



FACULTY OF ENGINEERING

**DEPARTMENT OF CIVIL AND ENVIRONMENTAL
ENGINEERING**

**LOAD DEFLECTION RELATIONSHIP OF A SOLID SLAB UNDER THE
ACTION OF CONSTRUCTION LOADS**

BY

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A Dissertation Submitted to Kyambogo University Graduate School in Partial
Fulfilment of the Requirements for The Award of a Master of Science in Structural
Engineering of Kyambogo University

AUGUST 2022

Approval

The undersigned approves that he has read and hereby recommends for submission to the Graduate School of Kyambogo University, a dissertation entitled: "Load Deflection Relationship of a Solid Slab under the Action of Construction Loads" in partial fulfilment of the requirements for the award of Master of Science in Structural Engineering Degree of Kyambogo University.

Name : Dr. Michael Kyakula

(Supervisor)

Signature :

Date :

Declaration

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

Date : 11th / 08 / 2022

Signature : Kigoye Eriya

Kigoye Eriya

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Date :

Signature :

Kigoye Eriya

Abstract

In Uganda, concrete placement methods have kept on improving over the years. There has been a shift from manual methods to the current use of concrete pumps which place very high volumes of concrete per minute. Small volume slabs are thus able to be cast in a short time but even before they set, their self-weight and that of its supports is taken up by the lower supporting slab. While execution of building operations is taking place, construction materials such as bricks, blocks, sand and aggregates are usually loaded onto the slabs. These construction loads, usually higher than design live loads are not considered at design stage of the slab. 87% of 118 construction sites which were picked at random and surveyed in Kampala had their slab supports removed and placed on top of them to provide support for an upper floor slab. Also 80.6 % of 124 construction sites surveyed had various construction material loads on them such as concrete blocks, fine aggregates, formwork etc. A three level building was constructed having 4000 mm length, 2000 mm width, 2000 mm elevation height from 1st to 2nd level, 2000 mm to 3rd level and resulting slab deflections monitored with the help of dial gauges exerted by loads contributed by freshly cast upper level slab and concrete blocks. Block construction loads were 26.57% more than the ultimate design slab loads. Deflections due to fresh concrete and its supports and that from loads due to concrete blocks which were loaded instantly were 1.15 mm and 11.815 mm respectively while the immediate deflection was 0.103 mm calculated using 2 KN/m² design live load.

Keywords: Reinforced Concrete, Construction loads, Load deflection relationship.

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List of Acronyms

ACI	American Concrete Institute
ASTM	American Standard for Testing of Materials
BS	British Standard
BSI	British Standards Institution
CEN	European Committee for Standardisation
DG-X	Dial Gauge Number
EC	Euro Code
E.O.C	End Of Casting
EN	European Standard
FEM/A	Finite Element Method/Analysis
KCCA	Kampala Capital City Authority
LC-Y	Load Cell Number
LVDT	Linear Variable Displacement Transducer
RC	Reinforced Concrete
S.O.C	Start Of Casting
UK	United Kingdom
UNBS	Uganda National Bureau of Standards
USA	United States of America
W/C	Water Cement Ratio

Dedication

I dedicate this report to my wife Daphine and son Elisha.

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

In the UK, slab shores, their removal and reshoring building procedures lead to high construction loads greater than slabs' self-weights in high-rise structures (Motter and Scanlon, 2018). Construction loads occur only when building works are taking place (CEN, 2005). A survey to investigate live loads present on slab elements in multi-storey concrete construction sites was done in the USA revealed live loads such as weight of workforce, equipment and materials (Ayoub and Karshenas, 1994). In the UK, 38% of the building failures occurred at the execution stage, 36% before execution caused by design, 25% while it's in use and 1% while carrying out demolition (Soane, 2018).

Over the past years, the construction industry in Kenya as well as Uganda has had a number of building failures due to professional negligence, poor construction practices, poor supervision, incompetent personnel, poor construction techniques, poor design, poor execution of work, and unprofessional use of construction materials (Irumba and Mwakali, 2020). Construction failure in Kiambu district Kenya and a number of them have been recorded (Irumba and Mwakali, 2020).

Design is aimed at ensuring that at the ultimate loads, the building is safe against collapse and that it is stiff enough to resist against very high deflections at working loads. Serviceability related problems due to very high deflections lead to costly repairs on non-structural elements thus working loads deflections should be below permissible values (Chang and Hwang, 1996).

Very fast unregulated high rise building constructions with formwork left in place is the reason why buildings fail at the execution stage (Ekolu and Alinaitwe, 2014). The formwork generates construction loads which are greater than design loads (Hicks *et al.*, 2009). It is known, in some cases, that construction loads are higher than the slabs' self-weight (Motter and Scanlon, 2018). They may also be higher than design loads in other cases (Hicks *et al.*, 2009).

Over 90% of buildings constructed in Uganda are made of Reinforced concrete (RC) (Tayebwa and Kyakula, 2005). Solid slabs form part of building elements of a RC structural frame. The construction industry in Uganda has changed the placement methods from manual means to current use of concrete pumps. Concrete pumps place approximately 1m³/minute of concrete (Heidelbergcement, 2021). Thus the self-weight of slabs and its supports loads are taken up by the lower slab. Very high construction loads are contributed by fresh concrete, material loads and shoring thus 38% of buildings fail during execution stage (Buitrago *et al.*, 2020). Poor supervision, unqualified personnel and poor construction techniques also lead to building failures in Uganda (Irumba, 2015). Building failures lead to deaths, loss of valuable investments and high debt burden to developing countries (Irumba and Mwakali, 2020).

118 construction sites in Kampala surveyed had 87 % of them remove formwork supports under their slabs after 28 days and the same are used on its top to support an

upper floor slab. In 124 construction sites, 80.6 % of them surveyed experienced construction loads like bricks, fine aggregates, coarse aggregates and timber. Since literature does not have raising, removal and reapplying formwork procedures (Haque and Mund, 2002), there was need to study how the load varies with deflection caused by various construction loads.

1.2 Problem Statement

Over the past decades, the concrete placing methods in Uganda have kept changing from the manual methods to the present system of using concrete pumps. Concrete pumps are capable of placing $1\text{m}^3/\text{minute}$ of concrete (Heidelbergcement, 2021). This implies that whole weight of wet concrete is transferred to the lower supporting slab and may lead to excessive deflection and cracking of lower supporting slab. Furthermore, construction materials are usually heaped on the slabs during construction (Ayoub and Karshenas, 1994). A baseline survey of 118 buildings under construction revealed that during the building process, 87 % of building sites in Kampala remove props below the slab after 28 days and these are placed on top of it to support a yet to be cast slab. It also revealed that in 124 sites, 80.6 % of the sites had construction loads such as bricks, blocks, sand, timber and aggregates placed on the slabs. High construction loads due to fresh concrete, formwork, and materials on slabs are some of the leading causes of failures of 38% of buildings during the construction phase (Buitrago *et al.*, 2020). Such failures lead to loss of lives, investments and subsequently an increased debt burden to future citizens in developing countries (Irumba and Mwakali, 2020). It is thus necessary to investigate the load-deflection relationship of the supporting solid slabs due to construction loads in order

to inform design of reinforced concrete slabs, formwork, supporting methods and material storage on construction site.

1.3 Research Objectives

1.3.1 Main Objective

The main objective of this research was to investigate the load-deflection relationship of a solid slab due to construction loads.

1.3.2 Specific Objectives

The specific objectives of this study were:

- i. To carry out a baseline survey of building construction practices as regards supports to slabs, materials used and construction loads on construction sites around Kampala.
- ii. To determine the load imposed onto the slabs by props, formwork and fresh concrete from an upper slab and construction materials.
- iii. To obtain the deflection of the slabs caused by loads from construction materials: formwork and fresh concrete from an upper slab and blocks.
- iv. To determine how the immediate and short-term load and deflection of a solid slab under the action of construction loads and freshly cast slab relate.
- v. To compare the deflections from structural design manual calculations and actual measurements experienced due to construction loads and freshly cast slab.

1.4 Research Questions

- i. What are common building practices on construction sites as regards to support to slabs, materials used and construction loads on construction sites around Kampala?
- ii. What is the load imposed onto the slabs by props, formwork and fresh concrete from an upper slab and construction materials?
- iii. What is the deflection of the slabs due to construction loads: formwork and fresh concrete from an upper slab overtime for a period of 28 days; and construction materials represented by concrete blocks on upper and lower slabs?
- iv. How can the immediate and short-term load Vs deflection performance of slabs caused by construction loads and freshly cast slab be determined?
- v. How do the deflections obtained from analysis using manual calculations and actual measurements experienced on a solid slab under construction materials loads and freshly cast concrete slab loads compare?

1.5 Research Justification

Excessive cracking and deflection are caused by very high construction loads contributed by the shoring and reshoring process in tall structures (Motter and Scanlon, 2018). A lot of money is thus spent in costly repairs. Not only that, excessive deflections and cracking leads to damage to partitions and finishes (BSI, 2004). A study to determine the load Vs deflection of solid slabs caused by construction material

loads needs to be carried out to curb the defects of overload in slabs during the construction phase.

1.6 Significance of the Research

Understanding behaviour of loads and deflection characteristics of slabs during construction will be helpful in:

- Design of lower supporting slabs while considering construction loads; design of formwork and props;
- Establishing the pumping rate for fresh concrete;
- Regulation of storage of construction materials like concrete blocks on site during construction stage (Ayoub and Karshenas, 1994) and
- Inform design of slabs with construction loads due to pumped concrete not previously provided for in literature (Hicks *et al.*, 2009).

1.7 Scope of the Research

1.7.1 Content scope

This research is limited to:

- Baseline surveys done on storied RC building sites in Kampala in order to investigate the nature of construction loads, materials and supporting methods of reinforced concrete slabs.
- Sampling of and testing of materials from locally available resources.

- Design and construction of a real-life model of concrete class C20/25 having 4000 mm long $\times$ 2000 mm wide $\times$ 2000 mm high to 2nd level $\times$ 2000 mm to 3rd level dimensions with 200 mm ground slab, 1000 mm $\times$ 1000 mm $\times$ 200 mm pad footings, 200 mm square size columns and 175 mm first and second floor slabs and 200 $\times$ 250 mm beams. The design is limited to slabs in storied RC residential buildings with design imposed load of 2kN/m².
- Casting of the second slab in under 10 minutes using a concrete pump and ready-mix concrete from a ready-mix company and monitoring deflection and loads using dial gauges and load cells respectively for selected prop positions.
- Construction materials like blocks loaded onto the first floor level and the resulting deflection measured.
- Analysis of findings using MS EXCEL 19 (Microsoft Corporation, 2019).

1.7.2 Geographical Scope

The study was done at Kyambogo University in Uganda; materials were obtained from local sources. Laboratory tests were conducted from Kyambogo University and TeClab Nalukolongo and a survey on building sites was done on construction sites around Kampala.

1.7.3 Time Scope

The research was done from August 2019 Up to November 2021.

1.8 Conceptual Framework

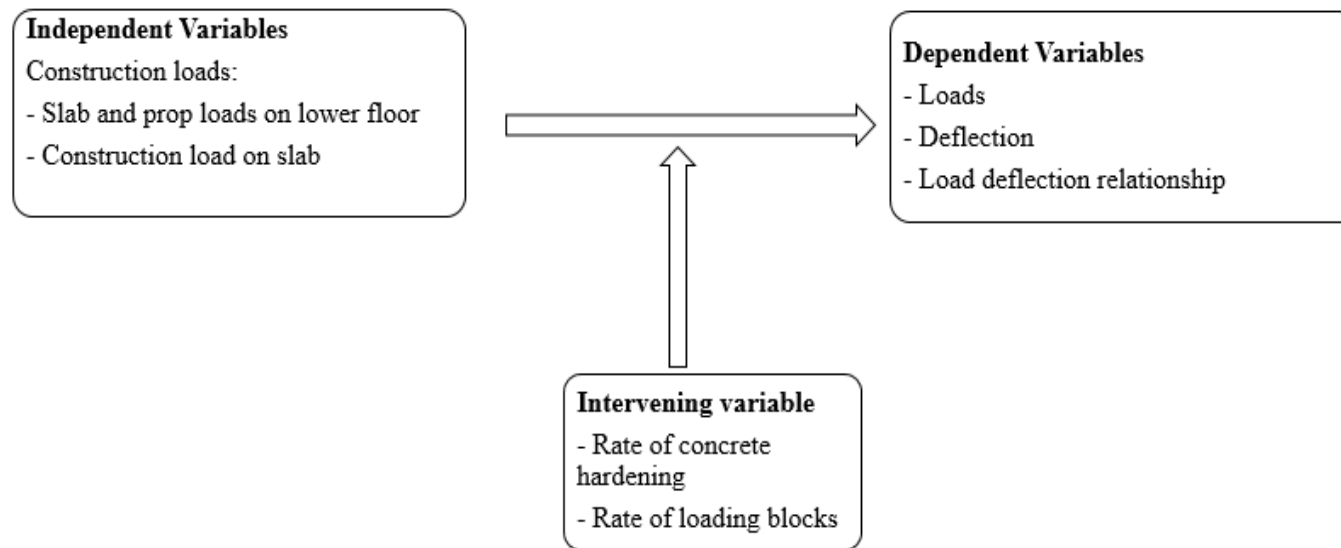


Figure 1.1: Conceptual Framework

1.9 Chapter One Summary

Chapter One gave a background for the change in methods of placing concrete in Uganda from manual means to use of hoists and presently use of concrete pumps. Concrete pumps cast high concrete volumes per minute thus it takes a short time to cast small volume slabs leading to the whole self-weight of its concrete slab and formwork supports to be taken up by the lower supporting slabs with excessive deflections and cracking expected as a result. The main objective of the research was to study how the load Vs deflection on solid slabs relate resulting from construction loads. In order to limit damage of temporary structures and hence the structure itself under construction, determining how the load Vs deflection relates resulting from construction materials like blocks, slab supports and fresh concrete is key. The time scope of the project was from August 2019 to November 2021 and it was carried out in Kyambogo University, having construction loads as independent variables and with loads, deflection and load deflection relationship as dependent variables. The proceeding chapter gives a detailed review of the published literature in relation to this research.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

A review of relative literature in relation to deflection in slabs due to construction loads on slabs is presented in this chapter. It covers the following themes; structural design, loading, deflection, time dependent load Vs deflection and construction related accidents.

2.2 Baseline survey

2.2.1 The Construction Industry in Uganda

From the data shown in **Table 2.1**, obtained from Kampala Capital City Authority (KCCA) directorate of physical planning, between the years 2012-2017, a total of 11050 plans were considered for development by KCCA. Of these, 4175 were approved, 6687 were deferred while 188 were rejected. According to rules of development in KCCA, a plan should not exceed Two and a half years after approval before being implemented.

Table 2.1: Summary of Status of Considered Development Applications

(Source: (KCCA, 2020))

YEAR	APPROVALS	DEFERRALS	REJECTIONS	TOTAL
2012	21	69	10	100
2013	697	2027	56	2780
2014	768	1537	48	2353
2015	1075	1351	47	2473
2016	974	1156	25	2155
2017	640	547	2	1189
GRAND TOTAL	4175	6687	188	11050

Over 90% of framed structures in Uganda are built using reinforced concrete (Tayebwa and Kyakula, 2005).

2.2.2 Construction accidents

2.2.2.1 Prop failures

During the construction stage of a building, there is a high probability of building failure and underestimating loads during construction. Prop design, assembly and striking of the same is a critical stage in construction (Buitrago *et al.*, 2020).

2.2.2.2 Causes of formwork failure

During the construction stage, construction loads in multi-storey structures are usually higher than design loads. To mitigate such, shoring is always done to provide support for such loads to avoid high stresses and deflections. It is essential to calculate the loads due to shores and those from the structure in order to obtain erection cycle time and enable proper shoring design. There is however no recommended shoring and reshoring procedure in the literature (Haque and Mund, 2002).

Temporal support system for cast in situ concrete elements are provided until the element is able to carry imposed loads on it by itself but its failure is sometimes caused by concentrated load contributed by construction material (Alamin, 1999). To curb occurrence of formwork failure, computer based models have been developed like the one indicated below in Figure 2.2.

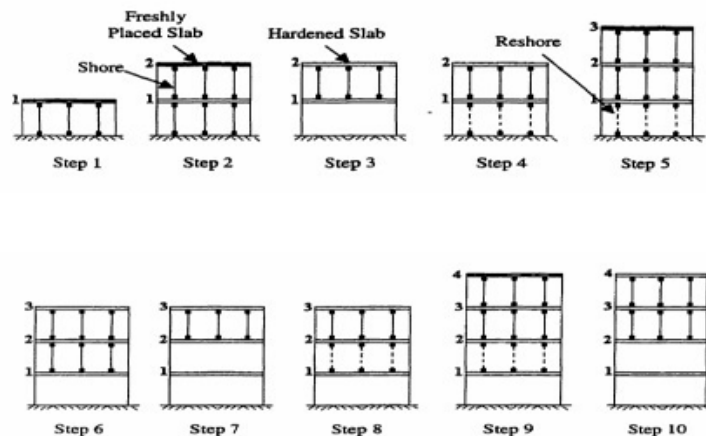


Figure 2.1: Shoring of Two floors above and reshoring one level below construction (Source: (Alamin, 1999))

2.2.3 Limiting formwork failures

Entire structures have been reported to fail due to shoring system failure most especially shore buckling caused by overload (Buitrago *et al.*, 2020).



Figure 2.2: (a) Buckling of shores during construction stage (b) Using Load Limiters

(Source: (Buitrago *et al.*, 2020))

“Load limiters” as shown in Figure 2.2 (b) above were used to act as “structural fuses” in temporal shoring systems to lower the working load and to keep it below acceptable limits (Buitrago *et al.*, 2020)

2.2.4 Age of loading the slab

Various projects have different times after which loads are applied onto slabs. It ranges from hours after casting to one, two or three days during which the slab should be hard enough for one to walk on top of it with no impressions made on the slab surface (Ayoub and Karshenas, 1994).

2.2.5 *Building Failures experienced in Uganda*

Building failures not only lead to deaths, but lead to injuries, property damage, losing of valuable investments but also environmental problems (like dust, rubble, floods, disease outbreaks and toxic emissions) (Irumba and Mwakali, 2020). Previously recorded failures are shown in Table 2.2 below.

Table 2.2: Construction failure examples in Uganda (Source: (Irumba and Mwakali, 2020))

Date	Failure type and Effect	Investigation into cause of failure
25th July 2006	Water trench wall collapse in Kansanga, Kampala District led to the death of two Sogea Satom Company employees.	
8th March 2006	Kalerwe Church building failure which led to 20 deaths.	
21st October 2004	Failure of Two high rise buildings eventually leading to debris burying five people under it at Seguku, Entebbe Road.	
31st August 2004	Collapse of proposed J & M Hotel at Bwebajja, Entebbe Road led to 11 deaths and 26 injuries.	The plan was not approved. Columns were weak.
2nd June 2000	Excavation failure at William Street, Kampala.	
14th Nov, 1999	Mosques belonging to Uganda Muslim Supreme Council (UMSC) collapsed in Mbarara, Four deaths and One injured person were recorded.	



a)



b)

Figure 2.3: Failure of Buildings

a) In Kiambu District, Kenya and b) In Uganda (Source (Alinaitwe and Ekolu, 2014))

No published findings were available from the investigations for each of the causes of the failures listed in **Table 2.2** above except one building in Bwebajja where materials were of poor quality, workmanship also poor, the structural elements design was inadequate design capacity of structural elements, poor methods of work, not following authority buildings and approval procedures and lastly there was not sound supervision of the works done on site by professionals (Irumba and Mwakali, 2020).

Timber formwork and scaffolds are typically used for construction of RC structures in developing countries. Hurriedly conducted construction with stay in place formwork supporting lower floors as other upper floors are being raised results in little time and inadequate attention to proper quality control measures like testing and inspection of recently cast elements before upper floors are cast too. It has been determined that there is a direct link between speedy but unregulated construction delivery and poor works delivery as shown in **Figure 2.3** (Alinaitwe and Ekolu, 2014).

In Uganda, poor supervision, use of unqualified personnel, and poor construction techniques have been attributed as the major reasons why buildings fail (Irumba, 2015). The capacity of workers involved in accidents is lowered on average by 37% (Irumba, 2015).

2.2.6 Construction loads

Construction load is that which is caused by execution activities yet absent when those activities are completed EN 1991-1-6:2005 (CEN, 2005). Reliability of a structure depends on its load history which includes construction loads (Stewart, 2001).

The Euro Code recommends a load amounting to 0.5 kN/m^2 (CEN, 2005) for non-permanent equipment like formwork, 1 kN/m^2 for personnel and hand tools respectively (CEN, 2005) but the use of load density for materials which can be stored or movable (BSI, 2010).

2.2.7 Structural loads

BS EN 1991-1-1:2002 (BSI, 2010) or manufacturers' specifications are used to estimate characteristic imposed and permanent loads used in structural design.

Formwork is a type of auxiliary construction work which is a type of work associated during construction but not present when building execution is completed according to EN 1991-1-6:2002 (CEN, 2005).

2.3 Deflection resulting from construction loads in slabs

2.3.1 *Structural design requirements*

A structure should be designed to transfer all loads acting on it in economically (BSI, 2010). It should also meet serviceability requirements through experimental investigation, calculations, past construction experience according to EN 1990:2002+A1:2005 (BSI, 2010).

2.3.1.1 Limit states for serviceability

Limit states for serviceability are concerned with appearance of construction works like high deflection and extensive cracking (BSI, 2010).

2.3.1.2 Deflection-Serviceability limit state

As stated previously, deflection parameter should be satisfied during structural design. Deflection estimation under working loads is necessary in concrete slab design (Desayi and Muthu, 2013). Accurate determination of the same is difficult due to cracking, creep, shrinkage (Desayi and Muthu, 2013); non-homogeneity of a material and support conditions also make deflection calculation difficult (Bamiyo *et al.*, 2016). Codes normally use span depth ratio to control deflections (Desayi and Muthu, 2013). Larger depth slabs improve the stiffness hence excessive deflection changes are prevented which are usually unsightly and cause discomfort (Aalami, 2008).

Cracking in partitions due to low deflection in floors is a defect while excessive damage to the same is a failure (Ayininuola and Olalusi, 2004). Failures lead to costly repairs and thus they should lie within allowable limits (Chang and Hwang, 1996). According to EN 1992-1-1, estimate of deflection by means of calculations is not necessary if the limit to

span effective depth ratio is not exceeded (BSI, 2004). When the actual moment is close to cracking moment, estimated deflections will not be the same as calculated ones (BSI, 2004).

Diagrammatical representation of vertical defections are shown in **Figure 2.4**.

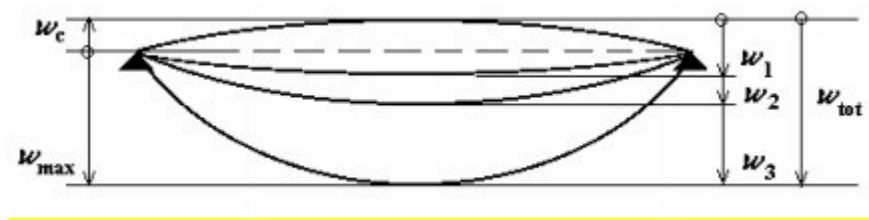


Figure 2.4: Vertical deflection representations

(Source: EN 1990 (BSI, 2010))

w_c = Precamber in unloaded structural element

w_1 = Initial permanent loads deflection

w_2 = Longterm permanent loads deflection

w_3 = Additional variable loads deflection

w_{tot} = Total of w_1 , w_2 and w_3

w_{max} = Total deflection taking into account the pre – camber (BSI, 2010).

Deflection measurements can be made using “close-range photogrammetry” (Whiteman *et al.*, 2002), “hydrostatic cell levelling” (Tovi, 2017), precise levelling (Vollum *et al.*, 2002), dial gauges (Bungey *et al.*, 2006) and Linear Variable Displacement Transducers (LVDT’s) (Galati *et al.*, 2008).

2.4 Immediate and short-term load Vs deflection of a solid slab caused by construction material and freshly cast slab

2.4.1 EN 1992-1-1 on deflection control limits

Quasi-permanent loads should not cause the deflection to exceed span/250 and span/500 during and after construction respectively. The deformation rate can be checked by applying span/depth limit or comparison made between limit value and calculated deflection value. When span to depth ratio is not exceeded, deflection in slab or beams may be taken to be less than the limits (BSI, 2004).

Calculating the limiting span effective depth according to EN 1992-1-1 (BSI, 2004) can be done using **Equations 2.1 and 2.2 below;**

If $\rho \leq \rho_0$,

$$\frac{l}{d} = k \left[11 + 1.5\sqrt{f_{ck}} \left(\frac{\rho_0}{\rho} \right) + 3.2\sqrt{f_{ck}} \left(\frac{\rho_0}{\rho} - 1 \right)^{3/2} \right] \dots\dots\dots \text{Equation 2.1}$$

If $\rho > \rho_0$,

$$\frac{l}{d} = K \left[11 + 1.5\sqrt{f_{ck}} \left(\frac{\rho_0}{\rho - \rho'} \right) + \frac{1}{12}\sqrt{f_{ck}} \left(\frac{\rho'}{\rho_0} \right)^{\frac{1}{2}} \right] \dots\dots\dots \text{Equation 2.2}$$

$$\frac{l}{d} = \frac{\text{span}}{\text{depth}} \text{ limit}$$

k = structural systems factor

$\rho_0 = (\sqrt{f_{ck}} 10^{-3})$, reinforcement ratio as reference

ρ

= reinforcement ratio for tension required at midspan and support (for cantilver)

for moment resistance

ρ' = reinforcement ratio for compression required at midspan and support

(for cantilver)for moment resistance

f_{ck} = is the compressive strength in Mpa units

d = effective depth

2.4.2 Elastic/Immediate deflection

Equation 2-3 according to ACI 318 is used to calculate the elastic or immediate deflection (Gullapalli, 2009);

$$\frac{1}{384} \frac{\omega l^4}{EI} \dots \dots \dots \text{Equation 2-3}$$

Where

ω = weight per linear metres squared

l = length

E = constant of Elasticity and

I = second moment of inertia

2.4.3 ACI 435R-95 on Deflection Control

ACI 435R-95 states the various ways of controlling deflections by employing design and construction techniques and materials selection. Design techniques like increasing the depth and width, construction techniques like control of shoring and reshoring procedures

while materials selection involves selection of appropriate materials for mix design that reduce shrinkage and creep (ACI Committee 435, 2003).

2.5 Deflections from structural design manual calculations and actual measurements experienced due to construction loads and freshly cast slab.

2.5.1 *Structural design*

Deflection design is one of the procedures undertaken in design of a structure (MacGinley and Choo, 2003). Sizing of a member is dependent on span–depth ratios (Mosley *et al.*, 2012).

2.5.2 *Design combined by testing*

Calculations as well as tests are sometimes used together in design. The tests help to confirm and to check the assumptions made while designing according to BS EN 1990 by using control experiments (BSI, 2010).

2.5.2.1 Test types

There are test types that aid in obtaining serviceability properties of the entire structure or structural elements for the applied loading condition and those done during execution to obtain particular information during the execution stage (BSI, 2010).

2.5.2.2 Load applied In situ

A structure may be able to carry loads which may be dissimilar from those achieved in design. Load testing in situ aids in revealing such information (Galati *et al.*, 2008). In situ testing is applied in situations where the study is on how a structure behaves when service loads are applied to it. The objective is to ascertain proper performance when the

structure is loaded over and above its working loads. In such cases measuring deflection is the main criteria to judge its performance whereby loading is prolonged for a given time when the slab has attained 28 days characteristic strength (Bungey *et al.*, 2006).

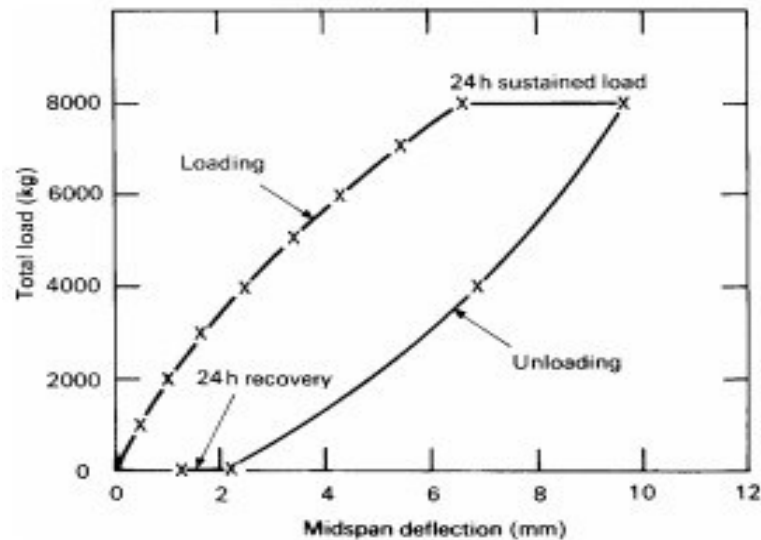


Figure 2.5: Typical load deflection test output curve

(Source: (Bungey *et al.*, 2006))

Mechanical dial gauges, supported on rigid support rather than electronic displacement transducers are used because they provide a faster visual load test progression assessment (Bungey *et al.*, 2006). Typical load deflection output test plot is shown in **Figure 2.5**.

2.5.2.3 Load application and measurement

Load application can be done in a controlled laboratory using a load actuator or hydraulic jack. The measurement of these loads can be done using load cells and sensors and the data stored on data loggers or data acquisition system.

2.5.3 Time dependent load deflection in literature

2.5.3.1 Slab strips partially restrained

A load and deflection prediction analytical method for a partially restrained slab strip was provided by (Muthu *et al.*, 2007). Ten slab strips, partially restrained were cast and subjected to a uniformly distributed load. Materials constituted of Ordinary Portland Cement, granite of size 12.7 mm, 5 mm steel bars and potable water. Dial gauges were used to measure deflections. The results showed that with higher strength of concrete, lower steel yield strength, low steel percentage, higher rigidity at the edges, a higher load enhancement can be achieved. The load deflection relationship obtained is shown in Figure 2.6.

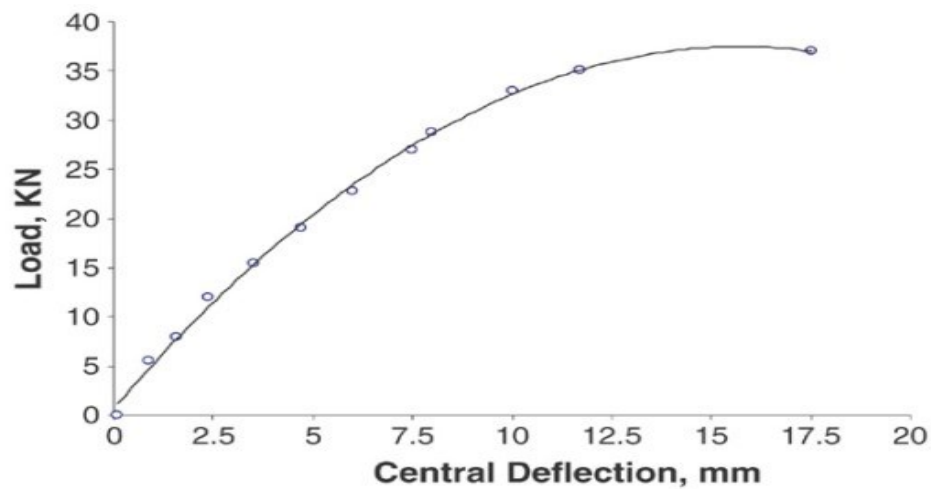


Figure 2.6: Load deflection relationship

(Source: (Muthu *et al.*, 2007))

2.5.3.2 In flat slabs

In a study on flat slabs which centered on early age concrete material properties, low temperature curing and measurement of the deflection (elastic and long-term) revealed

that compressive strength and elastic modulus of the early age concrete whose curing is carried out at low temperature is significantly overestimated. It was recommended that accurate determination of concrete properties is crucial so that the immediate and deflection in the long-term of slabs can be predicted (Park *et al.*, 2012).

In another study which focused on the deflection monitored overtime of flat slabs made of reinforced concrete, seven 6200 mm width $\times$ 7200 mm length continuous 3000 mm spanning flat slabs in each orthogonal direction and supported on nine columns of dimensions 200mm width $\times$ 200 mm depth $\times$ 1250 mm long. Deflections both elastic and time dependent, crack distribution, surface strains of concrete, external force-time variations were all recorded (Gilbert and Guo, 2005). It was realised that longterm defection measured experimentally is much more the shortem deflection. This is because stiffness is lost as a result of cracking because of influence of the load applied transversly to the slab and due to drying shrinkage (Gilbert and Guo, 2005). The magnitude of initial cracks due to construction is the major influence of the final deflection values (Gilbert and Guo, 2005).

2.5.3.3 Two-way slabs

A two-way floor slab reinforced concrete model for deflection due to construction loading led to the development of an algorithm which estimates the outcomes caused by construction procedures past deflection performance of reinforced concrete slabs spanning in two directions for long term loading in multi-storey buildings (Motter and Scanlon, 2018).

2.6 Chapter Two Summary

From the literature review, it has been shown that failure of formwork is common in buildings. Excessive loads during construction leads to excessive deflections due to upper slabs raising procedure. The proceeding chapter contains the methodology of the research.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

The methods which were used, materials, research setup as well as tools that were used to achieve the objectives of the research are presented in this chapter.

3.2 Experimental Set up (Research Design)

In order to find out the load Vs deflection of a solid slab resulting from loads due to construction, a systemic experimental programme was designed. The summary of experimental test programme has been provided in **Appendix A.8**.

3.3 Baseline Survey

A baseline survey, helped form the basis for dimensions of the experimental model, nature of slab supports and loads from construction materials which were block loads was carried out on multi-storey RC buildings in Kampala. To obtain relevant data in regard to this survey, Observation checklists were used as shown in **Appendix A.4** and **A.5**. MS EXCEL 19 (Microsoft Corporation, 2019) was used to analyse the data.

3.4 Slab and construction loads

Before the slab and construction loads could be determined, material tests had to be determined before and during the construction of the physical model.

3.4.1 Material Tests

In order to ascertain the properties of some elements in our study, tests had to be carried out on soil, fine aggregates, coarse aggregates and concrete. Tap water supplied by from

National Water and Sewerage Corporation was used. Conformity test certificates on cement and reinforcement were obtained from manufacturers.

3.4.2 Trial Mix Ratios

A concrete ratio of 1: 1.5: 3 (cement: sand: coarse aggregates), 0.68 water cement ratio producing a resultant strength of C20/25 was adopted based on mix design shown in **Appendix A.6** according to (Building Research Establishment, 1997). The trial mix of the concrete matrix was done manually using hands and the proportions were determined by weight batching. The trial mix proportioning are shown in **Table 3.1**

Table 3.1: Trial Mix Design proportions

Grade and mix C20/25 (1:1.5:3)			
W/C	0.68		
Cement (Kg)	Sand (Kg)	Coarse Aggregates (Kg)	Water (Kg)
4.42	6.63	13.25	3

3.4.3 Actual Concrete mixing, Compaction, Finishing and Curing

3.4.4 Preparation of Moulds

The moulds were smeared with oil and were filled with concrete using a scoop in layers and then vibrated in accordance with BS EN 12390-2 (BSI, 2019). They were finished off and left intact. After 24 hours, samples were demoulded and immersed in a curing tank where curing was done.

3.4.5 *Mixing protocol*

A mechanical concrete mixer was used in actual mixing of concrete for the model except where small volumes were required for example kickers where hand mixing was used.

3.4.6 *Workability and sampling fresh concrete*

Tests on fresh concrete were conducted to ensure adherence to research quality requirements. Only the slump test was used for workability tests. The procedures are illustrated below:

- Fresh concrete was sampled according to BS EN 12350-1:2019 (BSI, 2019). It involved disregarding the very first part and the very last part of a batch or ready mix truck and taking increments distributed throughout the concrete heap depth and exposed surface at a minimum of five different places using a scoop in a container,” (BSI, 2019).
- Slump Test was done using BS EN 12350 – 2: 2019 (BSI, 2019). The fresh concrete was compacted into a mould in the shape of a frustum of a cone. When the cone was withdrawn upwards, the distance the concrete which had slumped provided a measure of the consistency of the concrete (BSI, 2019).

3.4.7 *Compressive strength test*

- The compressive strength was done based on BS EN 12390-3:2019 (BSI, 2019). Specimens were loaded to failure in a compression testing machine conforming to EN 12390-4. The minimum load sustained by the specimen was recorded and the

compressive strength of the concrete was calculated based on BS EN 12390 - 3:2019 (BSI, 2019).

- Moulds of 150 × 150 × 150 mm sizes complying with BS EN 12390-1:2012 (BSI, 2012) were tested at 7, 14, 21 and 28 days. The moulds were water tight, non-absorbent and oiled to increased water tightness.
- Curing was done using water at $20^{\circ}\text{C} \pm 2^{\circ}\text{C}$ according to BS EN 12390-2:2019 (BSI, 2019).

3.4.8 Tests on Soil

Soil investigations were done by using trial pits. Undisturbed and disturbed samples of soil, taken at 1500 mm depth and transported immediately to the laboratory for investigation. Direct shear test was done based on BS 1377- 7: 1990 (BSI, 1990) so that soil bearing capacity using Terzaghi's equation could be calculated. Vertical load, normal to the specimen used for the test was applied. Consolidation took place until primary consolidation came to a stop. Shearing was done thereafter. Cohesion factor and internal friction angle were determined as shown in **Appendix A.3**.

3.4.9 Tests on Aggregates

Tests done included; Quartering of aggregates was used to sample aggregates in accordance to BS 812-102:1984 (BSI, 1984). A representative sample consisting of the average quality of the batch was obtained by thorough mixing, heaping to form shape of a cone, flattening the cone and then quartering it. A pair of quarters of aggregates, diagonally opposite to each other were chosen while the other was discarded until the sample mass required was obtained.

Flakiness index was done based on BS 812-105.1:1989 (BSI, 1989). Aggregate particles are classified as flaky when they have a thickness (smallest dimension) of less than 0.6 of their mean sieve size, this size being taken as the mean of the limiting sieve apertures used for determining the size fraction in which the particle occurs. The flakiness index of the aggregate sample was found by separating the flaky particles and expressing their mass as a percentage of the mass of the sample tested (BSI, 1989).

Water absorption and relative density were carried out based on BS 812-2:1995 (BSI, 1995). A wide mouthed glass jar bottle of 1 litre capacity was used. The weight of it, with water and sample were determined and the calculations enabled the obtaining the water absorption and relative density of aggregates.

Gradation and fines content assessment was carried out according to BS 812-103.1-1985 (BSI, 1985). Sieves were arranged in their descending order. Samples were sieved and the percentage of retained sample calculated. The cumulative percentage passing was plotted against sieve sizes and the relationship derived was compared to limits in the specifications of aggregates.

3.4.10 Tests on Cement

Cement laboratory reports were obtained from supplier called Hardware World which were done by Kampala Cement Limited. Tests were carried out at the UNBS laboratory conforming to US EAS 18-1:2017 (Composition, Specification, and Conformity Criteria for Common Cements on parameters like standard consistency, compression strength, weight and initial setting time). Test results report is provided in **Appendix A.2**.

3.4.11 Tests on Reinforcement

Laboratory reports for samples of reinforcement were obtained from Hardware World provided done by Steel and Tube Industries Ltd and Pramukh Steel Ltd. Tests were carried out at the UNBS laboratory conforming to US EAS 412-2:2013 (Steel for the reinforcement of concrete-Part 2: Ribbed bars). 8 mm and 12 mm diameter bars were tested in the size, weight/meter run, tensile strength, bend test and the grade. Results are provided in **Appendix A.1**.

3.4.12 Physical Model

From the baseline survey results, it was realised that slabs surveyed had a minimum width of 2000 mm, 4000 mm average length and on average 3000 mm height. Thus the above dimensions formed the basis for experimental model chosen for the study. A full scale physical model of a multi-storey structure was made having dimensions 4000 mm long $\times$ 2000 mm wide $\times$ 2000 mm high to 2nd level $\times$ 2000 mm to 3rd level, as shown in plan in Figure 3.1 was therefore designed.

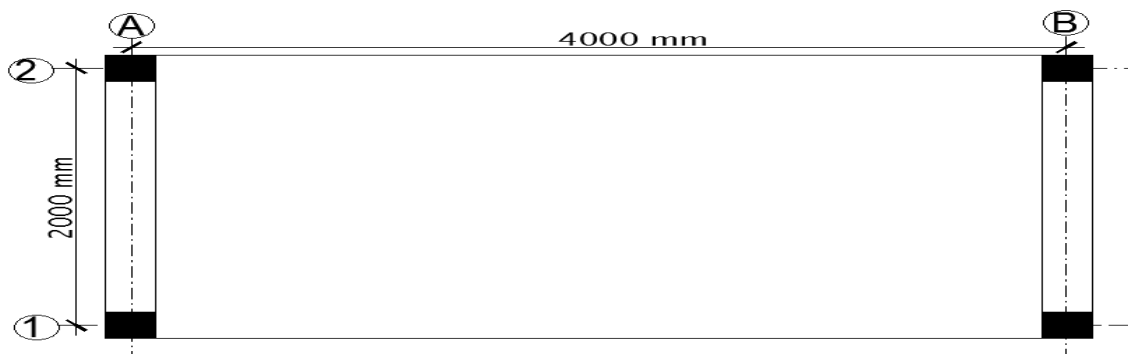


Figure 3.1: Plan of the model 4000 mm $\times$ 2000 mm

The model was comprised of ground floor level, first floor level and second floor level, as indicated in **Figure 3.2**.

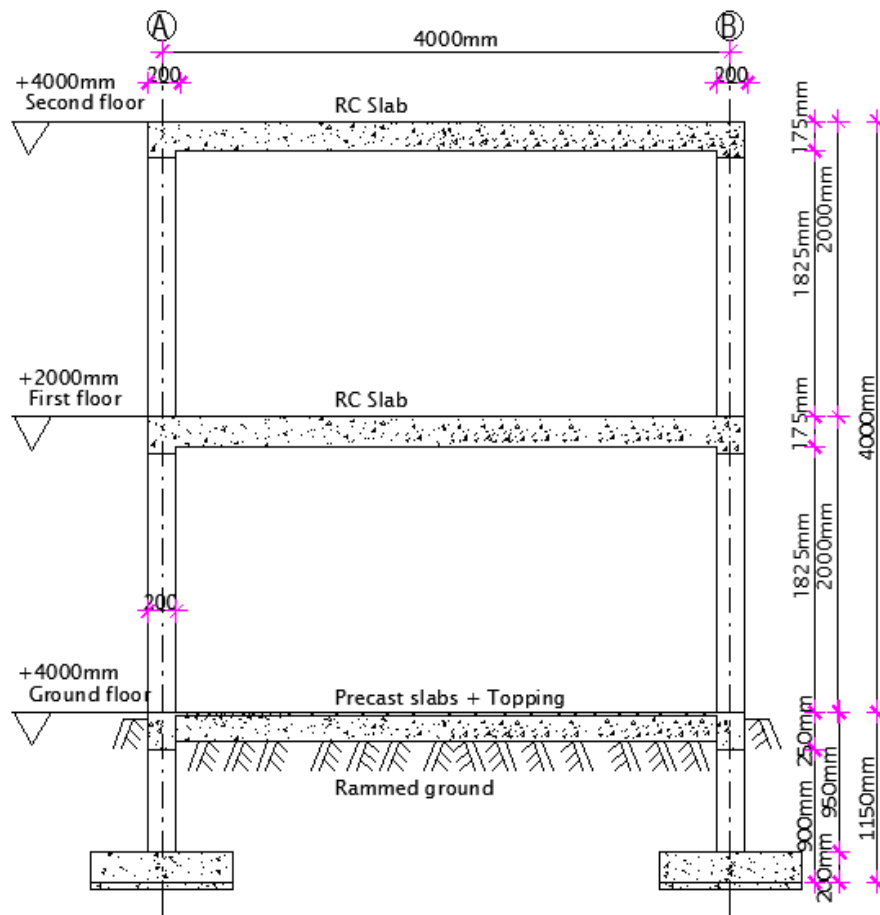


Figure 3.2: Longitudinal section through model

The model had 1000 mm $\times$ 1000 mm $\times$ 200 mm deep pad foundations, 200 $\times$ 250 mm ground beams, 200 mm $\times$ 200 mm column sections as shown in **Figure 3.3**. **Figure 3.3** shows the foundation layout.

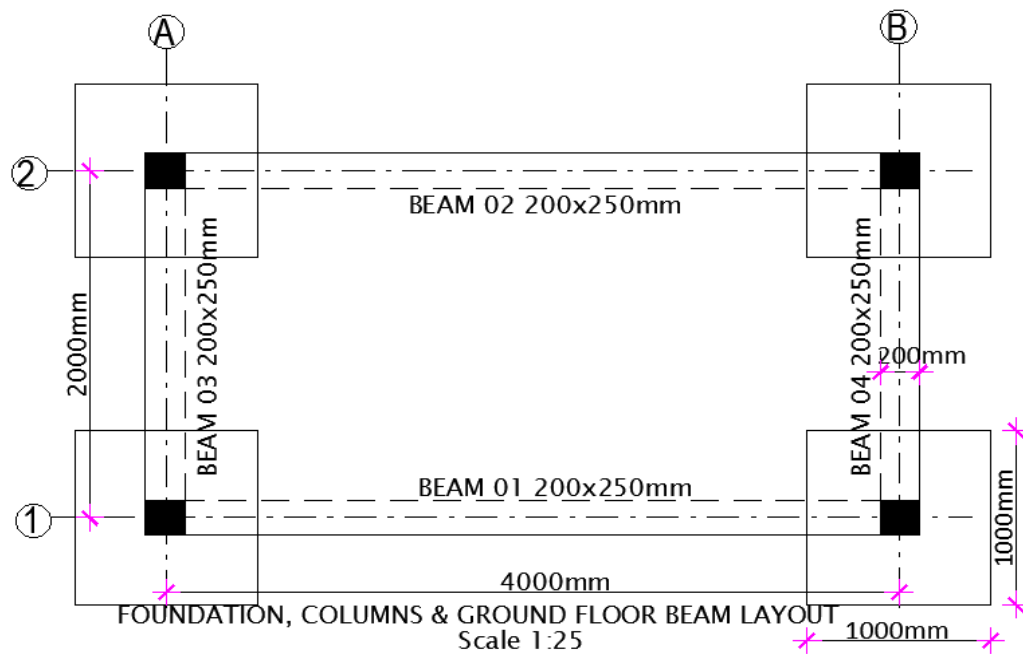


Figure 3.3: Foundation, Columns & Ground floor beams layout

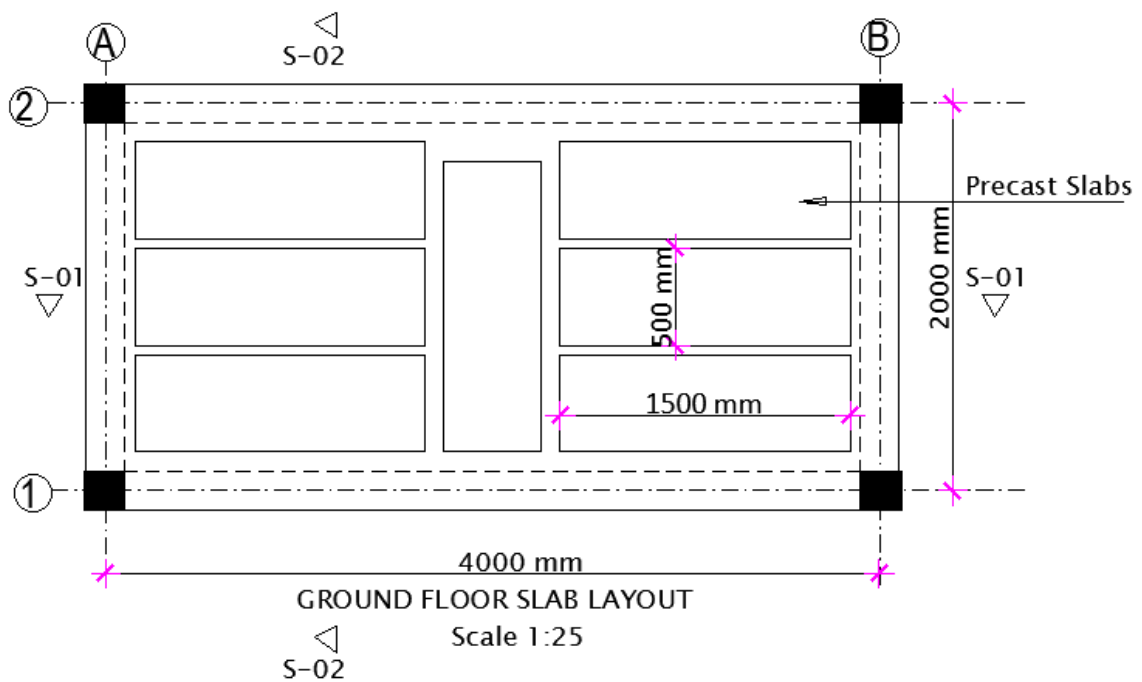


Figure 3.4: Ground floor slab layout

The ground slab, 250mm thick, contained precast slabs 200mm thick and 50mm concrete topping of Class 20/25 with ground beams **Figure 3.4**.

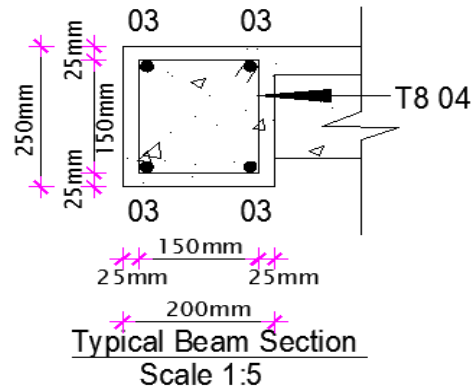


Figure 3.5: Typical 200 × 250mm beam section

All beams had dimensions 200 mm width × 250 mm depth reinforced with 2T12 reinforcement at the top and the bottom, T8 mm – 150 mm centre to centre links reinforcement. The tension and compression reinforcement was 1000 mm hooks into the column. The typical beam cross section is shown in **Figure 3.5**.

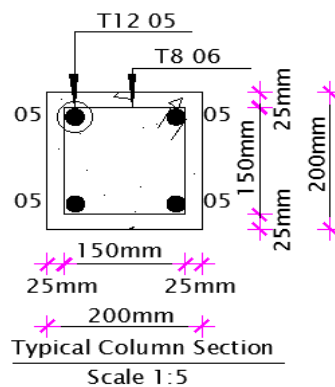


Figure 3.6: Typical 200 × 200mm column section

Columns were 200 mm × 200mm with T8 mm links spaced at 120mm centre to centre with longitudinal 4 T12 mm reinforcement as shown in **Figure 3.6**.

The first and the second level floor slab were 175mm thick with T12 mm primary reinforcement spanning along 4000 mm spaced at 200 mm centre to centre at the bottom and with secondary T12-300 centre to centre reinforcement spanning in the shorter

direction 2000 mm. At the supports, quarter span primary T12 mm reinforcement spaced at 200 centre to centre spanning along the 4000 mm length and with T12 mm secondary reinforcement spaced 300 mm centre to centre were provided as indicated **Figure 3.7**.

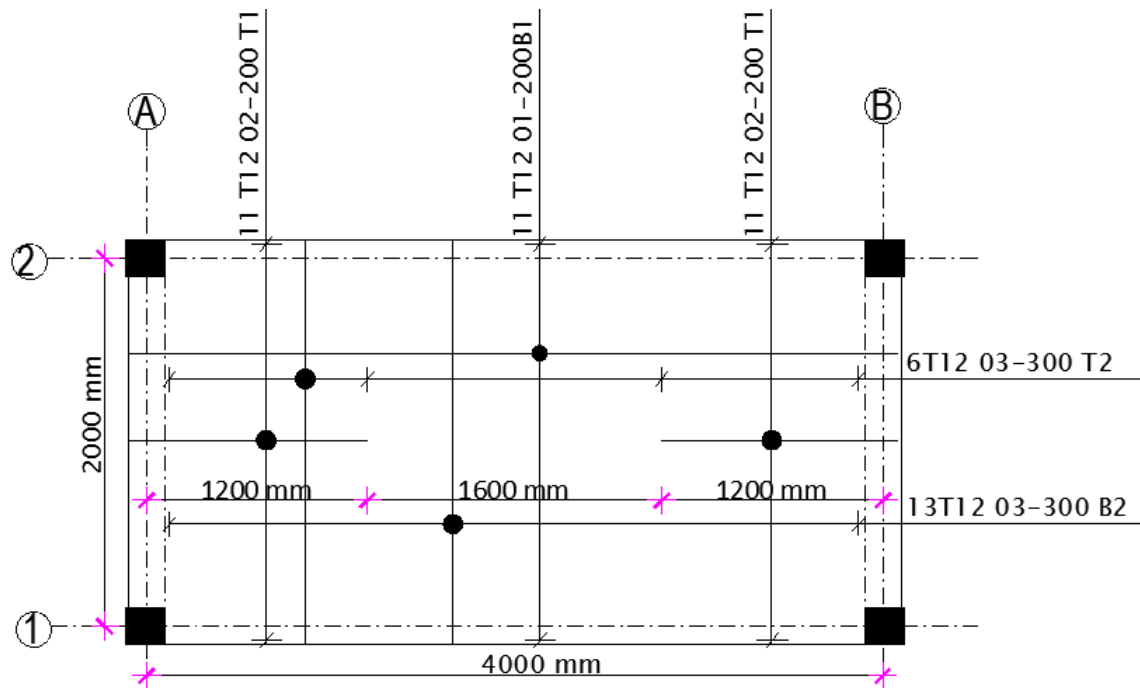


Figure 3.7: Typical First and Second floor slab reinforcement plan layout

3.4.13 Freshly cast reinforced concrete slab and props construction loads

- The construction procedures observed during a baseline survey done in Kampala revealed that props supporting first-floor slab on gaining 28 day strength were removed and used to support the next slab on the upper floor by placing it on top of the preceding slab.
- 25 props were used to support the proceeding slab on second floor. Load cells were placed under 4 props at select positions for measuring the fresh concrete load on the second floor for a period of 28 days. Dial gauges positioned underneath the

first-floor slab were used to measure slab deflection from loads contributed by the upper slab as shown in **Figure 3.8** and **Figure 3.9**.

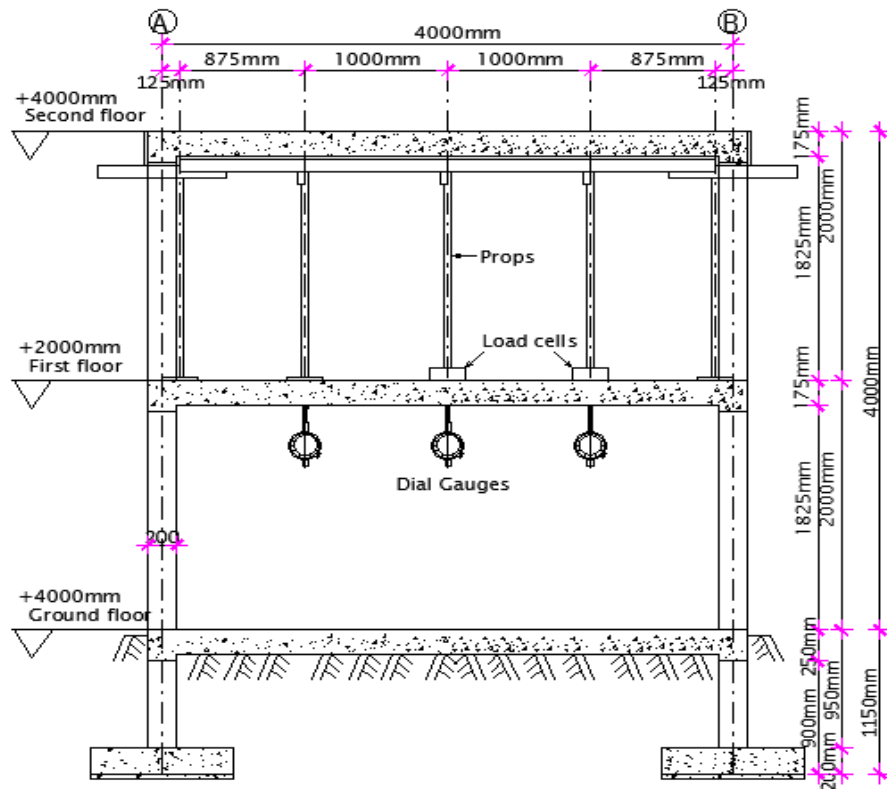


Figure 3.8: Section of mode with dial gauges and props

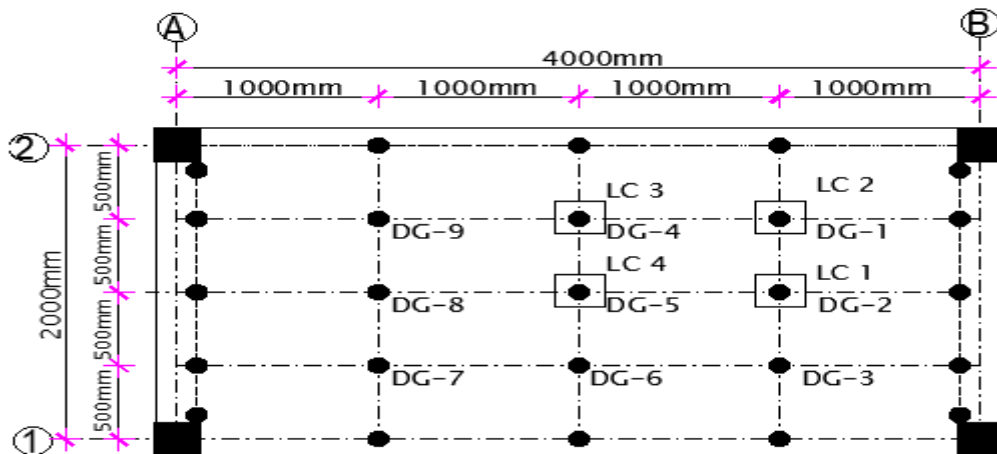


Figure 3.9: Dial gauge positions and corresponding load cell setup.

The upper second floor slab was cast in under ten (10) minutes with ready mix concrete as the construction load monitored for 28 days using load cells and resulting deflections from the time of casting.

3.4.14 Blocks acting as construction loads

- From construction slab raising process discovered from a baseline survey done in Kampala, temporal loading of slabs with concrete blocks is done during raising of wall partitions.
- The first-floor slab was thus loaded with 672 (blocks heaped in one place to raise all walls on slab as observed in baseline survey) loaded in 4 hours (at a loading rate of approximately 3 blocks per minute) as shown in **Figure 3.10**, **Figure 3.11** and **Figure 3.12**. The blocks were loaded from the outwards or edge of the slab towards the centre and then outward. The total volume occupied by the blocks was 3600mm length, 1800mm width and 1330mm height.

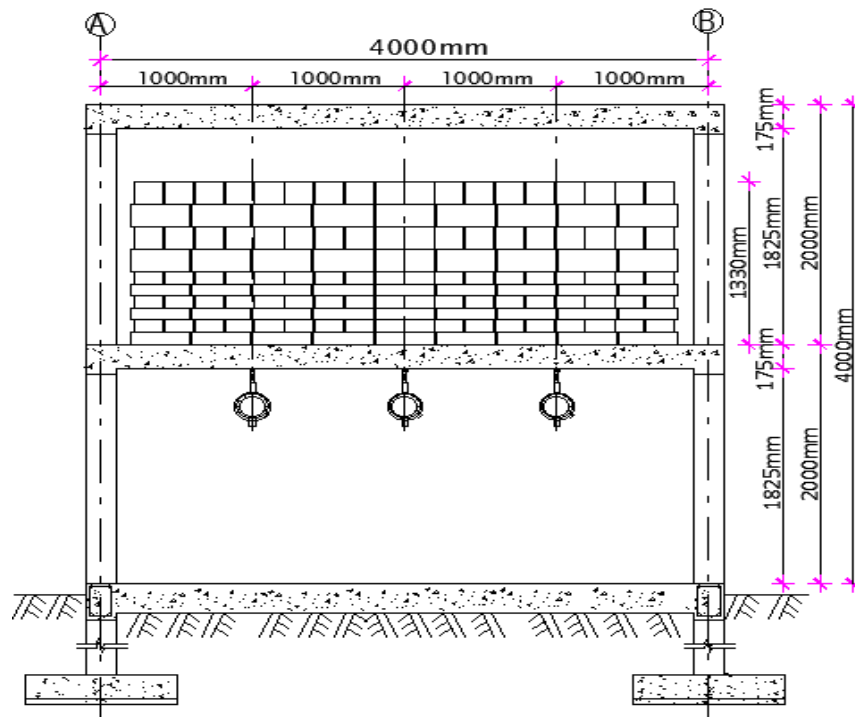


Figure 3.10: First floor slab loaded with blocks

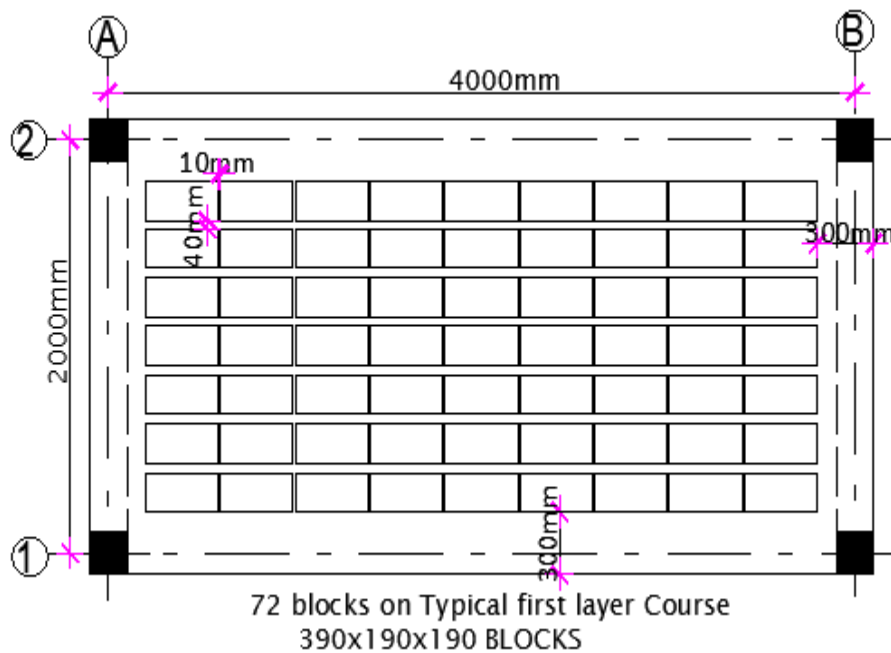


Figure 3.11: Plan of a typical first blocks course

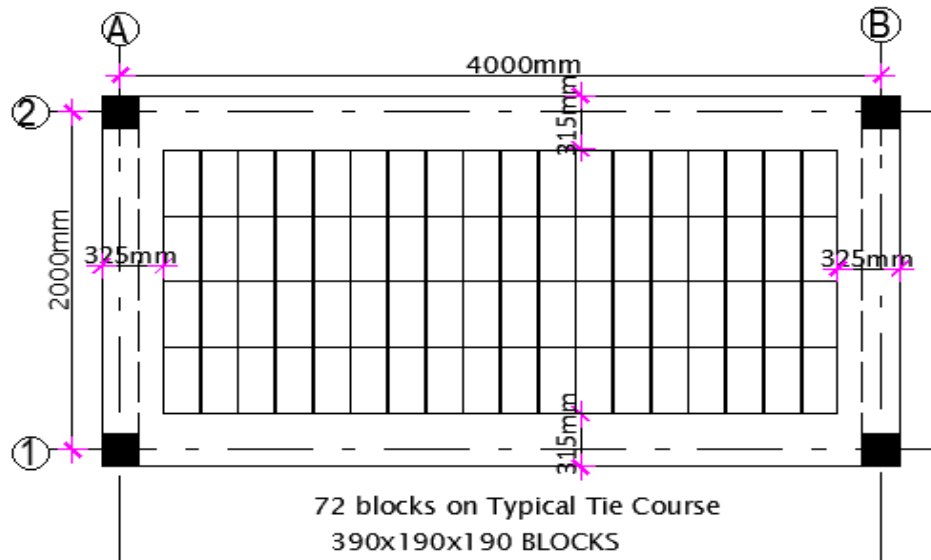


Figure 3.12: Plan of a typical tie blocks course

3.4.15 Tools used for data collection

Table 3.2: Data collection tools on the model

Tool	Details
Dial gauges	Were manufactured by ELE International, weight 0.5kg, dial gauge 25mm travel $\times$ 0.01mm divisions.
Load cells	These were of 350kg capacity of Mavin brand. Digital load weighing indicators, model XK3190-A12/A12E were used.
Dial gauge stands	Were fabricated from Kyambogo university mechanical laboratory, adjustable to required height using reducing bush.
Timer	An ELE model 85-0518 timer was used.

Data collection tools on the physical model is shown on **Table 3.2**. Photos of some of the tools used are shown in **Appendix A.9**.

3.4.16 Calibration of Test equipment reliability

The Test equipment were checked and calibrated to ensure that all equipment were in good working conditions. Calibration data is attached in the **Appendix A.7**.

3.4.17 Materials used for constructing the physical model

These included; concrete matrix materials which included sand, aggregates, water and cement, reinforcement for use in the foundation, beams and columns, timber as formwork. Their details are shown in **Table 3.3**. All those listed were carefully selected based on results obtained in the baseline survey.

Table 3.3: Materials used for constructing the physical model

Material	Details
Sand	Sand free from dust and impurities was obtained from Lweera, Masaka road because 70% of sand used on sites surveyed was from the above-named source.
Aggregates	Uniform sized 20 mm, granite aggregates, machine crushed were obtained from Ziobwe, Luweero district because 30.4% of aggregates used on sites surveyed was from the above-named source. Granite was used because 79.2% sites used it.
Water	Tap water supplied by National water and sewerage cooperation was used.

Reinforcement	Was purchased from a hardware outlet called Hardware World Limited. The brands used were Pramukh and Steel and Tube because 29.2% of sites used those brands
Timber	Was obtained from timber store dealers. They included, eucalyptus poles, 100 mm × 50 mm and 300 mm × 25 mm pieces.
Cement	Cement used was CEM IV/B 32.5 R - PPC, Nyati Brand manufactured by Kampala Cement limited was used because it was discovered that 29.2% of sites used this cement.

3.5 Deflection of the slabs due to construction loads

Dial gauges placed on dial gauge stands were used to monitor deflection as described in **Table 3.2**. The deflection results are provided in Chapter Four.

3.6 Immediate and short-term load Vs deflection of a solid slab contributed by construction loads and freshly cast slab

Dial gauges were used to measure deflections while loads were measured using load cells. Analysis and graphical relationships were drawn as presented in Chapter Four.

3.7 Deflections from structural design manual calculations

Before building the model, the analysis, design, element sizing, checks on deflections and calculations were done based on BS EN 1992-1-1 (BSI, 2004).

Elastic deflection due to slab-imposed loads was determined as follows from dimensions shown in the **Figure 3.13**;

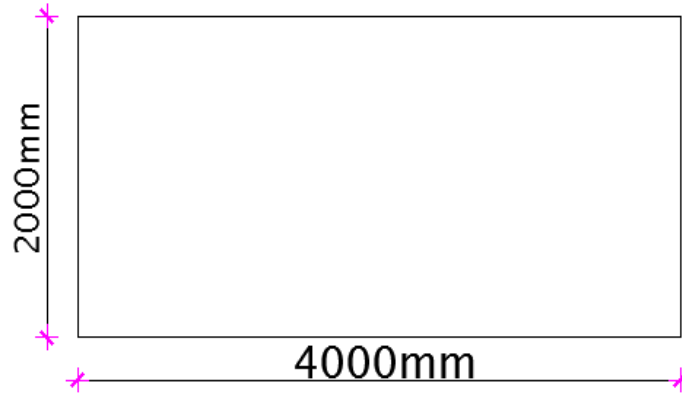


Figure 3.13: Model 4000 mm × 2000 mm

ACI 318 provides the following equation to determine elastic deflection (Gullapalli, 2009);

$$\text{Deflection} = \frac{\omega l^4}{384EI}$$

Live loads from EN 1991-1-1;

$$2 \text{ kN/m}^2 = 2 \times 2 = 4 \text{ kN/m}$$

$$E = 29 \text{ GPa} = 29 \text{ kN/mm}^2$$

$$\text{deflection} = \frac{4 \times 4000^4}{384 \times 29 \times 1000 \times (2000 \times 175^3) / 12} = \mathbf{0.103 \text{ mm}}$$

3.8 Chapter Three Summary

The previous chapter specified the methods and materials which were used in this study. A physical model was constructed. The dimensions, materials and supporting methods to be used in constructing the model were based on the baseline survey to be carried out in Kampala on actively running multi-storey sites of reinforced concrete nature. The proceeding chapter gives the analysis, discussion and presentation of results from the study.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This Chapter contains the results from the baseline survey and the experimental tests and measurements undertaken to investigate the load deflection relationship imposed on solid slab by more than one construction load.

4.2 Baseline survey

- From a baseline survey on 118 reinforced concrete building sites selected at random in Kampala, 87% of the sites remove supports from a lower reinforced concrete slab. The same props supports are transferred to the slab top surface to support the next slab on the upper floor.
- Another baseline survey on 124 reinforced concrete sites, selected at random through- out Kampala revealed that 80.6 % sites had construction loads such as bricks, blocks etc. as shown in **Table 4.1**. The scope of the research was not to measure construction loads which were observed on these sites.
- From **Table 4.1**, timber in its different forms appeared on 34% of the sites sampled. Bricks and blocks at 22.5% of the sites were the second most commonly appearing construction materials. Sites without construction loads were 19.4% mainly in the Central division where pumped concrete was commonly used.
- Construction loads are not considered by most designers when designing slabs in Uganda.

Table 4.1: Construction Loads data on sites in Kampala

S/N	ITEM	No	Percentage (%)
1	Reinforcement, Timber, Steel	1	1
2	Timber formwork	13	13.0
3	Timber poles	13	13.0
4	Timber for roofing	5	5.0
5	Timber Formwork and Poles	2	2.0
6	Timber boards	1	1.0
7	Tanks	3	3.0
8	Tank and sand	1	1.0
9	Bricks	9	9.0
10	Blocks	10	10.0
11	Sand	13	13.0
12	Bricks and sand	4	4.0
13	Blocks and sand	1	1.0
14	Sand and poles	1	1.0
15	Aggregates	4	4.0
16	Max span	7	7.0
17	Aggregates and Max pans	1	1.0
18	Max pans and poles	1	1.0
19	Debris	5	5.0
20	Iron sheets and tanks	1	1.0
21	Blocks and tanks	1	1.0
22	Steel	1	1.0
23	Steel formwork and bricks	1	1.0
24	Bricks, sand, mixer	1	1.0
SUB TOTAL		100	100
25	Sites without construction loads	24	19.4
TOTAL		124	100

4.3 Slab and construction loads

The following are tests carried out before and during the measurement of slab and construction loads on the physical model.

4.3.1 Material tests

4.3.1.1 Compressive strength Results

Table 4.2: Trial Mix compressive strength results

Mix proportion	7 days	28 days	Remarks
1:1.5:3	15.5	28	C20/25

Table 4.2 shows the mix proportions which were used to arrive at the desired strength. It was realised that mix ratio 1:1.5:3 gives a 28-day strength above characteristic strength class C/20/25 required for the experiment. A lean mix of 1:3:6 was used for blinding in concrete pads.

Table 4.3: Compressive strength results for elements cast

Area	28-day strength
Foundation	25.3
Columns	29.3
Ground Beams and slab	31.5
First Floor Beams and Slab	27.3
Second Floor beams and Slab	26.5

Table 4.3 shows average characteristic strength of concrete for various elements cast after 28 days of curing. Characteristic strengths above 25 Mpa was achieved.

4.3.2 *Workability/ slump results*

- True slump values ranging from 45-100 mm were got during mixing operations except for the collapse slump of 150 mm on second floor slab because pumped concrete was used.

4.3.3 Coarse and fine aggregates tests

Sieve analysis was done based on BS 812-103.1:1985 (BSI, 1985) using envelopes or limits obtained from BS 882:1992 (BSI, 1992).

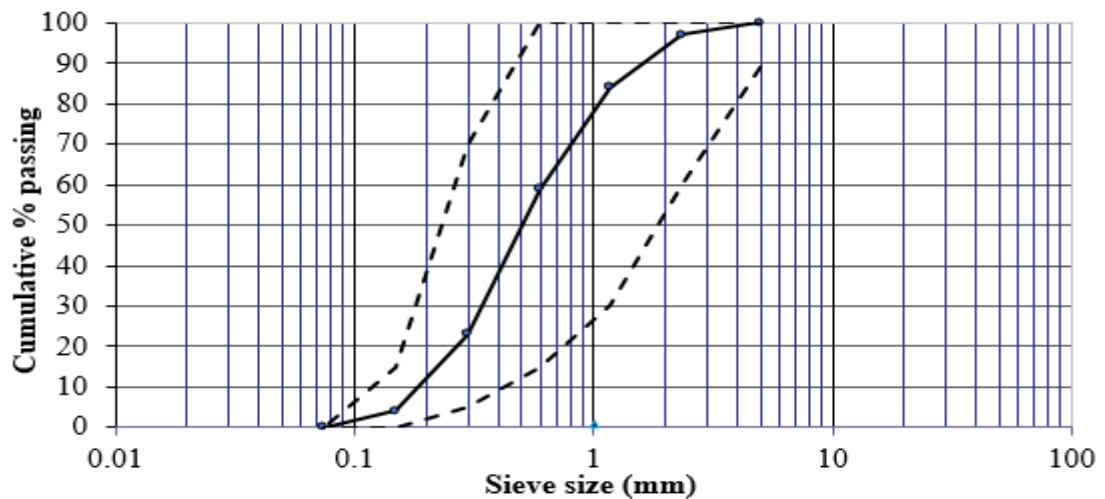


Figure 4.1: Fine aggregates grading

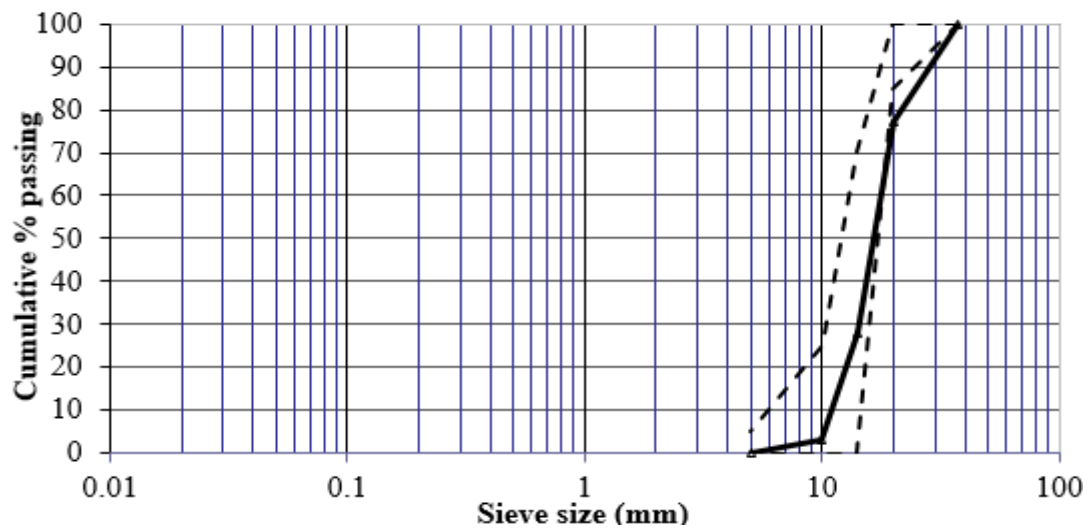


Figure 4.2: Coarse aggregates grading

- Results revealed that fine aggregates were well-graded while coarse aggregates were single 20mm sized aggregates respectively based on **Figure 4.1** and **Figure 4.2**. The limits of the graphs were obtained from BS 882.

- Coarse aggregates test results included: water absorption 0.16; relative density 2.668, flakiness index $28.7\% < 40\%$ (BS 882:1992 (BSI, 1992)), fines percentage 0.043%. Fines percentage in fine aggregates were 0.273%. Fines in fine and coarse aggregates were less than 4% limit based on BS 882:1992 (BSI, 1992);

4.3.4 Cement tests

Cement tests were done by manufacturers at UNBS. All cement test parameters tested had results which were passing required specifications as shown in **Appendix A.2**.

4.3.5 Reinforcement tests

Were done by manufacturer at UNBS and all were passing reinforcement checks as shown in **Appendix A.1**.

4.3.6 Soil investigation results

Cohesion factor C equal to 10.8, friction angle $\phi = 30^\circ$ and bearing capacity from Terzaghi's model was equal to 292.47 kPa.

4.3.7 Freshly cast slab construction loads

4.3.7.1 Load deflection time relationship due to freshly cast slab

Table 4.4 shows experimental data recorded from freshly cast slab for 28 days at the start of loading, during loading and unloading phase.

Table 4.4: Deflection Vs Time (Dial gauges 9, 8 and 5)

Time [minutes]	Cumulative				Remarks
	Time [minutes]	Deflection [mm]			
		DG-9	DG-8	DG-5	
0	0	0.659	0.675	1.011	S. O. C
10	10	0.714	0.67	1.011	E. O. C
15	25	0.714	0.67	1.011	
6	31	0.714	0.67	1.01	
6	37	0.739	0.67	1.01	

S.O.C - Start of concreting, E.O.C – End of concreting, DG-X-Dial gauge Number

As indicated in Table 4.4, the pumping, casting and finishing and finishing operations were done in less than 10 minutes since casting was commenced. In 37 minutes since casting was started, deflection increased by 12% for DG-9.

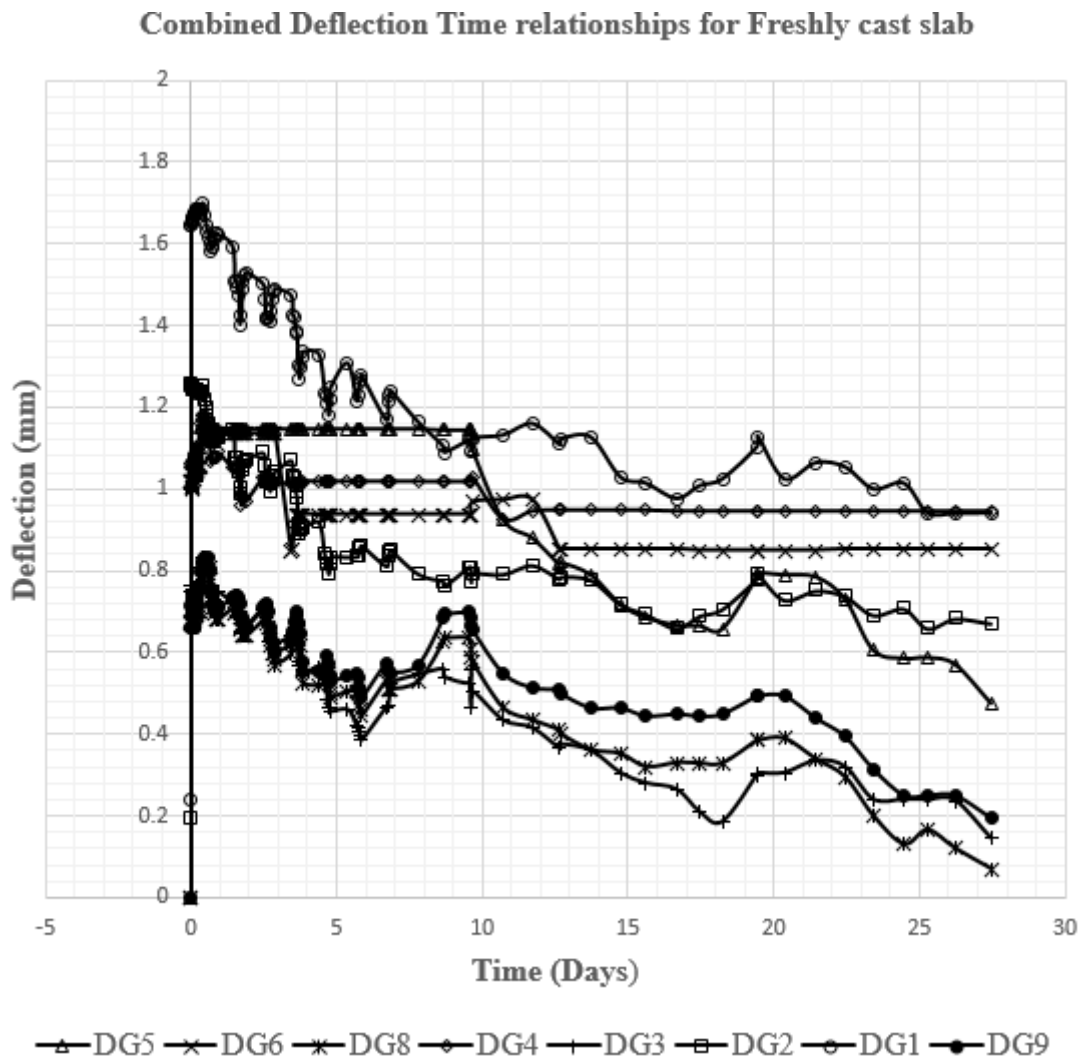


Figure 4.3: Deflection time curves on supporting slab from freshly cast upper slab

Figure 4.3 shows the deflection experienced on first floor slab due to loads from upper second floor slab for a period of 28 days.

Deflection was measured with the use of dial gauges DG9, DG8, DG7, DG6, DG5, DG4, DG3, DG2, DG1 in strategic positions as shown in **Figure 3.9**.

Generally, deflection decreased as concrete hardened. A typical curve excerpt in Figure 4.4 extracted from Figure 4.3 is explained further below.

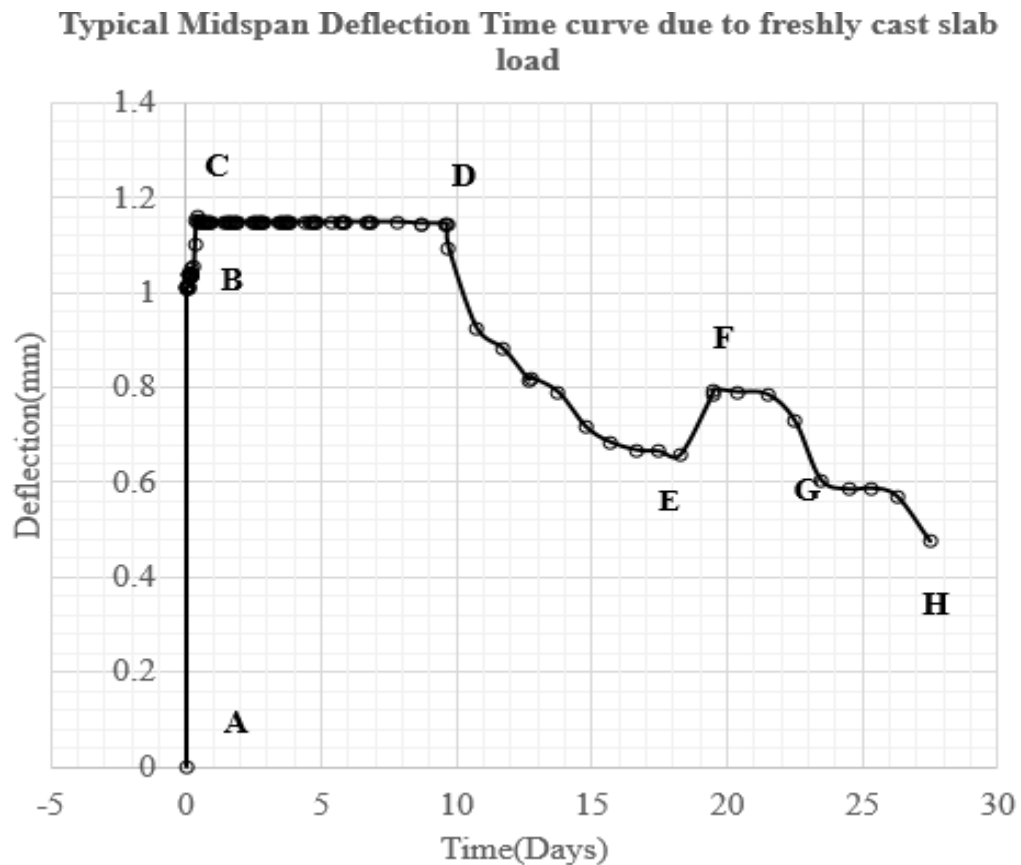


Figure 4.4: Typical mid-span deflection Vs time due using newly placed RC slab loads experienced by support slab

Points shown in the **Figure 4.4** above represent the following;

- Point A- represents the beginning of concreting
- Point B- represents the end of concreting
- Point C- is when the final setting of concrete happens
- Point D- is the 10th day of drying of concrete since beginning of concreting
- Point E- 18th day of drying of concrete since beginning of concreting

- Point F- 19th day of drying of concrete since beginning of concreting
- Point G- 23rd day of drying of concrete since beginning of concreting
- Point H- 28th day of drying of concrete since beginning of concreting

Thus **Figure 4.4**, the deflection rose sharply at the beginning of casting 0 mm (point A) to 1.01 mm (point B) after 10 minutes. It then rose from 1.01 mm (point B) to 1.159 mm (point C) after 9 hours 23 minutes from casting, assumed to be the final setting time of concrete. It reduced to point D (1.145 mm) from point C on the 10th day after casting. The deflection reduced sharply to 0.475 mm (point H) after 28 days since beginning of casting.

4.3.7.2 Load time relationship due to freshly cast RC Slab and props

Table 4.5: Some of Loads measured on load cells 1, 2, 3 and 4

Time Interval [minutes]	Cumulative time interval [minutes]	Load on load cells 1 to 4 [kg]				Activity
		1	2	3	4	
		24.29	19.89	81.14	79.44	B.C
0	0	167.76	128.08	233.39	254.8	S.O.C
10	10	167.92	127.73	233.23	254.78	E. O. C
15	25	168.08	127.63	233.22	254.78	Setting
6	31	168.42	127.44	233.19	254.87	Setting
6	37	168.68	127.29	233.16	255.09	Setting

B.C- Before Concreting, S.O.C - Start of concreting, E.O.C – End of concreting, DG-X-Dial gauge Number

- The load reduced as the concrete set indicated by the load cells at the edges 2 & 3 located as shown in **Table 4.5**. The load reduction when concrete had set small. The reduction was 0.6% for Load Cell 2 and 0.1% for Load Cell 3 at the beginning of casting operations. Small increase was 0.54% and 0.1% for Load Cell 1 and 4 at the centre for 37 minutes since beginning of concreting operations.

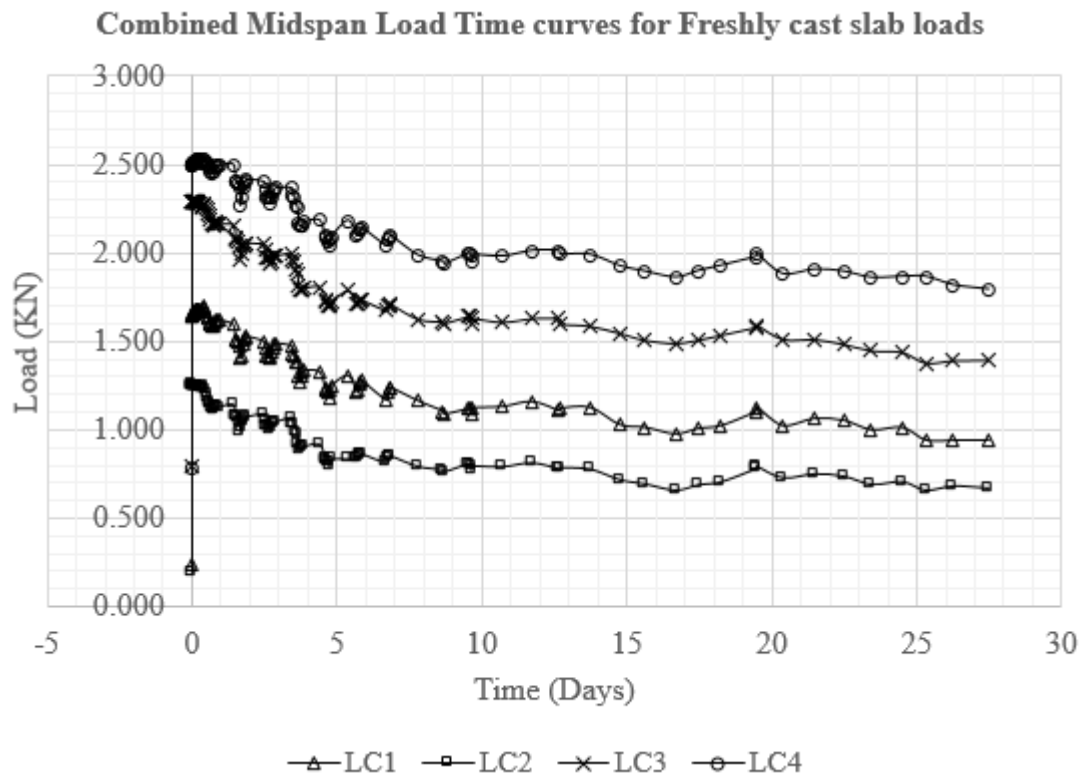


Figure 4.5: Load Vs time curves for lower supporting slab due to RC loads

- **Figure 4.5** displays the load Vs time curves imposed on first floor slab supporting freshly cast RC slab on second floor. The load is shown to reduce overtime for all load cells. Load reduced by 28%, 36%, 44% and 52% for Load Cell 4, 3, 1 and 2 respectively.

- A typical curve excerpt in Figure 4.6 extracted from Figure 4.5 is explained further below.

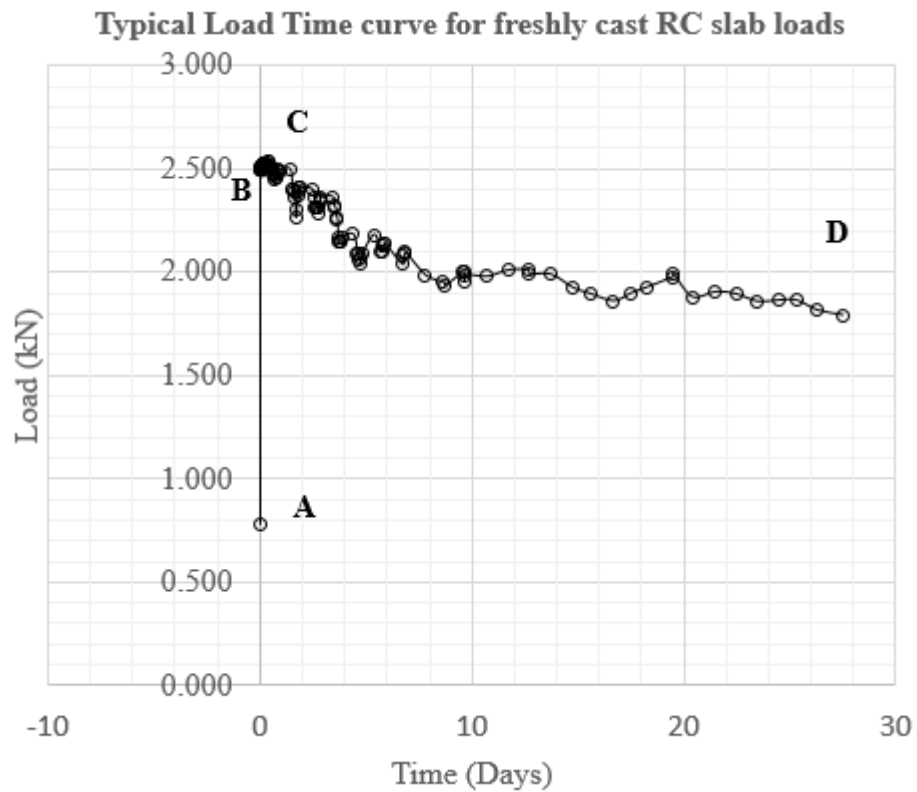


Figure 4.6: Typical Load Vs time curve for lower supporting slab due to RC loads of upper slab

- **Figure 4.6** indicates load Vs time behaviour for the supporting slab due a freshly RC slab loads and its props supports (from start of casting to up to 28 days).
- From **Figure 4.6**, sharp rise from 0.79 kN to up 2.55 kN was recorded from commencement of casting point A up to Point B, ten minutes after casting. The self-weight of the slab and beam formwork, props and reinforcement is indicated by Point A.

- A maximum load reached was 2.58 kN (point C) but dropped up to 1.83 kN (point D) by 29.1% after 28 days. The curing of the slab led to rises and falls in between.

4.3.7.3 Load deflection relationship due to freshly cast slab

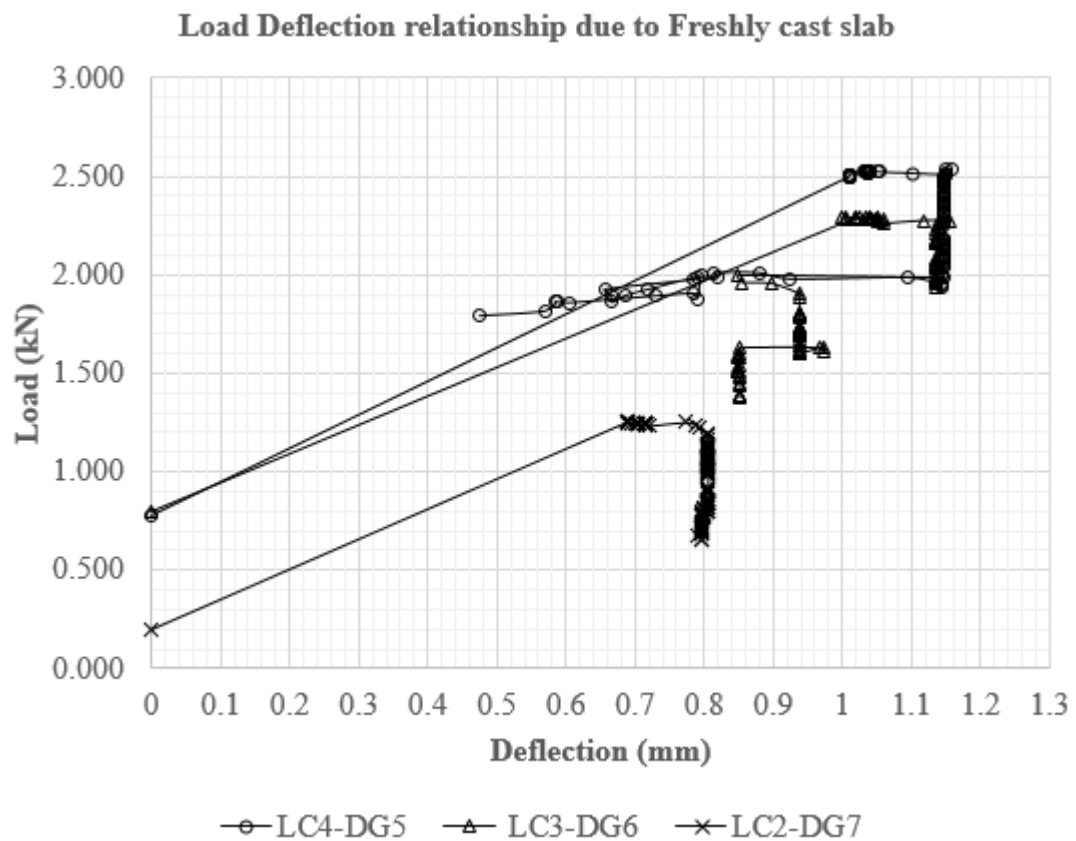


Figure 4.7: Load Vs deflection curves for supporting slab from freshly cast reinforced concrete slab loads

- **Figure 4.7** shows the combined load Vs deflection curves for supporting slab due to freshly cast reinforced concrete slab loads (From start of casting to 28 days).

- Generally load and deflection increased sharply at the start of casting. As the load remained constant, deflection continued to increase. Load decreased sharply as deflection remained constant. There was a final decrease in deflection and load.
- A typical curve excerpt in Figure 4.8 extracted from Figure 4.7 is explained further below.

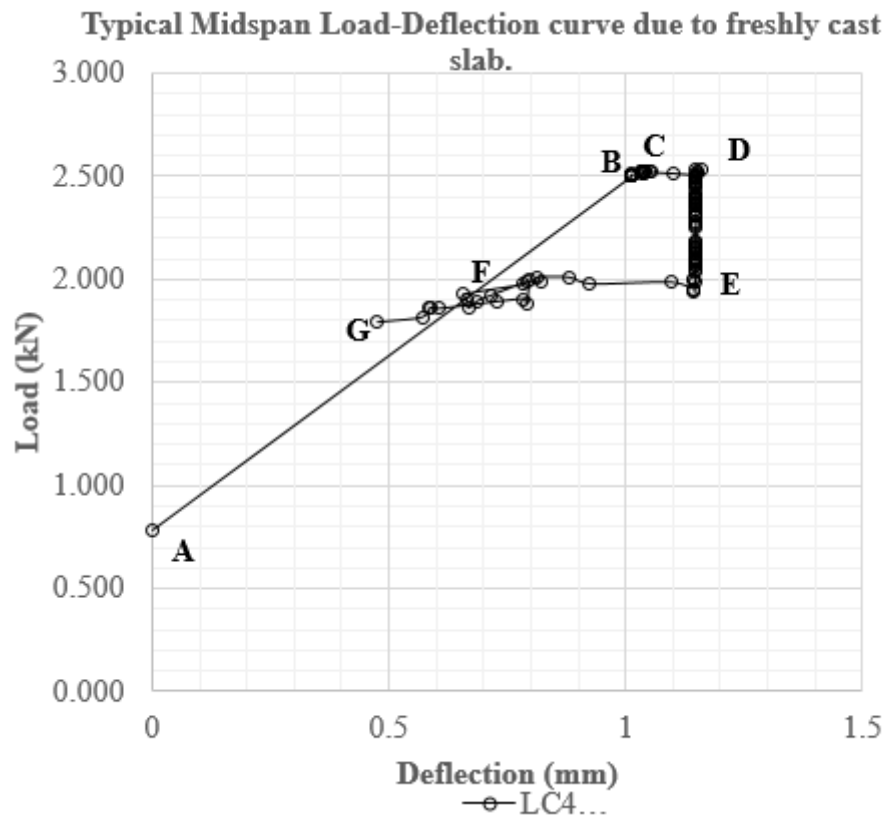


Figure 4.8: Load Vs deflection curve for supporting slab due to RC slab loads

- A typical Load Vs deflection graph for a lower slab on which formwork supports for a second floor slab are placed is shown in **Figure 4.8** monitored from the instant of casting up to 28 days period.

- Deflection increased sharply from 0 mm to 1.01 mm (indicated as point A to point B respectively) in under 10 minutes of casting. Further rose from 1.01 mm (point B) to 1.159 mm (point C) after setting a time of 9 hours 23 minutes from the time of casting from the RC slab and its supports loads.
- It thus the same till the 10th day (point D). A sharp drop in load point DE as observed on the 10th day.
- A deflection of 0.7 mm at Point F was recorded on the 14th day after drying.
- As concrete continued to dry, the applied load reduced from point E to Point G by 7.3%. After four weeks (point H), the final recorded deflection was 0.475 mm.
- As shown in the curve Figure 4.6, the weight reduced after 10 days implying that the columns and beams had started to take up some of the load. At ten days, the slab had achieved working strength and not the usual 7 days at which compressive working strength is usually tested.

Table 4.6: Comparison between experimental and manual deflection calculations

S/N	Experiment/Calculation	Deflection [mm]
1	Deflection due to loads from freshly cast upper concrete slab	1.159
2	Manually calculated Immediate/elastic deflection due to design live loads	0.103

According to **Table 4.6**, the experimental determined by fresh concrete and formwork loads was greater than the manually calculated design immediate/elastic deflection by live loads.

4.3.7.4 Discussion

- The self-weight load of freshly cast slab = $25 \times 0.175 = 4.375 \text{ kN/m}^2$.
- According to **Figure 3.9**, prop area being supported = $0.5 \times 1 = 0.5 \text{ m}^2$. Thus slab point load carried by prop = 2.188 kN.
- Since the 2.58 kN was the maximum recorded load read by the load cell in the experiment, it implies that self-weight of formwork was
 $= 2.58 - 2.188 = 0.1392 \text{ kN}$.

4.3.8 Blocks construction loads instantly loaded

4.3.8.1 Deflection Vs time for construction loads due to blocks

- A typical Deflection Vs Time plot from construction materials due to concrete blocks loaded on level two floor slab for Dial Gauge position 5 (DG5) is shown in **Figure 4.8**.
- Hollow and solid blocks of average weight 17.38 kg were loaded on the first-floor slab in a 4 hour period from outward to the centre and outward. They were stacked to a height of 1330 mm based on a baseline survey which revealed that 81.8% block loads onto the slab was varying from 1000mm and 1800mm.
- As shown in **Figure 4.8**, the deflection rose from point A to B, 0 mm to 8.9 mm respectively. It continued to increase by 32.75% from 8.9mm (point B) to 11.815mm (point C) in 11 day period.

- Whereas in the unloading phase which took 7 hours, the deflection dropped by 53.45% from 11.815 mm to 5.5mm (point D), **Figure 4.8**.
- Since the defection remained at 5.5 mm and did not return to zero, the slab was now in the inelastic range.

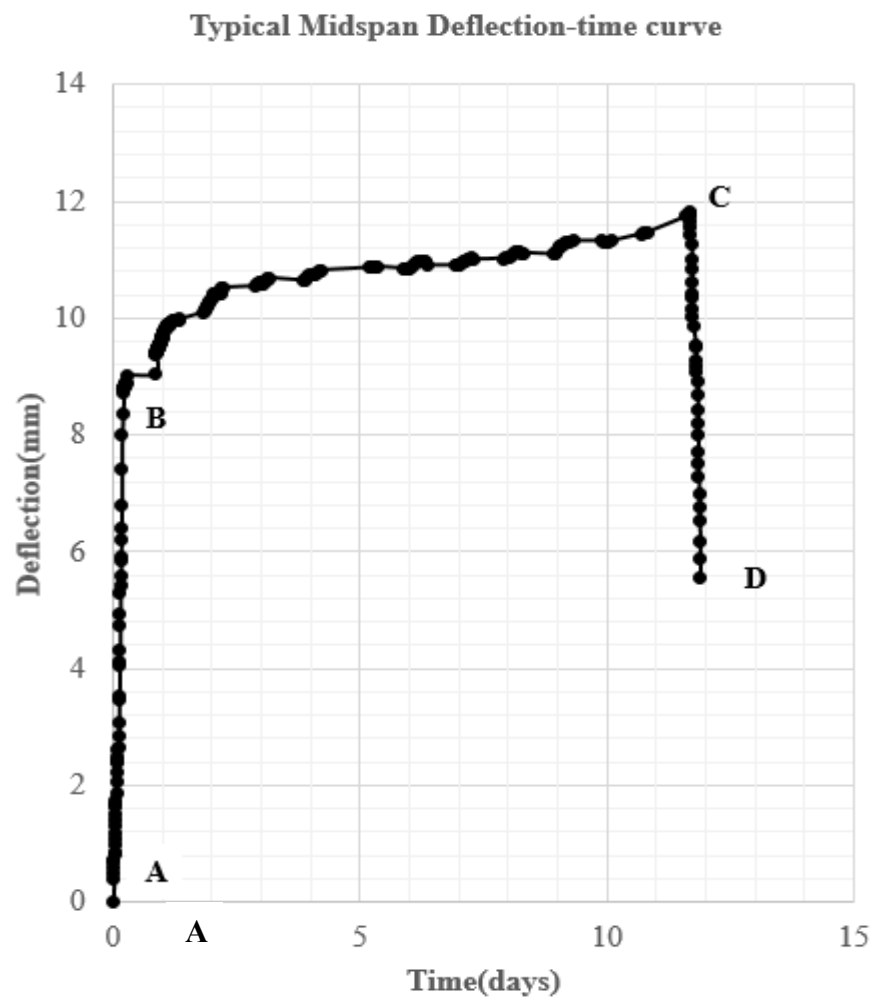


Figure 4.8: Typical Deflection Vs time curve due to concrete blocks construction loads stacked onto first floor slab

Table 4.7: Deflection results from experiment and calculation

S/N	Experiment/Calculated	Deflection [mm]
1.	Deflection from concrete blocks loads instantly stacked on first floor slab	11.815
2.	Manual deflection calculation:	
a.	Immediate/elastic deflection $\left(\frac{1}{384} \frac{\omega l^4}{EI}\right)$	0.103
b.	Short-term deflection limit of (span/250)	16

From **Table 4.7**, the deflection from the experiment from concrete blocks loads of 11.815 mm was lower than 16mm (span/250 mm) limit but higher than immediate deflection due to design loads of 0.103mm.

4.3.8.2 Load Vs deflection plot for construction loads due to blocks

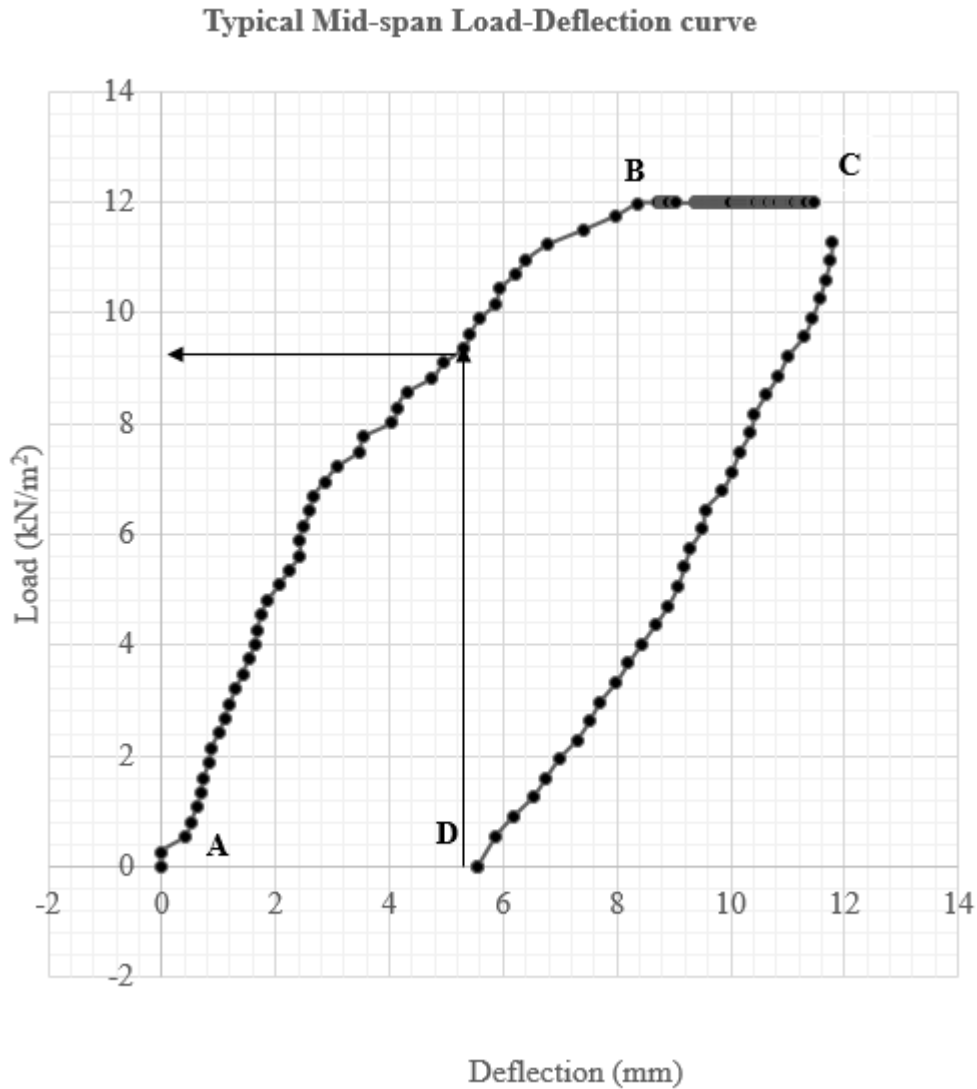


Figure 4.9: Load Vs Deflection from instantly loaded concrete blocks on the first floor slab

- The total loaded blocks was 672 blocks at a loading rate of 3 blocks per minute. Thus for every 20 blocks, the deflection value was read and recorded during the loading phase.

- According to **Figure 4.9**, it was during loading phase that the load rose from 0 to 11.9 kN/m² and deflection from 0 to 8.14 mm from the start of stacking operations until the end of loading, (point A to B) in the 4 hour period.
- Although loading did not change (point B to point C), deflection increased from 8.14 mm to 11.7 mm in 11 day period. Since the deflection continued to rise furthermore even though loading had ceased, the slab was now in the inelastic range.
- When unloading (point C to D), there was a deflection decrease from 11.7 mm to 5.55 mm and loading reduction from 11.9 kN/m² to 0 kN/m².

Discussion

- Short-term deflection limit of span/250 mm = 16mm during construction should not be exceeded due to loads by construction loads. The deflection at the end of the experiment of 11.814 mm is lower than the limit thus ok.
- Since the immediate deflection of 8.14 mm (point B) achieved at the instant of loading blocks (after all blocks are placed on the slab), it is supposed that a deflection of 5.43 mm (obtained by scaling down an immediate deflection of 8.14 mm using a partial live load factor of safety of 1.5) and the corresponding load of 9.2 kN/m² should not be exceeded as indicated on **Figure 4.9**.
- Blocks of dimension 0.2 × 0.2 × 0.4m (672 in total) stacked to 1.33m had a load of:

$$\frac{(17.38 \times \frac{9.81}{1000})}{(0.4 \times 0.2 \times 0.2)} = 10.66 \text{ kN/m}^3$$

Hence the load in m^2 is equal to $1.33 \times 10.66 = 14.32 \text{ kN/m}^2$

4.4 Deflection of the slabs due to construction loads

These have been provided in the section 4.3 above.

4.5 Immediate and short-term load Vs deflection of a solid slab by construction loads and freshly cast slab

These have been provided in section 4.3 above.

4.6 Deflections from structural design manual calculations

From the design calculations, the immediate deflection was **0.103 mm**.

4.7 Discussion

- The design live load Q_k used in design was 2.0 kN/m^2 . However, an imposed action of 14.32 kN/m^2 was experienced due to blocks.
- On the other hand, an imposed action of 4.4 kN/m^2 was imposed by freshly cast concrete from the second floor causing a point load on first floor of 2.58 kN or uniformly distributed load of 5.16 kN/m^2 .

4.8 Chapter Four Summary

Chapter 4 presented results from the study and their discussion. 87% of 118 randomly surveyed RC construction sites in Kampala had their props supports to a lower level RC slab are removed and were then used to support an upper floor when placed on the preceding slab. 80.6 % cases of 124 randomly surveyed RC construction sites were found with construction material loads on their slabs like blocks, sand, bricks, timber

and aggregates. The bearing capacity of the soil was calculated according to Terzaghi's model and 292.47 kPa. Various load Vs time, deflection Vs time and load Vs deflection curves are presented. The proceeding chapter presents the conclusions and recommendations for the research study.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 *Baseline survey*

- 87% of 118 building sites chosen at random had their prop supports to the soffits of lower reinforced concrete slabs removed and are used to support an upper floor slab placed on preceding slab.
- Construction loads such as bricks, blocks etc. were found on 80.6 % of 124 randomly selected RC sites mainly of residential type. Most sites in the Central division of Kampala did not have construction loads and pumped concrete was commonly used there.

5.1.2 *Slab and construction loads*

5.1.2.1 Slab loads

- The design live loads on the physical model constructed according to BS EN 1991-1-1 was 2 kN/m^2 and the self-weight of the same was 4.375 kN/m^2 .

5.1.2.2 Construction loads

- The slab area carried by the props was 0.5 m^2 as shown in Figure 3.9. The maximum load over that prop area was 2.58 kN or 5.16 kN/m^2 . This was 158% more than the design live load of 2 kN/m^2 .
- Live loads due to loaded blocks was 14.32 kN/m^2 while the design live loads was 2 kN/m^2 from BS EN 1991-1-1. Thus the live construction load from blocks of 14.32 kN/m^2 was greater than design live load of 2 kN/m^2 .

- The design ultimate load from expected dead load and live design load over the life of the structure was 14.77 kN/m^2 . This load was slightly higher than the live load imposed by blocks on the slab of 14.32 kN/m^2 .
- The actual slab load experienced at the time of experimental loading due to blocks was;

$$= G_k + Q_k$$

$$= \text{Dead load (self weight of slab)} + \text{Live load (weight due to blocks)}$$

$$= (4.375 + 14.32) = 18.695 \text{ kN/m}^2$$

- This was 26.57 % greater than design ultimate load which led to development of cracks, thus failing in serviceability before its occupation.

5.1.3 Immediate and short-term load Vs deflection of a solid slab from construction loads and freshly cast slab

- For the freshly cast construction load, a sharp increase in deflection at the instant of loading due to pumped concrete was recorded. This increased minimally until drying was complete (the 10th day of drying of the concrete). From the 10th day onwards, the deflection continued to decrease up to 28 days when unloading happened.
- For construction loads due to blocks, deflections increased sharply during the loading phase. It increased minimally up to the 11th day when unloading happened.

5.1.4 Deflection of the slabs due to construction loads

- A mid-span deflection of 11.815 mm and 1.159 mm from block loads and loads from a freshly cast RC slab together with its supports respectively were obtained experimentally.
- The 11.815 mm deflection due to concrete blocks, 1.159 mm from freshly cast slab loads and its supports were less than the deflection allowable limit of $\frac{\text{span}}{250} = 16 \text{ mm}$.

5.1.5 Deflections from structural design manual calculations

- The manual deflections from calculations was 0.103 mm due to design-imposed live load and was lower than the allowable deflection limit of $\frac{\text{span}}{250} = 16 \text{ mm}$.

5.2 Recommendations

- Design live loads are very low compared to actual construction loads. It is recommended that upper slabs should be constructed with supports to lower slab in place.
- The researcher recommends for future research survey taking actual measurements of construction material loads sites found on sites.
- Live loads during and after construction should not exceed design loads of a structure. For buildings with live load say 2 kN/m^2 only one course of blocks is required which seems unrealistic in practice. However, if live loads are

exceeded, a construction load limit according to this study of 9.2 kN/m^2 should not be exceeded to avoid serviceability problems due to cracking. Although it's safe, back propping at the same time is recommended where possible.

- Deflections from blocks was higher than that due to slab loads. It is thus recommended that slabs should not hold block loads for more than one month as was discovered on some sites in the baseline survey.
- Since construction loads are higher than live loads as seen in this experiment, it is recommended that they are considered in deflection and slab design calculations.
- Although it is recommended above that the slab design and deflections should consider construction loads and that slab props not be removed until construction is finished, this on the other hand is rather an uneconomic alternative.
- However, a much lower slab deflection would result when construction loads are considered in design of slabs because thicker slabs would be achieved in design. The thicker the slab, the higher the stiffness of the slab and hence the lower the deflection.

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APPENDIX

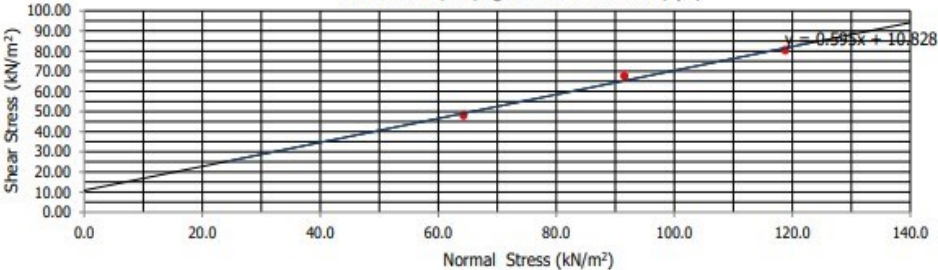
Appendix A.1: Reinforcement tests lab report results carried out at UNBS by Steel and Tube Industries dated 18th Feb 2020

S/N	Parameters	Results	Specification	Status
1	Diameter of bar (mm)	12	12	Pass
	Weight/meter run			
2	(kg/m)	0.87	0.835-0.941	Pass
3.	Tensile strength			
	Yield			
I.	strength(N/mm ²)	609	500 Minimum	Pass
	Tensile			
II.	strength(N/mm ²)	710	575 Minimum	Pass
III.	Elongation (%)	18	14 Minimum	Pass
		No signs of		
4	Bend test	rupture were	Shall show no signs	
		observed	of rupture	Pass
5	Grade	B500CWR	B500CWR	Pass

Appendix A.2: Cement tests lab report results carried out at UNBS by Kampala Cement Limited dated 8th October, 2020

S/N	Parameters	Results	Specification	Status
				NA (Not
1	Standard consistency	32	Not specified	Applicable)
2	Compression strength			
I.	2-day strength(N/mm ²)	11.3	10 Minimum	Pass
II.	7-day strength(N/mm ²)	21.9	Not specified	NA
III.	28-day strength(N/mm ²)	32.5	32.5-52.5	Pass
3	Weight(kg)	50	Not specified	NA
4	Initial setting time(minutes)	210	75 Minimum	Pass

Appendix A.3: Shear Box Test results

KYU MATERIALS LAB		SHEAR BOX TEST Grading Modulus and Grading Coefficient							
PREPARED BY : E.E		REVISION 00	Effective Date OCTOBER 2020	WORKING SHEET NO KYU-LTF-026	Page 1 of 1				
REVIEWED BY : E.E									
APPROVED BY :O.P									
PROJECT : RESEARCH PROJECT		LOCATION	TP1	DEPTH (m)	1.5				
CLIENT : KIGOYE ERIYA		SAMPLE NO.	2020/0488	DATE SAMPLED					
TECHNICIAN : N.H,E.E		CHECKED	O.P	DATE TESTED	14.10.2020				
REFERENCE TEST METHOD : BS : 1377 : PART 2 & 7 : 1990									
SAMPLE DESCRIPTION		REDDISH BROWN CLAY SOIL							
SPECIMEN DIMENSIONS									
MASS OF SPECIMEN (g)	124.3	124.3	124.3	AV. MASS OF SPECIMEN (g)	124.3				
HEIGHT OF SPECIMEN (mm)	20		SPECIMEN DIA (mm)	0	SPECIMEN AREA (mm ²)	36.0			
VOLUME OF SPECIMEN (mm ³)	72000		AV. MOISTURE CONTENT (%)	25.7	BULK DENSITY (Mg/m ³)	1.727			
SHEAR STRENGTH TEST RESULTS									
TEST NO.	VERTICAL LOAD (kg)	VERTICAL NORMAL STRESS (kPa)		DIAL GAUGE READING	PROVING RING COEFFICIENT (kPa/dlv.)	SHEAR STRESS (kPa)			
1	23.60	64.31		18	1	47.96			
2	33.60	91.56		25	1	67.58			
3	43.60	118.81		30	1	80.39			
Shear stress (kPa) against Normal Stress (kPa) 									
MOISTURE CONTENT DETERMINATION									
Test No.		1		2		3		4	
Container no.		H2		M1					
Mass of wet soil + container		M ₁ (g)	120.0	116					
Mass of dry soil + container		M ₂ (g)	101.0	98					
Mass of container		M ₃ (g)	27.0	27					
Mass of moisture		(g)	(m ₁ - m ₂)	19.0		18.0			
Mass of Dry soil		(g)	(m ₂ - m ₃)	74.0		71.0			
Avg. Moisture content		(%)	$\frac{(m_1 - m_2)}{(m_2 - m_3)} \times 100$	25.7		25.4			
Sample		Depth (m)	C (kPa)	ϕ (°)		Unit Weight (kN/m ³)			
2020/0488		1.5	10.8	30.0		16.94			
N _c		N _q	N _y	Qult (kPa)=		ALLOWABLE BEARING CAPACITY (kPa)			
30.14		18.40	20.09	877.40		292.47			

Appendix A.4: Construction Loads observation checklist

S/N	ITEM	Present(Y/N)	Length	Width	Height
1.	Eucalyptus timber scaffolding				
2.	Metals for roofing				
3.	Timber for roofing				
4.	Bricks/block work				
5.	Coarse aggregate				
6.	Sand/fine aggregates				
7.	Tanks				
8.	Reinforcement				
9.	None				
10.	Others				

Appendix A.5: Materials checklist

S/ N	ITEM	TICK APPROPRIATE ANSWER						
1.	Aggregates							
A	Size(mm)	40-5	20-5	40	20	14	10	All in
B	Quarry Type	Machine	Local					
C	Rock Type	Granite	Sandstone	Basalt	Quartzite			
D	Building sand	River	Lake					
2.	Cement							
A	Cement type	CEM I	CEM II	CEM III	CEM IV	CEM V		
B	Manufacturer	Tororo	Hima	Kampala	Simba			
C	Strength	32.5N	32.5R	42.5N	42.5R	52.5N	52.5 R	
3.	Reinforcement							
A.	Size(mm)	08	10	12	16	20	25	32
4.	Shoring							
A	Material	Timber	Steel	Plastic	Others			
B	Spacing(mm)	500- <700	700-<1000	1000-1200	Others			
5.	Curing methods	Water only	Building sand	Cement bags	Polythene bags	Gunny bags		
6.	Placement method	Hoists and wheel barrows	Concrete pumps	Ramps/wheel barrows	Scaffolds/mortar pans			

Appendix A.6 Mix design data (Building Research Establishment, 1997)

1.1	Characteristic strength		25 N/mm^2	At 28 days
	Proportion defective		5%	
1.2	Standard deviation	Fig 3, no data	8 N/mm^2	
1.3	Margin	(K=1.64)	$= 1.64 \times 8$ $= 13.12 \text{ N/mm}^2$	
1.4	Target mean strength		$= 25 + 13.12$ $= 38.12 \text{ N/mm}^2$	
1.5	Cement strength class	32.5		
1.6	Aggregate type: Coarse & Fine	Crushed		
1.7	Free water/cement ratio	Table 2, Fig 4	0.54	Use lower value = 0.54
1.8	Maximum free water/cement ratio	specified	0.65	
2.1	Slump	Specified	65mm	
2.2	Maximum aggregate size	Specified	20mm	
2.3	Free-water content	Table 3	225 kg/m^3	
3.1	Cement content		$= \frac{225}{0.54}$ $= 417 \text{ kg/m}^3$	
3.2	Maximum cement content	specified		
3.3	Minimum cement content	specified	$= 275 \text{ kg/m}^3$	
		Use 3.1 if ≤ 3.2 Use 3.3 if > 3.1		$= 417$ kg/m^3

3.4	Modified free water/cement ratio			
4.1	Relative density of aggregate (SSD)		2.668	Known
4.2	Concrete density	Fig. 5	$= 2350 \text{ kg/m}^3$	
4.3	Total Aggregate content		$= 2350 - 417 - 225$ $= 1708 \text{ kg/m}^3$	
5.1	Grading of fine aggregate	Percentage passing 600 μm sieve	$= 58.28 \%$	
5.2	Percentage of fine aggregate	Fig 6	$= 38\%$	
5.3	Fine aggregate content		$= 0.38 \times 1708$ $= 649.04 \text{ kg/m}^3$	
5.4	Coarse aggregate content		$= 1708 - 649.04$ $= 1059 \text{ kg/m}^3$	
Quantities	Cement (kg)	Water (kg or litres)	Fine aggregates(kg)	Coarse Aggregates (kg)
Per m^3 (to nearest 5kg)	420	225	650	1060

Appendix A.7: Tool Calibration Data

STANDARD USED: BS EN 932-5:2000				
Tool: Load cell				
Description: 350kg capacity of Mavin brand, Model XK3190-A12/A12E.				
Nominal value	Measured value	Deviation	Tolerance	Statement of Deviation Conformity
0.00 kg	0.00	0.00	+30 kg	OK
10.00kg	10.00	0.00	+30 kg	
Tool: Dial Gauge				
Description: 25mm travel × 0.01mm divisions, Model ZHE775				
0.00 mm	0.00 mm	0.00	±0.01 mm	OK
25.00 mm	25.00 mm	0.00	±0.01 mm	
Tool: Timer				
Description: ELE Model 85-0518				
0 min	0 min	0	10±1 min	OK
10 min	10 min	0	10±1 min	

Appendix A.8: Experimental Test Programme

S/N	ITEM	DURATION
1.	Calibration of laboratory equipment	1 week
2.	Baseline survey	3 months
3.	Sampling of materials, Mix design and trial mixing and testing concrete cubes	1 month
4.	Soil testing and procurement of materials for building model	1 week
5.	Construction of the model	1.5 months
6.	Compression, workability tests during construction	2 months
7.	Deflection measurement of first floor slab from formwork and freshly cast concrete due to second floor slab	1 month
8.	Loading first floor slab with blocks	4 hours
9.	Deflection measurement of first floor slab due to block construction loads	11 days
10.	Unloading blocks	7 hours
N.B: Activities occurrence overlap each other		

Appendix A.9: Photo Gallery

 A photograph showing several concrete cube moulds arranged in a row on a wooden surface. A brick wall is visible on the left side of the frame.	 A photograph showing four electronic load indicators with red displays and white labels, connected by wires. The labels have handwritten numbers: 3, 4, 12804, and 1676.																
Concrete cube moulds	Load Indicators																
 A photograph of a KET Wizard compression machine. The digital display shows the following test execution data: <table border="1"> <thead> <tr> <th>TEST EXECUTION</th> <th>CH1</th> </tr> </thead> <tbody> <tr> <td>00359.7kN</td> <td>0015.98MPa</td> </tr> <tr> <td>0000667 N/s</td> <td>-</td> </tr> <tr> <td>28/10/2020</td> <td>10:44:04</td> </tr> </tbody> </table> Additional information on the machine includes: KET logo, SERVICE & MAINTENANCE, SER DATE: 24/06/2020, NEXT DATE: 24/06/2021, DONE BY: ERIC KALEBE, and WIZARD CONTROL.	TEST EXECUTION	CH1	00359.7kN	0015.98MPa	0000667 N/s	-	28/10/2020	10:44:04	 A photograph showing a concrete cube being crushed in a compression machine. The machine's digital display shows the following test execution data: <table border="1"> <thead> <tr> <th>TEST EXECUTION</th> <th>CH1</th> </tr> </thead> <tbody> <tr> <td>00359.7kN</td> <td>0015.98MPa</td> </tr> <tr> <td>0000667 N/s</td> <td>-</td> </tr> <tr> <td>28/10/2020</td> <td>10:44:04</td> </tr> </tbody> </table> Additional information on the machine includes: KET logo, SERVICE & MAINTENANCE, SER DATE: 24/06/2020, NEXT DATE: 24/06/2021, DONE BY: ERIC KALEBE, and WIZARD CONTROL.	TEST EXECUTION	CH1	00359.7kN	0015.98MPa	0000667 N/s	-	28/10/2020	10:44:04
TEST EXECUTION	CH1																
00359.7kN	0015.98MPa																
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TEST EXECUTION	CH1																
00359.7kN	0015.98MPa																
0000667 N/s	-																
28/10/2020	10:44:04																
Compression machine reading values	Concrete cube under crushing																

	
Researcher taking deflection values	Dial gauge
	
Ground floor	First Floor



Crack



Crack



Crack



Crack



Block course loaded onto experimental slab



Blocks loaded onto experiment slab



Construction loads; props and slab



Construction loads; timber



Load cell under prop and indicator



Experiment model before casting upper slab