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ULK POLYTECHNIC INSTITUTE (ULK)

DEPARTMENT OF CIVIL ENGINEERING

OPTION: CONSTRUCTION TECHNOLOGY

ACADEMIC YEAR: 2023-2024

Submitted in partial fulfillment of the requirements for the award of an advanced diploma in Construction Technology.

Presented by: UWIMANA Jean Baptiste

Roll number: 202150071

Under the guidance of: Eng. Emmanuel RUKUNDO

Kigali, October 2024

DECLARATION

I do hereby declare that the work presented in this dissertation is my own contribution to the best of my knowledge. The same work has never been submitted to any other University or Institution. I, therefore declare that this work is my own for the partial fulfilment of the award of a Bachelor's degree with honors in Civil engineering at ULK POLYTECHNIC.

The Candidate name: UWIMANA Jean Baptiste

Signature of the candidate: …………………………………………………………

Date of submission: ………………/…………………………/……………………..…

APPROVAL

This is to certify that the dissertation work entitled “INTEGRATED DESIGN OF A SUSTAI

NABLE APARTMENT COMPLEX” is an original study conducted by Jean Baptiste UWIMANA, a candidate for the Bachelor degree in Civil Engineering under my supervision and guidance.

The supervisor’s name: Eng. RUKUNDO Emmanuel

Signature of the supervisor: ……………………………………….

Date of submission: ………/…………….../……………………….

DEDICATION

ACKNOWLEDGEMENT

I am indebted to the guidance and help received from everyone in the preparation and realization of this project. I am particularly very grateful to my supervisor, Eng. RUKUNDO Emmanuel, for the invaluable guidance, constant encouragement, and remarkable suggestions for this project. Their expertise and feedback contributed a lot to shaping mine. I also appreciate the faculty and staff of ULK POLYTECHNIC for the availing of all the facilities and providing a healthy environment for learning.

I owe special gratitude to my family and friends for supporting and understanding my psychological condition, which is responsible for enabling me to complete this work enthusiastically. I thank my classmates and colleagues for the camaraderie, exchange of ideas, and to which the critique given had much influence in the improvement of this project.

Finally, I am grateful to all the others whose names I may not have mentioned, yet they have supported me directly and indirectly in this initiative.

ABSTRACT

This final year project presents an integrated design for a sustainable apartment complex in Ulk Gisozi, aiming to harmonize architectural aesthetics with structural integrity. The primary objective was to develop a robust framework that accommodates the specific needs of the community while adhering to principles of sustainability and environmental responsibility.

The project involved a thorough site analysis and the formulation of design specifications based on key objectives, which included enhancing safety, optimizing resource use, and minimizing environmental impact. Detailed methodologies were applied, encompassing soil testing, load calculations, and compliance with relevant building regulations.

Chapter Four delves into the results and discussions of the structural design, focusing on the analysis of reinforced concrete (RC) members, including beams, columns, slabs, and walls. The design process employed various methodologies, such as manual calculations and software tools, to ascertain the structural viability and safety of the building.

The findings highlight the importance of incorporating sustainable practices into modern construction, illustrating how strategic material selection and innovative design solutions can lead to an efficient and durable structure. Ultimately, the project demonstrates a comprehensive approach to contemporary apartment complex design, serving as a model

for future developments that prioritize safety, efficiency, and ecological balance.

LIST OF FIGURES

LIST OF TABLES

Table of Contents

CHAPTER ONE: GENERAL INTRODUCTION

1.0: Introduction

Designing and constructing apartment buildings remain important in creating the urban phenomenon, which is relevant in its own way. Architectural and structural drawing is the basic step toward planning and completion of projects, which ensure the architectural view and the strength of materials in these projects. The demand for more effective living spaces is growing rapidly, including new innovations and design approaches to incorporate them.

This project addresses the challenge of creating an apartment complex that balances modern architectural aesthetics with robust structural integrity and sustainability. As cities continue to grow, there lies a demand for infrastructure provisioning, and such humane designs are anticipated to make, not just a new demand, but to follow guidelines toward environmental considerations, ensuring a better quality of life for its dwellers.

The main task of this project is to design detailed architectural and structural drawings for a modern apartment building; this includes modern design software to express the plans, elevations, sections, and structural details. Focus on sustainable design principles such as energy efficiency, use of eco-friendly materials, natural light, and ventilation.

This makes the project significant, as it will codify a model for the next coming residential projects that will find ways of being both aesthetic and structurally robust at the same time. The project will attempt to marry this parallel world of innovative design features into sustainable practices in order to become a template of responsible environmental urban living.

It would include detailed architectural and structural drawings of a modern apartment complex and show just how important good design is for sustainability and functionality in contemporary architecture.

1.1. Background of the study

Rwanda is undergoing rapid development and urbanization, leading to increased demand for sustainable housing solutions that efficiently utilize the country’s limited land resources. As the nation strives to improve living standards and achieve its Vision 2050 goals, there is a pressing need to develop innovative housing projects that address both environmental sustainability and urban growth.

The Gisozi area, home to the Kigali Independent University (ULK), is a prime location facing accommodation challenges for its staff. Due to the limited availability of safe and quality housing near the institution, ULK employees often encounter difficulties in finding convenient living arrangements, which can impact their well-being and work productivity. Given the university's large landholdings, there is an opportunity to address this issue by creating an apartment complex that provides high-quality, sustainable housing directly on campus.

This project, "Integrated Design of a Sustainable Apartment Complex," aims to explore how ULK can utilize its land to provide adequate housing for its staff, aligning with Rwanda's broader urban development goals. The apartment complex will not only improve the living conditions for ULK employees but also contribute to the Gisozi community by promoting economic growth, offering a model for sustainable construction, and supporting local businesses. By setting a standard for responsible land use and sustainable building practices, this project can serve as a case study for other institutions and developers in Rwanda.

1.2. PROBLEM STATEMENT

This takes place it the cities where demands for buildings for residential purposes remain high in the face of negligible or unsustainable architecture. Space resources are misused with traditional architectural and structural plans; this results in deep-lying problems in managing energy use, poor or meager natural light, minimum or lack of ventilation that is required, among other things. Such issues not only result in a reduction in the quality of life for these residents but can also contribute to wider environmental impacts, particularly through an increase in the consumption of energy as well as carbon emissions. To have to realize that while building technologies are advancing by light-years, tenets on which most of the apartment complexes are founded are on outdated principles of architectural design that do not in any way endorse anything remotely sustainable or close to modern living standards. The gap in design innovation makes the buildings unfriendly for the environment and both uncomfortable and dysfunctional for their occupants.

This project focuses on the specific problem: the need for a comprehensive design approach that fuses the modern architectural aesthetic with sustainable building practices.

The challenge is, thus, to come up with designs relating to the architecture and structure, meeting the maximization of space efficiency, enhancement of natural light and ventilation, and eco-friendly materials requirements.

This project will be focused on the development of detailed architectural and structural drawings of a modern complex of apartments that answer all the noted challenges. Sustainable design principles and innovative architectural solutions through this project will set a model for future residential developments, underlining environmental responsibility and a high living standard.

1.3 Objectives of the study

1.3.1 Main objectives

The main of this project of this project is to make an integrated design of a sustainable apartment complex design an apartment.

1.3.2 Specific Objective

The specific objectives of this project were:

1. To prepare floor plans, sections, elevations, site plans and perspectives
2. To investigate the bearing capacity of the soil.
3. To design the columns, beams, slab and stairs

1.4 Scope and Limitation of Project

Project Scope

The research covers aspects that are directly attributed to the design and structure of a contemporary apartment facility; the project involves the creation of full-fledged architectural and structural designs and entails the aspects of sustainable design.

- Design Elements:
- The architectural design will include floor plans, elevations, sections, and interior layouts developed to use the space efficiently and to be visually and spatially comfortable.
- The structural design will mainly consist of detailed drawing for the building framework whose elements are the foundations, columns, beams, and slabs to ensure design integrity

and safety.

 Technological Tools:

 The design in this project will be performed using developed design software supported by the use of AutoCAD for the architectural drawings and Revit for BIM in developing the design so that it can be accurate and scalable.

 Below are other tools applied to the structural analysis and sustainability assessment to assure environmental soundness, competitiveness, and user friendliness of the design.

 Sustainability Features

 The study would utilize designing a method that comprises concepts for sustainable materials, energy-efficient technologies that will encourage conservation of energy, and some green building practices such as natural lighting and ventilation, use of renewable energy such as solar panels

 Environmental impact assessment will be carried out to ensure that the project will be of minimum ecological footprint

 regulatory Compliance

 All designs shall comply with all local building, zoning and safety laws and standards so far as in effect at the date of completion.

 All certifications and signoffs by local authorities having jurisdiction will be obtained to evidence the design.

Project Limitations:

The research is not without its limitations, primarily due to resource challenges. The project is constrained by time, which inherently limits the depth and breadth of the research. Budgetary restrictions may further impede the ability to conduct comprehensive field studies and simulations, potentially impacting the overall robustness of the findings. Despite these challenges, the research aims to provide valuable insights into the design and sustainability of modern apartment facilities. The project is time-constrained, with the budget being another constraint likely to be limiting in terms of any depth and breadth of research. Proper field studies and thorough simulations might not be afforded in terms of time and resources for this project.

1.5 Significance of Study

1.5.1 Personal Significance

It is a normal practice for the final year students at Ulk Polytechnic institute to work on a project related to our studies. The personal interest of the student in the subject of this research is also our devotion to participate in the sustainable development of our country. This project allowed me to be familiarized with planning, design and analysis of structures for civil engineering software like ArchiCAD 24,

1.5.2 Academic Significance

Apart from student a well-executed final year projects showcase the quality of education and the skills students graduate with. This can enhance the school's reputation and attract potential students seeking a program that emphasizes real-world application. also, the project supervision process allows faculty members to demonstrate their expertise and guidance in specific areas of study. this can contribute to a positive perception of the school's faculty and the program's depth.

Projects can foster a culture of innovation and research within the school. Investigating new ideas and contributing to knowledge in a particular field can enhance the school's reputation for cutting-edge education. Certain projects might involve collaboration with external organizations, fostering industry partnerships and potentially leading to internship or job opportunities for future graduates

1.5.3 Social Significance

The apartment complex project will greatly benefit ULK by providing convenient, safe, and high-quality housing for its staff, which can help increase employee satisfaction and productivity. By utilizing the available land on campus, the project supports efficient land management and promotes sustainable development, aligning with Rwanda's urban growth strategies.

For the broader society, this apartment complex will contribute to the local community by offering modern housing solutions and setting a benchmark for future developments. It will also stimulate local economic growth through construction activities and create long-term opportunities for businesses around the complex. Overall, the project will enhance the living standards of ULK staff while positively impacting the surrounding community.

1.7 Organization of Study

This project is made up of five chapters where:

Chapter one: General introduction includes background of the study, problem statement, objectives, significance of the project, justification and delimitation of the project,

Chapter two: Literature review deals the literature review will include theories concerning architectural design.

Chapter three: this includes Materials and methods, Methodology will give information about location of site, different techniques applied to obtain information and data required and structural design methods and materials to be used.

Chapter four: Results and discussion will deal with result of structural design. Structure analysis calculations and discussion about the results and

Chapter five: conclusions and recommendations will state the output of the project and give some suggestions.

CHAP TWO: LITERATURE REVIEW

2.0 Introduction

The purpose of this literature review is to explore and synthesize existing research and scholarly articles related to the architectural and structural design of apartment complexes. This chapter aims to provide a comprehensive understanding of the foundational principles, current standards, and innovative practices within the field. By examining various aspects of design, from historical precedents to contemporary advancements, this review will highlight the evolution and integration of architectural and structural elements in apartment complexes. Additionally, the review will address the growing emphasis on sustainability and the impact of technological advancements on design processes.

2.1 Main reason to design

The primary aims of reinforced concrete design are to ensure the safety, durability, and functionality of structures while optimizing material usage for cost-effectiveness. This involves achieving an adequate load-bearing capacity to withstand various forces, such as tension, compression, shear, and torsion. Methods in reinforced concrete design typically include determining the appropriate sizes and reinforcement ratios for concrete members, ensuring proper placement and anchorage of steel reinforcement, and adhering to relevant codes and standards for design and construction. Design techniques often employ limit state design principles, which consider ultimate and serviceability limit states to ensure both safety and usability throughout the structure's lifespan.

Mosley, W. H., Bungey, J. H., & Hulse, R. (2012). Reinforced Concrete Design to Eurocode 2. Palgrave Macmillan.

2.2 Architectural Design

Principles of Architectural Design

Architectural design in apartment complexes revolves around creating functional, aesthetic, and sustainable living spaces. Key principles include:

- Functionality: Ensuring that the design meets the needs of its residents, including efficient use of space and ease of access (Ching, 2014).
- Aesthetics: Incorporating elements that enhance visual appeal and reflect cultural and contextual considerations (Unwin, 2013).
- Sustainability: Integrating eco-friendly materials and energy-efficient systems to reduce environmental impact (Vale & Vale, 2000).
- Safety and Compliance: Adhering to building codes and regulations to ensure the safety and well-being of occupants (Rudolph, 2016).
- Prominent architects and scholars, such as Le Corbusier and Frank Lloyd Wright, have significantly influenced these principles through their innovative approaches and theories. Their work emphasizes the importance of harmony between human habitation and the built environment, advocating for designs that cater to both aesthetic enjoyment and practical use (Curtis, 1996).

2.3 Structural Design

2.3.1 Definition of Structure

In the realm of architectural and structural design, the term "structure" refers to the framework that supports and shapes a building or complex, ensuring its stability, integrity, and safety. It encompasses the physical components that bear loads and resist forces, enabling the construction to stand upright and withstand various environmental stresses.

The primary functions of a structure include:

Load-Bearing: Structures must support both dead loads (permanent or static forces such as the building's own weight) and live loads (temporary or dynamic forces such as occupants, furniture, and environmental factors like wind and snow) Stability: Ensuring the building remains stable under various conditions, including seismic activity, wind pressure, and other potential disturbances Durability: The ability to endure wear and tear over time, resisting degradation due to factors like weather, usage, and material fatigue

Safety: Protecting occupants and contents by maintaining structural integrity and preventing collapse or failure (Ching, 2014).

The structure of a building typically includes several key components:

Foundation: The base that anchors the building to the ground, distributing loads to the soil

Framework: The skeletal structure, often composed of columns, beams, and load-bearing walls, which supports the floors and roof

Floors and Roofs: Horizontal planes that provide functional spaces and protection from the elements

Walls: Vertical elements that can be either load-bearing or non-load-bearing, serving both structural and spatial purposes

Understanding the principles of structural design is crucial for creating safe and functional buildings. Engineers and architects must collaborate closely to ensure that the aesthetic vision of a project aligns with structural requirements, thereby achieving a harmonious and effective design (Salvadori, 2002).

2.3.2 Reinforced Concrete Structures

Reinforced concrete is a composite material commonly used in the construction of apartment complexes due to its strength, durability, and versatility. It combines the compressive strength of concrete with the tensile strength of steel, resulting in a material that can withstand significant loads and stresses.

2.3.3 Principles of Reinforced Concrete Design

Reinforced concrete structures rely on a combination of materials and design principles to achieve their strength and functionality:

Material Composition: Concrete provides compressive strength, while steel reinforcement (rebar) offers tensile strength. The concrete protects the steel from corrosion and fire while the steel provides the necessary ductility and flexibility

Load Distribution: In reinforced concrete structures, loads are distributed through the concrete to the steel reinforcement, allowing the structure to handle various types of stresses and forces

Durability and Maintenance: Proper mix design, placement, and curing of concrete, along with adequate cover over the reinforcement, are essential for ensuring the long-term durability of reinforced concrete structures

Flexibility in Design: It can be molded into various shapes and forms, allowing for architectural creativity and flexibility

Cost-Effectiveness: Although the initial cost can be high, reinforced concrete structures require less maintenance and have a longer lifespan, making them cost-effective in the long term (Mamlouk & Zaniewski, 2017).

2.4 Concrete

Concrete is a widely used construction material composed of a mixture of cement, water, aggregates (such as sand, gravel, or crushed stone), and sometimes admixtures. It is known for its durability, versatility, and relatively low cost, making it suitable for a variety of building and infrastructure projects. When mixed, the cement reacts with water through a process called hydration, which hardens and binds the aggregates into a solid mass. Concrete can be molded into different shapes and forms before it sets, and its strength can be enhanced by reinforcing it with steel bars, known as rebar. (Neville, 2011).

2.4.1 Selection of Type of Concrete

The selection of the type of concrete for apartment complexes depends on several factors, including structural requirements, environmental conditions, and specific construction needs. The primary considerations include:

Strength Requirements: High-strength concrete is often chosen for structural elements like columns and beams to support heavy loads and multi-story buildings (Neville, 2011).

Durability: In environments exposed to harsh weather, chemical exposure, or heavy wear, durable concrete mixtures with appropriate additives and low permeability are selected to ensure longevity (Neville, 2011).

Workability: For complex architectural designs, highly workable concrete that can be easily molded into intricate shapes is preferred. This is often achieved through the use of admixtures that improve flowability without compromising strength (Neville, 2011).
Sustainability: Sustainable concrete options, such as those incorporating recycled materials or fly ash, are increasingly chosen to reduce environmental impact and improve the building's overall sustainability (Neville, 2011).
Choosing the right type of concrete is crucial for ensuring the structural integrity, durability, and sustainability of apartment complexes.

The table here shows the list of commonly used classes and also the lowest class appropriate various type of construction

Table 1 : : Strength classes of concrete

Class

Lowest class for use as specified

C12/15

C16/20

C20/25

Plain concrete

C25/30

Reinforced concrete

C30/37

C35/45

C40/50

C50/60

Pre-stressed concrete

2.4.2 INGREDIENTS OF CONCRETE

Cement

Cement is a crucial component in concrete, acting as the binding agent that holds the aggregate materials together. Its properties significantly influence the strength, durability, and workability of the concrete. The primary type of cement used in construction is Portland cement, which is composed of clinker (a mixture of limestone and clay) and gypsum.

The selection of cement type depends on several factors:

Strength and Setting Time: Different types of cement have varying rates of strength gain and setting times. For example, high early strength cement is used when quick form removal or rapid construction progress is required (Neville, 2011).

Durability: In environments exposed to aggressive conditions, such as sulfate-rich soils or marine settings, sulfate-resistant cement is preferred to enhance the longevity of the concrete (Neville, 2011)

.

Heat of Hydration: For mass concrete structures like foundations and large piers, low heat cement is used to minimize the heat generated during the curing process and reduce the risk of thermal cracking (Neville, 2011).

Environmental Considerations: Blended cements, which include materials like fly ash or slag, are chosen to improve sustainability and reduce the carbon footprint of concrete production (Neville, 2011).
Proper selection of cement is essential for achieving the desired performance characteristics of concrete in apartment complex construction.

2.4.3 Types of Portland cement

Portland cement types are categorized based on specific characteristics and applications:
Type I: General-purpose cement used in most ordinary concrete construction projects for its versatility and reliability.
Type II: Provides moderate sulfate resistance, making it suitable for environments with moderate sulfate exposure in soil or groundwater.
Type III: Known for its high early strength development, allowing for faster form removal and quicker construction progress.
Type IV: Designed for structures requiring low heat of hydration, such as massive concrete works, to minimize temperature rise during curing.
Type V: Offers high sulfate resistance, ideal for environments with severe sulfate exposure, such as marine structures or areas with high sulfate soils.
These types of Portland cement are selected based on specific project requirements to ensure optimal performance and durability (Neville, 2011).
Cement test.

Two way of testing cement:

- Field test
- Laboratory test

- Field test

Cement Field Tests on Construction Sites

On construction sites, the following field tests are commonly conducted to assess the quality and suitability of cement:

Visual Inspection: Cement bags are inspected for any signs of damage, moisture, or lumping, which could affect its quality.

Sampling: Representative samples of cement are taken from each batch or delivery for further testing or comparison.

Color Test: A simple visual check is performed to ensure the cement color matches the expected standard, indicating consistency in manufacturing.

Smell Test: Cement should have a characteristic odor. Unusual odors may indicate contamination or improper storage.

Temperature Test: Cement temperature is checked to ensure it is within acceptable limits for proper hydration and setting.

Consistency Test: A sample of cement is pressed between fingers to check its feel. It should be smooth and feel cool to the touch, indicating proper fineness and absence of lumps.

Float Test: A small amount of cement is sprinkled on water. It should float briefly before sinking slowly, indicating proper fineness and absence of excessive impurities.

Bulk Density Test: Cement is poured into a container and weighed to determine its bulk density, ensuring it meets specified requirements.

These field tests help verify basic quality parameters of cement on-site before it is used in construction activities.

Note:

These field tests provide preliminary checks to ensure cement quality on construction sites. For comprehensive quality assurance, laboratory tests are also conducted to verify specific properties and performance characteristics of cement.

2.4.4 Laboratory Tests for Cement

Chemical Composition Analysis: Determines the chemical composition of cement, including the percentages of key compounds such as silica, alumina, iron oxide, and calcium oxide. This analysis ensures the cement meets specified standards and requirements.

Fineness Test: Measures the particle size distribution of cement particles using sieves or specific instruments like air permeability apparatus (Blaine test). Fineness affects the cement's hydration rate and strength development in concrete.

Setting Time Test: Determines the initial and final setting times of cement paste using Vicat apparatus or Gillmore needles. Setting times influence construction schedules and concrete workability.

Soundness Test: Assesses the stability of cement against volume changes due to hydration or expansion. This test is crucial for ensuring durability and minimizing cracking in concrete structures.

Compressive Strength Test: Measures the strength development of cement samples by subjecting them to compressive forces in a controlled laboratory environment. This test verifies the cement's load-bearing capacity and performance over time.

Heat of Hydration Test: Determines the heat released during cement hydration, which is critical for assessing potential thermal cracking and controlling concrete curing temperatures in massive structures.

Specific Gravity Test: Calculates the specific gravity of cement to ensure it meets specified density requirements for proper proportioning in concrete mixes.

Chemical Tests: Include tests for sulfate content, alkali content, and chloride content to assess potential chemical reactions that could affect concrete durability and corrosion of reinforcement.

Setting Time and Mortar Consistency: Tests conducted to know how long it takes to set

2.4.5 Aggregates in Concrete

Aggregates are essential components in concrete, comprising granular materials such as sand, gravel, crushed stone, or recycled concrete. They contribute to concrete's volume, stability, and strength, with fine aggregates enhancing workability and coarse aggregates providing mechanical strength and durability. These materials constitute 60-80% of concrete volume, influencing its performance and economy by reducing the need for cement paste and enhancing dimensional stability (Neville, 2011).

Aggregates undergo grading and testing to ensure optimal particle size distribution, cleanliness, and resistance to weathering and chemical degradation. Using locally sourced or recycled aggregates promotes sustainability in construction practices by reducing environmental impact and transportation costs (Neville, 2011).

2.4.6 Aggregate sources

Aggregate sources refer to the origins or types of materials used as aggregates in concrete construction. These materials are essential components that contribute to the volume, stability, and strength of concrete. Here are common sources of aggregates:

Natural Aggregates:

Sand: Typically sourced from rivers, lakes, or quarries. It is fine-grained and used as a fine aggregate in concrete.

Gravel: Extracted from rivers, lakes, or quarries. It consists of rounded stones and is used as a coarse aggregate in concrete.

Crushed Stone: Quarried stone that is crushed and used as both fine and coarse aggregate in concrete.

Manufactured Aggregates: Recycled Concrete Aggregate (RCA): Crushed concrete from demolition waste that can be reused as aggregate in new concrete mixes.

Manufactured Sand (M-Sand): Crushed rock sand produced from hard granite stones, used as a substitute for river sand in concrete.
Slag Aggregates: Slag aggregate is a byproduct of the iron and steel manufacturing process, formed when molten slag is rapidly cooled with water or air, producing a hard, stony material. This aggregate is used in construction for its high density, durability, and stability, making it suitable for road bases, asphalt, and concrete. Its use in construction reduces waste and reliance on natural aggregates, promoting sustainability (Bhardwaj & Kumar, 2019; Provis & van Deventer, 2014).

Blast Furnace Slag: By-product of iron manufacturing processes, used as aggregate after crushing and screening.
Lightweight Aggregates:
Expanded Clay, Shale, or Slate: Lightweight aggregates produced by heating and expanding natural clay, shale, or slate.

Artificial Aggregates:
Fly Ash and Bottom Ash: By-products of coal combustion used as supplementary cementitious materials (fly ash) or as aggregates (bottom ash) in concrete.
Marine Aggregates: Marine aggregate consists of sand and gravel dredged from the seabed, used primarily in the construction industry. These aggregates are valued for their quality and consistency, making them suitable for concrete production, road construction, and other building applications. The extraction of marine aggregates helps to meet the demand for construction materials, particularly in regions where land-based resources are scarce, while also supporting sustainable resource management practices (CEMEX UK, 2020; The Crown Estate, 2013).

Dredged Aggregates: Extracted from the sea bed for construction purposes, often used in coastal or marine engineering projects.

Choosing the appropriate aggregate source depends on factors such as availability, cost, specifications for concrete strength and durability, and environmental considerations. Sustainable practices increasingly emphasize the use of recycled and locally sourced aggregates to reduce environmental impact and transportation costs. (Neville, 2011).

2.4.7 Quality of Good Aggregate

Good aggregate in concrete construction possesses several essential qualities that contribute to the strength, durability, and performance of concrete structures:

Cleanliness and Absence of Contaminants: Good aggregates should be free from organic materials, clay, silt, and other contaminants that can adversely affect concrete setting and durability.

Hardness and Strength: Aggregates should be sufficiently hard and strong to resist crushing, degradation, and wear during handling, mixing, and placement of concrete.

Particle Shape and Surface Texture: Angular or cubical-shaped particles with rough surfaces provide better interlocking and bonding with cement paste, enhancing the overall strength and durability of concrete.

Gradation and Particle Size Distribution: Well-graded aggregates with a balanced distribution of particle sizes (from fine to coarse) improve the packing density of concrete, reducing voids and improving workability.

Specific Gravity and Absorption: Aggregates with appropriate specific gravity and low absorption help achieve proper mix proportioning, reducing the risk of shrinkage and cracking in concrete.

Durability and Resistance to Weathering: Good aggregates should be durable and resistant to weathering, abrasion, and chemical reactions, ensuring long-term performance and durability of concrete structures.

Soundness and Stability: Sound aggregates maintain stability under different environmental conditions, including freeze-thaw cycles and chemical exposure, to prevent deterioration of concrete.

Cleanliness and Lack of Deleterious Substances: Aggregates should be clean and free from harmful substances such as sulfates, chlorides, and organic impurities that could compromise concrete durability and cause corrosion of reinforcement.

Density and Weight: Aggregates with suitable density and weight contribute to achieving desired concrete density and structural weight requirements.

Availability and Cost-Effectiveness: Ideally, good aggregates are locally available to minimize transportation costs and environmental impact associated with concrete production. Neville, A. M. (2011). Properties of Concrete. Prentice Hall.

2.4.8 Properties of good aggregate

Cleanliness: Good aggregates are free from organic matter, clay, silt, and other contaminants that could affect concrete performance and durability.

Hardness: Aggregates should be hard enough to resist crushing, degradation, and abrasion during handling, mixing, and placement of concrete.

Particle Shape: Angular or cubical-shaped particles with rough surfaces provide better interlocking and bonding with cement paste, improving concrete strength.

Surface Texture: Rough surfaces on aggregate particles enhance the bond between aggregate and cement paste, contributing to higher concrete strength and durability.

Particle Size Distribution: Well-graded aggregates with a balanced distribution of particle sizes (from fine to coarse) optimize packing density, reducing voids and improving concrete workability.

Specific Gravity: Proper specific gravity ensures that aggregates contribute to achieving desired concrete density without excessive weight.

Absorption: Low absorption capacity helps prevent excess water absorption, reducing the risk of shrinkage and cracking in concrete.

Durability: Good aggregates are durable and resistant to weathering, chemical reactions, and physical degradation over time.

Soundness: Sound aggregates maintain stability under different environmental conditions, including freeze-thaw cycles, ensuring long-term performance of concrete.

Absence of Deleterious Substances: Aggregates should be free from harmful substances such as sulfates, chlorides, and organic impurities that could impair concrete durability and cause corrosion., A. M. (2011). Properties of Concrete. Prentice Hall.

2.5 Water

Water used in concrete must be clean and free from harmful impurities like oils, acids, salts, and organic materials, as these can adversely affect the concrete's setting time, strength, and durability. Typically, potable water is considered suitable for concrete mixing. The water-to-cement ratio is crucial, as it influences the concrete's workability and strength; a lower ratio leads to higher strength and durability but reduces workability, whereas a higher ratio improves workability but may decrease strength (Portland Cement Association, 2019; Neville, 2011).

2.5.1 Quality of water to use in concrete

The quality of water used in concrete is critical for achieving desired strength and durability. Water must be free from impurities such as oils, acids, salts, alkalis, organic materials, and other harmful substances that can negatively impact the concrete's setting time and long-term performance. Generally, if water is fit for drinking, it is suitable for concrete production. Contaminants in water can cause issues like corrosion of reinforcement, reduced strength, and delayed setting times, making it essential to test water quality before use in concrete mixing (Portland Cement Association, 2019; Neville, 2011).

2.5.2 Curing water

Curing water is essential for maintaining adequate moisture content in concrete after it has been placed and finished, allowing the hydration process to continue. Proper curing ensures the development of desired strength, durability, and resistance to cracking. The water used for curing should be clean and free from contaminants that could negatively affect the concrete. Methods for curing include ponding, spraying, or covering the concrete with wet burlap or plastic sheets to retain moisture (Kosmatka & Wilson, 2016; ACI Committee 308, 2001).

2.6 Concrete mix design

Concrete mix design is the process of selecting suitable ingredients and determining their proportions to create a concrete mix with desired properties such as workability, strength, and durability. The process involves choosing the appropriate types and quantities of cement, water, aggregates, and admixtures. The key parameters in mix design include the water-to-cement ratio, aggregate size and grading, and the inclusion of any supplementary materials. The aggregate size typically ranges from fine particles (sand) to coarse particles (gravel or crushed stone), often between 0.075 mm to 37.5 mm in diameter. The objective is to achieve a balance between performance and cost, ensuring the concrete meets specific structural and environmental requirements (Kosmatka & Wilson, 2016; Neville, 2011).

2.6.1 Factors affecting the choice of mix proportions

The choice of mix proportions in concrete is influenced by several factors, including:

Strength Requirements: The desired compressive strength of the concrete is a primary consideration. Different structural elements may require different strengths, influencing the mix proportions of cement, water, and aggregates.

Durability: The environmental conditions to which the concrete will be exposed play a crucial role. For instance, exposure to harsh weather, chemical attacks, or freeze-thaw cycles will necessitate adjustments in mix proportions to enhance durability.

Workability: The ease with which concrete can be mixed, placed, and finished depends on its workability. Factors like the slump required for the construction process and the type of placement methods used will affect the water-cement ratio and aggregate sizes.

Aggregate Size and Type: The characteristics of the aggregates, including size, shape, and grading, significantly impact the mix proportions. Well-graded aggregates typically lead to better packing and reduced voids, affecting the cement and water requirements.

Water-Cement Ratio: This ratio is critical for determining the strength and durability of the concrete. A lower water-cement ratio generally leads to higher strength and durability but may reduce workability.

Admixtures: The use of chemical admixtures such as superplasticizers, retarders, and accelerators can modify the properties of concrete, allowing for adjustments in mix proportions to achieve the desired characteristics.

Specific Requirements: Some projects may have specific needs, such as lightweight concrete, high-early-strength concrete, or concrete with specific aesthetic finishes, all of which influence the mix design.

Cost: Economic considerations also play a role, with the aim to achieve the desired properties at the lowest possible cost. This involves optimizing the use of materials and possibly incorporating supplementary cementitious materials like fly ash or slag.

Standards and Specifications: Adherence to local and international standards, as well as project specifications, will guide the choice of mix proportions to ensure compliance with regulatory requirements and quality assurance. Neville, A. M., & Brooks, J. J. (2010). Concrete Technology. Pearson.

2.6.2 Admixtures

Admixtures are ingredients added to concrete, other than water, aggregates, and cement, to modify its properties and achieve desired characteristics. They are used to enhance the performance of concrete in various ways. The main types of admixtures include:

Plasticizers (Water Reducers): These improve the workability of concrete without increasing the water content, allowing for easier placement and compaction.

Superplasticizers (High-Range Water Reducers): These are more powerful than plasticizers and can significantly reduce the water content while maintaining workability, resulting in high-strength concrete.

Accelerators: These speeds up the hydration process of cement, allowing concrete to gain strength faster. They are useful in cold weather conditions or when early strength is required.

Retarders: These slow down the setting time of concrete, which is beneficial in hot weather or when long transportation times are involved.

Air-Entraining Admixtures: These introduce tiny air bubbles into the concrete, improving its resistance to freeze-thaw cycles and deicing chemicals.

Pozzolanic or Mineral Admixtures: These include materials like fly ash, silica fume, and slag, which enhance strength, durability, and workability while also reducing the permeability of concrete.

Corrosion Inhibitors: These protect steel reinforcement from corrosion, especially in environments exposed to chlorides, such as coastal areas or de-icing salts.

Shrinkage-Reducing Admixtures: These minimize drying shrinkage and cracking in concrete.

Coloring Admixtures: These are used to give concrete specific colors for aesthetic purposes.

Bonding Admixtures: These improve the bond between new and old concrete surfaces.

Admixtures help achieve specific performance requirements and address challenges during the construction process, ensuring the durability and longevity of concrete structures. Mehta, P. K., & Monteiro, P. J. M. (2014)

2.6.3 Concrete properties

Concrete possesses several important properties that make it a widely used construction material. These properties can be classified into fresh (or plastic) concrete properties and hardened concrete properties.

2.6.4 Fresh Concrete Properties

Workability: This refers to the ease with which concrete can be mixed, placed, compacted, and finished without segregation. It is influenced by the water content, aggregate size and shape, and the presence of admixtures.

Consistency: This is the measure of the wetness or fluidity of the concrete mix. It is typically assessed using the slump test, which indicates the mix's ability to flow.

Segregation: This is the tendency of the components of the concrete mix to separate. Good mix design and proper handling can minimize segregation.

Bleeding: This occurs when water rises to the surface of freshly placed concrete. Excessive bleeding can weaken the surface layer of concrete.

2.6.5 Hardened Concrete Properties

Compressive Strength: This is the capacity of concrete to withstand loads that tend to compress it. It is one of the most critical properties and is typically measured at 28 days after curing.

Tensile Strength: Concrete has relatively low tensile strength compared to its compressive strength. Reinforcement is often added to handle tensile forces.

Flexural Strength: This measures the ability of concrete to resist bending or flexural stresses.

Durability: This refers to the ability of concrete to withstand adverse environmental conditions such as freeze-thaw cycles, chemical attacks, and abrasion. Durable concrete lasts longer and requires less maintenance.

Permeability: This is the ability of concrete to resist the penetration of water or other substances. Low permeability improves durability, especially in structures exposed to aggressive environments.

Shrinkage: This is the reduction in volume of concrete as it dries and hardens. Shrinkage can cause cracking if not properly managed.

Creep: This is the slow, continuous deformation of concrete under a sustained load. It is important to consider in long-term structural design.

Modulus of Elasticity: This measures the stiffness of concrete and its ability to deform elastically when a load is applied. It is an important factor in structural analysis and design.

Thermal Expansion: Concrete expands and contracts with temperature changes. Understanding its coefficient of thermal expansion is crucial in preventing cracking due to

temperature variations.
Fire Resistance: Concrete is inherently fire-resistant due to its non-combustible nature. However, its performance in a fire depends on its composition and the structure's design.
Neville, A. M. (2011). Properties of Concrete.
2.6.6 Factors affecting the relationship between tensile and compressive strength

The relationship between the compressive and tensile strength of concrete is influenced by several factors, including:
Concrete Composition: The mix proportions of cement, water, aggregates, and admixtures can significantly affect the compressive and tensile strengths. Higher cement content generally increases both strengths, but the ratio between them can vary.
Water-Cement Ratio: A lower water-cement ratio usually increases the compressive strength of concrete, but it can make the concrete more brittle, thereby affecting the tensile strength.
Aggregate Characteristics: The type, size, shape, and grading of aggregates influence the bond between the cement paste and the aggregates, which in turn affects both compressive and tensile strengths. Well-graded and angular aggregates typically enhance the tensile strength.
Curing Conditions: Proper curing improves both the compressive and tensile strengths by ensuring adequate hydration of the cement. Poor curing can lead to weaker concrete with a reduced tensile to compressive strength ratio.
Age of Concrete: The relationship between compressive and tensile strength changes over time. Both strengths generally increase with age, but at different rates. Tensile strength development is slower compared to compressive strength.
Type of Cement: Different types of cement (e.g., ordinary Portland cement, high-strength cement) affect the rate and extent of strength development, influencing the compressive-tensile strength relationship.
Admixtures: Chemical and mineral admixtures can alter the microstructure of concrete,

affecting its strength characteristics. For example, superplasticizers can enhance compressive strength without proportionally increasing tensile strength.

Concrete Density: Higher density concrete typically has higher compressive and tensile strengths. Lightweight aggregates or the use of entrained air can lower density and influence the strength relationship.

Microcracks and Flaws: The presence of microcracks, either from drying shrinkage or thermal stresses, can significantly affect tensile strength more than compressive strength, as tensile strength is more sensitive to such imperfections.

Loading Rate: The rate at which loads are applied to concrete can influence its strength characteristics. Higher loading rates typically increase measured compressive strength, but tensile strength may not be similarly affected.

Environmental Conditions: Exposure to aggressive environments, such as chemical attack or freeze-thaw cycles, can degrade concrete, affecting both compressive and tensile strengths and their relationship. Mehta, P. K., & Monteiro, P. J. M. (2014). Concrete: Microstructure, Properties, and Materials. McGraw-Hill Education.

2.7 Tests on concrete

2.7.1 Tests on flesh concrete

Several tests are conducted on fresh (plastic) concrete to assess its properties and ensure it meets the required specifications for a particular application. Key tests include:

Slump Test: This measures the consistency and workability of fresh concrete. A cone-shaped mold is filled with concrete, lifted off, and the amount by which the concrete settles (slumps) is measured. It indicates the fluidity of the mix.

Compaction Factor Test: This test also measures workability, especially for concrete with low workability. It involves determining the ratio of the weight of partially compacted concrete to fully compacted concrete.

Flow Table Test: Primarily used for high workability mixes, this test measures the flow and spread of concrete when subjected to vibration on a flow table.

Vebe Consistometer Test: This measures the time required for concrete to be compacted into a defined shape under vibration. It is suitable for concrete mixes with low to medium workability.

Air Content Test: This determines the amount of entrained air in the concrete mix. Methods like the pressure method or volumetric method (using an air meter) are used. This is important for concrete exposed to freeze-thaw cycles.

Unit Weight Test: This measures the density of fresh concrete. A container of known volume is filled with concrete, and its weight is recorded to calculate the unit weight.

Temperature Test: This involves measuring the temperature of freshly mixed concrete to ensure it is within acceptable limits, which affects setting time and strength development.

Setting Time Test: This assesses the time taken for concrete to start setting (initial set) and to complete setting (final set). The Vicat apparatus is commonly used for this test.

Workability Test using a Kelly Ball: This involves dropping a hemispherical ball onto the surface of fresh concrete and measuring the indentation depth. It provides a quick assessment of workability.

Concrete Penetration Resistance Test: This test measures the resistance of fresh concrete to penetration by a standard probe, providing an indication of setting time and early-age strength development.

Flow Test for Self-Consolidating Concrete (SCC): This test evaluates the flowability and stability of SCC, which needs to fill formwork and encapsulate reinforcement without the need for vibration. The slump flow test and the J-ring test are common methods.

These tests help ensure that fresh concrete has the right properties for placement, compaction, and finishing, leading to durable and high-quality hardened concrete. Neville, A. M. (2011). Properties of Concrete. Pearson Education Limited.

2.7.2 Tests done on dry concrete

Tests on dry (hardened) concrete are crucial to evaluate its performance and ensure it meets design and safety requirements. Some of the key tests performed on hardened concrete include:

Compressive Strength Test: This is the most common test for hardened concrete. Cylindrical or cubic specimens are loaded until failure to determine the concrete's ability to withstand compressive forces.

Split Tensile Strength Test: Cylindrical concrete specimens are placed horizontally and loaded along their length. This test determines the tensile strength of concrete, which is important for understanding its behavior under tension.

Flexural Strength Test: Also known as the modulus of rupture test, it measures the concrete's ability to resist bending. Beams of concrete are loaded at the center while supported at both ends to determine their flexural strength.

Modulus of Elasticity Test: This test measures the stiffness of concrete by determining the relationship between stress and strain. It provides insights into the elastic properties of concrete.

Shrinkage and Creep Tests: These tests assess the long-term deformation of concrete under sustained load (creep) and the reduction in volume over time due to drying (shrinkage). They are critical for understanding long-term performance.

Durability Tests:

Water Permeability Test: Determines the concrete's resistance to water penetration, which is crucial for structures exposed to moisture.

Chloride Ion Penetration Test: Evaluates the resistance of concrete to chloride ion ingress, which can cause corrosion of reinforcement.

Sulfate Attack Test: Assesses the concrete's resistance to sulfate exposure, which can cause deterioration.

Abrasion Resistance Test: Measures the concrete's ability to resist surface wear and erosion, important for floors and pavements subjected to heavy traffic.

Freeze-Thaw Resistance Test: Assesses the concrete's ability to withstand cycles of freezing and thawing, which is critical for structures in cold climates.

Bond Strength Test: Measures the adhesion between concrete and reinforcing steel, ensuring effective load transfer in reinforced concrete structures.

Density and Unit Weight Test: Determines the density of hardened concrete, which can impact its strength and durability.
Carbonation Test: Evaluates the depth of carbonation in concrete, which can affect the pH and lead to corrosion of reinforcing steel.
Electrical Resistivity Test: Measures the concrete's resistance to the flow of electrical current, providing insights into its permeability and potential for corrosion.
Ultrasonic Pulse Velocity Test: Non-destructive test that measures the speed of an ultrasonic pulse through concrete, used to assess uniformity and detect defects.
Rebound Hammer Test: Also known as the Schmidt hammer test, it provides an estimate of the concrete's compressive strength by measuring the rebound of a spring-loaded mass impacting the concrete surface.
Core Testing: Involves extracting cylindrical samples from existing structures and testing them for compressive strength and other properties to assess in-situ concrete quality.
These tests provide a comprehensive understanding of the hardened concrete's mechanical properties, durability, and overall performance, ensuring that it meets the necessary standards and specifications. Neville, A. M. (2011). Properties of Concrete. Pearson Education Limited.

2.8 Concrete operations

Concrete operations encompass the various stages and processes involved in producing, handling, and placing concrete in construction projects. Key operations include:
Mix Design: This is the process of determining the proportions of cement, water, aggregates, and admixtures to achieve the desired properties of concrete. Factors such as strength, workability, durability, and economy are considered.
Batching: This involves measuring and combining the ingredients of concrete (cement, water, aggregates, and admixtures) in specified proportions. Batching can be done by

volume or by weight, with weight batching being more accurate.

Mixing: The materials are mixed to form a uniform and homogeneous concrete. Mixing can be done using various types of mixers, such as drum mixers, pan mixers, or continuous mixers, depending on the volume and specific requirements.

Transporting: Once mixed, concrete needs to be transported to the construction site. This can be done using trucks (transit mixers), dumpers, wheelbarrows, or even pumps for larger distances or difficult access areas.

Placing: This is the process of depositing the mixed concrete into the desired location within the formwork. Care must be taken to avoid segregation and ensure even distribution.

Compacting: After placing, concrete must be compacted to remove air voids and ensure proper consolidation. This is typically done using internal or external vibrators, hand tamping, or roller compacting, depending on the concrete type and application.

Finishing: Once compacted, the concrete surface is finished to achieve the desired texture and appearance. Finishing operations include screeding (leveling), floating (smoothing), troweling (polishing), and texturing (creating a specific surface finish).

Curing: Curing involves maintaining adequate moisture, temperature, and time to allow the concrete to achieve its intended properties. Methods include water curing (sprinkling, ponding), covering with wet burlap or plastic sheets, and applying curing compounds.

Formwork Removal: Formwork or molds are removed once the concrete has gained sufficient strength to support its own weight and any imposed loads. The timing of formwork removal is critical to avoid damage to the concrete.

Jointing: In concrete pavements and slabs, joints are provided to control cracking due to shrinkage and temperature changes. This includes contraction joints, expansion joints, and construction joints.

Surface Treatment: Depending on the application, additional surface treatments may be applied, such as sealing, coating, or applying decorative finishes to enhance durability and aesthetics.

Quality Control: Throughout the entire process, various tests and inspections are conducted to ensure the concrete meets the specified standards and requirements. This includes testing for workability, strength, and other properties both in the fresh and hardened states.

Repair and Maintenance: After construction, regular inspections and maintenance are performed to address any issues such as cracks, spalling, or surface wear, ensuring the longevity and performance of the concrete structure.These operations are critical for ensuring the quality, durability, and performance of concrete in various construction applications. Kosmatka, S. H., Kerkhoff, B., & Panarese, W. C. (2011). Design and Control of Concrete Mixtures. Portland Cement Association.

2.8.1 Failures in concrete structures.

Factors affecting failure

Concrete structures can fail due to a variety of factors. Here are some of the most common ones:

Material Quality:

Poor Quality Concrete: Using low-grade or improperly mixed concrete can compromise the structure's strength .

Substandard Reinforcement: Poor quality or inadequately protected reinforcing steel can corrode and weaken the structure.

Design Flaws:

Inadequate Design: Insufficient consideration of loads, structural analysis, or incorrect design assumptions can lead to failure.

Improper Detailing: Errors in reinforcement detailing, such as inadequate lap splices or insufficient cover, can cause weaknesses.

Construction Practices:

Improper Curing: Inadequate curing of concrete can lead to reduced strength and durability.

Poor Workmanship: Errors during placement, compaction, or finishing can create defects such as honeycombing or cold joints.

Environmental Factors:

Corrosion: Exposure to chlorides, sulfates, or other aggressive chemicals can corrode reinforcement and deteriorate concrete.

Freeze-Thaw Cycles: Repeated freezing and thawing can cause cracking and spalling in concrete.

Loading Conditions:

Overloading: Exceeding the design load limits can cause structural distress or collapse.

Impact Loads: Sudden impact loads, such as those from vehicle collisions, can damage concrete structures.

Durability Issues:

Alkali-Silica Reaction (ASR): A chemical reaction between alkalis in cement and reactive silica in aggregates can cause expansion and cracking.

Carbonation: The reaction of carbon dioxide with calcium hydroxide in concrete can reduce alkalinity, leading to reinforcement corrosion

Maintenance and Repair:

Neglect: Lack of regular maintenance can allow minor defects to develop into major issues.

Improper Repairs: Using incorrect materials or methods for repairs can exacerbate existing problems or introduce new ones.

Foundation Issues:

Settlement: Uneven or excessive settlement of the foundation can cause cracking and structural instability.

Soil Conditions: Expansive soils or poor load-bearing soils can lead to differential settlement and structural damage.

Understanding these factors and taking preventive measures during design, construction, and maintenance phases can significantly reduce the risk of failure in concrete structures

Neville, A. M., & Brooks, J. J. (2010). Concrete Technology. Pearson Education.

Reinforcement in concrete

Reinforcement in concrete refers to the incorporation of steel bars, mesh, or fibers within the concrete mix to enhance its tensile strength and ductility. Concrete is strong in compression but weak in tension, and reinforcement helps to address this weakness by carrying the tensile forces. The most common type of reinforcement is deformed steel bars (rebar), which have surface ridges to improve bonding with the concrete. The placement and amount of reinforcement are critical and must be carefully designed to ensure the structural integrity and durability of the concrete element. Properly reinforced concrete can better resist cracking and structural failure, extending the lifespan of the structure.

MacGregor, J. G., & Wight, J. K. (2012). Reinforced Concrete: Mechanics and Design. Pearson.

Steel reinforcement

Steel reinforcement, commonly known as rebar, possesses several key properties that make it an ideal material for reinforcing concrete structures:

High Tensile Strength: Steel has a high tensile strength, which allows it to absorb significant tensile forces that concrete alone cannot withstand.

Ductility: Steel is ductile, meaning it can undergo significant deformation before failure, providing warning signs of structural distress before catastrophic failure.

Bonding with Concrete: Steel has a good bonding affinity with concrete, especially when deformed bars are used. This bond ensures that the steel and concrete act together under load.

Thermal Compatibility: The thermal expansion coefficient of steel is similar to that of concrete, which minimizes differential thermal expansion and contraction issues.

Corrosion Resistance: While steel can corrode, protective measures such as proper concrete cover, coatings, and the use of corrosion-resistant steel alloys can enhance its durability in aggressive environments.

Elasticity: Steel has a well-defined yield point and elastic modulus, allowing engineers to predict its behavior under loads accurately.

Availability and Workability: Steel is widely available and can be easily fabricated into various shapes and sizes to suit different structural requirements.
Fatigue Resistance: Steel reinforcement can withstand cyclic loading conditions, which is crucial for structures subjected to repetitive stresses, such as bridges and high-rise buildings. MacGregor, J. G., & Wight, J. K. (2012). Reinforced Concrete: Mechanics and Design. Pearson.

2.9 Method used in design

2.9.1 Design Methodology

The recommended method is limit state design where account is taken of theory, experiment and experience. It is added that calculations alone are insufficient to produce a safe, serviceable and durable structure. Correct selection of materials, quality control and supervision of construction are equally important.
The criterion for design to be considered safe is that the structure should not become unfit for use, in other words it should not reach a limit state during its design life.

2.9.2 Criteria for safe design-limit states

The criteria for safe design in reinforced concrete structures focus on limit states, which include the ultimate limit state (ULS) for safety against collapse and the serviceability limit state (SLS) for functionality under normal usage. ULS ensures the structure can withstand maximum expected loads without failure, while SLS ensures comfort and usability by limiting deflections, vibrations, and cracks

ultimate limit state

The Ultimate Limit State (ULS) in reinforced concrete design ensures that structures can safely withstand maximum loads without collapsing. This involves considering factors like material strength, load combinations, and safety factors to prevent structural failure under extreme conditions, such as heavy loads, earthquakes, or strong winds. Pillai, S. U., & Menon, D. (2009). Reinforced Concrete Design. Tata McGraw-Hill.
Values of partial factor safety for materials for the ultimate limit state

Table 2 : Values of partial safety factor for materials for the ultimate limit state (BS 8110-1:1997, table 2)

Reinforcement(prestressed steel included)

1.05

Concrete in flexure or axial load

1.50

Shear strength without shear reinforcement

1.25

Bond strength

1.40

Others (e.g. bearing stress)

≥1.50

The main ultimate limit states and provisions are as follows

Strength: Ensures the structure can handle the highest loads without collapsing. This includes dead loads (permanent/static loads), live loads (temporary/moving loads), environmental loads (wind, earthquake, snow), and accidental loads (impact, explosions).

Stability: Ensures the structure remains stable under critical load conditions, preventing buckling or overturning.

Robustness: ensures that structures can withstand unforeseen events without collapsing disproportionately. Key aspects include redundancy (multiple load paths), ductility (ability to deform without failing), continuity (strong connections), and alternative load paths. These features help maintain stability under accidental loads such as impacts or explosions.

Provisions:

Adequate cross-sectional dimensions.

Sufficient and correctly placed reinforcement.

Proper design of joints and connections.

Use of safety factors to account for uncertainties in material properties, load estimations, and construction quality.

Serviceability limit states

reinforced concrete design ensures that a structure remains functional and comfortable under normal usage. It addresses:

Deflection: Limiting excessive bending to avoid damage and discomfort.

Cracking: Controlling crack width to prevent reinforcement corrosion and maintain aesthetics.

Vibration: Ensuring vibrations are within acceptable levels for comfort and structural integrity.

Durability: Ensuring the structure can withstand environmental conditions over its lifespan.

These considerations help maintain the usability and longevity of the structure. Pillai, S. U., & Menon, D. (2009). Reinforced Concrete Design. Tata McGraw-Hill.

Characteristic and design load

Characteristic Load refers to the load values that are not expected to be exceeded during the structure's lifetime, typically defined with a probability of exceedance of 5% or less. These include dead loads (permanent/static loads like the structure's own weight), live loads (temporary/moving loads such as occupants and furniture), and environmental loads (like wind, snow, and seismic forces).

Design Load is the load used in structural design, incorporating safety factors to account for uncertainties in the loads and material properties. It ensures that the structure can safely handle more than the expected maximum load. Design loads are calculated by multiplying characteristic loads by load factors specified in design codes and standards. Pillai, S. U., & Menon, D. (2009). Reinforced Concrete Design. Tata McGraw-Hill.

Load combinations

Load combinations in structural design involve combining various types of loads to account for different scenarios that a structure might experience during its lifetime. This ensures the structure's safety and serviceability under various conditions. The main types of loads considered include dead loads, live loads, wind loads, snow loads, and earthquake loads.

Design codes provide specific guidelines for combining these loads.

Common Load Combinations:

Dead Load + Live Load:

1.4×Dead Load+1.6×Live Load

Dead Load + Live Load + Wind Load:

1.2×Dead Load+1.2×Live Load+1.2×Wind Load

Dead Load + Live Load + Earthquake Load:

1.2×Dead Load+1.2×Live Load+1.2×Earthquake Load

These combinations are used to ensure that structures can safely withstand the different types of forces they will encounter throughout their service life. Pillai, S. U., & Menon, D. (2009). Reinforced Concrete Design. Tata McGraw-Hill.

Table 3 : Load combination (Bath, 2002)

CHAPTER THREE: RESEARCH AND METHODOLOGY

3.0 Introduction

Methodology is the systematic study of methods that are, can be, or have been applied within a discipline. Clearly, methodology approach depends on the type of work or research. The selected methodology approach usually dictates the success of a research. Thus, a research whose aim is to provide architectural design and structural design, as well as will provide related information to design process.

3.1. Choice of methodology

The right methodology for architectural and structural design of an apartment complex is the key to the success and efficiency of the process. It provides for a properly done design, with all the goals of the project met, including architectural and structural parts combined and up to the norms and standards of regulations and sustainability. Correctly chosen methodology provides for systematic and full design procedure that can be easily adapted to the needs and peculiarities of the project at hand.

The choice of a convenient methodology used in that research normally drives the successfulness of the research. If you have carried out a convenient research methodology, it is easy to get good results. Certain information is necessary to provide architectural design and structural design and will provide related information on the design process.

3.2. Techniques and methods used for data collection

3.2.1. Techniques0

Documentation

is method is oriented toward systematic research of all documents related to the project. In this project, this method will be used by reading different books and researching on the internet to understand how architectural design and structural design is done.

Observation

In this project "Architectural and Structural Design of an Apartment Complex," observation is coupled with the review and verification of design elements. Basically, it concerns the assurance of full compliance of architectural and structural plans with all regulations, client requirements, and standards governing the industry. Through observation and periodic review of the design process, possible problems can be detected at an early stage and thus solved, hence coherent, compliant, and efficient design before actual execution.

Methodology

In general, both quantitative and qualitative methods may be applied in research projects. In this project, we make use of quantitative methods.

Quantitative Methods

Quantitative research involves an investigation of numerical properties and phenomena, and their relationships. What is aimed at is to come up with mathematical models, theories, and hypotheses relevant to the project. Measurement becomes important since it provides a connection between empirical observations and mathematical expressions of relationships.

Following is the application of quantitative methods in this project:

Architectural Design:

Site Analysis: Gathering numerical data pertaining to site conditions, topography, and climate and analyzing them to inform the design.

Design Development: Measurements and calculations are used to make an in-depth architectural plan.

Sustainability: Numerical data will be applied in assessing and providing the sustainable design features.

Structural Design:

Load Calculations: Perform quantitative analysis in determining loads and how to ensure that the structure is stable.

Structural Analysis: The performance of the structural system is analyzed with the help of mathematical models and software.

Detailing: On the basis of the analysis, numerical specifications and detailed drawings are prepared.

Integration and Quality Assurance:

Coordination: Quantitative data helps in the integration of architectural and structural designs.

Compliance: Ensure that all the numerical calculations done are according to the regulatory standards and requirements.

Quality Control: Put in place numerical methods that control and ensure design accuracy throughout the project.

SOFTWARE USED

The following software tools are used in this project:

ArchiCAD: It is used for detailed architectural design and will permit the modeling and visualization of the apartment complex in detail. ArchiCAD will help in making very accurate architectural plans and include the integration of sustainable design features in it.

Prokon: Loading calculation and performance evaluation are done with the help of Prokon, which will provide all the necessary details related to analysis and simulation for the structural integrity of this design.

These will be indispensable in refining the architectural and structural elements of the project.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1. Introduction

An RC member formed structural unit comprises of beams, columns, slabs and walls which are interconnected in a rigid manner as to constitute a single structural frame. Hence the determination of these forces is among the key aspects of the design process the design of each member must satisfy these forces. Once the conceptual framing of the rigid concrete frame is done a thorough analysis of the frame may not be that straightforward; however, some rough estimates of the frame can often be performed once the overall functioning of the system is grasped.'

4.2. Analysis of the structure

To start with the wall systems which are built shall be calculated with respect to the integral loads of all other systems within them dry walls. Wall systems are bands and induces loads at either fixed or growth fitment assemblies. Many of the loads are variable in magnitude and position so there is a need to consider all possible critical arrangements of loads. First the structure itself is rationalized into simplified forms that represent the load-bearing mechanisms of the prototype. The calculation of internal forces within functionally distinct structural members is accomplished by one the several possible approaches including the following:

- Manual calculations
- Applying moment and shear coefficient

This particular reinforced concrete structure design aims at the ultimate limit state principles of design.

4.3. Structure Design

The RC design is one of the processes for the building construction in question. It is known that the purpose of the RC design is to enhance the safety of the structure. Major structural elements of reinforced concrete s. Built-in slabs, beams, columns, ramp footings and stair case. They are reinforced against bending or shear

The design of the reinforced concrete incorporates the following criteria:

-It is presumed that the concrete will not act in tension.

-The plane surface of a structural member remains a plane after the member is subjected to bending.

-It is defined that the maximum strain in concrete will be 0.0035 at the ultimate limit state.

-The distribution of strain in the concrete and strain in reinforcing steel is linear up to a certain distance from the neutral axis.

-Partial safety factors for loads

The load actually used in the design iscalled the design;it is the product of the load and the relevant factor γf

DL= γf *characteristic load

γf for a characteristic dead load I 1.4 and for live load

γf is 1.6

DL =1.4GK*1.6QK

-partial safety factors for material strength, according to BS8110 part 1,

γm is 1.15 for steel and 1.5 for concrete

loadings

the building regulations BS 1881

Relevant building

Regulations and Design Code

Commercial building intended use of the building

Roof-imposed 1.5KN/m2

Finishes 1.5 kn/ m2

-floor imposed and partitions 5kn/

Floor –Imposed and partitions 5 kN/m2

Stair -imposed 5kn/m 2 Stairs –Imposed 5 kN/m2

Apartiment building intended use roof imposed 3kn/m

-finishes 1.5kn/m 2

General loading condition

According to soil test result given by the worker in charge of ULK geotechnical laboratory,

the bearing capacity of ULK compound is 350kn/m2

Reinforced concrete structure (footing, beams, slab and stairs):

- concrete grade 30 with 20mm max.

Aggregate and mix ratio 350kg /m3

-Reinforcement:

Characteristic strength fy =460N/mm2

For stirrups fyv =250N/mm2

Material data

Self-weight of reinforced concrete 25kn/m3

Self-weight of masonry =18kn/m3

Self-weight of plaster =20kn/m3

Loads from the ceiling = 0.25 kn/m2

The structure analysis and reinforced concrete design calculations will be done by the use of computer software called PROKON and manual calculations

4.3.1Slab design

Figure4. 1. Critical panel

Types of panel: 760/570=1.33

For 1.33 is lesser than 2, our slab is a two-way slab.

Thickness of the slab ranges between lx/40 and lx/20

570/40= 14.25 cm

570/20=28.5 cm

Let us use the thickness of 20 cm

- characteristic dead load per square meter =1*1*.2*25kn/cu.meter = 5kn/m2
- characteristic live load per square meter =3kn/m2

4.1.4. Column design

Figure4. 2. Critacal column

Figure4. 3. Influance area

LOAD CALCULATIONS

Self-weight from Column with the height of 4.5 ml :1.4*0. 4*0.5*4.5*25 =31.5 kN

Self-weight from Column with the height of 3.5 ml :1.4*0. 4*0.5*3.5*25 =24.5 kN

Loads from the slab = 1.4*26.3*0.2*25=184kn

Loads from the beams =1.4*10.3*0.2*0.65*25 =40.5 kN

Loads from walls =1.4*4.85*0.2*2.85*18 =69.6 kn

Loads from wall plaster =1.4*4.85*3.3*2*0.03*20 =26.9 kn

Loads from floor finishes = 1.4*26.3*1.5 =55.2 kn

Loads from the ceiling = 1.4*26.3*0.25 =9.2 kn

Live loads = 1.6*26.3*3=126.2 kn

- Loads carried by a column in the basement lever N1 = total load

  dead load: [6(184+40.5+69.6+26.9+55.2+9.2)+(6*24.5)+31.5+(184+40.5+55.2)] = 2770.6KN

  Live load = 126.2*7 = 886.9 kn

  Total design load = 2770.6 kn +886.9 kn =3657.5 kn

- Loads carried by the column in ground floor lever N2

dead LOAD : [5(184+40.5+69.6+26.9+55.2+9.2)+(6*24.5)+(184+40.5+55.2)] kn

= 2353.7 kn

Live load = 126.2*6= 757.2 kn

Total design load = 2353.7 kn +757.2 kn =3110.9 kn

- Loads carried by the column at first floor lever N3

dead load: [4(184+40.5+69.6+26.9+55.2+9.2)+(5*24.5)+(184+40.5+55.2)] kn

= 1943.8 kn

Live load = 126.2*5= 631 kn

Total design load = 1943.8 kn +631 kn =2574.8 kn

- Loads carried by the column at second floor lever N4

dead load: [3(184+40.5+69.6+26.9+55.2+9.2)+(4*24.5)+(184+40.5+55.2)] kn

= 1533.8 kn

Live load = 126.2*4= 504.8 kn

Total design load = 1533.8 kn +504.8kn =2038.6 kn

 Loads carried by the column at third floor lever N5

dead load: [2(184+40.5+69.6+26.9+55.2+9.2)+(3*24.5)+(184+40.5+55.2)] kn

= 1123.9 kn

Live load = 126.2*3= 378.6 kn

Total design load = 1124 kn +378.6 kn =1502.6 kn

 Loads carried by the column at fourth floor lever N6

dead load: [1(184+40.5+69.6+26.9+55.2+9.2)+(2*24.5)+(184+40.5+55.2)] kn

= 714 kn

Live load = 126.2*2= 252.4 kn

Total design load = 714 kn +252.4 kn =966.4 kn

 Loads carried by the column at fifth dead load :(24.5+ 184+40.5+55.2) kn = 304.2 kn

Live load = 126.2 kn

Total design load = 304.2 kn +126.2 kn =430.4 kn

4.1.5. Footing design

I am going to design the footing by considering the total design load carried by the basement column that I calculated, equals to 3657.5 kn and with reference to the bearing capacity of ULK compound that the worker who is in charge of ULK geotechnical laboratory (Eng. NKIRANUYE Bonaventure) has told me which equals to 350kn/m2.

The total design load was given as found in the previous data of column design like this

Loads carried by a column in the basement lever N1 = total load

dead load: [6(184+40.5+69.6+26.9+55.2+9.2)+(6*24.5)+31.5+(184+40.5+55.2)] = 2770.6KN

Live load = 126.2*7 = 886.9 kn

Total design load = 2770.6 kn +886.9 kn =3657.5 kn

Characteristic dead load =2770.6/1.4= 1979 kn

Characteristic live load =886.9/1.6 = 554.31 kn

Total characteristic load = 1979+554.31 =2533.31 kn

By considering W =10% of total characteristic load

W= 10%*2533.31 kn

W=253.33 kn

Service load = dead load + live load +W

Service load =2533.31+253.33= 2786.64 kn

Area of footing = service load /bearing capacity

Area = 2786.64kn /350kn/m2

Area = 7.9 m2

Size of the square footing is given by the square root of the area

Size = QUOTE 7.9 = 2.8m by 2.8m

Design pressure = design load / area of footing

=3657.5 kn/2.8m*2.8 m

= 466.51 kn/m2

The design pressure is greater than the bearing capacity

Proposed size of column = 3.5m*3.5m

Design pressure = 3657.5kn / 3.5m*3.5m

= 298.5kn/m2

Height of footing = (3.5+0.5)/4 =1m

Moment on y-y = pressure *(af-ac)/2 *af*(af-ac)/4

= 298.5*1.55*3.5*0.775

= 1255knm

Moment on x-x=298.5*1.5*3.5*0.75

=1175knm

M max = 1255knm

K =M/fcubd2m

K = 1255*106/30*3500*1002

K = 0.01

Z = d (0.5+ QUOTE (0.25-k/0.9))= 870mm

Ast = M/0.95fyz = 1255*106/0.95*460*870 =3300mm2/m

Number of bars = 20Y16 @180

4.1.6. Beam design

Figure4. 4. critical beam

L max : 580cm

 Height of the beam =ranges between lmax/12 and lmaz /8

580cm/ 12 = 48cm

580cm /8 =72.5 cm

Let us use H = 65 CM

- Size of the breadth of the web ranges between h/3 and h/2

65/3 = 21 cm

65/2=32.5 cm

Let us use BW =25 cm

Figure4. 5. Support condition

Our beam is supported by 4 columns and it has 3 spans

Span 1 and span 2 are supporting an influence are of 25.062 square meters

Span 3 and span 4 are supporting an influence area of 16.358 square meters

Span 1and span 2

- Loads from the slab = 1.4*25.062*0.2*25kn/cu.meter =175.42 KN
- Loads from the beam =1.4*0.25*0.45*7.6*25 kn/cu.meter=30KN
- Loads rom the walls =1.4*0.2*3.2*2.85*18kn/cu.meter= 46 KN
- Loads from plaster =1.4*0.03*3.2*2.85*20kn/cu.meter =15.32 KN
- Loads from screeding =1.4*25.06*1.5kn/sq. meter =52.6 KN

Total design dead load = summation =319.34 kn

UDL = 319.34 /7.6 =42.01 Kn/m

Live load = 1.6*25.062 *3kn/sq. meter =120.3 kn

UDL = 120.3/7.6 =15.83kn/m

Span 3 and pan 4

- loads from the beam =1.4*12.3*0.25*0.45*25kn/cu.meter =38.58KN
- loads from wall = 1.4*12.3*2.85*0.2*18kn/cu.meter = 176.7 KN
- loads from plaster =2*1.4*12.3*2.85**0.03*20cu.meter =58.89 KN

- loads from screeding =1.4*16.3*1.5 kn/sq. Meter

total dead load =summation =422.86kn

UDL =422.86/8.1 = 52.20kn/m

live load 1.6*16.34*3kn/sq. meter =78.43KN

UDL =78.43/8.1 =9.68 kn/m

Point load

- Load from the slab =0.5* 1.4*2.09*0.2*25kn/cu.meter =7.3 KN
- Loads from wall = 0.5*1.4*3.1*2.85*0.2*18 kn/cu.meter =31.12 KN
- Loads from plaster = 0.5*1.4*3.1*2.85*0.03*20kn/cu.meter =3.7KN
- Loads from screeding =0.5*1.4*2.09*1.5kn/sq. Meter = 2.2 KN

Total design dead load =summation =44.32KN

live load = 0.5*1.6*2.09*3kn/meter = 5 KN

4.1.7. Stair design

Figure4. 6. Stairs case

Number of goings =24 pcs each has 31 cm

Number of goings of 1 fight =8 pcs

Height of one flight =3.5/3 =1.16m

Number of flights = 3

Number of risers =25 risers each has 14 cm

Length of the horizontal distance =2.19+1.25+ 0.5(02+0.2) =3.64 m

Length of going of flight= (number of goings * size of goings) + 0.5(lb1 +lb2)

=(8*0.31)+ 0.5(0.2+0.2)= 2.68 m

C = √ A2 +B2

C =√1.162+ 2.682=2.92 m

Angle of the pitch =tan-1 (1.16/2.68) = 23.4 =24 degrees

Thickness of the waist

D = lx /26

3.64/26 = 0.14m =14 cm

Thickness of the waist = d + cover+ 0.5 *diameter of main bar

14+2.5+5= 19.5 cm =20 cm

Load calculation

1 landing

Design dead load = 1.4*0.2*1*25 kn/cu.meter =7 kn/m2

design live load = 1.6*3 =4.8 kn/m2

total design load = 12.94 +8.88 =11.8 kn/m2

landing load =11.8*1.46*1.36=23.43 kn

2 stair slab

Design dead load =1.4*0.2*2.92*1.36*25 kn/cu.meter=27.8 kn

Live load =1.6*2.68*1.36*3 kn/sq. meter=17.5 kn

Total design load = 27.8+17.5 =45.3 kn

Total load on the span =45.3kn +23.43 kn =68.73 kn

Moment = w*L/10

L = 2.68cm+1.46= 4.14 m

Moment = 68.73*4.14/10= 28.45 knm

K= m/fcubd2

K= 28.45*106/30*1460*1402= 0.03

Z=d(0.5+√(0.25-k/0.9))

z=d(0.5+√(0.25-0.03/0.9))= 0.96d

We are going to use z = 0.95d

Z =0.95*140=133mm

As= M/0.95 fy z =28.45*109/0.95*460*133

As REQUIRED= 486mm2/m

As provided =549 mm2/m = 7Y10 @160mm

Conclusion

In conclusion, the architectural and structural design of the apartment complex was driven by a detailed understanding of both building design principles and structural integrity. The project successfully integrated architectural aesthetics with structural functionality, utilizing thorough site analysis and strategic selection of construction materials and structural systems.

Through the process of soil testing, load calculations, and compliance with regulatory standards, we ensured that the building is safe, sustainable, and well-suited to the site conditions. Environmental sustainability was also prioritized, aligning the project with green building principles to minimize environmental impact.

Overall, this project represents a comprehensive approach to modern apartment complex design, meeting both functional and aesthetic needs while supporting long-term durability. It serves as a valuable contribution to sustainable infrastructure and provides a model for future developments that prioritize safety, efficiency, and environmental responsibility.

CHAPTER FIVE: CONCLUSION AND RECOMMANDATIONS

5.1. CONCLUSION

In conclusion, the architectural and structural design of the apartment complex was driven by a detailed understanding of both building design principles and structural integrity. The project successfully integrated architectural aesthetics with structural functionality, utilizing thorough site analysis and strategic selection of construction materials and structural systems.

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Overall, this project represents a comprehensive approach to modern apartment complex design, meeting both functional and aesthetic needs while supporting long-term durability. It serves as a valuable contribution to sustainable infrastructure and provides a model for future developments that prioritize safety, efficiency, and environmental responsibility.

5.2. RECOMMANDATIONS

Given the scope of this project, I recommend prioritizing a comprehensive design approach that integrates functionality, safety, and sustainability. This will ensure that the housing solution not only meets the immediate accommodation needs of ULK staff but also enhances their well-being and supports long-term institutional goals.

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APPENDIX

Perspective Views

Perspective 1

Perspective 2

Perspective 3

Perspective 4

Perspective 5

4.2.2. Floor Plans

Ground floor plan

Foundation layout

First floor plan to fifth floor

Roof slab

Front side

Back side

Left side

Right side

2

2

2

2

2

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