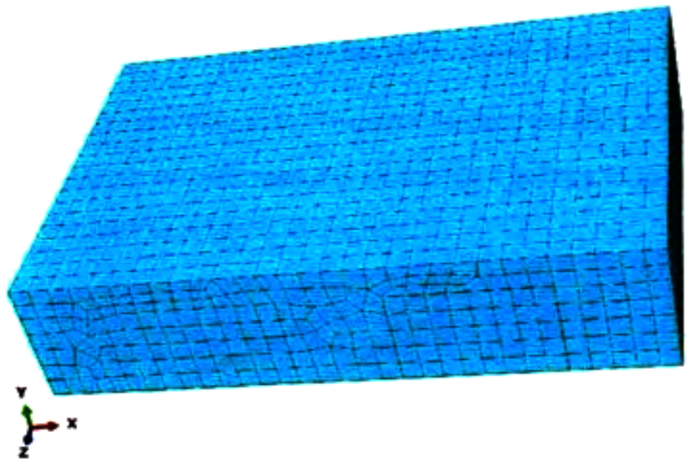


Figure 3.9: Meshed Burnt Clay Hollow Block Slab

3.4.9 Creating and Submitting an Analysis Job

After configuring the analysis, a job that is associated with model was created and submitted. There were two jobs which included parallel to rib and perpendicular to rib.

3.4.10 Viewing the Analysis Results

The Visualization module was used to read the output database generated during the analysis and to view the results of the analysis. The undeformed and deformed shapes of the hollow slab model were also viewed and a contour plot created.

3.4.11 Slab Models

The strength parameters of burnt clay hollow blocks were used in the modelling using ABAQUS to ensure the resultant slab is as close in behavior as possible to the hollow block slab. This required customizing the properties of the burnt clay hollow blocks.

An equivalent solid burnt clay block was used in the model slab. The solid burnt clay block was modelled in Abaqus software with its dimensions obtained by considering the second moment of area of the hollow block calculated parallel to the direction of the holes. A 230.9 x 300 x 150mm equivalent solid block was used resulting into a slab model of 911.8 x 600mm.

The horizontal load to apply to a model was determined from computation of the type seismic load on the floor of a storey structure, based on the static lateral force method as given in EC8.

Two (2) slab models were developed to represent loading parallel and perpendicular to the ribs. A calculated lateral load from seismic analysis alongside a gravity load were applied onto the models in the respective directions in relation to the ribs.

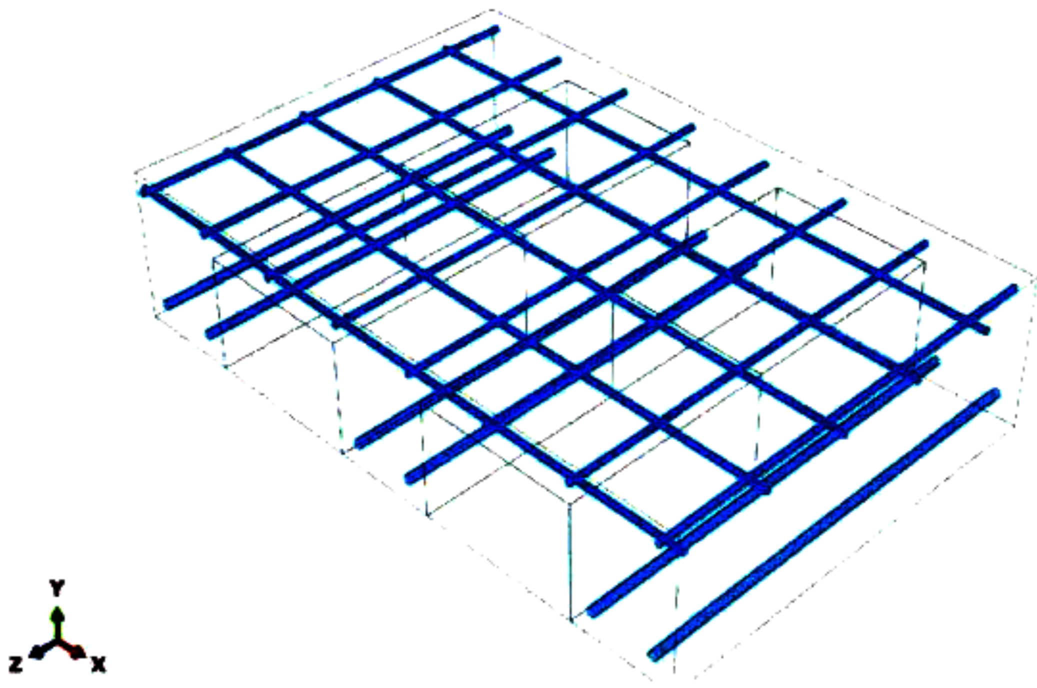


Figure 3.10: Modelled Burnt Clay Hollow Block Slab with Equivalent Solid Block

3.5- Chapter summary

This chapter presents the steps followed to obtain results of materials for concrete, the Burnt clay hollow block and Burnt clay hollow block slab specimen test and the Abaqus hollow block slab model behaviour under seismic action and the results are analyzed in chapter four.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter presents the results and discussion of the Burnt clay hollow block and Burnt clay hollow block slab specimen test results and the Abaqus hollow block slab model behaviour under seismic action.

4.2 COMPRESSIVE STRENGTH OF HOLLOW BLOCKS

The test results revealed that the load capacity of hollow blocks when loaded parallel to holes varied from 103.35kN – 123.93kN giving a compressive stress of 2.3N/mm^2 – 2.8N/mm^2, compared to the load capacity in the perpendicular direction of the holes of 45.6kN – 47.4kN giving a compressive strength of 1.0N/mm^2 – 1.05N/mm^2. This because of the cross-section area of partitions (13,800mm^2) in the direction of the holes is higher than the partition cross section area (9,000mm^2) in the plane perpendicular to holes. Table 4.1 shows results of hollow block compressive strength.

Table 4.1: Burnt Clay Hollow Block Compressive Strength Test Results

Direction of Application	Specimen	Area (mm^2)	Force (kN)	f_c (MPa)
Parallel to Burnt Clay Hollow Block Holes	1	45000	123.95	2.8
	2	45000	103.35	2.3
Perpendicular to Burnt Clay Hollow Block Holes	1	45000	45.6	1.0
	2	45000	47.4	1.05

4.3 GRADING OF AGGREGATES

Aggregates were tested and found that they were within the envelope as shown in the graph below. The tests revealed that the aggregates are well graded, for good concrete quality.

Results are attached in the appendix II. A graph showing the grading curve and the envelope for aggregates is shown in Figure 4.1

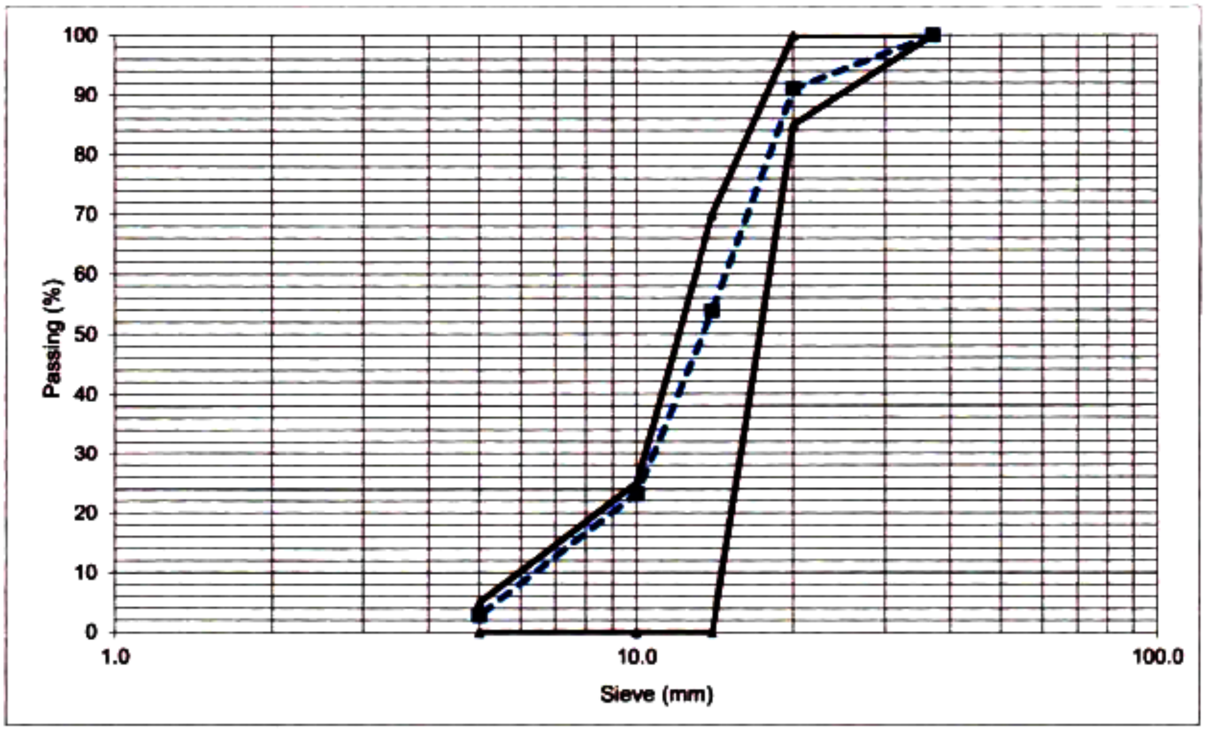


Figure4.1 Grading Curve and Envelope

Flakiness Index Test

The flakiness index test of the aggregates was twenty-seven-point two percent (27.2%) which is less than the maximum of thirty-five percent (35%), for quality concrete works as recommended by the ministry of works.

4.4 GRADING OF SAND

Sand was tested and found that it was within the envelope as shown in the Figure 4.2.

With the $D_{10} = 0.13$, $D_{30} = 0.32$, and $D_{60} = 0.85$

$$C_u = \frac{D_{60}}{D_{10}} = \frac{0.85}{0.13} = 6.5$$

And $C_c = \frac{(D_{30})^2}{D_{60} x D_{10}} = \frac{0.32^2}{0.85x0.13} = 1.0$

The coefficient of uniformity revealed that the sand is well graded since it was equal to 6 and the Coefficient of curvature revealed that the sand is well graded but the coefficients agreed, and therefore the sand is well graded is good for quality concrete. The silt content was two percentage (2%) which is less than four percentage (4%) maximum, for quality concrete (BS 812, 1989)

Results are attached in appendix I. The grading and the envelope for sand are shown in the Figure 4.2

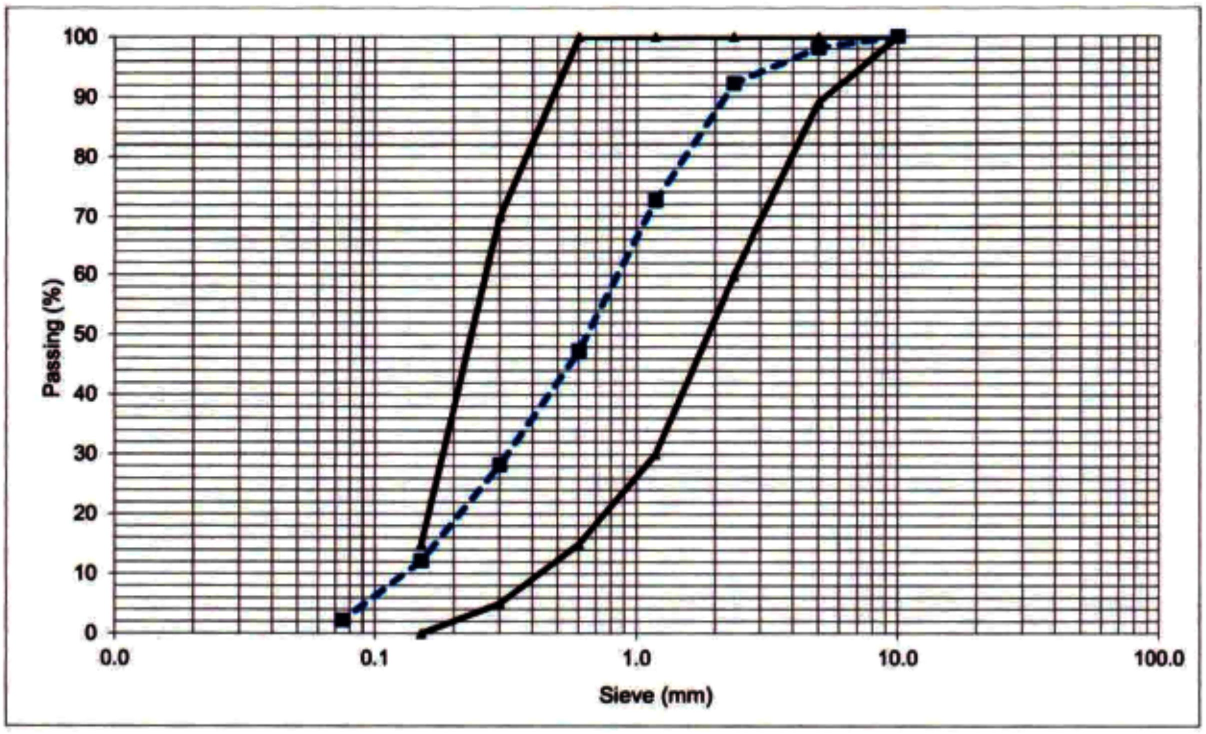


Figure 4.2 Grading Curve and Envelope

4.5 COMPRESSIVE STRENGTH OF CONCRETE CUBES

The concrete cubes tested yielded a 28-day characteristic compressive strength of 25.4N/mm^2. This value was within the desired concrete strength of 25N/mm^2. The results of compressive strength of cubes are presented in the table 4.2

Table 4.2: Compressive Strength of Concrete Cubes

Cubes	Weight of Cubes (Kg)	Compressive Force	Compressive Stress	X - $\bar{X}$	$(X - \bar{X})^2$
1	8.03	648.6	28.8	1.617	2.615
2	8.07	578.6	25.7	-1.483	2.200
3	7.97	641.4	28.5	1.317	1.734
4	8.04	603.2	26.8	-0.383	0.147
5	7.93	620.2	27.5	0.317	0.100
6	8.96	626.1	27.8	0.617	0.380
TOTAL			165.1		7.176

The mean compressive stress $\bar{X} = \frac{\sum f(x)}{n} = \frac{165.1}{6} = 27.183$

Standard deviation $\delta = \sqrt{\frac{(x-\bar{x})^2}{n}} = \sqrt{\frac{7.176}{6}} = 1.09$

The characteristic strength

$f_k = f_n - 1.64\delta = 27.183 - 1.64x1.09 = 25.379N/mm^2$

4.6 BURNT CLAY HOLLOW BLOCK SLAB SPECIMENS & MODELS

4.6.1 Laboratory Specimens

The 750 x 800mm hollow block slabs when tested revealed that the failure load varied from 315kN – 375kN when loaded parallel to the rib, giving a stress of 1.97N/mm^2 – 2.34N/mm^2 and the stress perpendicular to ribs varied from 1.04N/mm^2 – 1.2N/mm^2.

Table 4.3 below shows the failure load obtained when the load is applied parallel and perpendicular to the ribs for the slab specimens respectively.

Table 4.3: Slab Specimen Lateral Force Test Results

Specimen Size	Direction of Application	Specimen	Force (kN)	Cross-area (mm^2)	Compressive strength fc (N/mm^2)
800 x 750mm	Parallel to the Rib	1	375	160,000	2.34
		2	315		2.00
	Perpendicular to Rib	1	156	150,000	1.04
		2	186		1.24

From Table 4.1 and 4.3, it is seen that the compressive strength of the slab is closely related to that of the hollow blocks. Thus, the hollow blocks control the compressive strength of the slab.

The drawing showing the loading arrangement parallel to the rib of the slab specimen during laboratory test as in the Figure 4.3

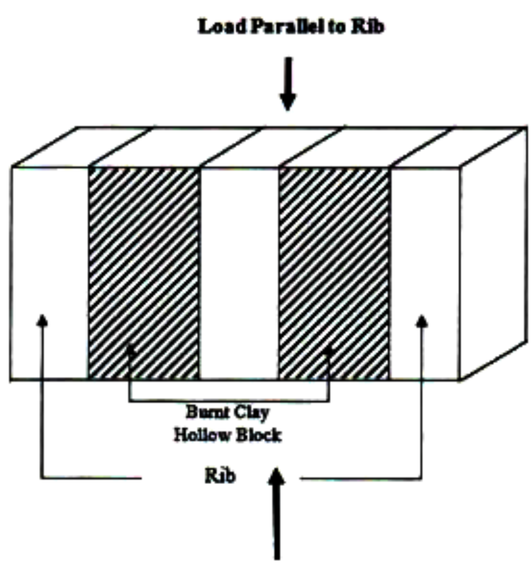


Figure 4.3: Loading arrangement of a Hollow Block Slab Parallel to the Rib

The drawing showing the loaded arrangement perpendicular to the rib of the slab specimen during laboratory test as in the Figure 4.4

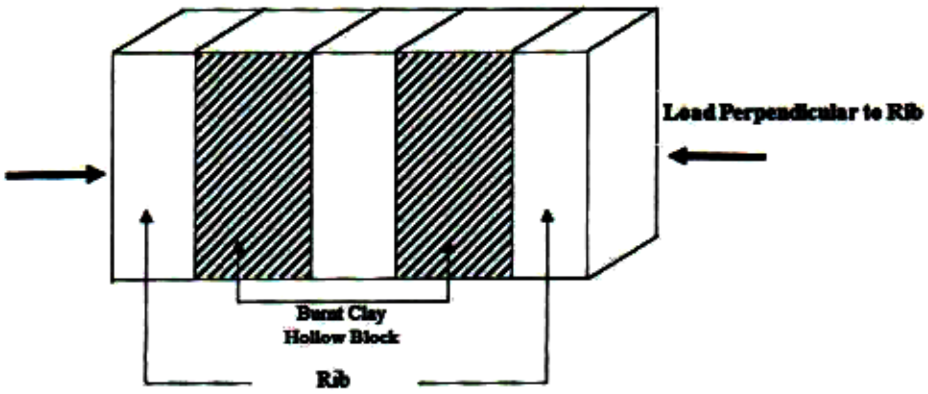


Figure 4.4: Loading arrangement of a Hollow Block Slab Perpendicular to the Rib

4.6.2 Model data input

Concrete, steel and brick densities and elastic properties were fed into ABAQUS to develop the model. Table 4.4 shows the model in put parameters that were used to develop and simulate the seismic conditions of a hollow slab.

Table 4.4: Model Input Parameters

S/N	Parameter	Value
1	Lateral Load	Parallel to Rib: 375 kN Perpendicular to Rib: 186 kN
2	Density • Concrete • Steel • Clay Block	2500kg/m³ 7850 kg/m³ 2130kg/m³
3	Modulus of Elasticity • Concrete • Steel • Clay Block	25000N/m² 210000N/m² 21300N/m²
	Poisson's Ratio • Concrete • Steel • Clay Block	0.2 0.3 0.17

4.7 BURNT CLAY HOLLOW BLOCK SLAB BEHAVIOUR AND FAILURE MODE

The hollow block slab model revealed that the stress in the hollow block slab model when loaded parallel to ribs was a maximum of $2.151x10^6 N/m^2$ ($2.151N/mm^2$) in the plane of application of load and the stress when loaded perpendicular to the rib the stress was a maximum of $1.074x10^6 N/m^2$ ($1.074N/mm^2$) in the plane of application of load respectively.

4.7.1 Parallel to the Rib

Failure of the slab started from the burnt clay hollow blocks transferring the stresses to the ribs. These stresses were concentrated at the mid span of the rib, as shown in Figure 4.1. the light colour indicate positions of the rib, the model shows that when the hollow block has failed the stresses are transferred to the rib. However, during testing when the hollow block failed, the whole slab had failed.

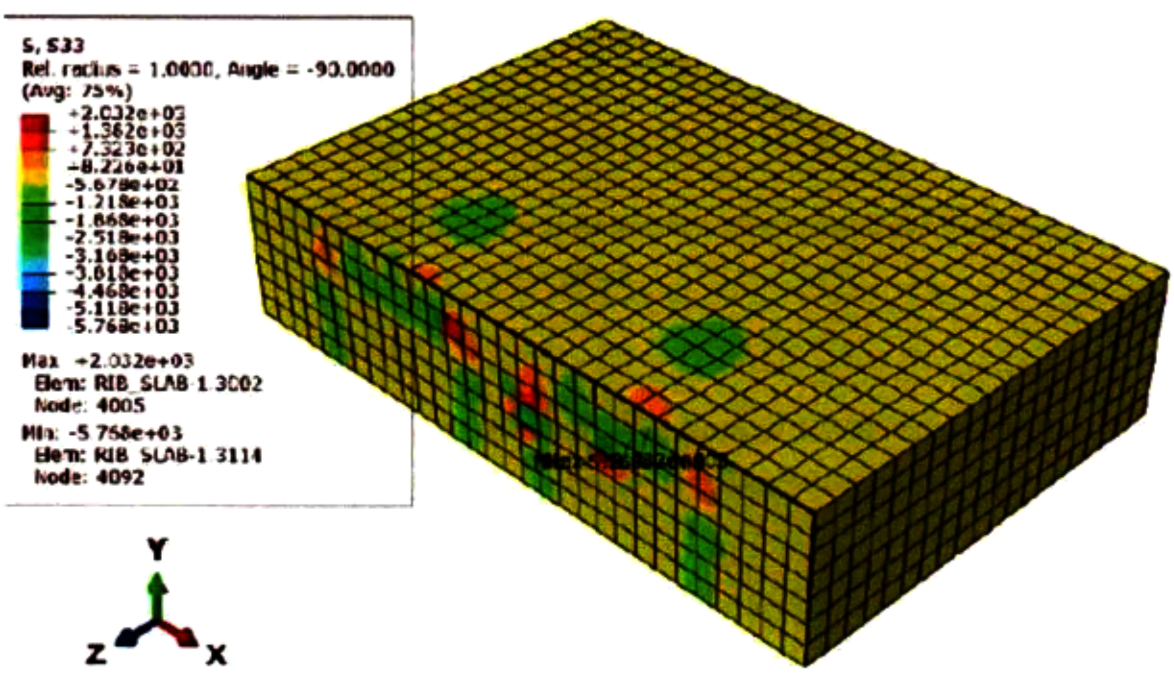


Figure 4.1: Stresses concentrated at Rib Mid-Span

4.7.2 Perpendicular to the Rib

The burnt clay hollow blocks fail under compression load with the severity of the failure starting from the side of application of load. This propagates through the rib compressing the burnt clay hollow blocks toward the opposite end of the slab.

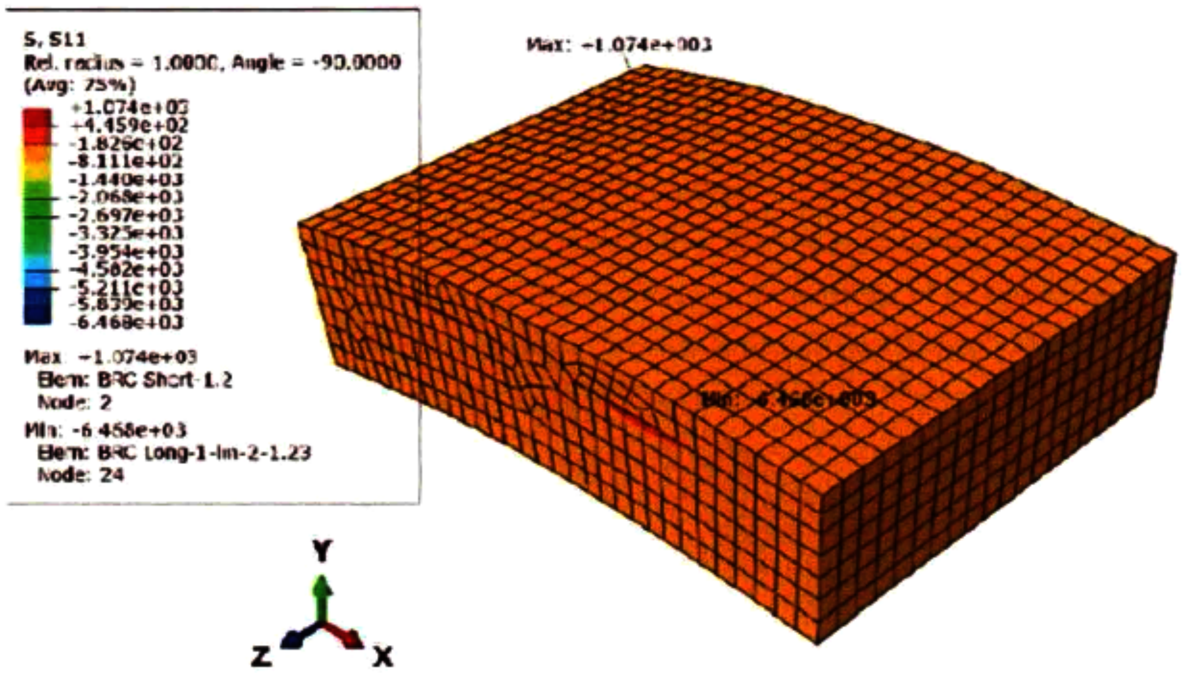


Figure 4.2: Compressive Stresses at rib mid-span increasing towards the Burnt Clay Hollow Block

4.8 COMPARISON OF RESULTS

From the laboratory specimen, it can be seen that the stress of 1.97N/mm^2 – 2.34N/mm^2 in the hollow block slabs when loaded parallel to the rib is almost twice the stress of 1.04N/mm^2 – 1.2N/mm^2 when loaded perpendicular to the ribs.

From the computer models, it can also be seen that the stress in the hollow block slab model when loaded parallel to ribs was a maximum of 2.151x10^{6}N/m^2 (2.151N/mm^2) in the plane of application of load and the stress when loaded perpendicular to the rib the stress was a maximum of 1.074x10^{6}N/m^2 (1.074N/mm^2) in the plane of application of load respectively.

It can therefore be seen that a maximum stress of 2.151N/mm^2 in the hollow slab when loaded parallel to the rib is about twice the maximum stress of 1.074N/mm^2 when the slab is loaded perpendicular to the rib. These results agree with those obtained from the laboratory hollow slab specimens of 2.34N/mm^2 and 1.2N/mm^2 when loaded parallel and perpendicular to the rib respectively. Where the stress ratio of stresses is comparable to that of the test results.

4.9 LIMITATIONS OF BURNT CLAY HOLLOW BLOCK SLABS

Since hollow block slabs are constructed with blocks and ribs running in one direction usually the shorter span, this constrains the slab to act as one-way spanning with different strength in each direction. From the experiments and models discussed above, the failure mechanism starts with the failure of the burnt clay hollow blocks which exerts pressure at the mid-span of the ribs. In case of seismic action, the hollow block slab diaphragm does not have sufficient strength and will fail before transmitting the effects of seismic action to the various connected lateral load-resisting systems.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

In this study, four (4) physical models were made and subjected to compressive tests and two 3-D finite element models were built with ABAQUS to simulate the hollow block slab behavior under seismic action in the direction of the ribs and the plane perpendicular to the ribs. This chapter presents the conclusion and recommendations based on the findings of the study.

5.2 CONLUSION

It can be concluded from the results in the tests that the compressive strength of burnt clay hollow blocks, has a great influence on the horizontal load capacity of the slab and the strength parallel to the holes is about twice that perpendicular to the holes. This does not satisfy the requirement of equal strength in both directions.

From the results in the tests that the compressive strength of burnt clay hollow blocks has a great influence on the horizontal load capacity of the slab and the strength parallel to the ribs is about twice that perpendicular to the ribs. The study further concluded that hollow block slab is weaker when lateral loads are applied in a direction perpendicular to the ribs

The laboratory and model results also revealed that the failure of the slab started from the burnt clay hollow blocks transferring the stresses to the ribs and these stresses were concentrated at the mid span of the rib.

The loaded hollow slab failed under compression load with the severity of the failure starting from the side of application of load in the plane perpendicular to the rib. This propagated through the rib compressing the burnt clay hollow blocks toward the opposite end of the slab. The study further concluded that hollow block slab is weaker when lateral loads are applied in a direction perpendicular to the ribs

From the computer model, the results revealed that the compressive strength of the hollow block slab had a great influence on horizontal capacity of the slab and the compressive strength parallel to the ribs is twice that perpendicular to the ribs. The study further showed that the hollow block slab is weaker when lateral loads are applied in the direction perpendicular to the ribs. Therefore, the results of the computer model and the laboratory tests revealed that the hollow block slab does not have the same resistance to the seismic lateral load in the direction perpendicular and parallel to the rib.

The professionals in the field should restrain the burnt clay hollow slabs in both directions according to the EN 1998, (Euro Code 8)

5.3 RECOMMENDATION

Whereas hollow block slabs may reduce the weight and minimize construction cost of the structure, under seismic action the blocks will fail first. This study only investigated the performance of hollow block slabs under seismic action represented by lateral load in the plane of the slab. Therefore, there is need to carry out further research to establish seismic design parameters for Burnt clay hollow block slabs and also establish the earthquake magnitudes that can be resisted by the slab.

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APPENDIX I: GRADING OF SAND

Tested in accordance with BS 812: Part 103.1						
Sample reference:				Sampling date:		
Section:				Testing date:		
Location:				Technician:		
Source:				Layer:		
Sample description:						
Dry wt before washing				Moisture Content		
Dry wt after washing				Initial Dry Weight (g):	1000.29	
Sieve (mm)	**Partial Retained Mass(g)**	**Cumulative Retained Mass (g)**	**Cumulative Retained (%)**	**% Passing (%)**	**Grading Limits *Fine Aggregate type* (%)**	
10.0	0.00	0.00	0.00	100	100	100
5.0	18.98	18.98	1.90	98	89	100
2.36	59.16	78.14	7.81	92	60	100
1.18	195.75	273.89	27.38	73	30	100
0.60	253.14	527.03	52.69	47	15	100
0.300	191.14	718.17	71.80	28	5	70
0.150	160.25	878.42	87.82	12	0	15
0.075	99.96	978.38	97.81	2		
PAN						

APPENDIX II: GRADING OF AGGREGATES

Tested in accordance with BS 812: Part 103.1						
Sample reference:				Sampling date:		
Section:				Testing date:		
Location:				Technician:		
Source:				Layer:		
Sample description:						
Dry wt before washing				Moisture Content		
Dry wt after washing				Initial Dry Weight (g):	3612.12	
Sieve (mm)	**Partial Retained Mass(g)**	**Cumulative Retained Mass (g)**	**Cumulative Retained (%)**	**% Passing (%)**	**Grading Limits *Coarse Aggregates* (%)**	
37.0	0.00	0.00	0.00	100	100	100
20.0	324.46	324.46	8.98	91	85	100
14.0	1340.60	1665.06	46.10	54	0	70
10.0	1106.66	2771.72	76.73	23	0	25
5.0	739.27	3510.99	97.20	3	0	5
PAN						

CENTRAL MATERIALS LABORATORY

Client Kiberu Faisal

Project: PERFORMANCE OF BURNT CLAY HOLLOW BLOCK SLAB UNDER SEISMIC ACTION IN UGANDA

Date: 17th August 20

Grading of Sand

Sieve Size	Mass Retained (g)	% Mass Retained	% Accumulation	% Mass Passing	Specifications: Concrete Works Bs 882:1992
10	0	0	0	100	100
5	18.98	1.9	1.90	98	89 to 100
2.36	59.16	5.91	7.81	92	60 to 100
1.18	195.75	19.57	27.38	73	30 to 100
600	253.14	25.31	52.69	47	15 to 100
300	191.14	19.11	71.80	28	5 to 70
150	160.25	16.02	87.82	12	0 to 15

TOTAL MASS OF SAMPLE = 1000.29e

Silt content = $\frac{mass\ of\ silt\ content}{mass\ of\ sample} X\ 100 = \frac{500-444.26}{500} X\ 100 = 11.1\%$

CHIEF MATERIALS ENGINEER
MINISTRY OF WORKS
AND TRANSPORT
KAMPALA

Chief Materials Engineer

APPENDIX III: TEST RESULTS FOR BURNT CLAY HOLLOW BLOCKS

CENTRAL MATERIALS LABORATORY

Client: Kiberu Faisal

Project: PERFORMANCE OF BURNT CLAY HOLLOW BLOCK SLAB UNDER SEISMIC ACTION IN UGANDA

Date: 17th August 2018

Burnt Clay Hollow Block Compressive Strength Test

Direction of Application	Specimen	Area (mm^2)	Force (kN)	f_c (MPa)
Parallel to Burnt Clay Hollow Block Holes	1	45000	123.95	2.8
	2		103.35	2.3
Perpendicular to Burnt Clay Hollow Block Holes	1	45000	45.6	1.0
	2		47.4	1.05

Chief Materials Engineer

CHIEF MATERIALS ENGINEER
MINISTRY OF WORKS
AND TRANSPORT
KAMPALA

APPENDIX IV: COMPRESSIVE STRENGTH OF CONCRETE CUBES

CENTRAL MATERIALS LABORATORY

Client: Kiberu Faisal

Project: PERFORMANCE OF BURNT CLAY HOLLOW BLOCK SLAB UNDER SEISMIC ACTION IN UGANDA

Date: 17th August 2018

COMPRESSIVE STRENGTH OF CONCRETE CUBES

CUBES No.	MASS OF CUBES (kg)	AREA (mm^2)	COMPRESSION FORCE (kN)	COMPRESSION STRESS mPa
1	8.03	22500	648.6	28.8
2	8.07		578.6	25.7
3	7.97		641.4	28.5
4	8.04		603.8	26.8
5	7.93		620.8	27.5
6	8.96		626.1	27.8

....
Chief Materials Engineer

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APPENDIX V: SLAB SPECIMEN LATERAL FORCE TEST RESULTS

CENTRAL MATERIALS LABORATORY

Client: Kiberu Faisal

Project: PERFORMANCE OF BURNT CLAY HOLLOW BLOCK SLAB UNDER SEISMIC ACTION IN UGANDA

Date: 17th August 2018

SLAB SPECIMEN LATERAL FORCE TEST RESULTS;

Specimen Size	Direction of Application	Specimen	Force (kN)	Cross-area (mm^2)	Compressive strength fc (N/mm^2)
800 x 750mm	Parallel to the Rib	1	375	160,000	2.34
		2	315		2.00
	Perpendicular to Rib	1	156	150,000	1.04
		2	186		1.24

05.[illegible]

Chief Materials Engineer

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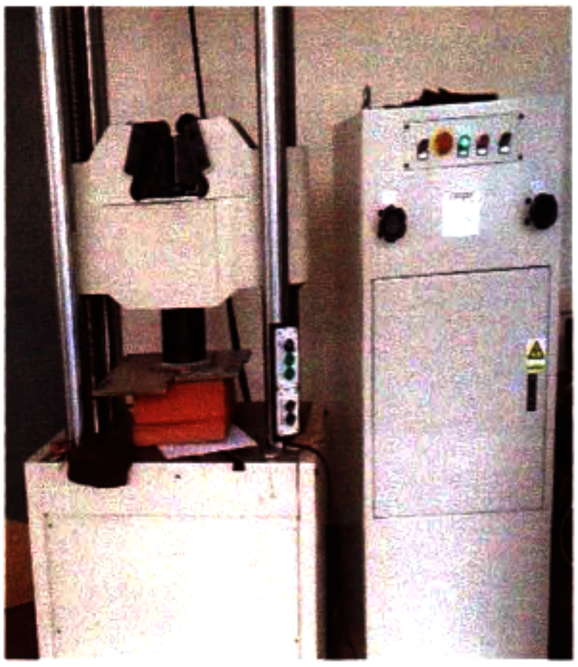
APPENDIX VI: PHOTOGRAPHS

P1: TESTING BURNT CLAY HOLLOW BLOCKS



P2: CRUSHED SLAB SAMPLE WHEN LOADED PERPENDICULAR TO THE RIBS

P3: SLAB SAMPLE FAILING WHEN LOADED PARALLEL TO THE RIBS