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ACADEMIC YEAR 2023/2024

DEPARTMENT OF CIVIL ENGINEERING

FINAL YEAR PROJECT

ARCHITECTURAL AND STRUCTURAL DESIGN OF A BUILDING APARTMENT

CASE STUDY OF GASABO GISOZI SECTOR

Submitted in partial fulfillment of the requirements for the Award of

ADVANCED DIPLOMA

IN CONSTRUCTION TECHNOLOGY

Presented by: **BIREKE BYA BIRAGI Matthieu 202150143**

Under the guidance of: Eng MUKESHIMANA ANNONCE

Kigali, September 2024

DECLARATION

I, **BIREKE BYA BIRAGI Matthieu,** hereby declaration that this work titled **structural and architectural design of building apartment G+3** which will be located in GISOZI GASABO district is our own work, that it has not been submitted for any degree of examination in any other higher learning institution, and that all the sources we have used or quoted, have been indicated and acknowledged by complete references.

BIREKE BYA BIRAGI Matthieu

202150143

Signature……………………………

CERTIFICATION

This is to certify that the project work entitled **" Architectural and structural design of a tree storied residential building in Gisozi District"** is a work done by BIREKE BYA BIRAGI Matthieu, in partial fulfilment of the requirement for the award of advanced diploma in civil engineering department, construction technology option at ULK POLYTECHNIC INSTITUTE during the academic year 2023-2024

Date…/…./……….

Date…/…./……….

Supervisor signature……………….

H.O.D signature……………….

DEDICATION

We dedicate this work to:

Almighty God,

Our lovely parents,

Our supervisor and head of Civil Engineering Department,

ULK POLYTECHNIC staff

All our lectures,

All students of Civil Engineering in ULK POLYTECHNIC,

Our brothers and sisters,

Colleagues and friends

ACKNOWLEDGMENT

First and foremost, I would like to express my deepest gratitude to God Almighty for his endless blessings, guidance, and strength throughout this journey. Without his grace, this achievement would not have been possible.

I extent my heartfelt appreciation to my parents and family members for their unwavering love, support and encouragement. To my friends who have been a constant source of motivation and joy, thank you for your companionship and understanding.

I am sincerely grateful to the Head of the Civil Engineering department, Eng Bonaventure, for his exceptional leadership and guidance. My deepest thanks go to all the lectures who have imparted their knowledge and wisdom, shaping my academic path.

A special note of appreciation goes to my supervisor, eng MUKESHIMANA Annonce, for his invaluable guidance, support and constructive feedback throughout this project. His mentorship has been crucial to the successful completion of this work.

Special thanks to ULK Polytechnic, particularly the civil engineering department and construction Technology Options, for providing me with a strong educational foundation and nurturing environment.

Lastly, I wish to acknowledge my classmates and everyone who contributed to this project. Your collaboration, insights, and support have been invaluable throughout this process.

ABSTRACT

This project, titled "Structural and Architectural Design of a G+3 Residential Apartment in Gisozi, Rwanda," was undertaken as part of the requirements for obtaining an Advanced Diploma at ULK Polytechnic Institute. The project encompasses both architectural conception and structural design, with a strong emphasis on effective communication to all stakeholders. Each section of the project is clearly numbered to facilitate easy navigation, allowing users to quickly access specific areas of interest. The design process was informed by a wide range of references and follows the standards set out in various authoritative documents, particularly the British Standards (BS). The structural analysis began with the calculation of all expected loads, including the building's self-weight. The architectural design includes detailed plans showing the dimensions and overall shape of the building. The structural design covers critical elements such as beams, slabs, columns, stairs, and foundations, adhering to the guidelines of BS 8110-1:1997. Detailed plans and reinforcement schedules for these elements are also provided. The total cost of the building is estimated at 281,433,500 Rwf. The design criteria are primarily based on British Standards.

Structural Design Details:

1. Slab Design:

- The slab was designed with a cover of 25mm, a thickness of 15cm, and an effective depth of 12.495cm.

- Provided reinforcement: As = 20mm² with T8 bars at 250mm center-to-center spacing.

- The slab was evaluated for deflection and deemed satisfactory, with both maximum positive and negative moments being adequately resisted.

- No shear reinforcement was required, as the shear stress (0.13 N/mm²) was well below the shear capacity (0.48 N/mm²).

- Bar spacing was set at 251mm, less than the permissible spacing of 3d (373.5mm), to prevent cracking.

2. Beam Design:

- The beam was designed with a total height of 50cm, aligned with ly/15 and ly/8 requirements.

- Flange width: 133.33cm; beam height: 40cm.
- Design load: 221.52kN/m.
- Reinforcement provided: 3T16 bars (603mm²).
- Shear reinforcement was unnecessary as the shear stress (0.38 MPa) was below the shear capacity (0.443 MPa).
- Deflection criteria were met with an actual span-to-depth ratio of 8.71, well below the permissible ratio (41.6).

3. Column Design:

- The most loaded column (C-C2) was designed as a square column with dimensions of 400mm x 400mm.
- Effective heights: 2350mm along the major axis, 2391mm along the minor axis.
- The column was classified as a braced short column.
- Reinforcement provided: 4T16 (804mm²) with 10mm diameter bars spaced at 300mm.
- Stirrups: 8mm diameter bars.

4. Footing Design:

- The footing was designed for a soil bearing capacity of 300 kN/m².
- Serviceability load: 476.54 kN; ultimate load: 740.68 kN.
- A square footing of 2.5m x 2.5m was selected, keeping the design stress within the soil's bearing capacity.
- Footing depth: 600mm to resist punching shear.
- Reinforcement spacing: 335mm.

5. Stair Design:

- The stair was designed for a height of 3000mm between the ground and first floors, with a flight length of 3m at an angle of 30.96°.

- The design included 20 risers and 19 goings, each 300mm in dimension.
- Landing reinforcement: 8T12 (901mm^2); no shear reinforcement was required.
- Span-to-depth ratios were within permissible limits, and 2T16 (226mm^2) reinforcement was provided for the flight.
- Moment for the flight: 13.28 kNm.

This detailed overview covers both the architectural and structural aspects of the project, ensuring compliance with design standards while contributing to the growth of Gisozi's urban landscape.

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LIST OF ABREVIATIONS

CAD : Computer-Aided Design

GIS : Geographical Information System

PPC : Portland Pozzolan

ACI : American Concrete Institute

Mpa : Mega-pascal

AIA: American Institute of Architects

ICC: International Code Council

ASCE: American Society of Civil Engineers

RC: Reinforced Concrete

LRFD: Load and Resistance Factor Design

LSD: Limit State Design

ULS: Ultimate Limit State

SLS: Serviceability limit state

FEM: Finite Element Method

ly: Long span of the slab

lx: short span of the slab

d : slab thickness

h0 : slab Effective height

GK: Characteristic Dead load

QK: Characteristic live load

w_c: Self-weight of the slab

γ_c: unit weight of concrete

b: breath of slab

q: self-weight of slab

BS: British-Standard

n: design

M: moment

M_{sx} : moment about x-axis

M_{sy}: moment about y-axis

β_{sx}: moment coefficient about x-axis

β_{sy}: moment coefficient about y-axis

F: Ultimate Force

L: Effective span

β_{vx}: shear force coefficient about x-axis

β_{vy}: shear force coefficient about y-axis

MRC: Moment of Resistance of Concrete

f_{cu}: compressive strength of concrete

A_s: Area of steel

K: lever arm factor

Z: lever arm

K_{bal}: design lever arm

As req: Area of steel Required

As prov: Area of steel provided

mm: millimeter

m: meter

cm: centimeter

kn: Kilo-Newtown

N: Newtown

mm2: millimeter square

m2: meter square

cm2: centimeter square

m3: cubic meter

S max: maximum spacing

D: diameter

π: pi

min: minimum

max: maximum

As min: Area of steel minimum

As max: Area of steel maximum

V: shear stress

Uc: shesr capacity

fy: yield strength of reinforcement

bw: web width

MF: Modification Factor

fs: the design

ht: total height

%: percent

W: Uniformly distributed load

F: Design load per span

Φ: diameter

L0: Unbraced length of column

Le: Effective length of column

β: coefficient referred to slenderness ratio

LL: live load

N: Newtown

Ac: Cross-sectional Area

V: Ultimate shear force

T: tear

R: rise

QTO: Quantity Take-Off

UCM: Unit Cost Method

G: Going

C/C: center to center

λ: slenderness ratio

a: side of column

pu: Ultimate pressure

B and L: footing dimensions

$\sum M$: sum of moment

RCD: Reinforced Concrete Design

AS': Area of steel in compression

Chapter One: GENERAL INTRODUCTION

1.1. Background of the study

Kigali, the vibrant capital of Rwanda, is at the heart of the nation's rapid urbanization and economic growth. As the primary city, it plays a crucial role in Rwanda's vision of becoming a middle-income country by 2035 and a high-income country by 2050. The urbanization rate in Kigali has led to increased demand for housing, particularly residential apartments, which has become a critical area of study for urban development and planning.

Rwanda is about 13 million people but is projected to surpass 20 million in 2042 and 30 million 2076, the population growth rate is about 2, 58 % over a year. In the past and currently, land scarcity and population growth have been the subject of extensive debate in the development of Rwanda.

Rwanda has been well known for having one of the highest population densities in Africa, with at the same time scarce natural resources, primarily land. Rwanda's high population growth has put a high demand in many living domains such as water provision, food provision, and electricity repartition but also in infrastructure; Population's growth is one of the most development brakes for every country in the actual world. Living places start being rare and more and more expensive (Imasiku & Ntagwirumugara, 2019).

Rwanda is a country with an area of 26,338km2 and it has one of the highest population densities in Africa with 525 habitants per square kilometer; as clearly identified based on the population density there is shortage in land and is now needed to use the space economically; constructions should be erected on small areas but with many floors allowing availability of large area of use on

small land surfaces. The city of Kigali is the capital of the country and by that the most populated and most visited city of the country. Kigali the city most affected by population growth; with population on a rapid increase; the City of Kigali is fast becoming one of the most

densely populated cities in Africa with an area of730 km2 with 1,745,555inhabitants, the city has a density
2,391 inhabitants per km2, in the term of shortage in land in Rwanda it's the most affected city in the country (Manirakiza, et al., 2020).

Kigali's population has been growing at an impressive rate, with current estimates exceeding 1.2 million residents. This growth is spurred by rural-to-urban migration, a burgeoning middle class, and youthful demographic seeking better economic opportunities. Consequently, the demand for residential apartments has escalated, necessitating innovative and sustainable housing solutions.

1.2. Problem Statement

According to the population density of Rwanda, there is a scarcity of land. However, the capital city of Kigali is now known to be one of the cleanest and fastest growing cities in Africa in terms of economic opportunities and infrastructure development, and its citizens have seen relative
Improvements in their socioeconomic conditions, education, and health. Kigali, like other Rwandan cities, is characterized by rapid urbanization, scarcity of land, strict construction regulations, and an intensity of unplanned settlements. As a result, uncontrolled urban sprawl has occurred, affecting the distribution of quality basic amenities. (Manirakiza, et al., 2020).The growing urban population in Kigali, Rwanda, has led to increased demand for affordable and sustainable housing solutions. The current housing infrastructure is insufficient to meet this demand, resulting in overcrowding and inadequate living conditions. This project aims to address this issue by designing and constructing a three-story residential apartment building that adheres to modern architectural standards, local regulations, and sustainable building practices. In order to provide safe, comfortable, and affordable living spaces that can serve as a model for future residential developments in Kigali.

1.3 Research objectives

1.3.1 General objectives

The primary objective of this study was to provide a comprehensive architectural and structural design for a three-story apartment building located in Kigali City, precisely within the Gasabo District and Gisozi sector.

1.3.2. Specific objectives

To achieve the main objective of this project, the following specific objectives were laid out:

-To provide architectural drawings of the apartment building

-To conduct the structural design of the apartment building

-To provide the cost of the apartment.

1.4. Research question

-what strategies can be employed to optimize space utilization within the apartment units while ensuring comfort and livability?

-How could the structural design of the three-story apartment building be done to ensure safety, stability, and functionality?

-What could be the estimated cost associated with implementing the proposed architectural and structural design?

1.5.Significance of the study

1.5.1. Personal benefits

Participating in this study provided a practical opportunity to apply theoretical knowledge gained during my course to a real-world project, provided a chance to enhance my civil engineering knowledge, with a special emphasis on reinforced concrete design which is one of its core focal points, it improves my research skills through the investigation of best practices, materials, and technologies relevant to my project.

1.5.2. Academic& Scientific benefits

The findings of this study have the potential to serve as a foundational reference and guiding framework for future researchers and scholars.

1.5.3. Socio-economic benefits

By designing cost effective residential apartments, the project can help address the housing more affordable for low-land middle-income families

Provides a chance to contribute to addressing the housing needs in Kigali, potentially improving living conditions for residents.

A construction projects often have a multiplier effect on the local economy by stimulating demand for materials, service and goods.

The construction phase of the project will creates jobs for local workers, from laborers to skilled tradespeople and professionals.

1.6. Methodology

To achieve our objectives, a combination of well-thought-out methods and processes was employed, contributing to the comprehensive completion of our work:

Firstly, the architectural layout plan of the building was meticulously crafted using the advanced capabilities of computer-aided design, specifically utilizing graphisoft's archicad 24, this technology not only enhanced precision but also allowed us to visualize and iterate upon the architectural concepts effectively. Secondly, for the rigorous analysis and design of the building's structure, we were guided by the British Standard code; this established set of regulations and practices ensured that our structural considerations aligned with internationally recognized standards, enhancing the safety and durability of the proposed building; we have manually designed the structural components, ensuring that every element was optimized for functionality and strength; after that we used methods as quantity takeoff, unit cost method and bottom up estimating to evaluate the cost of the building; finally, we combined our work in a full report with all the references. This report contains every stage of our work, from the architectural sketches, the structural design to the cost and estimation of the overall project. The final report was presented as part of a final-year project.

1.6.1. Architectural Design

1.6.1.1. Architectural Layout Plan

Software Utilization:

The architectural layout plan of the building was meticulously crafted using the advanced capabilities of Graphisoft's ArchiCAD 24. This software enhanced precision and allowed us to visualize and iterate upon the architectural concepts effectively.

1.6.1.2. Concept Development :

Initial design concepts were developed based on site analysis, local housing needs, and aesthetic considerations. Multiple design options were created and refined through iterative feedback.

1.6.1.3. Detailed Drawings:

Detailed architectural drawings, including floor plans, elevations, and 3D renderings, were produced to ensure a comprehensive visualization of the building.

1.6.2. Structural Design

1.6.2.1. Guiding Standards:

For the rigorous analysis and design of the building's structure, we were guided by the British Standard Code (BS). This established set of regulations and practices ensured that our structural considerations aligned with internationally recognized standards, enhancing the safety and durability of the proposed building.

1.6.2.2. Manual Design:

We manually designed the structural components, ensuring that every element was optimized for functionality and strength. This included calculations for load-bearing elements such as foundations, beams, columns, and slabs.

1.6.3. Cost Estimation

1.6.3.1. Quantity Takeoff:

An accurate quantity takeoff was conducted to determine the materials required for the construction of the building. This process involved measuring the quantities of each material needed based on the detailed drawings.

1.6.3.2. Unit Cost Method:

The unit cost method was employed to estimate the cost of each material and labor component. This involved determining the cost per unit of measure (e.g., per square meter) for each construction activity.

1.6.3.3. Bottom-Up Estimating:

Bottom-up estimating was used to compile detailed cost estimates from the lowest level of work packages to the overall project cost. This method ensured a thorough and accurate budget estimate.

1.7. Organization of the study

This research was structured into five chapters, each contributing a distinct dimension to the study. In Chapter 1, the general introduction established a solid foundation, introducing key components such as the research's background context, problem statement, objectives, scope, benefits, significance, chosen methodology, and a roadmap outlining the report's organization. Chapter 2 delved into the literature review, elucidating vital terminologies and delving into pertinent theories that intricately connected to the research's subject matter. Chapter 3 provided an insightful methodology, outlining the study area and detailing the approach undertaken for a successful study completion. In Chapter 4, the discussion and results section offered a comprehensive analysis of calculations, theories, and intricate details regarding the structural and architectural design, as well as cost and estimation considerations for the apartment building. Thissection highlighted the synergistic relationship between these aspects, integral to the holistic evolution of the building's design. Finally, Chapter 5 encapsulated the conclusion and recommendations, presenting a synthesized ending and forward-looking insights that aligned withthe research's central theme

CHAPTER TWO. LITERATURE REVIEW

2.1 Reinforced Concrete

Reinforced concrete is an essential material in modern construction, renowned for its strength and versatility. As we plan the design of a multistory apartment building, it is critical to comprehend the fundamental aspects of reinforced concrete, including its strength and composition. Reinforced concrete is a composite material that combines concrete and steel reinforcement to enhance its durability and strength. Concrete offers high compressive strength, while the embedded steel provides tensile strength, making reinforced concrete suitable for a wide range of structural applications. This technique, first patented by Joseph Monier in 1867, saw extensive adoption in the early 20th century and is now prevalent in the construction of buildings, bridges, dams, and other infrastructures due to its capacity to withstand heavy loads and harsh conditions (Neville & Brooks, 2010).

2.2 Reinforced Concrete Composition

Reinforced concrete is composed of two main components: concrete and steel reinforcements.

2.2.1. Concrete

Concrete is a composite material consisting of a mixture of aggregates (sand, gravel, crushed rocks) held together by a binder of cement and water. Occasionally, admixtures are added to modify certain properties of the concrete, such as workability, durability, and hardening time. While concrete exhibits high compressive strength, it has low tensile strength, which is why it is often reinforced with steel (Mindess, Young, & Darwin, 2003).

2.2.2. Cement

Cement acts as a binding agent in concrete, enabling the aggregates to form a compact and durable mass. It is produced by grinding clinker, created by calcining raw materials primarily composed of lime (CaO), silica (SiO_2), alumina (Al_2O_3), and iron oxides (Fe_2O_3). With a standard density of 1440 kg/m³, cement was pioneered by Joseph Aspdin in the UK in 1824 (Lea, 1971). Cement can be classified into two types: hydraulic and non-hydraulic. Hydraulic cement, which sets and hardens through a reaction with water, is suitable for wet conditions and underwater applications. Non-hydraulic cement, on the other hand, requires drying and reacts with carbon dioxide in the air to set (Hewlett, 2004).

When cement is combined with fine aggregates such as sand, it forms mortar for masonry. When mixed with both sand and gravel, it produces concrete. Hydraulic cement is particularly valued for its ability to set in damp environments and underwater, providing durability and resistance to chemical attacks (Taylor, 1997)

2.2.3. Aggregates

Aggregates are granular materials such as sand, gravel, and crushed stone that provide volume, stability, and strength to concrete. They are categorized based on size: fine aggregates (particles smaller than 4.75 mm) and coarse aggregates (particles larger than 4.75 mm). Fine aggregates, often referred to as sand, improve the workability and finishability of concrete, while coarse aggregates contribute to the concrete's strength and structural integrity (Kosmatka, Kerkhoff, & Panarese, 2002).

Fine aggregates are typically natural sand, which can be obtained through mining processes or from crushed stone or sandy materials. Coarse aggregates consist of larger particles and are sourced from materials such as river gravel and stone particles obtained from rock formations. The properties of aggregates, including size, shape, and texture, significantly influence the quality and performance of the concrete mix (Mehta & Monteiro, 2014).

Aggregates are critical in providing the necessary bulk and strength to concrete. They help control shrinkage and expansion, enhance durability, and reduce the overall cost of the concrete by minimizing the amount of cement required (Mindess, Young, & Darwin, 2003).

The table 1 illustrates the classification of aggregates by size and their common uses.

Tableau 2.1 ; Aggregates classification by size and common use (Kemper & Chepil, 1965)

Aggregate Size Range	Type of Aggregate	Common Uses
Coarse Aggregates		
> 19 mm	Crushed Stone (19-25mm)	Concrete production, road base, Drainage
	Crushed Stone (25-38mm)	Concrete production, road base, Drainage
9.5 mm - 19 mm	Gravel (9.5-12.5mm)	Concrete production, road construction, Drainage
	Gravel (12.5-19mm)	Concrete production, road construction, Drainage
4.75 mm - 9.5 mm	Gravel (4.75-6.35mm)	Concrete production, road construction, drainage
	Gravel (6.35-9.5mm)	Concrete production, road construction, Drainage
Fine Aggregates		
2.36 mm - 4.75 mm	Fine Sand (2.36-2.95mm)	Concrete production, mortar, plaster, bedding material
	Fine Sand (2.95-4.75mm)	Concrete production, mortar, plaster, bedding material
0.075 mm - 2.36 mm	Medium Sand (0.075-1mm)	Concrete production, mortar, plaster,

		bedding material
	Fine Sand (1-2.36mm)	Concrete production, mortar, plaster, bedding material
< 0.075 mm	Fine Sand (0.075mm)	Concrete production, mortar, plaster, bedding material

2.2.4. Admixture

Admixture An admixture is a material added to concrete to alter or enhance its properties. These substances are incorporated into the concrete mix along with cement, water, and aggregates, usually just before or during the mixing process. Admixtures can lower the cost of concrete construction or ensure specific desired qualities in the hardened concrete. They also serve as an emergency measure to mitigate issues that arise during the construction process (Mehta & Monteiro, 2014).

2.2.5. Water

Water in concrete is used to initiate the chemical reaction known as hydration with the cement, which results in the setting and hardening of the concrete. It also helps in achieving the desired workability and consistency of the concrete mix during the placement and finishing processes. Additionally, proper curing with water is essential to maintain moisture in the concrete for continued hydration and strength gain over time (Mehta & Monteiro, 2014).

2.2.6. Reinforcements

Steel reinforcements, commonly known as rebar (short for reinforcing bar), are essential components in reinforced concrete structures. Concrete has high compressive strength but is weak in tension. To address this limitation, rebar is embedded within the concrete to provide tensile strength and enhance overall structural performance. Typically made from carbon steel, rebar comes in various shapes, including round and deformed bars, to provide mechanical anchorage to the concrete. These reinforcements are strategically placed according to engineering design and detailing to resist tensile stresses and prevent cracking or failure (Gambhir, 2014).

The combination of concrete and rebar forms a composite material that possesses superior strength and ductility, allowing the structure to bear loads efficiently and resist deformations under various conditions. In engineering practice, steel reinforcements are crucial for ensuring the structural integrity, durability, and safety of buildings, bridges, dams, and other critical infrastructure projects (Mindess, Young, & Darwin, 2014).

2.2.7. Reinforced Concrete Properties

- **Compressive Strength**

Concrete's compressive strength (fc) is its capacity to resist compression or squeezing forces before failure. This property is determined through compression tests on concrete specimens and is influenced by factors such as the water-cement ratio, cement type, aggregate characteristics, and curing conditions. Engineers use compressive strength to design concrete mixes for specific applications, ensuring that the strength meets the required specifications. Regular testing is crucial for quality control in construction to ensure performance and structural safety (Neville, 2011).

- **Tensile Strength**

Concrete alone has low tensile strength, making it prone to cracking under tensile forces. Incorporating steel reinforcements significantly enhances the tensile strength of reinforced concrete (RC), as the steel bars or mesh resist stretching forces, thereby improving overall structural performance (Mehta & Monteiro, 2014).

- **Flexural Strength**

The synergy between concrete's compressive strength and steel reinforcements' tensile strength results in high flexural strength. This property allows RC members, such as beams and slabs, to withstand bending forces and effectively distribute loads (Kosmatka & Wilson, 2016).

- **Creep**

Creep refers to the time-dependent deformation of concrete under sustained load. This phenomenon occurs due to the ongoing hydration process within the concrete's microstructure, leading to gradual deformation under constant compressive stress. Factors influencing creep include stress level, temperature, humidity, and mix proportions. Creep is particularly significant in high-strength concrete and can occur over periods ranging from weeks to years. Engineers must consider creep in the design of long-term structures subjected to sustained loads to ensure structural integrity and safety throughout their service life (ACI Committee 209, 2014).

- **Ductility**

Reinforced concrete exhibits good ductility, meaning it can undergo significant deformation before failure. This property is crucial in earthquake-prone regions, as it allows structures to absorb and dissipate energy during seismic events, enhancing their ability to withstand earthquakes (Mehta & Monteiro, 2014).

- **Durability**

Reinforced concrete structures are renowned for their durability and long service life. Concrete's resistance to weathering and chemical attacks, combined with the protective role of steel reinforcements against corrosion, ensures long-term structural integrity (Kosmatka & Wilson, 2016).

Tableau 2.2 : Concrete and Steel Property (Neville, 1995:

	CONCRETE	**STEEL**
Strength in tension	Poor	Good
Strength in compression	Good	Good but not for slender bars
Strength in shear	Fair	Good
Durability	Good	Good but corrodes if Unprotected
Fire resistance	Good	Poor for high temperature

2.2.8. Architectural design of apartment

2.2.8.1. Introduction

An apartment is a self-contained housing unit that takes up only a portion of a building for human habitation. Apartment buildings are known by numerous names in different countries, such as an apartment building, apartment house, block of flats, tower block, or high-rise, especially if they include a large number of rentable units. Buildings serve several functions, one of which is to offer healthy and comfortable surroundings for human activity. A structure must offer floor area, room volume, shelter, light, and facilities for working, living, learning, curing, and processing, among other things. Furthermore, the structure must provide a healthy and comfortable inside environment for those who use it (Sreeshna, 2016).

2.2.8.2. Essential building elements with standard dimension

Floor area shall mean usable covered area of a building at any floor level. The floor area shall be determined on the basis of plan dimensions between wall surfaces without finishes, and shall not include any area occupied by built in cupboards, wardrobes, cabinets or any dividing wall (Allen & Iano, 2014)

2.2.8.3. Room sizing

In the context of the Apartment Space Standards documents, the term "minimum" signifies that if any measurement or dimension falls below this specified minimum value, we are likely to raise

concerns or objections regarding a planning application. On the other hand, when the phrase "at least" is employed, we will consider dimensions or provisions that are slightly smaller than what is specifically defined. We will provide comments or objections based on the significance of the deviation and the frequency of such instances. (Measurements are expressed in square meters, and the numbers indicate either minimum required areas or recommended ranges of dimensions for various room sizes) (Panero & Zelnik, 1979)

-Living room: 11-18.6 m²

-Kitchen: 5.5-9.8 m²

-Double bedroom: 10-11 m²

-Single bedroom 6.5 m²

-Living rooms should have a minimum width of 3.2 meters;

Double/twin bedrooms should have a minimum width of 2meters; Single bedrooms should have a minimum width of 2 meters (Panero & Zelnik, 1979)

All bedrooms should have a minimum length of 3 meters at the planning application stage; applicants should provide details of proposed overall floor space and a breakdown of room sizes. Bedroom numbers are based on all being single bedrooms except for where one single can make up the number of bed spaces required. If more single bedrooms are used to make up number then the minimum overall space required will be increased (Allen & Iano, 2014).

2.2.8.4. Corridors spacing

Corridor should be not less than 120cm wide so that wheelchair users can position themselves to opened door in the end wall of a corridor or at the side (Panero & Zelnik, 1979).

2.2.8.5. Size for windows and doors

Every work area needs a window leading to the outside world. The window area which transmits light must be at least 1/20 of the surface area of the floor in the work space. The total width of all the windows must amount to at least 1/10 of the total width of all the walls. Height of the windowbreast from the ground is greater or equal to 0.9m. The total height of all windows must be 50% of the width of room. The minimum inside width of a door opening is 70cm. Disabled persons have special requirements. The minimum convenient door width for the ambulant disabled is 80cm. This is too narrow for wheelchair users, but 90cm is usually adequate. Door opening height at least 185cm, but normally 195-200cm (Allen & Iano, 2014) .

2.2.8.6. Full bathroom dimensions

Bath/shower combination with toilet and sink: 1.4m x 2.4m

This is based on the minimum size of the bath so if you're going for a bigger bath the 1.4m side ofthis bathroom will change slightly (Panero & Zelnik, 1979).

2.2.8.7. Exit ways

Exit ways are the important components in building which should be designed in the safe way andfor firefighting because they provide security for occupants. They are some kinds of exit ways such as staircases, ramps and lifts. Stairs governed by building regulations must have a width of 1.0m and a ratio of 17/28 (Rise to Tread) (Ching & Winkel, 2012)

2.2.8.8. General Requirements of good architectural design

Architectural is the process and product of planning, designing and construction. It has to do with the planning, designing and constructing form, space and ambience that reflect functional, technical, social, economic, environment, and aesthetic consideration. The buildings must benefits from an integrated design approach that focuses on meeting a list of requirement. Building can be more effective, exciting places to work, learn, and live by encouraging adaptability, improving comfort, supporting sense community, and by providing connection to the natural environment, natural light and view (Iyengar, 2015)

2.2.8.9. Importance of architectural drawing to structural design

Architectural drawings are the foundations of building designs and play an important part in transforming a concept into a viable structure. As a result, they provide a wealth of information to the structural designer, such as measurements, structure framing, and trial sections, particularly for roof structures and foundations. They also supply the nature and kind of materials for the structural designer's early stage of design. Other goals include developing design ideas into a logical proposal, communicating ideas and concepts, convincing clients of the design's advantages, allowing a construction contractor to construct it, and serving as a record of the completed work (McGuire & Schiffer, 1983)

Applicable load on the building

The loads are the forces that act on a structure they belong to one of two broad categories dead loads and live loads.

2.2.8.10. Dead load

Dead loads are those that are permanent, including the weight of structure itself. dead loads in a building include the weight of non structural components such as floor coverings, partitions and suspended ceilings. All the loads mentioned thus far are forces resulting from gravity and are referred to as gravity (Smith, 2016)

2.2.8.11. Live load

Live load on a structure refers to the temporary and variable loads caused by people, furniture, equipment, vehicles, and other dynamic factors. Unlike permanent dead loads, live loads are transient and can change over time. Engineers consider live loads during structural design to ensure the safety and capacity of the structure to support these varying loads during its use (Smith, 2016).

2.2.9. RC Design methods

A reinforced concrete structure should be designed to satisfy the following criteria:

- ✓ Adequate safety, in items stiffness and durability
- ✓ Reasonable economy

2.2.9.1. Load and Resistance Factor Design (LRFD)

Load and Resistance Factor Design is a structural design method widely used in the US. It involves factoring both the loads and material strengths to account for uncertainties and ensure safety. Load factors are applied to different load types, while resistance factors are applied to material strengths. This provides a margin of safety and allows for more economical designs without compromising structural integrity. LRFD is recognized for its reliability and precision in engineering, making it a preferred approach for reinforced concrete and other materials. (Galambos & Ravindra, 1981)

2.2.9.2. Working stress Method (WSM)

The Working Stress Method (WSM) is a conventional design approach for reinforced concrete structures. It assumes that concrete and steel behave linearly elastically within their proportional limits. The method involves calculating working stresses in concrete and steel under applied loads and comparing them to allowable stresses. If the working stresses are within permissible limits, the design is considered safe. However, WSM has limitations, as it does not account for non- linear behavior at ultimate loads or variations in material properties. Modern design methods like the Limit State Method and Load and Resistance Factor Design (LRFD) provide more reliable and efficient alternatives to WSM in structural engineering practice. (Korabu, 2006)

2.2.9.3. Limit State Method (LSM)

Limit State Method (LSM) involves considering two distinct limit states: the Ultimate Limit State (ULS) and the Serviceability Limit State (SLS).

2.2.9.4. Ultimate Limit State (ULS)

At the ULS, the structure is approaching failure or collapse. The Limit state method ensures that the structure can safely resist the maximum loads it may encounter without reaching failure. This involves analyzing various load combinations, such as dead loads, live loads, wind loads, and earthquake loads, to assess the structure's strength and stability. Safety factors are applied to these loads and material strengths to provide a margin of safety against failure. (Korabu, 2006)

2.2.9.5. Serviceability Limit State (SLS)

At the SLS, the structure is still functional and safe, but excessive deflections, cracking, or other serviceability issues may occur. The Limit state method ensures that the structure performs adequately under normal service conditions. It considers factors like deflection limits, vibration, and other serviceability criteria to ensure user comfort and functionality. (Korabu, 2006)

2.2.9.6.Load combination

Load combinations refer to prescribed sets of various load types applied to a structure to assess its safety and performance comprehensively. The goal of load combinations is to consider the simultaneous effects of different loads, such as dead loads, live loads, wind loads, earthquake loads, and others, to ensure that the structure can withstand the most critical and severe loading conditions it may encounter during its service life. These combinations are defined by engineering standards and codes, incorporating specific load factors and safety margins to account for uncertainties and material variations. (Troxell & Davis, 1968)

2.2.10. Reinforced concrete elements

2.2.10.1. Beams

Beams are horizontal members that bear vertical loads and withstand bending and shear. The design must adhere to the ultimate and serviceability limits. The following is the basic approach to be followed: preliminary analysis and member size, load estimation (with an arrangement to give maximum moment); full analysis and design of reinforcing serviceability calculations. The beam segment might be single or double reinforced (Mosley & Bungey, 1990)

2.2.10.2. Slab

Slab is an important structural element which is constructed to create flat and useful surfaces such as floors, roofs, and ceilings. It is a horizontal structural component, with top and bottom surfaces parallel or near so. Commonly, slabs are supported by beams, columns (concrete or steel), walls, or the ground. The depth of a concrete slab floor is very small compared to its span (Smith, 2016).

Slabs are classified according to the method of support as follows:

i. **Simply Supported Slabs**: In simply supported slabs, the slabs are supported at their two opposite ends by beams or walls. The support creates a clear span between the supports, and the slab remains free to move vertically at the supports. Simply supported slabs are commonly used in single-span applications and are efficient for smaller spans. (Smith, 2016)

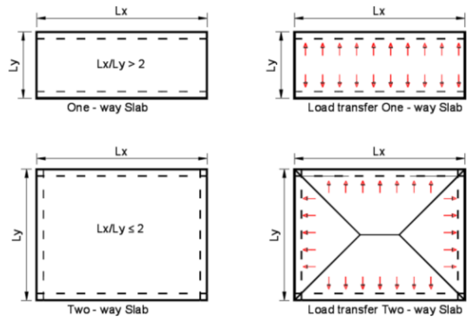
ii. **Continuous Slabs**: Continuous slabs are those that are supported over multiple spans by beams or walls. In this configuration, the slab is continuous across more than two supports, and the moments and shears are distributed along the entire length of the slab. Continuous slabs are advantageous for larger spans and provide enhanced load-carrying capacity and stiffness compared to simply supported slabs. (Smith, 2016)

Slabs are classified according to how loads are distributed and transferred within the slab structure as follows:

i. **One-Way Slab**: A one-way slab is a type of reinforced concrete slab where the main reinforcement bars (also known as the "longitudinal bars" or "main bars") are provided in one direction only. The slab is supported on two opposite sides by beams or walls, and the loads are mainly carried in one direction along the span of the slab. The main reinforcement is placed in the direction perpendicular to the supports, ensuring the slab's strength to resist bending and shear forces along this direction. One-way slabs are commonly used in narrow strip-like structures or buildings where the span along one direction significantly exceeds the span along the other direction (Mosley & Bungey, 1990).

In one way slab, the ratio of longer span (l) to shorter span (b) is equal or greater than 2, i.e longerspan (l)/Shorter span (b) ≥ 2

ii. **Two-Way Slab**: A two-way slab is a reinforced concrete slab where the main reinforcement bars are provided in both directions, perpendicular to each other. This arrangement of reinforcement allows the slab to efficiently distribute and transfer loads in two directions, both along the length and width of the slab. The slab is supported on all four sides by beams or walls, and the loads are evenly distributed across the entire surface. Two-way slabs are widely used in regular floor systems of buildings, as they provide better load-carrying capacity and stiffness compared to one- way slabs. They are suitable for larger and more evenly distributed loads, offering a versatile and efficient solution for a wide range of structural applications (Mosley & Bungey, 1990).



In two way slab, the ratio of longer span (l) to shorter span (b) is less than 2; i.e. Longer span (l)/Shorter span (b) < 2

Figure 2.1 : One way and two way slab load transfer and differences **(Wang & Salomon, 1979)**

Columns are vertical load-bearing elements that play a crucial role in supporting the weight of a building or structure and transferring these loads to the foundation. They are designed to withstand compressive forces and bending moments generated by the loads from the superstructure (Elwood & Eberhard, 2009).

In the analysis it is necessary to classify the column into one of the following types:

i. Short columns

Short columns are structural columns with a small slenderness ratio (lex/h or lex/b). Their compact nature allows them to primarily resist loads through direct compressive strength, and they are less prone to buckling (Elwood & Eberhard, 2009).

ii. Slender columns

Slender columns are characterized by a high slenderness ratio (lex/h or lex/b). They are tall and slender, making them more susceptible to buckling and lateral instability under compressive loads(Elwood & Eberhard, 2009).

iii. Braced columns

Braced columns are structural columns that are supported and reinforced by walls or other forms of bracing to resist lateral loads. They are designed to provide stability and prevent lateral buckling or deformation under applied loads. The bracing system enhances the column's ability to withstand horizontal forces, such as wind or seismic loads, effectively transferring these loads to the foundation. Braced columns play a critical role in providing lateral stability to buildings and other structures, ensuring their safety and performance. (Elwood & Eberhard, 2009).

iv. Unbraced columns

Unbraced columns are structural columns that do not have lateral support from walls or bracing. They rely solely on their bending capacity to resist lateral loads, making them more susceptible to buckling and lateral deformation. Unbraced columns are primarily found in structures where lateral stability is achieved through other means, such as the overall building configuration or other lateral load-resisting systems. (Elwood & Eberhard, 2009).

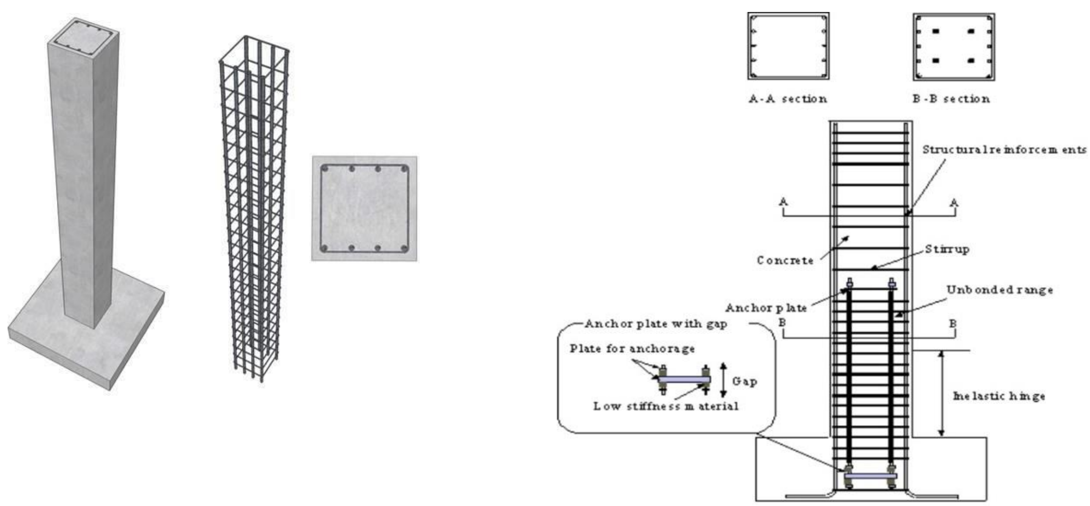


Figure 2.2 : Reinforced concrete column

(Elwood & Eberhard, 2009).

2.2.10.3. Stair

Stair is a part of a building that provides ascending or descending route of travel formed by a single flight or by a combination of two or more flights and one or more intervening landings a stair comprises the following parts risers, treads or going, landing, waist, upper and lower connecting structure and rails we distinguish several types of stairs: straight run stair, spiral with newel stair, circular stair (Gambhir, 2008) .

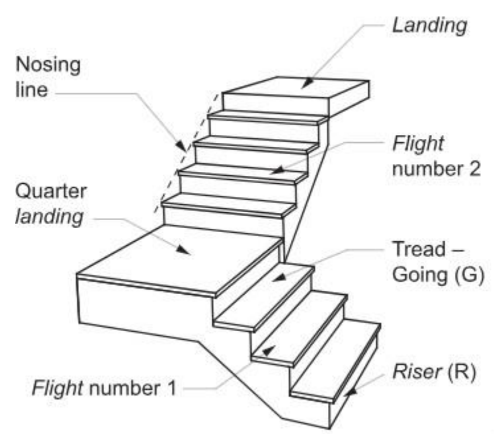


Figure 2.3 : Stair components (Gambhir, 2008)

2.2.10.4. Foundation

Foundation is the lower part of the building usually located below the ground level which transmit the load of the super structure to the soil The foundations transfer and spread the loads from a structure's columns and walls into the ground. In the design of the foundations, the areas of the bases in contact with the ground should be such that the safe bearing pressures will not be exceeded Settlement takes place during the working life of the structure, therefore the design loading to be considered when calculating the base areas should be those that apply to the serviceability limit state (Varghese, 2009) .

Various foundation types cater to diverse construction needs. Strip footings support walls, pad footings hold point loads, and raft foundations distribute weight across expansive slabs. Pile foundations drive columns deep into stable soil, while pier foundations offer sturdy support. Caisson foundations suit bridges, isolated footings uphold single points, and combined footings assist multiple nearby columns. Strap footings merge techniques for shared loads, mat foundations handle heavy loads and poor soil, and slab-on-grade foundations combine floors and support. Raft-slab foundations spread loads, grade beam foundations bolster walls, and deep foundations transfer weight downward, encompassing piles, piers, and caissons (Varghese, 2009).

CHAPTER THREE. MATERIALS AND METHODS

3.1 Introduction

This chapter outlines the methodology employed to achieve the research objectives. To gather all necessary information, various data collection techniques were utilized, including documentation and sourcing data form different origins. Additionally, British standards were applied for designing various structural elements, and multiple cost estimation methods were employed to determine the overall project cost. Each of these methods is discussed in detail in this chapter

3.2 Description of the study area

The study has been carried out in Kigali city, Gasabo district, Gisozi sector.

In the illustration below, the focus is directed towards the Gisozi sector, the designated study area characterized by its distinctive features, with a prominent emphasis placed on the intended building location, clearly demarcated by a conspicuous red square that serves to highlight its significance within the broader context.

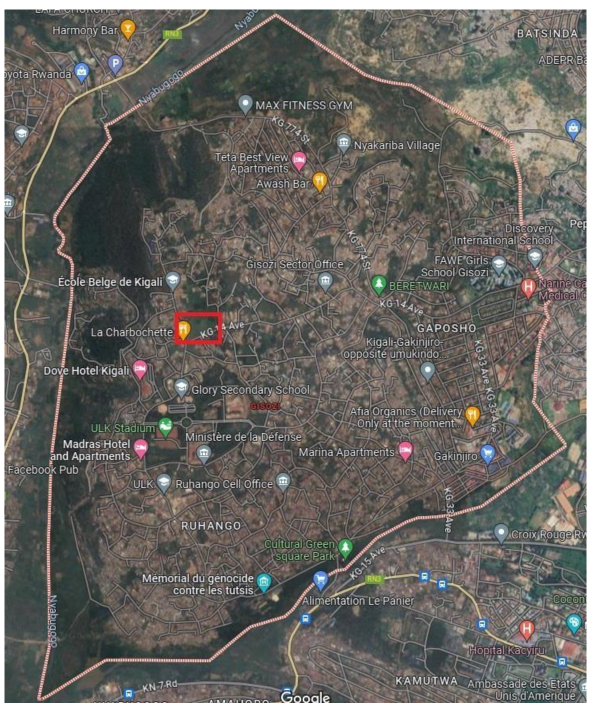


Figure 3.4 : Gisozi sector map

The illustrative representation presented in the figure below offers a detailed insight into the designated area for the building's location, with a specific focus on the intended building space elegantly demarcated by a prominent white square.

Figure3. 5 : **location map**

3.3 Architectural design

Following careful evaluation of all building criteria, comprehensive architectural plans were methodically developed to guarantee that the finished structure not only serves its intended purpose but also has a visually appealing and aesthetically harmonious design. These designs were rigorously generated using archicad software, allowing for a smooth and fast design process. Architects were able to digitally model the building using archicad, properly expressing its spatial layout, structural features, and aesthetic appearance, ensuring a thorough and exact depiction of the envisioned construction. The architectural drawings functioned as a critical medium to communicate the design objective, supporting productive cooperation with clients, engineers, and other stakeholders engaged in the building process through the careful blending of functional features and artistic sensibility.

3.4 Structural design

Multi-storied structures commonly feature prismatic sections, prevalent in developing countries, to effectively resist applied loads with minimal deformation between parts. The primary goal of structural design is to ensure the structure safely receives and transmits loads, while also achieving functionality, serviceability, feasibility, and aesthetics. The design process aims to make the structural elements efficient, elegant, and economical, considering both safety and economy. Reinforced concrete finds extensive use in various structures, such as bridges, buildings, tunnels, and more, due to its versatility, durability, fire resistance, and moldability. The design principles discussed here are applicable to any structure, provided information on axial force, shear, and moments along each member's length is available. For our multistory building, the design involves elements like slabs, beams, columns, and footings, combining them cohesively. By adhering to good construction practices, concrete proves to be a crucial and reliable building material.

2.2.11. Slab design

3.4.2. Code used in design

Tableau 3.3 : BS 8110-1997 : design of concrete structure

Types	Descriptions
BS 8110-1997 : the structural use of concrete(British standard) Relevant Building Regulations and Design Code	Relevant Building Regulations and Design Code
1. Finishes : 1KN/m^2 2. Self-weight of concrete 24KN/m^2 3. Seft-weight of masonry walls 18KN/m^2 4. Safety factor 1.2 5. Cement 350kg/m^3	General loading conditions

Severe (external) and mild (internal)	Exposure conditions
Concrete : grade C 30 Reinforcement : - Characteristic strength fy= 460N/mm^2 - For foundation fy= 460N/mm^2 - f_{cu}= 25N/mm^2	Material data
Soil condition	Allowable bearing capacity:300kn/m^2 (average bearing capacity of soil in the city of Kigali)
For dead load: 1.4 For live load: 1.6	Partial factors of safety for load combination

The design of slab was done by following the following condition and steps:

3.4.2.1. Slab panel choice

The design of slab was done firstly by choosing the critical panel which is the biggest panel

3.4.2.2.Determination of type of slab

Condition:

If $l_y/l_x \leq 2$,the slab is a two-way slab

If l_y/L_X >2 the slab is one-way slab

Where:

Ly is long span and lx is short span

3.4.2.2. Slab thickness

The thickness of slab must lay between the panel $lx/_{20}$ and $lx/_{40}$ where l^x is the shorter side of the panel

Effective height (ho) = thickness of the slab- concrete cover

3.4.1.3.Load calculation

Dead load: the weight of the slab itself, as well as the weight of any permanent fixtures, partitions,and non-moveable elements of the building, such as walls, columns, and mechanical systems.

Live load: temporary and variable loads caused by occupancy, furniture, equipment, and peoplemoving within the building.

It divided into:

- w_c=1.4*d*γ_c*b

Where:

W_c : is the self-weight of the slab

d : thickness of slab

γ_c : unit weight of slab

b : breath of slab (1m)

- Finishes= q+b

Where :

q : self-weigh of the slab

GK= w_c+ Finishes

3.4.1.4.Bending moment calculation

Bending moment calculation was done by firstly determining if the slab is one way or two way slab.

For the bending moment calculation the following formulas were used:

$\lambda = ly/lx$

Where λ is the ratio of the long side (ly) over the short side (lx)

Bending moment in the short span:

$$Mx = \alpha sx * n * lx^2$$

Bending moment in the short span:

$My = \alpha sy * n * ly^2$

Where:

-n is the total load on the slab

-αsx and αsy: coefficient related to the designed slab.

-lx is the short side of the panel

-ly is the long side of the panel

It important to know that the during the design for Moment we have to design for maximum moment among negative moment (Msx^-,Msy^+) and maximum moment among positive moments (Msx^+,Msy^-).

When we are doing slab design the following options for moment are adopted:

Option 1: design of all moments(Msx^- , Msx^-, Msy^-,Msy^+)

Option 2: design for all maximm moments (Msx^-,Msy^-) and maximum moment among positive moments moment (Msx^+,Msy^+)

Faur our design the option two will be use

For example ly/lx =1.2

Msx^-(sagging moment)=0.042*n*$(lx)^2$

Msx^+ (hogging moment)= 0.032*n*$(lx)^2$

Msy^-= 0.032*n*$(ly)^2$

Msy^+ = 0.024*n*$(ly)^2$

Type of panel and moments considered	Short span coefficients, βsx								Long span coefficients, βsy for all Value of l_y/l_x
	Values of l_y/l_x								
	1.0	1.1	1.2	1.3	1.4	1.5	1.75	2.0	
Interior panels									
Negative moment at continuous edge	0.031	0.037	0.042	0.046	0.050	0.053	0.059	0.063	0.032
Positive moment at mid-span	0.024	0.028	0.032	0.035	0.037	0.040	0.044	0.048	0.024
One short edge discontinuous									
Negative moment at continuous edge	0.039	0.044	0.048	0.052	0.055	0.058	0.063	0.067	0.037
Positive moment at mid-span	0.029	0.033	0.036	0.039	0.041	0.043	0.047	0.050	0.028
One long edge Discontinuous									
Negative moment at continuous edge	0.039	0.049	0.056	0.062	0.068	0.073	0.082	0.089	0.037
Positive moment at mid-span	0.030	0.036	0.042	0.047	0.051	0.055	0.062	0.067	0.028
Two adjacent edges discontinuous									
Negative moment at continuous edge	0.047	0.056	0.063	0.069	0.074	0.078	0.087	0.093	0.045
Positive moment at mid-span	0.036	0.042	0.047	0.051	0.055	0.059	0.065	0.070	0.034
Two short edges discontinuous									
Negative moment at continuous edge	0.046	0.050	0.054	0.05T	0.060	0.062	0.06T	0.0T0	—
Positive moment at mid-span	0.034	0.038	0.040	0.043	0.045	0.047	0.050	0.053	0.034

Two long edges discontinuous									
Negative moment at continuous edge	—	—	—	—	—	—	—	—	0.045
Positive moment at mid-span	0.034	0.046	0.056	0.065	0.072	0.078	0.091	0.100	0.034
Three edges discontinuous (one long edge continuous)									
Negative moment at continuous edge	0.057	0.065	0.071	0.076	0.081	0.084	0.092	0.098	—
Positive moment at mid-span	0.043	0.048	0.053	0.057	0.060	0.063	0.069	0.074	0.044
Three edges discontinuous (one short edge continuous)									
Negative moment at continuous edge	—	—	—	—	—	—	—	—	0.058
Positive moment at mid-span	0.042	0.054	0.063	0.071	0.078	0.084	0.096	0.105	0.044
Four edges discontinuous Positive moment at mid-span	0.055	0.065	0.074	0.081	0.087	0.092	0.103	0.111	0.056

Tableau3.4 : bending moment coefficient for rectangular anels supportedbon faur sides with provision for torsion at corners

3.4.1.5.Shear force calculation

The formula used to calculate shear force over the long span and the short span are:

$Vsx= \beta_{\gamma x}*n*l_x$

$Vsy= \beta_{\gamma y}*n*l_y$

Where: Vsx and Vsy are shear force coefficient from 3.15 of the code BS 8110-1:1997

Tableau 5 : ultimate bending moment and shear force in one-way spanning slab

	End support/ slab connection				At first interior support	Middle interior span	Interior support
	Simple		Continuous				
	At the outer support	Near middle of end span	At outer support	Near middle of end span			
Moment	0	0.086FL	-0.04FL	-0.075 FL	-0,086FL	-0.063FL	-0.063FL
Shear	0.04F	-	0.046F	-	0.6F	-	0.5F

Where

- F is ultimate design load (1.4GK+1.6 QK)
- L is the effective span

3.4.1.6. Moment of resistant of concrete(MRC)

The maximum amount of force that a concrete segment can withstand without breaking is known as its moment of resistance. Ensuring that the structure can safely withstand the imposed loads is a crucial idea in structural design. (Ching & Francis D.K., 2014)

MRC= 0.156 fcu*b*d (fou: compressive strength of concrete, b: width(lm), d: thickness of slab)

If M<MRC, no compression bars required

3.4.1.7.Slab area of steel calculation

Known as the "steel ratio" or "reinforcement ratio," the area of steel reinforcement needed for a concrete slab is an essential component of structural design that guarantees the slab can bear applied loads without experiencing undue deformation or failure (Ching & Francis D.K., 2014).

K=M/(fcu*b*d, Kbal= 0.156, if K<Kbal there is no compression.

With: K: Lever arm factor

$$z = d(0.5 + \sqrt{0.25} - \frac{k}{0.9}) < 0.95d$$

If not z= 0.95d

$as\ req = \frac{M}{0.95*fy*z}$ With as req: area of still required

Area of steel provides will be find to the area of steel required by checking in the table of groups of bars

Tableau 3.6 : area of groups of bars

Diameter(mm)	Number of bars in groups							
	1	2	3	4	5	6	7	8
6	28	56	84	113	141	169	197	226
8	50	100	150	201	251	301	351	402
10	78	157	235	314	392	471	549	628
12	113	226	339	452	565	678	791	904
16	201	402	603	804	1005	1206	1407	1608
20	314	628	942	1256	1570	1884	2199	2513
25	490	981	1472	1963	2454	2945	3436	3927
32	804	1608	2412	3216	4021	4825	5629	6433

3.4.1.8.Defection check

Monitoring and controlling deflection is crucial to maintaining the structural integrity, functionality, and appearance of a building. Excessive deflection can lead to cracking, misalignment of finishes, and discomfort for occupants.

Basic span to effective depth ratio was found in the table 3-9 of the code BS 8110-1:1997.

Tableau 3.7 : basic span/effective depth ratio for rectangular or flanged beams

Support conditions	Rectangular section	Flanged (bw/b) ≤ 0.3
Cantilever	7	5.6
Simply supported	20	16
Continuous	26	20.8

Calculation of modification factor

$$M\ f = 0.55 + \frac{477 - fs}{120\left(0.9 + \frac{M}{bd^2}\right)} \leq 2.0$$

With: $fs = \frac{2}{3} fy * \frac{asreq}{asprov} * \frac{1}{Bb}$

Allowable span/d=basic span/d*MF

Actual span/d=span/d

If allowable span/d < actual span/d the slab is satisfactory with respect to deflection.

Beams design

The beam design was done following these steps and condition:

3.4.1.9.Preliminary design

The preliminary design of the beam was done to find the various basic parameters of the beam which are the height,the breadth and the flange.Here down are the formulas and conditions that guided the preliminary design:

The total height (ht) of the beam has to be in the range below:

$$\frac{ly}{15} \leq ht \leq \frac{ly}{8}$$

Where: Ly is the largest span between two consecutive beams.

The breadth of the section (width of the web bw) of the beam varies between

$$0.5 \leq \frac{bw}{ht} \leq 1$$

The flange of (bf') of the beam is to be the lesser of:

1. $\frac{ly}{3}$
2. $\frac{lx}{2}$
3. $12ht + bw$

Cross-section of t-beam is assumed to be

$\frac{ly}{15} \leq h \leq \frac{ly}{10}$

3.4.1.10. Loading

The following conditions were respected we can calculate the load on the beam using specific coefficients provided in the table 3.14 of the BS code

Conditions:

a) Characteristic imposed load Qk may not exceed characteristic dead load Gk

b) Loads should be substantially uniformly distributed over three or more spans;

c) Variations in span length should not exceed 15 % of longest

Dead load gk is the sum of:

-Weight of slab : slab thickness*slab width * unit weight of concrete

-Weight of down stand: bw* h * unit weight of concrete

-Finishes

Imposed load: characteristic imposed load * slab width

Design uniformly distributed load, W= (1.4Gk + 1.6Qk)

Design load per span, F= W*span

Tableau 3.8 : Design ultimate bending moments and shear forces **(Arya, 2022)**

	End support	*End span*	*Penultimate support*	*Interior span*	*Interior support*
Moment	0	0.09Fℓ	–0.11Fℓ	0.07Fℓ	–0.08Fℓ
Shear	0.45F	–	0.6F	–	0.55F

`

3.4.1.11. Reinforcement

After the ultimate bending moments and shear forces were found the reinforcements were calculated following these formulas:

-Effective depth (d) which is the distance from the top surface of the beam to the centroid of the tensile reinforcement was found by using this formula:

$$d = h - cover - \emptyset link - \frac{\emptyset main}{2}$$

-Lever arm factor (K) calculation:

$$k = \frac{m}{fcubd^2}$$

-Lever arme

$$\frac{z}{d} = 0.5 + \sqrt{0.25 - \frac{k}{0.9} > 0.95}$$

Where:

Z: Distance from the centroid of the tensile reinforcement to the extreme fiber in compression of the beam's cross-section.

d: Effective depth of the beam.

K: Lever arm factor, as explained in previous responses.

The expression essentially establishes a condition that the ratio of Z to d should meet in order to ensure the proper behavior of the beam under bending. This condition helps ensure that the tensile reinforcement and concrete work together effectively to resist bending moments and provide structural stability.

- Tensile reinforcement calculation

The expression below is used to calculate the required amount of tensile reinforcement. This equation helps determine the appropriate size and quantity of reinforcement bars needed to safely carry the bending moments that the beam may experience during its service life.

$As = \frac{M}{0.87fyz}$

3.4.1.12. Shear reinforcements

The amount and spacing of shear reinforcements depends on the area of tensile steel reinforcement present in the beam.

-Shear stress calculation:

$$U = \frac{V}{bd}$$

Where:

Ʊ: represents the shear stress

V: denotes the maximum shear force acting on the beam.

b: represents the width of the beam's cross-section. It's the horizontal dimension of the beam perpendicular to its length.

d: This represents the depth (or height) of the beam's cross-section. It's the vertical dimension of the beam.

-Shear capacity

The expression $uc = \frac{0.79}{1.25}(\frac{100as}{bd})^{\frac{1}{3}}(\frac{fcu}{25})^{\frac{1}{3}}(\frac{400}{d})^{\frac{1}{4}}$

represents a formula used to calculate the critical shear stress in a reinforced concrete beam. This formula is often employed in structural engineering to assess the shear capacity of a beam's cross-section.

-Shear range check

$$(Ʊc + 0.4) < Ʊ < 0.8\sqrt{fcu}$$

This expression helps ensure that the shear stress within the beam's cross-section falls within a safe and acceptable range.

Ʊc: This represents the critical shear stress, which is the shear stress at which the beam is expected to experience failure due to shear forces. It's an important design parameter for shear analysis.

Ʊ: This is the actual shear stress that the beam experiences due to applied loads. It's calculated based on the external loads, beam dimensions, and other factors.

fcu: This is the compressive strength of the concrete used in the beam.

*** (Ʊc + 0.4) < Ʊ**

This condition ensures that the calculated shear stress (Ʊ) is greater than a certain minimum value, which includes the critical shear stress (Ʊc) plus an additional margin of safety (0.4). It's important to ensure that the actual shear stress exceeds this lower limit to prevent shear failure.

***Ʊ < 0.8√(fcu)**

This condition sets a maximum allowable shear stress (Ʊ) based on the square root of the compressive strength of the concrete (fcu). It's critical to ensure that the shear stress does not exceed this upper limit to prevent overstressing the beam's capacity.

-check for deflection

Basic span/effective depth ratio for a rectangular or flanged beam = 20.8

This ratio serves as a reference for evaluating the adequacy of the span-to-depth ratio in the design. Calculation of modification factor

$$Mf = 0.5 + \frac{477-fs}{120(0.9+\frac{M}{bd})}$$

Where:

MF: This represents the modification factor for tension reinforcement. It adjusts the nominal strength of the beam to account for the actual behavior of the reinforcement under load.

fs: This is the design shear stress in the beam. It's a measure of the shear forces experienced by the beam due to applied loads.

M: This denotes the maximum bending moment that the beam is expected to experience.

b: This represents the width of the beam's cross-section, measured horizontally perpendicular to the beam's length.

d: This is the effective depth of the beam.

Check the Permissible Effective Span/Depth Ratio

Depth ratio for a rectangular or flanged beam = 20.8

Permissible Effective Span/Depth Ratio = Depth ratio*MF

Calculate Actual Span/Depth Ratio:

Actual span/depth ratio = lx / d

Span/Depth Ratio Comparison:

If the calculated actual span/depth ratio is less than the permissible ratio the span-to-depth ratio is within acceptable limits.

Column design

The design of column was done by computing the most loaded internal column by calculating its influence area and determines the total load on each floor part of column

Check if the column is classified as being short if:

$$\frac{lex}{h} < 15 \ and \ \frac{ley}{b} < 15$$

3.4.1.13. Effective height calculation

The equation $Le = \beta Lo$ represents a relationship used in structural engineering to calculate the effective height (Le) of a column based on the unbraced length (Lo) and a coefficient (β) that takes into account the column's end conditions and lateral bracing.

Where:

Le: represents the effective height of the column.

Lo: denotes the unbraced length of the column, which is the distance between points where the column is restrained against lateral movement (braced points).

β: This coefficient, often called the "slenderness ratio factor," accounts for how the column is braced and restrained against lateral movement. It varies based on the type of column end conditions. Our column was classified in the End condition 1 which signifies that the column is fully restrained and by that the value of the factor is 0.75.

Load calculation

The load supported by our column is the total weight it carries from the building's components and occupants. This load includes both permanent (dead load) and temporary (live load) weights. Engineers calculate and design columns to handle these loads safely, considering factors like materials, dimensions, and reinforcement. This ensures the column won't fail or deform under the applied forces, contributing to the overall stability and safety of the structure.

Dead Load (Gk): The permanent weight of the structural elements, finishes, and fixtures that are part of the building. It includes the weight of the column itself and other non-moving components.

Live Load (LL): The variable and transient loads caused by occupants, furniture, equipment, and other temporary loads. The Live load value of our building was 2KN/m2 as stated in the BS code for an apartment building except for the roof which was a without access except for maintenance and by that its live load is 0.75KN/m.

The unfactored and factored loads were computed from the fifth floor to the ground floor and they were used to find the required reinforcements steels.

3.4.1.14. Reinforcement calculation

$$As = \frac{nN - o.35 * fcu * Ac}{0.7 * fy}$$

Where:

As: This represents the required area of tensile reinforcement, in square millimeters (mm²)

N: This is the axial load applied to the concrete member, expressed in newtons (N).

fcu: This is the compressive strength of the concrete, typically measured in megapascals (MPa)

Ac: This denotes the cross-sectional area of the concrete member, usually in square millimeters (mm²)

fy: This is the yield strength of the reinforcement steel, typically in megapascals (MPa)

The equation calculates the required area of tensile reinforcement necessary to balance the effects of the axial load and the concrete's compressive strength. By providing adequate tensile reinforcement, we ensure that the member can withstand both axial and bending loads while maintaining its structural integrity.

Foundation design

3.4.1.15. Footing area calculation

Footing area = (serviceability load +10% of serviceability load)/bearing capacity of soil

3.4.1.16. Footing real pressure calculation

$$real\ pressure = \frac{Unfactored\ load + 10\%Unfactoredload}{footing\ area}$$

Footing real pressure, also known as actual bearing pressure or applied bearing pressure, refers to the load per unit area that is actually transmitted from the structure's foundation or footing to the underlying soil. It is calculated by dividing the total load carried by the footing by the area of the footing in contact with the soil. This calculation takes into account the actual loads from the structure, including dead loads, live loads, and any additional imposed loads.

3.4.1.17. Ultimate bearing pressure (Pu) calculation

$$ultimate\ bearing\ pressure = \frac{Factored\ load}{footing\ area}$$

Ultimate bearing pressure (Pu) is the maximum load per unit area that the soil can safely withstand without undergoing excessive settlement or failure.

3.4.1.18. Reinforcements calculation

the equation $As = \frac{M}{0.87fyz}$ applied to footings in structural engineering to calculate the required area of tensile reinforcement for a reinforced concrete footing subjected to bending moment (M). This equation is used to ensure that the footing can safely resist the bending forces and maintain its structural integrity. applied to footings in structural engineering to calculate the required area of tensile reinforcement for a reinforced concrete footing subjected to bending moment (M). This equation is used to ensure that the footing can safely resist the bending forces and maintain its structural integrity.

3.4.1.19. Check for punching shear

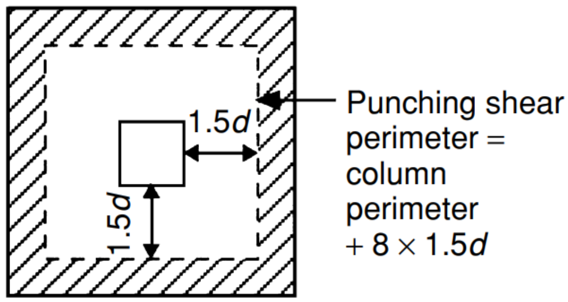


Figure 3.6 : Critical section for punching shear (Arya, 2022

$$Punching\ shear\ stress\ \mho = \frac{punching\ force}{criticalperimeter * d}$$

The equation Ʊ = (punching force) / (critical perimeter * d) is used to calculate the punching shear stress in a reinforced concrete footing. This equation assesses the shear stress at the critical perimeter around a column or pedestal to determine if the footing is adequately designed to resist punching shear failure.

Where:

Ʊ: represents the punching shear stress, usually measured in pascals (Pa)

Punching force: is the total vertical force applied to the footing by the column or pedestal, typically in newtons (N).

Punching force = pu*critical area

Critical perimeter: This is the boundary around the column or pedestal where shear failure is most likely to occur. It's defined based on a certain distance from the column, often given as a fraction of the effective depth of the footing.

The critical perimeter is defined by this equation: (3d+column side length) *4

d: This represents the effective depth of the footing, measured in the same units as the critical perimeter.

3.4.1.20. Shear capacity

The expression $uc = \frac{0.79}{1.25}(\frac{100as}{bd})^{\frac{1}{3}}(\frac{fcu}{25})^{\frac{1}{3}}(\frac{400}{d})^{\frac{1}{4}}$ represents a formula used to calculate the critical shear stress in a reinforced concrete footing.

The condition Ʊc>Ʊ must be respected to assure that punching failure will not occur.

3.4.1.21. Check for face shear

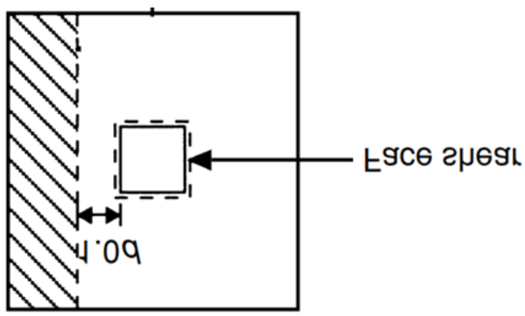


Figure 3.7 : Face shear critical section (Arya, 2022)

Maximum shear stress Ʊmax occurs at face of column. Hence

$$Ʋmax = \frac{N}{column\ perimeter * d}$$

Ʋmaxmust be inferior to$permissible\ shear\ which\ is$ $0.8\sqrt{fcu}$

3.4.1.22. Check for transverse shear

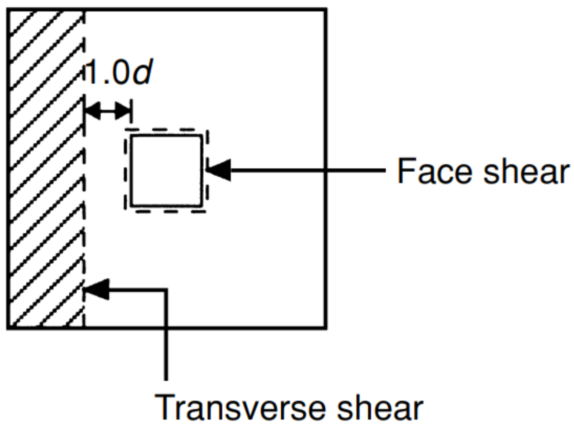


Figure 8 : Critical section for transverse and face shear **(Arya, 2022)**

$Ultimate\ shear\ force\ (V)$=$load\ on\ shaded\ area$=$earth\ pressure*area$ 31

Design shear stress Ʋ is $Ʋ = \frac{V}{bd}$

If Ʋc>Ʋ no shear reinforcement will be required; if not, provide shear reinforcements

Stair design

The staircase must be designed in a way that there will be a comfort when one is climbing it. It is necessary to check for the conformability of the staircase. Check if 550-2R+T<700, where R=riser and T = Tread.

Note: T+1=R

>Steps for Design:

Step 1: Calculate the effective length of stairs

Step 2: Calculate the effective depth of the stairs (Check L/d ratio)

Step 3: Calculate loadings on stairs

Step 4: Calculate the Maximum Bending Moment and Shear Force

Step 5: Check for depth against bending moment

Step 6: Calculate the required steel bars (As)

3.4.1.23. Loads on stair

Self-weight safety factor x thickness of the equivalent horizontal slab x 1m x 1m x unit weight of reinforced concrete.

Finishes safety factor x thickness of finishes.

Live load-safety factor (1.6) x live load of stair

3.4.1.24. Required reinforcements

$$As = \frac{M}{0.87fyz}$$

3.5. COST AND ESTIMATION

The comprehensive construction cost was derived by employing a combination of the unit cost approach, the quantity takeoff technique, and the bottom-up estimating methodology. The synthesis of these three methodologies was pivotal in achieving the intended outcome.

3.5.1. Calculation of Material Quantities

3.5.1.1.Reinforced concrete

The reinforced concrete was evaluated in terms of m3; the proportions of materials in one cubic meter of reinforced concrete can vary based on factors such as desired strength and local construction practices.

The amount of reinforcement in a cubic meter of concrete can vary widely based on the specific structural requirements of the project. However, in a typical reinforced concrete structure, you might find around 80 to 250 kg of steel reinforcement per cubic meter of concrete. This can include various types of reinforcement such as rebars (steel bars), wire mesh, or other types of structural steel elements. We will consider an average of 170 kg of reinforcements per cubic meter

Item	**Amount**	**Unitary price**	**Total price**
Cement (kg)	400	232,5	93.000
Aggregates (kg)	1000	85	102.000
Water (l)	160	Negligible	Negligible
Steel reinforcements(kg)	170	1.500	255.000
Total			450.000

Table: material evaluation for one cubic meter of reinforced concrete

With one m^3 of reinforced concrete costing around 450.000 Rwf. The reinforced concrete wasused for beams, columns, slabs and the column base footings.

3.5.1.2.Beam

Length of beams on one floor: 36m

Beams thickness: 0.4m

Beam height: 0.50m

RC volume needed for one floor: $36 * 0.40 * 0.5 = 7.2 \approx 8m^3$

3.5.1.3.Colum

Cross section area of column: $0.16m^3$

Height of column: 3m

RC volume needed: $3m * 0.16 = 0.48\ m^3$

RC volume need= $3mm*0.16m^2*22=10.56m^3$

3.5.1.4.Slab

Slab thickness: 0.15m

Slab area: slab for ground floor = $156.5m^2$

The remind slab area : $(156.5m^2)+(1*3)=159.5m^2$

RC volume needed: $0.15 * 159.5 = 23.92\ m^3 \approx 24\ m^3$

3.5.1.5.Footing

Footing area: 6.25m2

Footing depth: 0.6m

RC volume needed: 6.25 * 0.6 = 3.75m3 for one concrete pad footing

For all the footings: $3.75*23= 86.25m^3$

3.5.1.6.Wall plastering

For wall plastering and painting the unit to be used is square meter as the plaster and the painting is going to be applied on surfaces. The price for plaster to be applied on 1m2 is 15.000 Rwf , the price of paint to be applied on 1m2 is 45.000 Rwf and the price of floor tilling per square meter is 80.000 Rwf

3.5.1.7.Wall pastering

Length of walls : 36 m

Height of walls : 3m

Area to plaster : area * 2(interior and external walls)

: 36 * 3 * 2 = 216m^2

Wall painting will be the same than wall plastering = 216m^2

3.5.1.8.Floor tilling

Area to be tilling for each floor= 156.5m^2

3.5.1.9.Masonry wall

The masonry wall was evaluated as follow

Wall length: 36m

To calculate the volume of bricks and mortar needed to build a wall with a length of 36meters and a wall thickness of 20 cm (0.2 meters), we need to consider the dimensions of the wall and the volumes of the individual components (bricks and mortar). Let's break down the calculation step by step:

- **Brick amount**

Given the size of a standard brick (approximately 215mm x 102.5mm x 65mm), the volume of one brick is (0.215m+0.01) x (0.065m+0.01) = 0.01687m^2

To calculate the total numbers of bricks needed for the wall:

Total number of bricks = Wall area/ area of one brick

Total number of bricks = 108m^2 / 0.01687m^2

Total number of bricks ≈ 6428.57*2=12857.14≈ 13000 bricks

Let consider the wastage

13000*5/100= 650 bricks

Total numbers of bricks = 13000+650= 13650bricks

The market value of 1000 bricks is 300.000 Rwf

- **Volume of mortar**

The volume of mortar depends on the thickness of the mortar joints and the surface area of the joints. Assuming a standard joint thickness of 10mm (0.01 meters), we need to calculate the total surface area of the joints for the given area of bricks

Total joint surface area = total area of bricks considering joint – total area of bricks without consider joint

Total area of bricks without consider joint= (0.215m) x (0.065m+)= 0.0139 m^2 =

13650bricks*0.0139= 190.75m^2

Total area of bricks considering joint= 13650*0.01687= 227.745m^2

Volume of mortar will be = total area of bricks considering joints-total area of bricks without considering joints*(thickness of wall)= 227.745m^2-190.75m^2 *(0.2m)= 7.3m^3

3.5.1.10. Unit elements

Several elements were taken as unit; they are listed below with their prices

- **Doors**

Double entrance door : 270 000 Rwf

Wooden door: 200.000 Rwf

- **Windows**

Double hung-window

150 000 Rwf(1.5m*1m)

3.5.1.11. Preliminary works

- Site cleaning: (27m*44m)= 1188m^2

1m^2 cost 2 000Rwf

- Enclosure, shack and office: 2.000.000Rwf

3.5.1.12. Sanitary appliance

Suppy and installation of wc with all accessories and all requirements: 250.000Rwf

Supply and installation ion of ceramic wash hands basin complete with accessories and all requirements: 100.000Rfw

Earthwork

Excavation and site levering: 6.500.000Rwf

3.5.1.13. Curtain wall

1m^2 of curtain walls cost 60.000Rwf

Height=3m

Length=5.5m

Area = 16.5m^2

3.5.1.14. Building Project Final Cost and Estimation Result

Project Details:

Project Name: Architectural and structural design of a three storey residential apartment

Project Location: Kigali city

Total Estimated Project Cost: 281.433.500 Rwf

Amount in words: two hundred eighty-one million, four hundred thirty-three thousand, five hundred Rwandan francs.

Summary: The final estimated cost for the Architectural and Structural design of a 3 storey apartment building project is 281.433.500 Rwf

CHAPTER FAUR. DISCUSSION AND RESULT

4.1 Architectural design description

Architectural Design Description The residential apartment is thoughtfully designed to maximize space and functionality while providing comfort and aesthetic appeal.

The layout includes the following key features:

• Balcony (6x3m): The apartment features a spacious balcony measuring 6x3 meters, providing ample outdoor space for relaxation, enjoying the view, and entertaining guests. The balcony enhances the living experience by bringing in natural light and fresh air.

• Living Room and Dining Area (6x7m): The living room is combined with the dining area in an open-plan design, covering a total area of 6x7 meters. This expansive space is ideal for hosting gatherings and offers flexibility in furniture arrangement. The integration of these two spaces promotes a sense of openness and connectivity.

• Kitchen (2.8x3.8m): The kitchen is designed with efficiency in mind, measuring 2.8x3.8 meters. It is conveniently located near the dining area, allowing for easy meal preparation and serving. The layout supports a functional workflow, with sufficient countertop space and storage.

• Stock/Storage Room (2.8x1.8m): A dedicated storage room of 2.8x1.8 meters provides practical space for storing household items, keeping the living areas clutter-free.

• Master Bedroom with Bathroom:

• Bedroom (3.8x3.8m): The master bedroom offers a comfortable sleeping space, measuring 3.8x3.8 meters. It is designed to accommodate a large bed and additional furniture, creating a private retreat within the apartment.

• Bathroom (2.8x1.8m): Attached to the master bedroom, the bathroom spans 2.8x1.8 meters and includes essential fixtures. The en-suite design enhances privacy and convenience.

• Second Bedroom with Bathroom:

• Bedroom (4.8x2.8m): The second bedroom, measuring 4.8x2.8 meters, is designed to be versatile, suitable for guests, children, or as a secondary living space.

• Bathroom (2.8x1.8m): An attached bathroom of 2.8x1.8 meters serves the second bedroom, ensuring that occupants have their own private facilities.

• Staircase (4x3m): The staircase, measuring 4x3 meters, connects the different floors of the apartment. Its design prioritizes safety, accessibility, and aesthetic appeal, complementing the overall interior design.

The illustration below showcases the ground floor plan of the building, and since all the levels are uniform, it serves as a comprehensive representation of the floor plans for the entire building

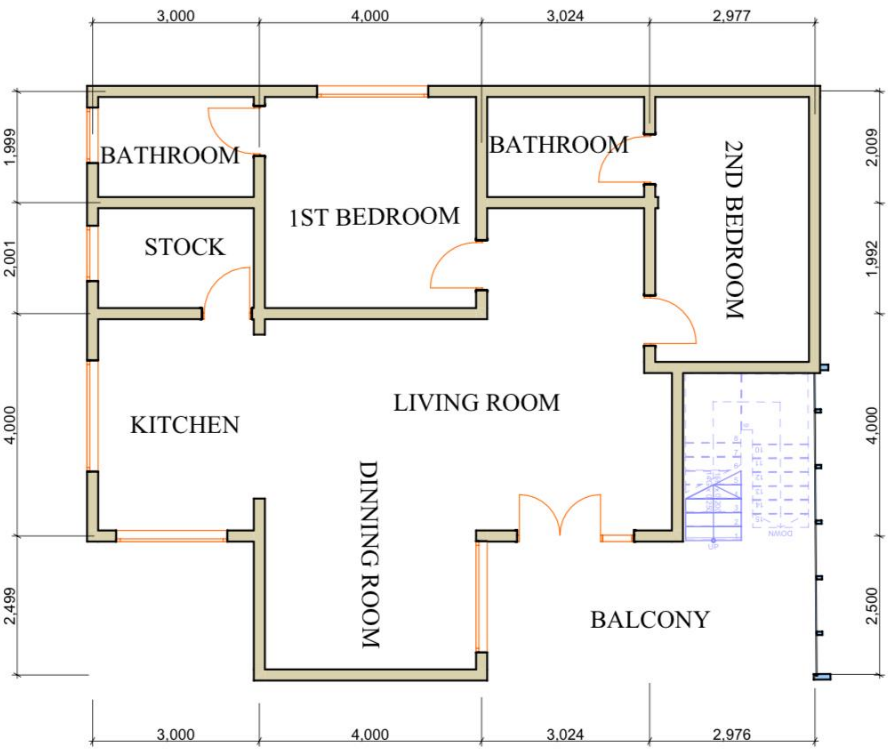


Figure4.1: floor plan

4.2 Structural design

The figure bellow illustrate the structural layout plan with structural elements to be designed highlighted

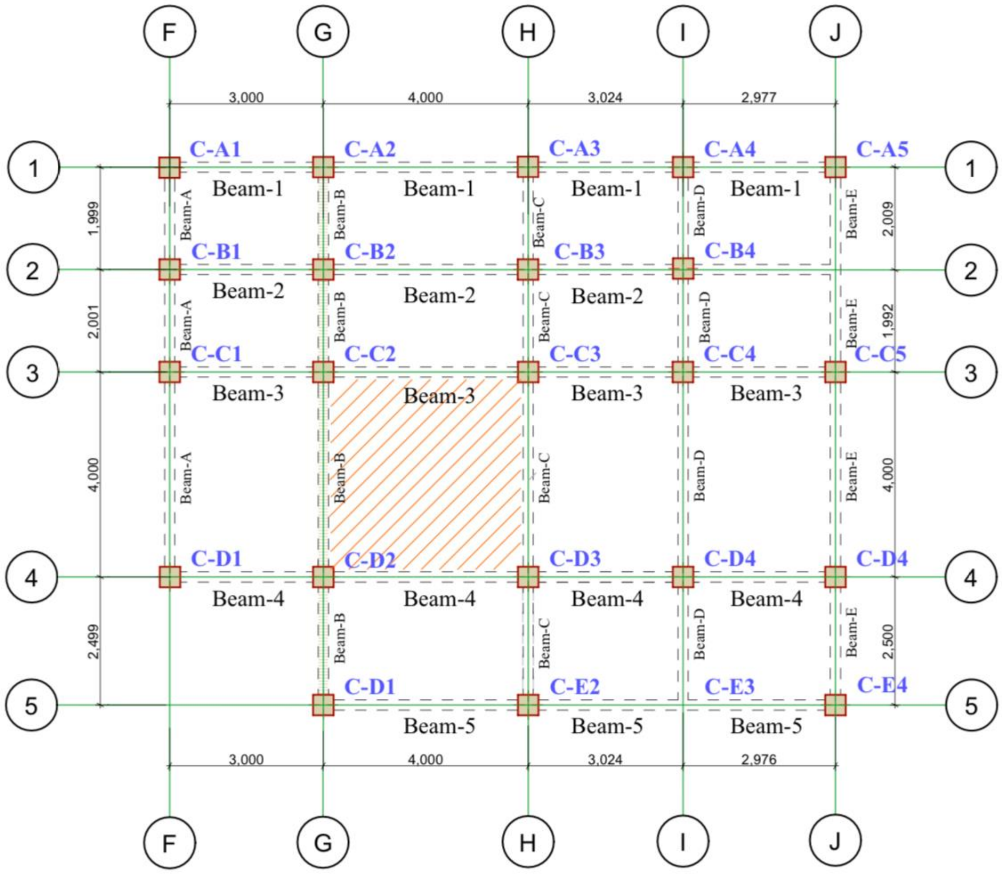


Figure 4.2: structural layout plan

4.2.1 SLAB DESIGN

The figure below display the chosen critical slab with is parameters.

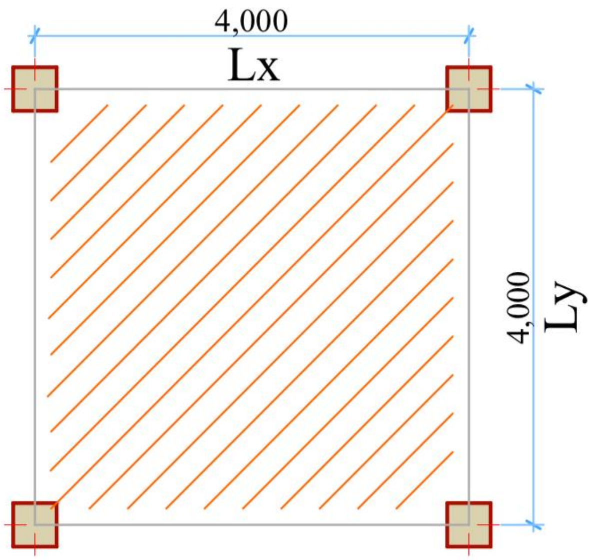


Figure 4.9 : chosen slab panel parameters

4.2.1.1 Assumption

cover: 25mm

bar diameter: 10mm

finishes: 1kn/m^2

services: 1kn/m^2

partitions: 1kn/m^2

live load according to the code bs(8110-1997) : 2kn/m^2

fcu : 25mpa, fy: 460mpa

characteristic live load for roof without access except maintenance : 0.75kn/m^2

unit weight of concrete : 24kn/m^3

4.2.1.2. Type of slab

ly=4.0m and lx= 4.0m

$\frac{ly}{lx} = \frac{4.0}{4.0} = 1 < 2$**, mean the slab is two way**

Tow way slab spanning in both direction

4.2.1.3.Choise of slab panel

The chosen panel of the slab is the one with the largest side in order to obtain the greatestthickness of the slab

Preliminary sizing of slab

Thickness of the slab

The thickeness of the slab heve to be between $\frac{lx}{40}$ and $\frac{lx}{20}$; $\frac{lx}{40} = 0.1m$ and $\frac{lx}{20} = 0.2m$
Because in general the range for the thickness of slab is 12cm≤h≤20cm, we take
H=15cm

Effective depth (h_0) or d

Ho= thickness of the slab –nominal cover- Φ bar/2 = 15cm-2.5 cm-0.005cm = 12.495cm

4.2.1.4. Loading

Weight of reinforced concrete=24 KN/m^3

Self-weight of slab = ϒ concrete * thickness of slab= = 24*0.15 = 3.6 KN/m^2

Characteristic dead load GK = 3.6+1+1+1=6.6 KN/m^2

Design load n=(1.4*6.6+1.6*2)=9.24+3.2=12.44 KN/m^2

$Gk=6.6KN/m^2$

$Qk=2\ KN/m^2$

For 1m width $n=12.44\ KN/m^2*1=12.44\ KN/m^2$

(n= Total distributed load on the slab panel)

4.2.1.5. Bending moment in restrained slab

Knowing $\frac{ly}{lx} = 1.0m$, Bending moment coefficients are

ßsx- =0.031 ßsy- = 0.032

ßsx+=0.024 ßsy+= 0.024

Bending moment

$Msx= ßsxnlx^2$

$Msy= ßsynly^2$

$Msy- = 0.032*12.44*4^2=6.36$ KNm

$Msy+= 0.024*12.44*4^2=4.77$ KNm

$Msx- =0.031*12.44*4^2=6.17$ KNm

$Msx+=0.024*12.44*4^2=4.77$ KNm

$ASmin= 0.0013*b*h= 0.0013*1000*150= 195mm^2/m$

1. **Maximum moment is 4.77 KNm (Mmax (+ve)**

MRC= 0.156 fcubd²$= 0.156*25N/mm^2*1000*(124.5)^2= 60450975N/mm^2$

$=60.45N/mm^2$

M< MRC, No compression bars are required.

K= M/fcubd²$=\frac{4.77*10^6}{25*1000*(124,5)2} = 0.012 < 0.156$, No compression bars

Z= d (0.5+ √0.25- K/0.9) < 0.95d= 0.98d > 0.95d

Let us take Z= 0.95d= 0.95*124,5mm= 118.275mm

ASreq= M/0.95fyz= $\frac{4.77KNm*10^6}{0.95*460*118.275}$=92,2877 mm^2

ASmin= 0.13*AC/100= 0.13*h*b/100=0.13*150*1000/100=195mm^2

ASmax=4*AC/100=4*150mm*1000mm/100=6000mm^2

ASprov=201mm^2 T8@ 250 C/C

Panel	My(+)	K	Z	Asreq	Select
1	4.77KNm	0.012	118.275mm	92,28mm^2	T8@250C/C

4.2.1.6. Check for deflection

Mmax (+ve)=4.77knm

Basic Spand/d=26

M/bd^2=4.77*10^6/1000*(124.5)^2=0.52

MF=$0.55+\frac{447-fs}{120(0.9+M/bd2}$

Fs=$\frac{2}{3}fy*\frac{Asreq}{Asprov}*\frac{1}{Bb}=\frac{2}{3}*460*\frac{92,28}{201}*\frac{1}{1}=140.7N/mm2$

MF=$0.55+\frac{447-140.7}{120(0.9+0.52)}=2.34\ >2\ then$ MF=2

Allowable span/d=Basic span/d *MF= 26*2=52

Actual spand/d =4000/124.5= 32.1

Allowable span/d >actual span/d ,the slab section is satisfactory with respect to deflection.

2. Mmax(-ve)=6.36KNm

MRC=0.156 $fcubd^2$ =0.156*25N/mm^2*1000*$(124.5mm)^2$=60.4KN/mm^2

M<MRC, no compression bars are required

K=M/$fcubd^2$=6.36*10^6/25*1000*$(124.5)^2$=0.016< 0.156, no compression bars ok!

$$z = d(0.5 + \sqrt{0.25 - \frac{k}{0.9}} < 0.95d = 0.98d > 0.95d$$

Let take z=0.95d =0.95*124.5mm=118.275mm.

ASreq= M/0.95fyz= $\frac{6.36KNm*10^6}{0.95*460*118.275}$=123.05 mm^2

Asmin= 0.13*AC/100= 0.13*150*1000/100=195mm^2

Asmax= 4*Ac/100= 4*150*1000/100=6000mm^2

Asprov should be between Asmin and Asmax but close for Asmin

Asprov= 251mm^2 **T8@200C/C**

Check for deflection

Mmax (-ve) =6.36knm

Basic span/d = 26

M/bd^2=6.36*10^6/1000* $(124.5)^2$= 0.41

Fs=$\frac{2}{3}fy * \frac{Asreq}{Asprov} * \frac{1}{Bb} = \frac{2}{3} * 460 * \frac{123.05}{251} * \frac{1}{1} = 150.33\ N/mm2$

MF=$0.55 + \frac{447-fs}{120(0.9+M/bd2}$

MF=$0.55 + \frac{447-150.33}{120(0.9+0.69)} = 1.57$<2 ok !

- Allowable span/d =Basic span/d * MF = 26*1.57= 40.82
- Actual span/d= 4000/124,5=32.12

Allowed span/d >actual span/d, the slab section is satisfactory with respect to deflection.

Panel	Mx(-)	K	Z	Asreq	Select
1	6.36	0.016	118.27	123.05	T8@200c/c

3. Msy (+ve)=4.77knm^3

MRC= 0.156 fcubd^2= 0.156*25N/mm^2*1000*(124.5)^2= 60450975N/mm^2 =60.45N/mm^2

M< MRC, No compression bars are required.

K= M/fcubd^2=$\frac{4.77*10^6}{25*1000*(124,5)2} = 0.012 < 0.156$, No compression bars

Z= d (0.5+ √0.25- K/0.9) < 0.95d= 0.98d > 0.95d

Let us take Z= 0.95d= 0.95*124,5mm= 118.275mm

ASreq= M/0.95fyz= $\frac{4.77KNm*10^6}{0.95*460*118.275}$=92,2877 mm^2

ASmin= 0.13*AC/100= 0.13*h*b/100=0.13*150*1000/100=195mm^2

ASmax=4*AC/100=4*150mm*1000mm/100=6000mm^2

ASprov=201mm^2 T8@ 250 C/C

Panel	My(+)	K	Z	Asreq	Select
1	4.77KNm	0.012	118.275mm	92,28mm^2	T8@250C/C

4.Msx (-ve) = 6.17KNm

MRC=0.156fcubd^2= 0.156*25*1000*(124.5)^2= 60.45KNm

M<MRC, no compression bars are required

M<MRC, no compression bars are required

K=M/fcubd^2=6.17*10^6/25*1000*(124.5)^2=0.015< 0.156, no compression bars ok!

$$z = d(0.5 + \sqrt{0.25 - \frac{k}{0.9}} \quad < 0.95d = 0.98d > 0.95d$$

Let take z=0.95d =0.95*124.5mm=119.375mm.

ASreq= M/0.95fyz= $\frac{6.17KNm*10^6}{0.95*460*118.275}$=123.05 mm^2

Asmin= 0.13*AC/100= 0.13*150*1000/100=195mm^2

Asmax= 4*Ac/100= 4*150*1000/100=6000mm^2

Asprov should be between Asmin and Asmax but close for Asmin

Asprov= 200mm^2 **T8@250C/C** the spacing considered is for 201mm^2/m

Panel	My(+)	K	Z	Asreq	Select
1	6.17KNm	0.02	118.275mm	123.05mm^2	T8@250C/C

4.2.1.7. Check for shear

Vsx=Bvx*n*lx=0.33*12.44*4=16.42 kn

Vyx=Bvy*n*ly=0.33*12.44*4=16.42 kn

Vmax =16.42kn

$U = \frac{Vmax}{bd} = \frac{16.42*10^3 kn}{1000*124.5} = 0.13$ N/mm^2

Vu= $0.8\sqrt{fcu} = 4.73$ N/mm^2

U<Vu, the ultimate shear ok !!!!

$Vc = \frac{0.79}{1.25} (\frac{100As}{bd})^{\frac{1}{3}} (\frac{fcu}{25})^{\frac{1}{3}} (\frac{400}{d})^{\frac{1}{4}}$

$Vc = \frac{0.79}{1.25} (\frac{100*251}{350*124.5})^{\frac{1}{3}} (\frac{25}{25})^{\frac{1}{3}} (\frac{400}{124.5})^{\frac{1}{4}}$ = 0.48 Mpa

Condition

$(\frac{100As}{bd})^{\frac{1}{3}}$ <3 ok !!

$(\frac{fcu}{25})^{\frac{1}{3}}$ =1 ok!!

$(\frac{400}{124.5})^{\frac{1}{4}}$ >1 ok!!!

U<Vc, 0.17N/mm2<0.48 n/mm2, no shear reinforcement required

4.2.1.8. Crack control

Allowed 3d spacing= 3*124.5= 373.5mm

Maximum spacing= 251m, spacing ok!

The structure is satisfactory with respect to craking

4.2.2. DESIGN OF BEAM

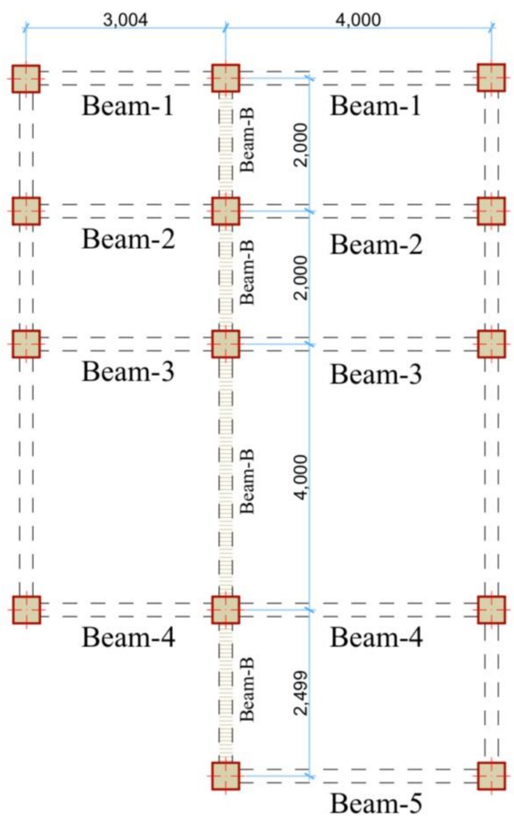


Figure 4.10 : beam to be designed to be designed (beam B)

The total height (ht) of the beam has to be in the range below:

$\frac{ly}{15} \leq ht \leq \frac{ly}{8}$ ly=4.0m = 400cm

$\frac{400}{15} \leq ht \leq \frac{400}{8}$=26.66≤ht≤50

Let take 50cm

The breath of the section (width of the web) of the beam varies between

$0.5 \leq \frac{bw}{ht} \leq 1$ = 0.5*50≤ bw ≤ 50

25≤bw≤50

The breath or width of the web of beam bw=40cm

Dimension of the beam t-section

Bw= 40cm

Hf=15cm

Ht=50cm

4.2.2.3. Loading

Specific coefficient provided in the B.S

Condition

a) Characteristic imposed load QK may not exceed characteristic dead load GK
b) Loads should be substantially uniformly distributed over three or more span
c) Variation is span length should not exceed 15% of longest

Dead load is the sum of :

Weight of slab: slab thickness*slab width * unit weight of concrete

0.15*4*24=14.4 KN/m

Weight of dowstand : bw*h*unit weight of concrete: 0.4*0.4*24= 3.84 KN/m

Finishes: 1.5*4= 6 KN/m

Gk = 14.4+3.84+6= 24.24 KN/m

Imposed load: characteristic imposed load*slab width

Qk = 2*4=8KN/m

Design uniformly distributed load, W=(1.4GK+1.6QK)= 1.4*24.4+1.6*8= 46.4 KN/m

Design load par span, F=W*span=46.4*4= 221.52 KN/m

4.2.2.4. Design moment and shear forces

Support A

Bending moment = 0 KN/m

Shear force = 0.45*F = 0.45*221.52 = 99,68kN

Span AB and ED (End Spans)

Bending moment AB = 0.09Fl = 0.09*221.52*2.5= 49.84kNm

Bending moment ED =0.09Fl = 0.09*221.52*2= 39,87 kNm

Shear force, V = 0 kN

Support B and D (penultimate supports)

Bending moment B = -0.11Fl = -0.11*221.52*2.5= -60.91 kNm

Bending moment D = -0.11Fl = -0.11*221.52*2= -48.73 kNm

Shear force , V= 0.6F =0.6* 221.52 = 132.912 kN

Span BC and DC (Interior spans)

Bending moment = 0.07Fl = 0.07*221.52*4= 62.025kNm

Bending moment = 0.07Fl = 0.07*221.52*2= 31.012 kNm

Shear force, V = 0 kN

Support C (Interior support)

Bending moment = -0.08Fl = -0.08*221.52*4= -70.88 kNm

Shear force, V = 0.55F =0.55* 221.52 = 121.83 kN

4.2.2.5. Reinforcement calculation

Span AB and ED (End Spans-bottom reinforments)

Bending moment AB: 49.84 KN/m

Effective flange width: $bw + \frac{0.7l}{5} = 400 + \frac{0.7*2500}{5} = 350mm$

The concrete cover on 8mm links is 25mm and if 16mm main bars in vertical pairs are required,

The effective depth will be:

$d = h - cover - \emptyset link - \frac{\emptyset main}{2}$

$d = 500 - 25 - 8 - \frac{16}{2} = 459mm$

$M = \frac{M}{fcubd^2}$

$M = \frac{49.84*10^6}{25*350*459^2} = 0.0124 < k' = 1.56$

No compression reinforcement required

Lever arm

$\frac{z}{d} = 0.5 + \sqrt{0.25 - \frac{k}{0.9} > 0.95}$

$\frac{z}{d} = 0.5 + \sqrt{0.25 - \frac{0.0124}{0.9} > 0.95}$

= 0.984>0.95

Taken z=0.95d= 0.95*459= 436.05mm

$Asreq = \frac{M}{0.87*fyz}$

$Asreq = \frac{49.84*10^6}{0.87*460*436.05mm} = 285,6mm^2$

Let provide 2T16(402mm^2)

Span BC and CD (middle spans)

Bending moment: 62.05KN/m

From above, effective depth, d= 459mm and effective width of beam, b=350mm, z= 436.5mm

As is:

$Asreq = \frac{M}{0.87*fyz}$

$Asreq = \frac{62.05}{0.87*460*436.5mm}$ = 318.32 mm^2

Provide 2T16 (402mm^2)

Let provide for all beams 3T16 (603mm^2)

4.2.2.6. Shear reinforcements

The amount and spacing of shear reinforcements depends on the are of tensile steel reinforment depends on the are of tensile steel reinforcement present in the beam.

The minimum tension steel at any point 3T16. Hence As= 603mm^2

The maximum shear is at support B and D (132.91 KN)

$u = \frac{v}{bd} = \frac{132.91*10^3}{350*459} = 0.38$ Mpa

$0.8\sqrt{fcu} = 0.8\sqrt{25} = 4Mpa \ > 0.8Mpa < 5Mpa$

$uc = \frac{0.79}{1.25}(\frac{100As}{bd})^{\frac{1}{3}}(\frac{fcu}{25})^{\frac{1}{3}}\ (\frac{400}{d})^{\frac{1}{4}}$

$uc = \frac{0.79}{1.25}(\frac{100*603}{350*459})^{\frac{1}{3}}(\frac{25}{25})^{\frac{1}{3}}\ (\frac{400}{459})^{\frac{1}{4}}$ = 0.443 Mpa

Uc+0.4= 0.443+0.4= 0.883 Mpa

(Uc+0.4)<U<0.8$\sqrt{fcu} = 0.8\sqrt{25} = 4Mpa < 5Mpa$

$As = 2\frac{\pi\phi^2}{4}\ \ where\ \phi = 8$

$As = 2\frac{3.14*8^2}{4} = 100.5mm^2$

$sv = \frac{As*0.87*fy}{bw(u-uc)}$

$sv = \frac{100.5*0.87*460}{350(0.88-0.443)}$

Sv $\leq$ 365.3mm

Sv max= 0.75*459= 344,25 mm

Use spacing of Sv= 200mm

4.2.2.7. Check for deflection

$$\frac{width\ of web}{effective\ depth\ of\ flange} = \frac{400}{459} = 0.9$$

Basic span/effective depth ratio for a rectangular or flanged beam = 0.28

Modification factor

MF=$0.55 + \frac{447-fs}{120(0.9+M/bd2}$

Were

$$\frac{M}{bd^2} = \frac{49.84*10^6}{1000*459^2} = \ 0.23$$

$$fs = \frac{2fy\ asreq}{3asprov} * \frac{1}{bb}\ were\ bb = 1\ and\ fs\ is\ the\ design$$

$$fs = \frac{2*460*285}{3*603} = 144.9$$

MF=$0.55 + \frac{447-144.}{120(0.9+0.23)} = 2{,}2$

Let take MF= 2

Permissible effective span/depth ration= 20.8*2= 41.6

Actual span/depth ratio= lx/d=4000/459= 8.71

8.71< 41.6 hence ok

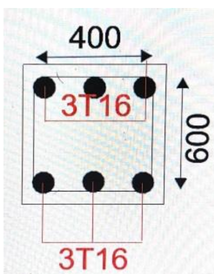


Figure 11 : section beams

4.2.3. DESIGN OF COLUMN

Here down is the most loaded column figure and its loaded area.

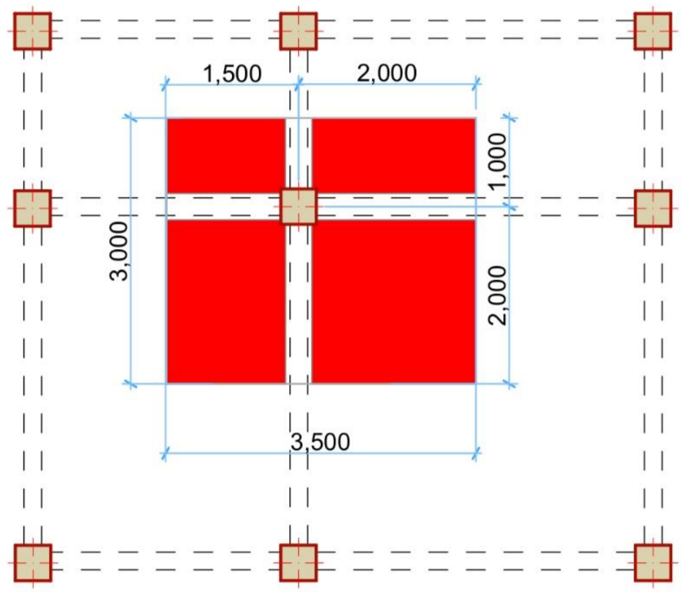


Figure 4.12 : loaded area of chosen column (C-C2)

We assume 400mm*400mm column

The column is classified as being short if

$$\frac{lex}{h} < 15 \; and \; \frac{ley}{b} < 15$$

Where:

Lex: effective height in respect of the major axis.

Ley: effective height in respect of the minor axis

b :width of a column (dimension of cross-section perpendicular to h).

h: depth of cross-section measured in the plane under consideration.

Lex= overall height of the column –height of beam

Ley= overall height of the column – effective depth of the beam

Overall height of the column=3m=3000mm

h =650 mm and d=609 mm

lex=3000mm-650mm=2350mm

ley=3000mm-609mm=2391mm

$\frac{2350}{400} < 15 \; and \; \frac{2391}{400} < 15$

5.87<15 and 5.97<15

Our column is a braced short column

Effective height of the column

$Le = \beta Lo$

Were

Lo : clear height of column

=overall height of column-depth of the beam

=3000-609= 2391mm

β: This coefficient, often called the "slenderness ratio factor," accounts for how the column is braced and restrained against lateral movement. It varies based on the type of column end conditions. Our column was classified the End condition 1 which signifies that the column is fully restrained and by that the value of the factor is 0.75

$\beta = 0.75$

$Le = \beta Lo = 0.75x2391 = 1793.25$ mm

Slenderness ratio

$\lambda = \frac{Le}{a}$

where a is the side of column

λ=1793.25/400

λ=4.48

Loading

Column from roof to 3th floor

Loads calculation

Load calculation on roof slab

-Self-weight of slab=24*0.15=3.6 KN/m2

-Finishing under slab: 1 KN/m2

- Characteristic dead load GK=3.6+0.43+0.57=4.6 KN/m2

-self weigth of beam= 0.40*0.65*24= 6.24 KN/m

- Unfactored loads = 6.24 KN/m

-factored load = 1.4*6.24 = 8.74 KN/m

Area and length of tributary area of column

Loading area of Column= 2.5*3= 7.5m^2

Total length of beam= 2.5+3= 5.5m

Load calculation on column

Tableau 9 : **load calculation on column (roof to 3rd)**

Unfactored loads	**Factored loads**
Roof slab= 4.6*7.5=34.5 KN	7.64*7.5= 57 KN
Beam= 6.24*5.5= 34.32 KN	8.74*5.5= 48.07 KN
Self-weight of column = 0.4*0.4*3*24= 11.52 KN	11.52*1.4= 16.128 KN
Total = 80.05	121,19 KN

Unfactered load = 80.05 KN

Factored load = 121.19 KN

Reinforcement

Short braced columns supporting an approximately symmetrical arrangement of beams

N= 0.35 fcu AC+ 0.7ASfy

$$\boldsymbol{AS = \frac{N-0.35*fcu*AC}{0.7*fy}}$$

Where:

Ac= b*h =400*400=160000mm^2

fy=460N/mm^2

fcu=25N/mm^2

N: factored load

$$AS = \frac{121.19-0.35*25*160000}{0.7*460} = -4507mm^2$$

Negative area means that there is no reinforcement required but we provide the minimum wich is equal to 0.4%AC=0.004*160000=640mm^2

Let’s provide **4T16 (804mm2)**

Column from 3th to 2th floor

Load calculation

Load calculation on slab

Slab self-weigth=thickness of slab*unit weigth of RC

Slab self-weigth = 0.15*24= 3.6 KN/m^2

Finishes: 1 KN/m^2

Gk = 4.6 KN/m^2

Qk= 2 KN/m^2

-unfactored loads= 4.6 KN/m^2

-factored load= (1.4*4.6)+(1.6*2)=6.44+3.2=9.64 KN/m^2

Load calculation on beam

Self-weigth of beam=0.4*0.65*24=6.24 KN/m

-unfactored loads = 6.24 KN/m

-factored loads= 1.4*6.24=8.736 KN/m

Load calculation on wall self weigth of wall= 3*18*0.2= 10.8 KN/m

-Unfactored load= 10.8 KN/m

-factored load= 10.8*1.4= 15.12 KN/m

Area and length of tributary area of column

Loading area of column = 2.5*3=7.5m^2

Total length of beam= 2.5+3= 5.5m

Loads calculation on column

Tableau 4.10 : loads calculation on column (3th to 2th)

Unfactored loads	Factored loads
Slab= 4.6*7.5=34.5KN	9.64*7.5= 72.3 KN
Beam=6.24*5.5=34.32 KN	8.736*5.5=48.048 KN
Self weigth of column=0.4*0.4*3*24=4.52 KN	4.52*1.4=16.1 KN
Wall= 10.8*5.5=59.4 KN	15.12* 5.5= 83.16 KN
Load from upper floor= 80.5 KN	121.19 KN
Total= 213.24 KN	340.79 KN

Unfactored load= 213.24 KN

Factored load= 340.79 KN

Reinforcement

Shoot braced columns supporting an approximately symmetrical arrangement of beams

N= 0.35 fcu AC+ 0.7ASfy

$$\boldsymbol{AS = \frac{N-0.35*fcu*AC}{0.7*fy}}$$

Where:

Ac= b*h =400*400=160000mm^2

fy=460N/mm^2

fcu=25N/mm^2

N: factored load

$$AS = \frac{\mathbf{340.79\ KN}-0.35*25*160000}{0.7*460} = -4346mm^2$$

Negative area means that there is no reinforcement required but we provide the minimum wich is equal to 0.4%AC=0.004*160000=640mm^2

Let’s provide **4T16 (804mm2)**

Column from 2th to 1th floor

Load calculation

Load calculation on slab

Slab self-weigth=thickness of slab*unit weigth of RC

Slab self-weigth = 0.15*24= 3.6 KN/m^2

Finishes: 1 KN/m^2

Gk = 4.6 KN/m^2

Qk= 2 KN/m^2

-unfactored loads= 4.6 KN/m^2

-factored load= (1.4*4.6)+(1.6*2)=6.44+3.2=9.64 KN/m^2

Load calculation on beam

Self-weigth of beam=0.4*0.65*24=6.24 KN/m

-unfactored loads = 6.24 KN/m

-factored loads= 1.4*6.24=8.736 KN/m

Load calculation on wall self weigth of wall= 3*18*0.2= 10.8 KN/m

-Unfactored load= 10.8 KN/m

-factored load= 10.8*1.4= 15.12 KN/m

Area and length of tributary area of column

Loading area of column = 2.5*3=7.5m^2

Total length of beam= 2.5+3= 5.5m

Loads calculation on column

Tableau 4.11 : loads calculation on column (2^{sd} to 1st)

Unfactored loads	Factored loads
Slab= 4.6*7.5=34.5KN	9.64*7.5= 72.3 KN
Beam=6.24*5.5=34.32 KN	8.736*5.5=48.048 KN
Self weigth of column=0.4*0.4*3*24=4.52 KN	4.52*1.4=16.1 KN
Wall= 10.8*5.5=59.4 KN	15.12* 5.5= 83.16 KN
Load from upper floor=213.24 KN	340.79 KN
Total= 345.8KN	560.398KN

Unfactored load= 345.8KN

Factored load= 560.398KN

Reinforcement

Shoot braced columns supporting an approximately symmetrical arrangement of beams

N= 0.35 fcu AC+ 0.7ASfy

$$AS = \frac{N-0.35*fcu*AC}{0.7*fy}$$

Where:

Ac= b*h =400*400=160000mm^2

fy=460N/mm^2

fcu=25N/mm^2

N: factored load

$AS = \frac{560.398\,\boldsymbol{KN} - 0.35*25*160000}{0.7*460} = -4346mm^2$

Negative area means that there is no reinforcement required but we provide the minimum wich is equal to 0.4%AC=0.004*160000=640mm^2

Let’s provide **4T16 (804mm2)**

Column from 1st to grand floor

Load calculation on slab

Slab self-weigth=thickness of slab*unit weigth of RC

Slab self-weigth = 0.15*24= 3.6 KN/m^2

Finishes: 1 KN/m^2

Gk = 4.6 KN/m^2

Qk= 2 KN/m^2

-unfactored loads= 4.6 KN/m^2

-factored load= (1.4*4.6)+(1.6*2)=6.44+3.2=9.64 KN/m^2

Load calculation on beam

Self-weigth of beam=0.4*0.65*24=6.24 KN/m

-unfactored loads = 6.24 KN/m

-factored loads= 1.4*6.24=8.736 KN/m

Load calculation on wall self weigth of wall= 3*18*0.2= 10.8 KN/m

-Unfactored load= 10.8 KN/m

-factored load= 10.8*1.4= 15.12 KN/m

Area and length of tributary area of column

Loading area of column = 2.5*3=7.5m^2

Total length of beam= 2.5+3= 5.5m

Loads calculation on column

Tableau 4.12 : loads calculation on column (1st to grand floor)

Unfactored loads	Factored loads
Slab= 4.6*7.5=34.5KN	9.64*7.5= 72.3 KN
Beam=6.24*5.5=34.32 KN	8.736*5.5=48.048 KN
Self weigth of column=0.4*0.4*3*24=4.52 KN	4.52*1.4=16.1 KN
Wall= 10.8*5.5=59.4 KN	15.12* 5.5= 83.16 KN
Load from upper floor=345.8KN	560.398 KN
Total= 476.54 KN	740.68KN

Unfactored load= 476.54 KN

Factored load= 740.68KN

Reinforcement

Shoot braced columns supporting an approximately symmetrical arrangement of beams

N= 0.35 fcu AC+ 0.7ASfy

$$\boldsymbol{AS = \frac{N - 0.35 * fcu * AC}{0.7 * fy}}$$

Where:

Ac= b*h =400*400=160000mm^2

fy=460N/mm^2

fcu=25N/mm^2

N: factored load

$$AS = \frac{740.6\boldsymbol{KN} - 0.35*25*160000}{0.7*460} = -4345.5mm^2$$

Negative area means that there is no reinforcement required but we provide the minimum wich is equal to 0.4%AC=0.004*160000=640mm^2

Let's provide **4T16 (804mm2)**

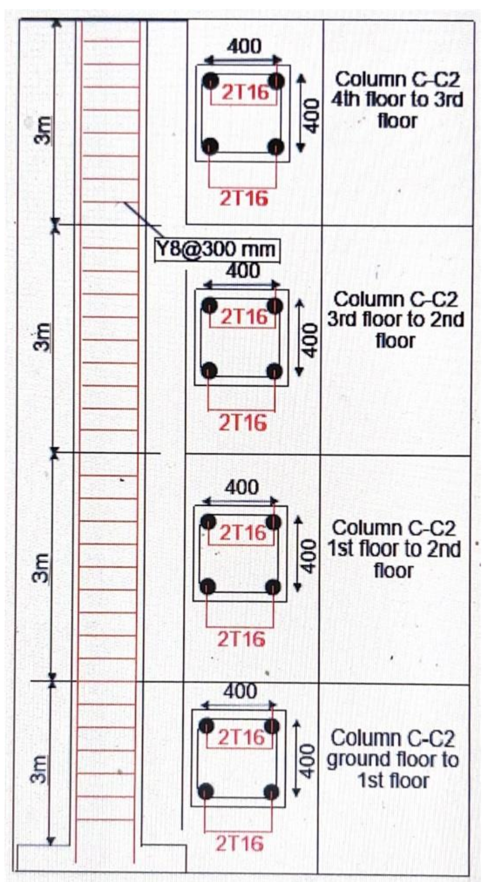
-Size or diameter of stirrups = ¼ of the largest bar = 16/4= 4mm

-12* diameter main bar= 12*16=192mm

- the smallest cross-sectional dimension of the column=400mm

Stirrups of 8mm diameter will be used, spaced at **300mm**

Tableau 4.13section of the column



4.2.4. FOOTING DESIGN

Dimension specification

The column 400*400

The safe bearing pressure is assumed to be 300 KN/m^2

Fcu =30 Mpa and fy= 460 Mpa

Serviceabity load Nm= 476.54 KN

Ultimate load Nm= 740.68KN

Footing area= (serviceability load+ 10% of serviceability load)/Bearing capacity of soil

Footing area= $\frac{476.54+47.654}{300}$=1.74m^2

Side of footing =$\sqrt{1.74mm^2 =}$1.31mm^2, let take 2.5 m square footing to have our foundation safe:

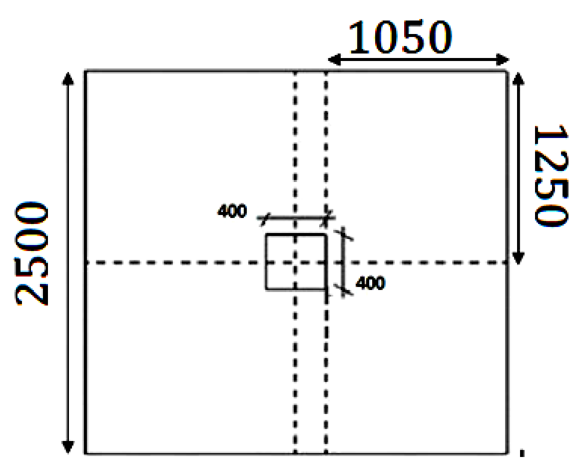


Figure 4.13 : footing parameters

Real pressure = $\frac{476.54KN}{2.5^2} = 76.24kn/m2$

The ultimate bearing capacity = $\frac{740.68KN}{2.5^2}$ = 118.49 KN/m^2

(design stress<bearing capacity)= foundation is safe

Bending reinforment

Length of the beyong the face of the column= (2-0.4)/2 = 0.8m

The critical section at the column face is show in the figure below :

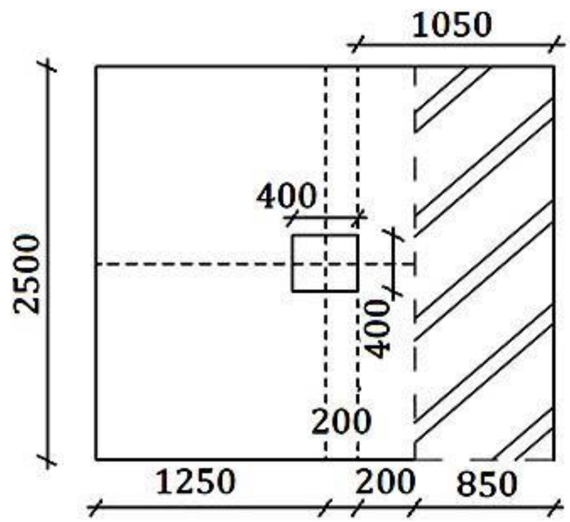


Figure 4.14 : **critical section at the column face**

Moment along x-axis

$$mx = \frac{pu*b*l^2}{8} = \frac{118.49*2.5*2.5^2}{8} = 231.42kn/m$$

Moment along x-axis

$$my = \frac{pu*b^2*l}{8} = \frac{118.49*2.5*2.5^2}{8} = 231.42kn/m$$

Mmax = 232.42KN/m

$$d = \sqrt{\frac{Mmax}{0.156*fcu*b}} = \sqrt{\frac{231.42*10^6}{0.156*25*1000}} = 243.37mm$$

K= $\frac{M}{fcubd^2} = \frac{231.42*10^6}{25*1000*243.37}$ = 0.155< kbal=0.156

No compression reinforcement required

Z/d= 0.5 + $\sqrt{0.25 - \frac{k}{0.9}} > 0.95$

Z/d= 0.5 + $\sqrt{0.25 - \frac{0.155}{0.9}} = \ 0.78 < 0.95$

Take Z = 0.78d = 0.78* 243.37 = 189.83mm

As = $\frac{M}{0.95\ fy\ Z}$= $\frac{232.42*10^6}{0.95*460*189.83} = 2800.26$ mm2

Late provide **5T25**

As provide = 3927mm2

Check punching shear

Earth pressure : 223.40 KN/m^2

Critical perimeter = (3d+ 400)*4 = (3*243.37)*4 = 2920.44mm

Area within perimeter= (2500*2500)-(3d+400)= 6250000-533060.61= 5716939.38mm^2

=5.71m^2

Pouching force = pu*critical area= 118.49*5.71=676.577 KN

Pouching shear dress U=$\frac{pouching force}{critical perimeter} = \frac{676.577}{2920.44} = 0.23 N/mm^2$

$$uc = \frac{0.79}{1.25}(\frac{100As}{bd})^{\frac{1}{3}}\ (\frac{400}{d})^{\frac{1}{4}}$$

$$uc = \frac{0.79}{1.25}(\frac{100*3927}{1000*243.37})^{\frac{1}{3}}\ (\frac{400}{243.37})^{\frac{1}{4}} = 0.79 N/m^2$$

Uc>C the footing will fail under pouching, we need to increase the thickness of footing pouching shear check in using d= 600mm

Z/d= 0.5 + $\sqrt{0.25 - \frac{k}{0.9}} > 0.95$

Z/d= 0.5 + $\sqrt{0.25 - \frac{0.155}{0.9}} = \ 0.78 < 0.95$

Take Z = 0.78d = 0.78* 600 = 468mm

As = $\frac{M}{0.95\ fy\ Z}$= $\frac{232.42*10^6}{0.95*460*468}$ = 1136.43 mm2

Late provide **5T25**

As provide = 2454mm2

Check punching shear

Earth pressure : 223.40 KN/m^2

Critical perimeter = (3d+ 400)*4 = (3*600)*4 = 8800mm

Area within perimeter= (2500*2500)-(3d+400)= 1.41m^2

Pouching force = pu*critical area= 118.49*1.41=167.07 KN

Pouching shear dress U=$\frac{pouchingforce}{criticalperimeter} = \frac{167.07}{8800} = 0.01 N/mm^2$

$uc = \frac{0.79}{1.25}(\frac{100As}{bd})^{\frac{1}{3}}\ (\frac{400}{d})^{\frac{1}{4}}$

$uc = \frac{0.79}{1.25}(\frac{100*2454}{1000*600})^{\frac{1}{3}}\ (\frac{400}{600})^{\frac{1}{4}} = 1.651 N/m^2$

Uc > uc the footing will resist under punching shear

Face shear

Maximum shear stress Umax occurs at face of column. Hence

Umax= $\frac{N}{column\ perimeter*d}$=$\frac{748.68}{(4*400)*600}$ = 0.77 < permissible = $0.8\sqrt{40} = 5.05$

Transverse shear

Ultimate shear force (v) load on shaded= eath pressure*area = 118.49*(0.45*25) = 1333KN

Design shear stress u is u=$\frac{v}{bd} = \frac{133300}{1000*600} = 0.22 < uc$

No shear reinforment is required

Cracking

The bar spacing does not exceed 7500mm or 3d an minimum reinforcement is less than 3%

Allowable clear spacing of 3 bars = 3d= 3*600= 1800mm

Actual clear spacing < 47000/ fs < 300

Where

$fs = \frac{2*fy*asrequired}{3*asprovide} * \frac{1}{Bb} = \frac{2*460*1136}{3*2454}$=175.96

Then clear spacing<47000/fs<300

Clear spacing= 267.10mm

Let take clear spacing of 125mm according to the table.

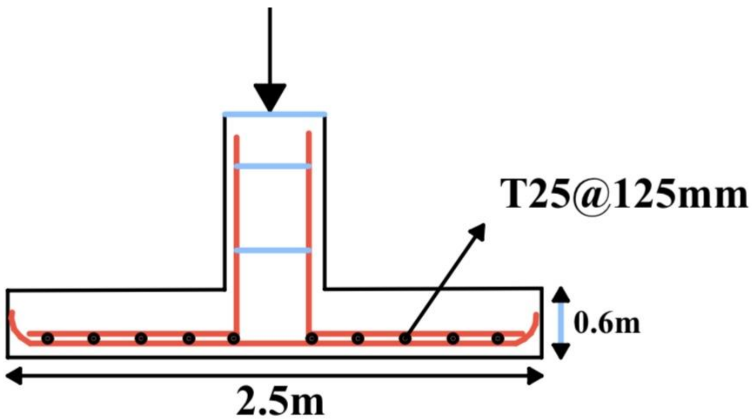


Figure 4.15 section of the footing

4.2.5. DESIGN OF STAIR

Preliminary sizing of stair case members

Height from ground floor slab to first floor slab = 3000mm

Height from ground floor to landing = 3000/2= 1500mm

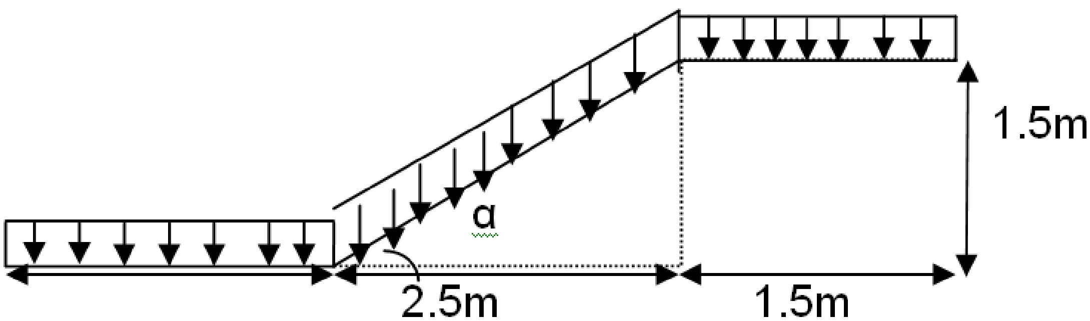


Figure 4.16 : **stair representation**

$tan\Theta = \frac{1.5}{2.5} = 0.06, tan^{-}$ (0.06)= 30.96^{0}

Fligth^2 = 2.5^2+1.5^2 =2.9

Let take 3m

Rises

Assuring a suitable rise when average rise is between 150mm and 300mm, let us take 150mm.

Numbers of rise = flight/150= 20 rises

Goings

550< 2R+D<700 let take 600mm

2R+G=600mm

G=300mm

Number of going = rise-1 = 20-1= 19 goings

Waist of the slab (h)

H=le/20

Where le=effective span

The effective span of simply-supported stair case without stringer beams should be taken as the horizontal distance between supports.

Le=4000mm

H=4000/20=200mm

Average thickness of the staircase

t=2Y+R/2

where R=150mm

y= $h\left(\frac{\sqrt{G^2+R^2}}{G}\right) = 200\left(\frac{\sqrt{300^2+150^2}}{300}\right) = 223.6\ mm\ let\ take\ 224mm$

$t = \frac{2*224+150}{2} = 299mm$

Average thickness of stair case= 300mm

Landing

Self-weight of slab= unit weigth of concrete*waist of landing= 24*0.2=4.8KN/m^2

Self- weigth of slab = unit weigth of concrete*waist of landing = 20*0.2= 4.8KN/m^2

Finishing = 1KN/m^2

Dead load = 4.8 + 1 = 5.8KN/m^2

Design load, n=(1.4*GK)+(1.6*QK)=11.32 KN/m^2

Consider 1m width, nd=n*1m= 11.328KN/m^2 *1m= 11.32KN/m^2

Design load for landing(n)=11.32KN/m^2

Figure

W= (load landing) + load from staircase

W=(11.328KN/m^2 *1*6)+ 11.32= 29.432 kn/m

Vmax= wl/2 =$\frac{29.432*4}{2}$ =58.86 kn

Mmax = $wl^2/8$=$\frac{29.432^2*4^2}{8}$=58.86 knm

Maximum shear V= 58.86kn

Maximum moment M=58.86knm

Let assume Ө main bar

d=h-cover-Ө/2= 200-25-12/2=169mm

$k = \frac{M}{fcubd^2} = 0.082 < kbal = 0.0156$

No compression reinforcement required.

Z=$d\left(0.5 + \sqrt{0.25 - \frac{0.082}{0.9}}\right) < 0.95d = 0.89d < 0.95d$

Let us take z=0.89*169=150.41 mm

$Asreq = \frac{M}{0.95fyz} = \frac{126.70*10^6}{0.95*460*150.41} = 895.49\ mm^2$

Provide **8T12 (901mm^2)**

Asmin = $\frac{0.13Ac}{100} = \frac{0.13*1000*169}{100} = 219.7\ mm^2$

As min< as req < as max the condition is verified.

Check for shear

$U = \frac{V}{bd} = \frac{58.86*10^3}{1000*169} = 0.34N/mm^2$

Vu= 0.8 $\sqrt{fcu} = 4N/mm^2$

U<Vu, then ultimate shear ok!!!!

Vc=$\frac{0.79}{1.25}(\frac{100As}{bd})^{\frac{1}{3}}(\frac{fcu}{25})^{\frac{1}{3}}(\frac{400}{d})^{\frac{1}{4}}$

Vc=$\frac{0.79}{1.25}(\frac{100*901}{1000*169})^{\frac{1}{3}}(\frac{25}{25})^{\frac{1}{3}}(\frac{400}{169})^{\frac{1}{4}}$

Vc=0.632*0.81*1*1.24= 0.634N/mm^2

Shear capacity = 0.634 N/mm^2>shear stress = 0.34 N/mm^2 hence no shear reinforcement is required.

Check for deflection

Modification factor for tension reinforcement M.F:

$MF = 0.55 + \frac{477-fs}{120(0.9+m/bd^2}$

$\frac{M}{bd^2} = \frac{58.86*10^6}{1000*169^2} = 2.06$

$fs = \frac{2}{3}*fy*\frac{Asreq}{Asprov}*\frac{1}{bb} = \frac{2}{3}*460*\frac{895.49}{901}*\frac{1}{1} = 304.79$

$MF = 0.55 + \frac{477-304.79}{120(0.9+2.06)} = 1.03 < 2$

Permissible effective span/ depth = 20.8*1.03= 21.424

Actual span/ depth< permissible span/d, hence ok !!

Flight

Self-weight for the slab = unit weight of concrete*average thickness= 24*300*10^{-3}= 7.2 kn/m^2

Finishing= 1kn/m^2

Dead load = 7.2+1= 8.2 kn/m^2

Imposed load=2kn/m^2

Design load n = (1.4* GK)+(1.6*QK)= 10.08+3.2= 13.28 kn/m^2

Design load of flight n= 13.28 knm

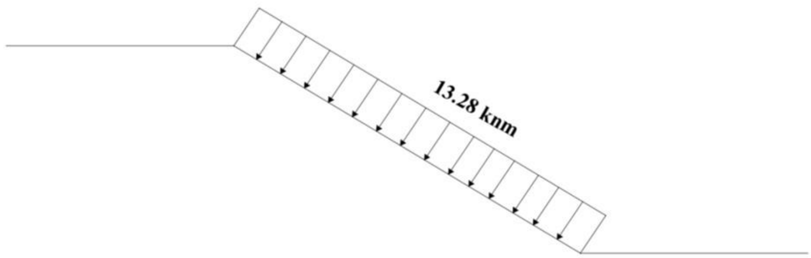


Figure 4.17 : moment on stair flight

$M = \frac{fle}{10}$

Where F=w*l= (13.28*2.5)= 33.2kn

$M = \frac{3.2*4000}{10} = 13280N = 13.28KN$

b=1000mm and d= thickness of slab or waist-cover-Θ/2

the bar diameter Θ is assumed to be 12mm

d=200mm-25m-12/2=169mm

$k = \frac{M}{fcubd^2} = \frac{13.28*10^6}{25*1000*169^2} = 0.018 < kbal = 0.156$

No compression reinforcement required

Z= $d\left(0.5 + \sqrt{0.25 - \frac{0.018}{0.9}}\right) > 0.95d = 0.97d > 0.95d$

Let us take z=0.95d=0.95*169= 160.55 mm

$Asreq = \frac{M}{0.95fyz} = \frac{13.28*10^6}{0.95*460*150.41} = 188.75\ mm^2$

Provide 2T12 (226mm^2)

As min = $\frac{0.13AC}{100} = \frac{0.13*1000*169}{100} = \ 219.7\ mm^2$

As max =$\frac{4AC}{100} = \frac{4*1000*169}{100} = 6760\ mm^2$

As min > AS req < As max, the condition is not verified As provide will be between As min and As max but near As min.

As prov= 226mm^2

∑Ma=0.13.28+(V_B*2.5)-13.28-(13.28* 2.5^2/2)

2.5V_B=13.28+13.28+(13.28*3.125)

2.5V_B=41.5

V_B= 41.5/2.5=16.6 kn

∑fy=0, V_B+V_A=13.28*2.5

V_B+V_A= 33.2

V_A= 33.2-16.6=16.6 kn

Max shear = 16.6kn

Shear stress design

U=$\frac{v}{bd} = \frac{10.6*10^6}{1000}$= 0.098N/mm^2

Vu=0.8$\sqrt{fcu}\ = 4\ N/mm^2$

U<Vu, then ultimate shear ok !!!

Vc=$\frac{0.79}{1.25}(\frac{100As}{bd})^{\frac{1}{3}}\ (\frac{fcu}{25})^{\frac{1}{3}}\ (\frac{400}{d})^{\frac{1}{4}}$

$Vc = \frac{0.79}{1.25} (\frac{100*226}{1000*169})^{\frac{1}{3}} (\frac{25}{25})^{\frac{1}{3}} (\frac{400}{169})^{\frac{1}{4}}$

Vc= 0.38N/mm^2

Shear capacity = 0.38 N/mm^2>shear stress = 0.098 N/mm^2 hence no shear reinforcement is required.

Check for deflection

Modification factor for tension reinforcement M.F:

$$MF = 0.55 + \frac{477 - fs}{120(0.9 + m/bd^2}$$

$$\frac{M}{bd^2} = \frac{13.28*10^6}{1000*169^2} = 0.46$$

$$\text{fs} = \frac{2}{3} * \text{fy} * \frac{\text{Asreq}}{\text{Asprov}} * \frac{1}{\text{bb}} = \frac{2}{3} * 460 * \frac{188.75}{226} * \frac{1}{1} = 256.12$$

$$\text{MF} = 0.55 + \frac{477 - 256.12}{120(0.9 + 0.46)} = 1.9 < 2$$

Permissible effective span/ depth = 20.8*1.9 = 39.52

Actual span/depth ratio= lx/169=2500/169=14.79

Actual span/ depth< permissible span/d, hence ok !!

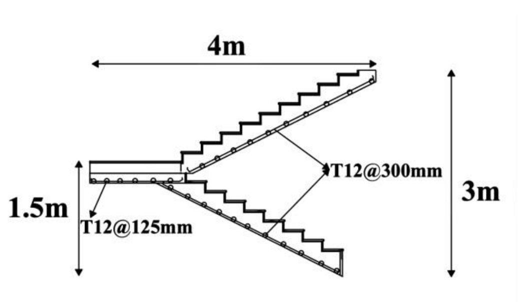


Figure4.19: section of the stair

4.3. DISCUSSION

Slab Design

The slab was designed with a cover of 25mm, a thickness of 15cm, and an effective depth of 12.495cm. The provided reinforcement was As = 20mm² with T8 bars at 250mm center-to-center spacing. The slab was evaluated for deflection and was found satisfactory, with both maximum positive and negative moments being adequately resisted. Shear reinforcement was not required, as the shear stress of 0.13 N/mm² was well below the shear capacity of 0.48 N/mm². To prevent cracking, a bar spacing of 251mm was used, which is less than the permissible spacing of 3d (373.5mm).

Beam Design

The beam was designed with a total height of 50cm, which aligns with the requirements of ly/15 and ly/8. The beam flange width was 133.33cm, and the height of the beam was 40cm. The design load was 221.52kN/m, and reinforcement was provided with 3T16 bars (603mm²) for all beams. Shear reinforcement was deemed unnecessary as the shear stress (0.38 MPa) was less than the shear capacity (0.443 MPa). The beam met deflection criteria with an actual span-to-depth ratio (8.71) well below the permissible ratio (41.6).

Column Design

The most loaded column, labeled C-C2, was chosen for detailed design. A square column with dimensions 400mm x 400mm was assumed. The effective heights were 2350mm along the major axis and 2391mm along the minor axis. The column was classified as a braced short column, meeting the conditions for bracing with (lex/h) and (ley/h) both less than 15. The column was designed for a total unfactored and factored load from the roof to the ground floor, with 4T16 (804mm²) reinforcement provided. Spacing was set at 300mm using 10mm diameter bars, and 8mm stirrups were used.

Footing Design

The footing design was based on a soil bearing capacity of 300 kN/m^2, typical for Kigali. The serviceability load was 476.54 kN, with an ultimate load of 740.68 kN. After calculating the footing area required, a square footing of 2.5m x 2.5m was chosen, which was sufficient to keep the design stress within the soil's bearing capacity. The footing depth was increased to 600mm to resist punching shear, and the spacing of reinforcement was set at 335mm.

Stair Design

The stair was designed for a height of 3000mm between the ground and first-floor slabs. The flight length was 3m, with an angle of 30.96°, ensuring suitable use with a rise of 150mm. The stairs had 20 risers and 19 goings, each 300mm in dimension. For the landing, reinforcement of 8T12 (901mm^2) was provided, and no shear reinforcement was required as the shear stress was satisfactory. The stair design was adequate for deflection, with actual span-to-depth ratios within permissible limits, and 2T16 (226mm^2) reinforcement was provided for the flight, with a moment of 13.28 kNm.

4.4. COST ESTIMATION

Bill of quantity and cost estimation substructure

SN	Description	Unit	Quantity	Rate (Rwf)	Total amount (Rwf)
	PRELIMINARY WORKS (provisional)				
	Site clearing	m^2	$1188m^2$		2.376.000
	Enclosure, shack and office	LS	1		2.000.000
	SUBSTRUCTURE				
	EARTHWORKS (Provisional)				
	Excavation and site leveling				
	Excavation works and site leveling prior to setting out and foundation works to include hauling of excavated soil from construction site.	LS	1		6.500.000
	Excavation works for foundation to include maintaining and supporting trenches sides and keeping them free from water, mud and fallen materials				
	For column bases (footings)	m^3	86.25	50.000	4.312.000
	FONDATION WORKS (Provisional)				
	Vibrated reinforced concrete for:				
	column bases (footings)	m^3	86.25	450.000	38.812.500

	SUB-TOTAL: SUBSTRUCTURE				**54.000.500**
	SUPERSTRUCTURE				
	GROUND FLOOR				
	REINFORCED CONCRETE WORKS				
	Vibrated reinforced concretefor:				
	Columns	m^3	10.56	450.000	4.752.000
	Floor beams	m^3	8	450.000	3.600.000
	Slab	m^3	24	450.000	10.800.000
	Masonry wall				
	Bricks	Nr	13 650	300	4.095.000
	Mortar	m^3	7.3	200.000	1.460.000
	SUB-TOTAL: SUPERSTRUCTURE				**24.707.000**
	WALL FINISHES				
	WALL PLASTERING & PAINTING				
	Wall plastering External and Internal walls	m^2	216	15.000	3.240.000
	Painting external and internal Walls	m^2	216	45.000	9.720.000
	Prepare and application of lime plaster to:				
	External and Internal walls	m^2	216	5.000	1.080.000
	SUB-TOTAL: WALL FINISHES				14.040.000

	FLOORING				
	FLOORING				
	Floor tiling with corresponding Tiles	m^2	156.5	80.000	12.520.000
	SUB-TOTAL: FLOORING and WALL FINISHES				**26.560.000**
	WINDOWS				
	Supply and fixation of glazed window with aluminum frames to include locking devices and accessories, painting and all Requirements				
	Double-hung window 1500mm x 1500mm	Nr	4	130.000	520.000
	Double-hung window 100 mm x 100 Mm	Nr.	3	70.000	210.000
	SUB-TOTAL: WINDOWS				**730.000**
	DOORS				
	Double entrance door 2500 mm x 2500 mm	Nr	1	220.000	220.000
	Wooden door 2100 mm x 900 Mm	Nr.	5	130.000	650.000
	SUB-TOTAL: DOORS				**870.000**
	SANITARY APPLIANCES				
	Supply and installation of WC with all accessories and all requirement	Nr.	2	220.000	440.000
	Supply and installation ion of ceramic wash hands basin complete	Nr	3	100.000	300.000

	with accessories and all requirements.				
	SUB-TOTAL: SANITARY APPLIANCES				**740.000**
	SUB-TOTAL:GROUND FLOOR				**53.607.000**
	GRAND TOTAL: GROUND FLOOR AND SUBSTRUCTURE				**107.607.500**

External work

SN	Description	Unit	Quantity	Rate(Rwf)	Total amount (Rwf)
1	Construction of fence	Item	1	10.000.000	10.000.000
2	Parking's and footpaths	Item	1	3.000.000	3.000.000
3	Garden	Item	1	5.000	5.000
	GRAND TOTAL				**13.005.000**

Summary of cost and estimation of the building

SN	ITEM	AMOUNT(RWF)
1	Foundation and ground floor	107.607.500
2	First floor	53.607.000
3	Second floor	53.607.000
4	Third floor	53.607.000
5	External work	13.005.000
	GRAND TOTAL	**281.433.500**

Additional Notes:

- All cost figures are provided in Rwf.
- The estimated costs are based on the information available at the time of estimation and may besubject to change.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The objective of this project was to do the architectural and structural design of a building apartment in Gisozi Gasabo district. Through detailed analysis and careful planning, the objective was attained. The architectural design focus on optimizing space usage while providing a comfortable and aesthetically pleasing in living environment. The design carefully considered the needs of modern living, incorporating practical features such as well-arranged rooms, balconies and efficient circulation areas. In parallel, the structural design which included the slabs, beams, columns, footing and stair was analyzed for stability, safety and durability. Load bearing capacity, material choices, and construction techniques were examined to meet safety standards and ensure the longevity of the structure. Special attention was given to seismic resilience due to Rwanda's location in region with moderate seismic activity. The project also considered environmental sustainability and urban integration. By aligning with modern building standards and contributing to the evolving urban landscape of Gisozi this apartment design will support the area's growth while ensuring long-term viability. Ultimately, this building will not only serve as residence but also enhance the urban aesthetic, providing a lasting and valuable contribution to the community.

5.2. Recommendation

To any students who's inspired by the work done in this project its recommended to give their contribution on the project and work on the design of the remaining items such as, electrical plumbing installations, rainwater

For anyone planning to design a similar building, it's recommended to use different design software tools. This not only speeds up the process but also helps reduce mistakes that might happen when designing by hand.

REFERENCE

1. Imasiku, K., & Ntagwirumugara, E. (2019) An Impact Analysis of Population Growth on Energy-Water-Food-Land Nexus for Ecological Sustainable Development in Rwanda
2. Neville, A. M., & Brooks, J. J. (2010) Concrete Technology
3. Mindess, S., Young, J. F., & Darwin, D. (2003) Concrete Technology
4. Hewlett, P. C. (2004) Lea's Chemistry of Cement and Concrete
5. Taylor, H. F. W. (1997) Cement Chemistry
6. Kosmatka, Kerkhoff, & Panarese (2002) Design and Control of Concrete Mixtures
7. Mehta, P. K., & Monteiro, P. J. M. (2014)
8. Neville, A.M.(2011)properties of concrete, 5th Edition
9. Kosmatka, S.H.& Wilson, M.l.(2016) design and control of concrete mixture, 16th Edition
10. Allen, E., & Iano, J.(2014). Fundamentals of Building Construction: Materials and Methods.
11. Arya, C. (2022). Design of Structural Elements: Concrete, Steelwork, Masonry and TimberDesigns to Eurocodes. London: CRC Press.
12. Chen, W. F. (2007). Plasticity in reinforced concrete. . New-York: J. Ross Publishing.
13. .Ching, F., & Winkel, S. (2012). Building Co des Illustrated 4thed. Chicago: Wiley.
14. Day, K. W. (2006). Concrete mix design, quality control and specification. London: CRC press. Dodson, V. (2013). Concrete admixtures. Mumbai: Springer Science & Business Media.
15. Elwood, K., & Eberhard, M. (2009). Effective Stiffness of Reinforced Concrete Columns. ACIStructural Journal , 10 (4).
16. Galambos, T., & Ravindra, M. (1981). Load and resistance factor design. Engineering Journal,AISC , 18 (3), 78-84.
17. Gambhir, M. (2008). Design of reinforced concrete structures. Chicago: PHI Learning Pvt. Ltd.

18. Imasiku, K., & Ntagwirumugara, E. (2019). An impact analysis of population growth on energy- water-food-land nexus for ecological sustainable development in Rwand. Food and Energy Security , 9 (1).

19. Iyengar, K. (2015). Sustainable architectural design: An overview. New-York: Routledge.

18. Smith, P. (2016). Structural design of buildings. New-York: John Wiley & Sons.

19. Sreeshna, K. (2016). Analysis and Design of an Apartment building. IJISET– InternationalJournal of Innovative Science, Engineering & Technology , 3 (3), 456-479.