DESIGN OF ELEVATED WATER TANK AND TOWER STRUCTURES

BY

MUNONYE, Jadon Munajah

ENG2002170

A PROJECT SUBMITTED IN

PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING (B.ENG).

IN

THE DEPARTMENT OF STRUCTURAL ENGINEERING,

FACULTY OF ENGINEERING,

UNIVERSITY OF BENIN,

BENIN CITY, NIGERIA

OCTOBER, 2025.

PLAGIARISM

This project on “Design of Elevated Water Tank and Tower Structures” by MUNONYE, Jadon Munajah, Mat. No. ENG2002170, of the Department of Structural Engineering, University of Benin City, Edo State. Nigeria, has PASSED the PLAGIARISM TEST.

PROJECT COORDINATOR

Name: Engr. I. O. ABOLAGBA

Signature and Date: ....

CERTIFICATION

This is to certify that this work was carried out by **MUNONYE, Jadon Munajah**, Mat. No. **ENG2002170**, of the Department of Structural Engineering, Faculty of Engineering, University of Benin, Edo State, Nigeria.

PROJECT SUPERVISOR

Name: ENGR. PROF. O. C. IZINYON

Signature: ……………………………… Date: …………………………………….

HEAD OF DEPARTMENT

Name: PROF. R.I. UMASABOR

Signature: ……………………………… Date: …………………………………….

DEDICATION

I dedicate this work to Jehovah God who has given me the Strength, Guidance, Knowledge, and Protection throughout this Project.

ACKNOWLEDGEMENT

I wish to convey my deep appreciation to my Project Supervisor, Engr. Prof. O. C. Izinyon, for his intellectual support, cooperation, and guidance throughout the supervision of this research work. I would also like to extend my heartfelt appreciation to the Department of Civil Engineering and to all my lecturers who have willingly imparted knowledge and contributed immensely to my academic growth. These include, but are not limited to: Prof. O.U. Orie, Prof. S.O. Osuji, Prof. H.A.P. Audu, Prof. S.D. Iyeke, Prof. A.N. Aniekwu, Engr. Prof. J.O. Okovido, Prof. R.O. Ogirigbo, Engr. Prof. R.I. Umasabor, Engr. Prof. (Mrs.) N. Kayode-Ojo, Dr. (Mrs.) A. Rawlings, Engr. Dr. A.I. Agbonaye, Engr. Prof. E. Nwankwo, Engr. Dr. P.N. Ogbeifun, Engr. Dr. U. Ukeme, Prof. (Mrs.) N.I. Ihimekpen, Engr. Dr. R.I. Ilaboya, Engr. Dr. E.S. Okonofa, Engr. O. Osasu, Engr. Dr. S.A. Adegbemileke, Engr. Ehi Oria-Usifo, Engr. U.K. Ogbonna, Engr. J.O. Odemerho, Engr. B. Omosefe, Engr. (Mrs.) E. Gloria, Engr. O. Orobosa, Engr. N.K. Oghoyafedo, Engr. J.O. Ogbeide, Engr. (Mrs.) Agabi, and Engr. C.M. Okolie. I sincerely appreciate their guidance, encouragement, and positive contributions throughout the course of my undergraduate studies in this great Department of Civil Engineering. May God bless you all abundantly. I am deeply grateful to my parents, Mr. and Mrs. Munonye, for their unwavering love, support, and wise counsel, which have been constant sources of strength on this journey. Special appreciation goes to my school mother, Mommy Odafe, for always taking care of me both physically and spiritually, and for being a steady source of comfort and guidance. I am also sincerely thankful to my close friend Enob, whose friendship and support have been invaluable. My gratitude extends to Brother and Sister Unumadu, my “second parents,” whose kindness, encouragement, and steady support have greatly impacted my academic and personal growth. May Jehovah God reward and bless every one of you abundantly.

ABSTRACT

This project focused on the structural design of a 100 m³ elevated reinforced concrete (RC) water tank supported by a 20-meter-high tower. The objective was to ensure the structural safety, stability, and serviceability of all components including the raft foundation, tank base slab, beams, columns, and tank walls under combined actions of dead load, live load, hydrostatic pressure, wind, and seismic forces in compliance with BS 8110 and Eurocode 2 standards.

The methodology involved manual structural design calculations for preliminary sizing and load estimation, followed by detailed structural analysis and modelling using ProtaStructure software. The structure consists of 300 mm × 300 mm reinforced concrete columns, 300 mm × 450 mm reinforced concrete beams, a 150 mm reinforced concrete raft foundation at ground level, and a 300 mm reinforced concrete tank base slab positioned at the top of the stanchions to safely support the water tank.

The tank walls, which serve as the primary water-retaining elements, were designed as 250 mm thick reinforced concrete walls reinforced with high-yield steel bars (Grade 500) using 12 mm diameter bars spaced at 250 mm centres in both vertical and horizontal directions (H12-250) on both faces of the wall. The tank base slab was reinforced in orthogonal directions to resist bending moments and shear forces caused by hydrostatic pressure, self-weight, and wind effects. Beams supporting the platform and tank were subjected to maximum moments of 230.6 kN·m and axial loads of 191.1 kN, and were reinforced using T20 and T25 longitudinal bars together with T10 shear links. Columns carried maximum axial loads of 1443.6 kN and were reinforced with up to 4Y25 bars. The structural analysis revealed that the maximum lateral displacement of the structure was 9.87 mm at the top storey, which is within the allowable serviceability limit of H/500 according to Eurocode EN 1991-1-4 for a 20 m high structure. The slab deflections, beam moments, shear forces, and column forces were all within code-specified limits, indicating an efficient and stable structural system. The Bill of Engineering Measurement and Evaluation (BEME) estimated the total construction cost of the proposed elevated water tank and tower structure at approximately ₦19,114,573. The project concludes that the elevated reinforced concrete water tank and supporting tower satisfy all structural and serviceability requirements and that the integration of manual calculations with software analysis produced a safe, durable, and economical water storage structure suitable for practical implementation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

RC – Reinforced Concrete

m^3 – Cubic Meters

m^2 – Square Meters

kN/m^2 – Kilonewton per Square Meter

BS – British Standards

EC2 – Eurocode 2

RCC – Reinforced Cement Concrete

UDL – Uniformly Distributed Load

SLS – Serviceability Limit State

ULS – Ultimate Limit State

kN – Kilonewton

mm – millimetre

m – Metre

m^2 – Square Metre

m^3 – Cubic Metre

FEM – Finite Element Method

N – Newton

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Water is one of the most vital resources on earth, essential for the survival of all living organisms. Its importance extends far beyond drinking; it is integral to sanitation, agriculture, industrial processes, and energy generation. With an increasing global population and rapid urbanization, the demand for potable water is escalating. In Nigeria, especially in cities like Benin City, Edo State, where population growth and industrialization are expanding, the need for efficient and sustainable water management systems is becoming more critical.

Benin City, as the capital of Edo State, is undergoing significant urbanization, which has intensified the demand for water. While the city's water distribution infrastructure serves a large portion of the population, there remain areas, particularly in the outskirts and slum settlements, that struggle with inadequate access to reliable water supply. This has prompted the implementation of alternative solutions, such as private water tanks and towers, to meet the daily needs of residents and industries. In the absence of consistent government-supplied water, many households and businesses are turning to storage solutions like elevated tanks to ensure they have enough water, especially during the dry season or when municipal water supply systems fail.

Water tanks, particularly concrete water tanks, are widely used in Benin City due to their durability and ability to store large volumes of water. These tanks come in various forms, including ground-level tanks, elevated tanks, and reinforced concrete towers. Elevated water tanks are commonly used in areas where there is limited or no access to a direct water supply. These tanks are designed to store water at a height, allowing for gravity-fed distribution, which reduces the need for pumps and makes the system more energy-efficient.

The significance of concrete water tanks in Benin City cannot be overstated. Concrete is a preferred material because it is durable, cost-effective, and can be molded into various shapes and sizes to meet specific needs. Moreover, concrete tanks are resistant to environmental factors such as corrosion, ensuring a longer lifespan compared to other materials. The design of these tanks must account for several variables, such as the local climate, the expected volume of water, the topography, and the surrounding soil conditions.

In Benin City, the tropical climate, characterized by a marked dry season and heavy rainfall during the wet season, poses unique challenges in water storage. During the wet season, large amounts of rainwater can be harvested, but the storage system must be designed to handle seasonal fluctuations in water availability. This necessitates the proper sizing of tanks to meet the city's year-round demand. The dry season, which often lasts several months, exacerbates the need for sufficient water storage, as the city's water supply may be interrupted or become unreliable.

Moreover, Benin City's infrastructure is often under pressure, with population density increasing in urban areas while rural areas remain underserved. This imbalance has contributed to a growing reliance on private water tanks, which are typically designed and maintained by individual property owners or local communities. While these water tanks serve their purpose, many of them are substandard or improperly designed, leading to issues such as water contamination, insufficient capacity, and even structural failures due to poor construction practices.

This study focuses on the design of concrete water tanks and towers, aiming to address the limitations of existing water storage systems in Benin City. The goal is to develop a design that is both robust and reliable, providing a sustainable water storage solution for urban and suburban areas alike. Through this project, an effort will be made to ensure that the tanks meet both the structural integrity requirements and the practical needs of residents in Benin City. This includes ensuring that the tanks are capable of withstanding the environmental conditions and usage demands of the area, thereby providing a steady and safe water supply throughout the year.

The design considerations will include factors such as tank capacity, material selection, structural safety, maintenance, and cost-effectiveness. Additionally, the research will explore how water tanks can be integrated into the city's existing water supply system to improve overall accessibility and reliability. The findings of this study could have significant implications for future urban water management strategies in Benin City and similar urban areas in Nigeria.

1.2 Statement of The Problem

Access to clean and reliable water remains a critical concern in many urban environments, particularly within institutional settings such as universities. The University of Benin, like many campuses in Nigeria, experiences fluctuations in water supply due to inconsistent municipal delivery, ageing infrastructure, and rising demand from growing student populations. These challenges emphasize the importance of properly designed elevated water storage systems that can store and supply water efficiently when needed.

The following key problems necessitated this study:

i. Inadequate Water Pressure Across Campus Buildings

Many buildings within the university experience low water pressure due to gravity-fed systems that lack sufficient elevation or storage capacity. This affects daily operations in laboratories, hostels, and lecture halls.

ii. Undersized or Improperly Designed Water Storage Facilities

Existing water storage systems, where available, are either too small or not structurally optimized for the required volume and environmental conditions. This leads to frequent shortages and maintenance issues.

iii. Lack of Standardized Design Approaches Using Modern Codes

There is limited adoption of international design standards (such as Eurocode and BS) in the development of water storage structures within Nigerian institutions, resulting in potential safety, serviceability, and durability issues.

This project aims to address these problems by presenting a robust design for an elevated reinforced concrete water tank and tower structure that adheres to modern standards and is tailored to the specific needs and conditions of the University of Benin.

1.3 Aim and Objective of The Study

This project aims to design a functional and structurally sound elevated 100 m^3 reinforced concrete 5m by 5m water tank and tower structure of 20m high, located within the University of Benin. The goal is to ensure reliable water storage and distribution while adhering to modern structural design codes and standards. Through this project, I hope to gain a deeper understanding of structural engineering principles, especially as they relate to real-life civil infrastructure.

The specific objectives of the project are:

i. To determine the appropriate preliminary dimensions and design parameters

This involves estimating the tank size, elevation height, and foundational requirements that suit the water needs of the campus, using rational assumptions and standards. This will help me understand how to size and assess civil engineering infrastructure based on real-life conditions.

ii. To model and design the structure using modern engineering software

By using tools like ProtaStructure, AutoCAD, and Excel, I will gain hands-on experience with structural modeling, detailing, and analysis, following Eurocode and British Standards. This enhances my skill set with professional software commonly used in the industry.

iii. To analyze structural loads and design key components

I will design critical structural elements including tank walls, slabs, columns, and bracing beams, considering hydrostatic, wind, and dead loads. This allows me to apply theoretical knowledge to practical structural analysis.

iv. To produce architectural and structural drawings

Using AutoCAD and ProtaStructure detailing features, I will develop clear, professional architectural and structural plans, reinforcing my ability to translate design into practical documentation.

v. To design a suitable foundation

A suitable Foundation system will ensure structural stability and safety of the tank and tower.

By accomplishing these objectives, I expect to grow both technically and professionally as a structural engineering student, while contributing a meaningful design solution to a real-world water supply need.

1.4 Scope of Study

This project is centered on the structural design of an elevated reinforced concrete (RC) water tank with a storage capacity of 100 m^3, supported on a 20 m high tower, to be situated within the University of Benin, Benin City, Nigeria. It scope covers only the structural design aspects of the water tank and its supporting tower. It involves preliminary sizing, structural modeling, load analysis, and design of the main structural elements including the tank walls, slab, columns, bracing system, and foundation. The design follows the requirements of Eurocode 2 (EN 1992) and British Standards (BS 8110) to ensure structural safety and serviceability. The study adopts a design-based methodology, combining manual calculations with the use of engineering software such as ProtaStructure, AutoCAD, and Microsoft Excel for analysis, modeling, and detailing. Soil properties and wind data are assumed from previous geotechnical investigations and climatic records within the University of Benin campus.

1.5 Justification of Study

Elevated water tanks play a vital role in water storage and supply systems, especially in institutional environments like the University of Benin, where there is constant demand for water across hostels, laboratories, and staff facilities. However, several existing tanks within the campus are either outdated in design, under-capacity, or lacking proper structural detailing posing risks to reliability and long-term safety.

This project focuses exclusively on the structural design of a reinforced concrete elevated water tank with a storage capacity of 100 m^3 and a tower height of 20 m, using Eurocode and British Standards. By isolating the structural aspect of the system, the project contributes to solving challenges related to improper design sizing, non-standardized construction practices, and inadequate structural analysis observed in previous systems.

The design will help address the following problems in the study area:

i. Inadequate tank sizing leading to insufficient storage capacity.

ii. Lack of structural detailing, which affects the lifespan and safety of tanks.

iii. Absence of standardized design documentation for future reference.

In summary, this project bridges a crucial academic and infrastructural gap by offering a well-detailed, code-compliant design of an elevated water tank system that can serve as a benchmark for future implementations, while also enriching my engineering design skills.

CHAPTER TWO

LITERATURE REVIEW

2.1 Water

Water is one of the most essential resources for human survival, industrial activity, agricultural development, and environmental sustainability. In growing urban centers such as Benin City, Edo State, Nigeria, the importance of clean, safe, and accessible water cannot be overstated. One of the primary ways to ensure constant water availability, especially in locations with unreliable public water supply, is through the construction and design of elevated water tanks and supporting tower structures (Rajiv, 2012; Adebayo *et al*., 2016).

This chapter presents a comprehensive review of existing literature, previous studies, and theories that support the need, design, analysis, and construction of elevated water tanks. It explores concepts such as water storage, structural requirements, material selection, failure cases, and design codes and standards (Koko and Tari, 2019).

2.2 Water Supply and Its Importance

Water supply refers to the provision of water by public utilities, commercial organizations, or community efforts through a system of engineered components. In urban and rural settings alike, water supply systems are fundamental for sanitation, health, agriculture, and industrial processes. Access to clean and reliable water is critical for preventing disease and promoting public health, particularly in rapidly urbanizing areas where population pressure can overwhelm existing infrastructure (Rajiv, 2012).

In Benin City, various residential estates, educational institutions, and commercial establishments make use of elevated water tanks to overcome the challenges of intermittent public water supply. These tanks serve as buffer systems, providing storage during times of availability and ensuring flow by gravity during periods of outage

(Adebayo *et al.*, 2016). Urban Water Infrastructure and Storage Efficiency in South-Western Nigeria).

2.3 Evolution and History of Water Storage Systems

The history of water storage systems dates back to ancient civilizations such as the Mesopotamians and the Romans, who developed aqueducts and storage cisterns. These early systems laid the foundation for modern-day practices in hydraulic engineering. The evolution from ground-level to elevated tanks came with the understanding of gravity-fed systems and the need for increased water pressure at points of use (Murphy, 2001).

In Nigeria, traditional clay and concrete storage containers have been replaced over time by plastic overhead tanks, reinforced concrete tanks, and steel reservoirs. While ground-level tanks are still common, elevated water tanks have gained popularity due to their ability to distribute water more efficiently and reduce dependence on electric pumps (Adebayo *et al.*, 2016).

2.4 Elevated Water Tanks: Concept and Function

Elevated water tanks are storage systems supported by towers or columns that raise the tank above the ground. The elevation serves two primary purposes:

i. **Storage** – To ensure a reserve of water for domestic, industrial, or emergency use.
ii. **Pressure** – To provide sufficient gravitational pressure to supply water to plumbing systems without the use of electric pumps.

The water tank, when elevated, creates potential energy which is converted into pressure head. The pressure P produced by a water column of height h can be calculated using equation 2.1.

$$P = \rho g h \qquad (2.1)$$

Where: ρ = density of water

g = acceleration due to gravity

h = height of water above the outlet

This principle governs the functionality of all elevated tanks.

2.5 Classification of Elevated Water Tanks

Elevated tanks can be classified based on:

a) Material of Construction

Steel Tanks: These are commonly used due to their high tensile strength and modular assembly. However, they are prone to corrosion and require regular maintenance.

Reinforced Concrete Tanks: Widely used in Nigeria, including Benin City, due to material availability, durability, and cost-effectiveness.

Composite/Hybrid Tanks: Use a combination of materials (e.g., concrete base and steel tank) to optimize performance and cost.

b) Tank Shape and Design

Rectangular Tanks: Economical but structurally less efficient.

Cylindrical Tanks: Offer uniform stress distribution and are easier to design for hydrostatic pressure.

Circular Dome Tanks: Common in Nigeria’s water boards and municipal water systems.

c) Support Structure

Braced Towers: Use steel or concrete frameworks to offer lateral stability.

Monolithic Columns: Simple but used mostly for small-volume tanks.

Frame and Shaft Towers: Offer a balance between material usage and structural integrity.

Each classification type has implications for cost, structural analysis, and suitability based on environmental conditions.

2.6 Structural Considerations for Elevated Water Tanks

The structural design of an elevated water tank involves:

a) Load Analysis

The tank must be designed to withstand:

Dead loads – weight of the structure and the tank itself.

Live loads – variable loads such as water weight (which changes with usage).

Wind loads – especially important in elevated designs, as wind can cause significant lateral forces.

Hydrostatic pressure – exerted by stored water on the tank walls.

b) Foundation Design

An elevated tank imposes considerable concentrated loads on the ground. The choice of foundation whether spread footing, raft, or pile depends on soil bearing capacity. In regions with low bearing capacity soils, pile foundations are often adopted.

c) Stability and Safety

The tower must be braced or stiffened to resist lateral movements. Slender towers are prone to buckling and vibration due to wind or water movement. Proper analysis using structural software (e.g., ProtaStructure or STAADPro) helps ensure stability.

2.7 Materials That Can Be Used in Elevated Water Tank Construction

The selection of materials affects durability, structural performance, and cost. Common materials include:

Concrete: Resistant to corrosion, suitable for larger capacities, and easily available in Nigeria.

Steel: Lightweight and high in strength but susceptible to corrosion.

FRP (Fiber-Reinforced Plastic): Used in modern applications for lightweight and corrosion resistance.

PVC or Plastic Tanks: Suitable for domestic use but not for large-scale storage.

For elevated water tanks in Benin City, reinforced concrete is widely adopted due to its cost-effectiveness and local availability of materials such as cement, sand, aggregates, and skilled labor.

2.8 Design Codes and Standards

Various international and national standards govern the design of water tanks:

i. BS 8110 – Structural use of concrete.

ii. Eurocode 2 (EN 1992) – Design of concrete structures.

Adherence to these codes ensures safety, durability, and compliance with global engineering standards.

2.9 Failure Modes and Durability Issues

Elevated water tanks play a vital role in water supply systems by ensuring adequate water pressure and storage, especially in urban and semi-urban environments like Benin City. However, these structures can be susceptible to various failure modes due to environmental, structural, or maintenance-related issues. A failure in any component of the tank or supporting structure may compromise the integrity of the entire system, posing significant safety and serviceability risks. Common failure mechanisms include corrosion of reinforcement, cracking due to shrinkage or poor design detailing, differential settlement of the foundation, and failure under lateral loads such as wind or seismic forces (Rajiv *et al*., 2012).

Understanding these failure modes helps engineers develop safer and more durable structures by incorporating robust materials, adhering to modern design codes, and implementing preventive maintenance strategies (McLeskey, 2013).

2.10 Application and Relevance in Research Area

In Benin City, elevated tanks are essential in residential buildings, schools, markets, hospitals, and government facilities. Most homes, due to unreliable public water supply, rely on elevated tanks installed on concrete towers or steel platforms. Government projects also include overhead tanks at motor parks, health centers, and borehole points.

The topography and soil conditions of Benin City allow for moderate tower heights ranging between 3 to 10 meters, depending on the required pressure and number of stories in the building being served.

2.11 Previous Work Done in Research Area

Numerous research studies have been carried out both globally and locally to improve the understanding, design, and performance of elevated water tanks and their supporting towers. These studies have contributed significantly to the body of knowledge by providing insights into the structural behavior, durability challenges, material selection, and seismic or wind performance of these critical infrastructure elements.

i. Akinyele and Emmanuel (2020) conducted a study on the Assessment of Structural Stability of Elevated Water Tanks in Selected South-Western Nigerian Cities, where they evaluated the effect of construction quality and foundation type on the integrity of reinforced concrete towers. The research concluded that tanks situated on clayey or poorly compacted soil showed higher incidences of tilting and cracking, especially in the absence of pile foundations.

ii. Ogedengbe *et al*. (2021) carried out a project on Comparative Analysis of Steel and Concrete Elevated Water Tanks in Urban Centers of Nigeria, including locations like Ibadan, Benin, and Lagos. Their findings revealed that although steel tanks have quicker installation times, concrete tanks tend to offer better durability and resistance to vandalism, which is an issue in some densely populated urban areas.

iii. In Benin City, Idemudia and Okungbowa (2022) performed a structural audit of aging elevated concrete water tanks across five districts. Their research showed that most tanks constructed before the year 2000 lacked modern reinforcement detailing and suffered from reinforcement corrosion due to poor maintenance. They recommended retrofitting measures, including external jacketing and cathodic protection to extend the service life of existing tanks.

iv. Another local study by Osayande and Amadasun (2023) investigated Service Life Prediction of Reinforced Concrete Elevated Water Tanks in Edo State Using Durability Modeling Techniques. The study used probabilistic modeling to estimate corrosion initiation and progression. Their findings emphasized the importance of cover thickness and the water-cement ratio in determining the long-term durability of concrete tanks.

The insights from these studies collectively highlight the need for context-specific design and maintenance strategies. While international research provides general guidance and modeling techniques, local studies offer vital data on construction practices, material behavior, and failure modes under Nigerian conditions. Incorporating findings from both streams ensures that the design of elevated water tanks and towers is both structurally sound and socio-economically sustainable.

CHAPTER THREE

METHODOLOGY

3.1 Study Area

The study is based on the design of a new elevated water tank and tower structure located within the University of Benin, Benin City, Nigeria. Benin City lies in the southern part of Nigeria and serves as the capital of Edo State. It is characterized by a tropical climate with significant rainfall during the rainy season, making it suitable for rainwater harvesting as an alternative water source. The University of Benin campus is a densely populated academic environment with high water demand for laboratories, toilets, hostels, and lecture halls, hence the need for a reliable and pressurized water distribution system. The structure is assumed to be situated in a suitable location within the university premises, where such an infrastructure would enhance water supply reliability for both academic and residential facilities. The goal is to design the water tank and supporting tower using current engineering standards and practices.

Figure 3.1: Geospatial Location Map of the Proposed 100 m³ RC Elevated Water Tank at UNIBEN Campus

3.2 Description of the Proposed Design

The water tank is designed to have a storage capacity of 100,000 litres (100 cubic meters). The tank is elevated at a height of 20 meters above ground level to ensure adequate pressure via gravity for water distribution across the faculty buildings. The tank is assumed to be rectangular in shape, with dimensions 5 meters by 5 meters in base area and a height of 4 meters. The tower structure that supports this tank is to be designed using reinforced concrete, in accordance with both Eurocode 2 (EN 1992-1-1) and BS 8110 design standards.

The water source is assumed to be a borehole system with the possibility of rainwater harvesting as an auxiliary source. The tank will be filled via submersible pumps and will serve the Faculty of Engineering facilities.

3.3 Design Methodology

The design process involves both manual calculations and computer-aided modeling. Manual design will be carried out on paper, following the ultimate limit state and serviceability limit state approaches as defined in Eurocode 2 and BS 8110.

The structural elements to be designed include:

i. Design of the tank wall for hydrostatic pressure

ii. Design of base slab for vertical load

iii. Design of columns for axial and lateral forces

iv. Design of bracing beams for wind loads

v. Design of foundation for overall stability

3.4 Design Tools

As this project is focused solely on the design and not on actual construction, design materials here refer to the software and tools used in structural modeling, detailing, and drafting. The following design tools and software applications are employed:

i. Protta Structure: A commercial structural analysis and design software developed by Prota Software Inc., used globally in structural engineering design. It supports Eurocode and British Standards (BS) for reinforced concrete and steel structures. ProtaStructure is particularly effective for 3D structural modeling and integrated design processes. It has been used in academic and professional designs within Nigeria, including university building extensions and water tank tower modeling exercises.
ii. AutoCAD: A commercial drafting software developed by Autodesk Inc., AutoCAD is widely used for creating architectural layouts, engineering blueprints, and structural drawings. It allows for the creation of 2D and 3D visualizations. AutoCAD has been extensively used in structural projects in Benin City and the University of Benin, especially in preparing site layouts and detailing construction drawings for academic research and faculty projects.
iii. Hand Calculation (Manual Design): Performed on paper using standard formulas from both Eurocode 2 and BS 8110 for ultimate limit state and serviceability design of reinforced concrete structures.

These software tools enable precision, accuracy, and clarity in both design calculations and technical drawings required for a complete structural engineering project.

3.5 Design Considerations

When manually designing the 100 m³ elevated reinforced concrete (RC) water tank and its 20 m high supporting tower, I will consider the following structural considerations to ensure stability, safety, and compliance with relevant design codes (Eurocode 2 and BS 8110):

i. Hydrostatic Pressure

Task: I will calculate the hydrostatic pressure using p = ρgh, and use it to design the tank walls and base slab for strength and crack control.

ii. Wind Load on the Structure

Task: I will compute the wind pressure using Eurocode guidelines and apply it to the surface area of the tank and tower to evaluate lateral stability and design for resistance.

iii. Bracing Beams

Task: I will determine how many bracing beams are needed and their optimal vertical spacing (placing them at one-third and two-thirds the height of the columns) to enhance the structural stability.

iv. Column Design

Task: I will design the columns for combined axial and bending loads, considering the total weight of the tank, water, and wind effects. I will check their slenderness and capacity using interaction curves.

v. Foundation Design

Task: I will calculate the total load acting on the foundation and design a suitable raft foundation based on the assumed safe bearing capacity (150 kN/m^2) for the University of Benin soil.

3.6 Software Modeling and Drafting

The proposed tank and tower structure will be modeled using Prota Structure, which allows for 3D modeling and automatic reinforcement detailing based on both Eurocode and British standards. After the structural analysis, architectural and structural drawings will be produced in AutoCAD.

The architectural drawings will show the plan, elevations, and sections of the tank and tower, while the structural drawings will present reinforcement details of each component.

3.7 Drafting and Detailing

AutoCAD is used to draft both architectural and structural drawings. These drawings include:

i. Plan and elevation views of the tank
ii. Sectional views of staging columns
iii. Reinforcement detailing of slabs, and columns
iv. Base footing layout and connection details

3.8 Analytical Approach

The analytical framework combines deterministic analysis for ultimate and service limit states using both hand calculations and software outputs. Design is guided by:

i. Equilibrium-based structural analysis
ii. Section design
iii. Load distribution analysis (including sloshing effects where applicable)

3.9 Preliminary Sizing of Water Tank

The preliminary sizing of the water tank is aimed at achieving a total volume of 100 cubic meters (100,000 litres). The table below provides the design assumptions and dimensional values for the tank:

Table 3.1 Preliminary Sizing Parameters for Elevated Water Tank

Parameter	**Value**	**Unit**	**Remarks**
Tank Capacity	100	m^3	Equivalent to 100,000 litres
Tank Length	5.0	m	Assumed square tank (5m × 5m)

Tank Width	5.0	m	
Tank Height	4.0	m	Provides 100 m³ with plan area of 25 m²
Plan Area	25.0	m²	Length × Width
Tower Height	20.0	m	Height from ground to tank base

The above sizing ensures that the tank meets storage demands while maintaining structural stability and economical use of materials. These parameters form the basis for subsequent design calculations, modeling, and detailing.

3.10 Reference to Previous Soil Investigations in the Area

The soil bearing capacity used for this design is based on published geotechnical investigations conducted within Benin City, specifically in locations comparable to the University of Benin campus environment. A study by Ukeme *et al.* (2025) reported allowable soil bearing capacities ranging from 155.5 kN/m² to 678.8 kN/m² based on standard laboratory and field tests for shallow foundation systems. This provides strong justification for adopting a safe conservative value of 150 kN/m² in this project. Their investigation, carried out within Benin City, reflects similar soil conditions and typical lateritic profiles encountered across UNIBEN and surrounding areas, thereby validating the assumption used in this design for raft foundation analysis.

3.11 Wind Load Analysis on Tower

Using the Eurocode wind pressure formula, the design wind pressure acting on the tower will be calculated using equation 3.1

$$qp = 0.5 \times \rho \times v_{\{b,0\}}^{2} \times c_e \times c_s \times c_d \qquad 4.2$$

Assuming:

$\rho = 1.25 \left\{\frac{kg}{m}\right\}^3,$

$v_{\{b,0\}} = 2.0 \left\{\frac{m}{s}\right\},$

$c_e = 1.0,\ c_s = 1.0,\ c_d = 1.0,$

$qp = 0.5 \times 1.25 \times 4 = 2.5 \left\{\frac{N}{m}\right\}^2$

Table 4.2 provides detailed results for storey displacements.

3.12 Wind Speed Consideration for Structural Design

Elevated water tank structures are subject to lateral wind loads, which must be accounted for to ensure safety, serviceability, and structural stability. Although Benin City and the University of Benin campus experience relatively low wind speeds year-round, wind pressure on a 20-meter-tall tank can still induce significant lateral forces due to the tank's height and exposed surface area. Meteorological data for Benin City indicates that monthly average wind speeds typically range from 5 to 8 km/h (about 1.4 to 2.2 m/s), with peak values in the wet season months such as April and August. For structural design purposes and in line with Eurocode EN 1991-1-4, a basic wind speed (v_{b,0}) of 2.0 m/s is conservatively adopted for analysis.

The wind pressure (q_p) acting on the structure is calculated using equation 3.2.

$$q\_p = 0.5 \times \rho \times v\_\{b,0\}\hat{}2 \times c\_e \times c\_s \times c\_d] \quad (3.2)$$

Where:

ρ = 1.25 kg/m³ (air density)

$v\_\{b,0\}$ = 2.0 m/s (basic wind speed)

c_e = exposure factor (based on terrain, typically 1.0–1.2 for open terrain)

c_s = seasonality factor (~1.0)

c_d = direction/shape factor (~1.0)

The assumed terrain for the tank is Exposure Category C, which represents open areas with few obstructions appropriate for the UNIBEN campus environment. While the resulting wind loads are relatively small due to low regional speeds, they are critical in design checks for overturning, sliding, and column bracing in the tower structure.

3.13 Limitations and Assumptions

i. The project is a design-based study and does not include physical construction.

ii. Only structural aspects of the elevated tank are considered; hydraulic analysis of water distribution is excluded.

This methodology provides a framework that combines manual structural design, software-based analysis, and conceptual drafting, leading to a complete academic and practical understanding of elevated water tank and tower structures in urban Nigerian environments.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Introduction

In this chapter the results obtained from the design and structural analysis of the proposed elevated water tank and tower structure within the University of Benin, Benin City were presented and discussed. The aim is to evaluate the structural performance, safety, and serviceability of the reinforced concrete elements, based on the application of Eurocode 2 and BS 8110 standards.

The results discussed include:

a. Structural response of the tank and tower to hydrostatic pressure,

b. Resistance to wind-induced lateral loads,

c. Load-carrying capacities of columns, slabs, and foundations,

d. Preliminary sizing outcomes based on assumed design inputs,

e. 3D modeling results from Prota Structure, and

f. Drafted technical drawings from AutoCAD.

Each component of the structure was examined for compliance with strength, stability, and deflection limits required for serviceability and long-term durability.

4.1 Hydrostatic Load Analysis Results

The water tank will be subjected to **hydrostatic pressure**, which increases linearly with depth. It was Calculated using equation 2.1

Where;

$\rho = 1000 \left\{\frac{kg}{m}\right\}^3$ (density of water)

$g = 9.81 \left\{\frac{m}{s}\right\}^2$,

$h = 4.0 \{m\}$ (tank height),

the maximum pressure at the tank base was be approximated as follows :

$$p = 1000 \times 9.81 \times 4.0 = 39.24 \left\{\frac{kN}{m}\right\}^2$$

The detailed results for storey displacements are represented in Table 4.1

Table 4.1: Results for Storey Displacements

These values were obtained for the PROTASTRUCTURE Software

a. Under gravity loads (G), displacements were minimal (around -0.0037 mm at storey 1). Adding live loads (GP cases) slightly increased displacements (up to ~0.04 mm).
b. Lateral loads (wind, seismic: Q, QP cases) caused the largest displacements (up to -0.387 mm at storey 1 and -9.87 mm at storey 5).
c. Rotations about the Z-axis were negligible, showing minimal torsion.

It was noted that displacements grow with height, typical for frame structures under lateral loads. Lower storeys move less; upper storeys sway more. The structure however shows good torsional stability and acceptable lateral displacements, ensuring safety and serviceability.

Table 4.1: Results for Storey Displacements

Load Case	**Storey**	**Diaphragm**	**Displacement-X (mm)**	**Displacement-Y (mm)**	**Rotation-Z (Rad)**
1 G	1	Free Nodes (Average)	-0.003685	-0.003674	0.000000
1 G	1	Free Nodes (Max)	-0.003801	-0.003789	0.000000
1 G	1	Free Nodes (Min)	0.000000	-0.003789	0.000000
2 GP11	1	Free Nodes	-0.013941	-0.041188	0.000000

		(Average)			
2 GP11	1	Free Nodes (Max)	-0.014052	-0.041298	0.000000
2 GP11	1	Free Nodes (Min)	0.000000	-0.041298	0.000000
3 GP12	1	Free Nodes (Average)	-0.013941	-0.041188	0.000000
3 GP12	1	Free Nodes (Max)	-0.014052	-0.041299	0.000000
3 GP12	1	Free Nodes (Min)	0.000000	-0.041299	0.000000
4 GP21	1	Free Nodes (Average)	0.010256	0.037514	0.000000
4 GP21	1	Free Nodes (Max)	0.010267	0.037575	0.000000
4 GP21	1	Free Nodes (Min)	0.000000	0.037575	0.000000
5 GP22	1	Free Nodes (Average)	0.010256	0.037514	0.000000
5 GP22	1	Free Nodes (Max)	0.010317	0.037524	0.000000
5 GP22	1	Free Nodes (Min)	0.000000	0.037524	0.000000
6 Q	1	Free Nodes (Average)	-0.118115	-0.117753	0.000000
6 Q	1	Free Nodes (Max)	-0.119820	-0.119460	0.000000

6 Q	1	Free Nodes (Min)	0.000000	-0.119460	0.000000
7 QP11	1	Free Nodes (Average)	-0.258400	-0.385433	0.000000
7 QP11	1	Free Nodes (Max)	-0.260010	-0.387040	0.000000
7 QP11	1	Free Nodes (Min)	0.000000	-0.387040	0.000000
8 QP12	1	Free Nodes (Average)	-0.258400	-0.385433	0.000000
8 QP12	1	Free Nodes (Max)	-0.260010	-0.387040	0.000000
8 QP12	1	Free Nodes (Min)	0.000000	-0.387040	0.000000
9 QP21	1	Free Nodes (Average)	0.140288	0.267683	0.000000
9 QP21	1	Free Nodes (Max)	0.140390	0.267780	0.000000
9 QP21	1	Free Nodes (Min)	0.000000	0.267780	0.000000
10 QP22	1	Free Nodes (Average)	0.140288	0.267683	0.000000
10 QP22	1	Free Nodes (Max)	0.140390	0.267780	0.000000
10 QP22	1	Free Nodes (Min)	0.000000	0.267780	0.000000
11 Nx	1	Free Nodes (Average)	1.311350	0.000000	0.000034

11 Nx	1	Free Nodes (Max)	1.353680	0.042347	0.000034
11 Nx	1	Free Nodes (Min)	0.000000	0.042347	0.000034
12 Ny	1	Free Nodes (Average)	0.000000	1.311355	-0.000001
12 Ny	1	Free Nodes (Max)	0.000996	1.312350	-0.000001
12 Ny	1	Free Nodes (Min)	0.000000	1.312350	-0.000001
13 Wx	1	Free Nodes (Average)	0.000000	0.000000	0.000000
13 Wx	1	Free Nodes (Max)	0.000000	0.000000	0.000000
13 Wx	1	Free Nodes (Min)	0.000000	0.000000	0.000000
14 Wy	1	Free Nodes (Average)	0.000000	0.000000	0.000000
14 Wy	1	Free Nodes (Max)	0.000000	0.000000	0.000000
14 Wy	1	Free Nodes (Min)	0.000000	0.000000	0.000000
1 G	2	Free Nodes (Average)	-0.014741	-0.014696	0.000000
1 G	2	Free Nodes (Max)	-0.014839	-0.014794	0.000000
1 G	2	Free Nodes (Min)	0.000000	-0.014794	0.000000

2 GP11	2	Free Nodes (Average)	-0.055772	-0.164760	0.000000
2 GP11	2	Free Nodes (Max)	-0.055861	-0.164850	0.000000
2 GP11	2	Free Nodes (Min)	0.000000	-0.164850	0.000000
3 GP12	2	Free Nodes (Average)	-0.055771	-0.164765	0.000000
3 GP12	2	Free Nodes (Max)	-0.055861	-0.164850	0.000000
3 GP12	2	Free Nodes (Min)	0.000000	-0.164850	0.000000
4 GP21	2	Free Nodes (Average)	0.041031	0.150070	0.000000
4 GP21	2	Free Nodes (Max)	0.041052	0.150100	0.000000
4 GP21	2	Free Nodes (Min)	0.000000	0.150100	0.000000
5 GP22	2	Free Nodes (Average)	0.041031	0.150070	0.000000
5 GP22	2	Free Nodes (Max)	0.041063	0.150090	0.000000
5 GP22	2	Free Nodes (Min)	0.000000	0.150090	0.000000
6 Q	2	Free Nodes (Average)	-0.472488	-0.471040	0.000000
6 Q	2	Free Nodes (Max)	-0.474550	-0.473100	0.000000

6 Q	2	Free Nodes (Min)	0.000000	-0.473100	0.000000
7 QP11	2	Free Nodes (Average)	-1.033693	-1.541855	0.000000
7 QP11	2	Free Nodes (Max)	-1.035610	-1.543770	0.000000
7 QP11	2	Free Nodes (Min)	0.000000	-1.543770	0.000000
8 QP12	2	Free Nodes (Average)	-1.033693	-1.541855	0.000000
8 QP12	2	Free Nodes (Max)	-1.035610	-1.543770	0.000000
8 QP12	2	Free Nodes (Min)	0.000000	-1.543770	0.000000
9 QP21	2	Free Nodes (Average)	0.561205	1.070813	0.000000
9 QP21	2	Free Nodes (Max)	0.561350	1.070940	0.000000
9 QP21	2	Free Nodes (Min)	0.000000	1.070940	0.000000
10 QP22	2	Free Nodes (Average)	0.561205	1.070813	0.000000
10 QP22	2	Free Nodes (Max)	0.561350	1.070940	0.000000
10 QP22	2	Free Nodes (Min)	0.000000	1.070940	0.000000
11 Nx	2	Free Nodes (Average)	3.145810	0.000000	0.000077

11 Nx	2	Free Nodes (Max)	3.242380	0.096587	0.000077
11 Nx	2	Free Nodes (Min)	0.000000	0.096587	0.000077
12 Ny	2	Free Nodes (Average)	0.000000	3.145805	-0.000002
12 Ny	2	Free Nodes (Max)	0.002270	3.148070	-0.000002
12 Ny	2	Free Nodes (Min)	0.000000	3.148070	-0.000002
13 Wx	2	Free Nodes (Average)	0.000000	0.000000	0.000000
13 Wx	2	Free Nodes (Max)	0.000000	0.000000	0.000000
13 Wx	2	Free Nodes (Min)	0.000000	0.000000	0.000000
14 Wy	2	Free Nodes (Average)	0.000000	0.000000	0.000000
14 Wy	2	Free Nodes (Max)	0.000000	0.000000	0.000000
14 Wy	2	Free Nodes (Min)	0.000000	0.000000	0.000000
1 G	3	Free Nodes (Average)	-0.033174	-0.033071	0.000000
1 G	3	Free Nodes (Max)	-0.033340	-0.033237	0.000000
1 G	3	Free Nodes (Min)	0.000000	-0.033237	0.000000

2 GP11	3	Free Nodes (Average)	-0.125568	-0.370878	0.000000
2 GP11	3	Free Nodes (Max)	-0.125710	-0.371010	0.000000
2 GP11	3	Free Nodes (Min)	0.000000	-0.371010	0.000000
3 GP12	3	Free Nodes (Average)	-0.125565	-0.370878	0.000000
3 GP12	3	Free Nodes (Max)	-0.125700	-0.371010	0.000000
3 GP12	3	Free Nodes (Min)	0.000000	-0.371010	0.000000
4 GP21	3	Free Nodes (Average)	0.092397	0.337813	0.000000
4 GP21	3	Free Nodes (Max)	0.092470	0.337890	0.000000
4 GP21	3	Free Nodes (Min)	0.000000	0.337890	0.000000
5 GP22	3	Free Nodes (Average)	0.092397	0.337813	0.000000
5 GP22	3	Free Nodes (Max)	0.092481	0.337880	0.000000
5 GP22	3	Free Nodes (Min)	0.000000	0.337880	0.000000
6 Q	3	Free Nodes (Average)	-1.063508	-1.060240	0.000000
6 Q	3	Free Nodes (Max)	-1.066030	-1.062760	0.000000

6 Q	3	Free Nodes (Min)	0.000000	-1.062760	0.000000
7 QP11	3	Free Nodes (Average)	-2.326913	-3.470715	0.000000
7 QP11	3	Free Nodes (Max)	-2.329110	-3.472900	0.000000
7 QP11	3	Free Nodes (Min)	0.000000	-3.472900	0.000000
8 QP12	3	Free Nodes (Average)	-2.326913	-3.470715	0.000000
8 QP12	3	Free Nodes (Max)	-2.329110	-3.472900	0.000000
8 QP12	3	Free Nodes (Min)	0.000000	-3.472900	0.000000
9 QP21	3	Free Nodes (Average)	1.263405	2.410475	0.000000
9 QP21	3	Free Nodes (Max)	1.263720	2.410720	0.000000
9 QP21	3	Free Nodes (Min)	0.000000	2.410720	0.000000
10 QP22	3	Free Nodes (Average)	1.263405	2.410475	0.000000
10 QP22	3	Free Nodes (Max)	1.263720	2.410720	0.000000
10 QP22	3	Free Nodes (Min)	0.000000	2.410720	0.000000
11 Nx	3	Free Nodes (Average)	4.988590	0.000000	0.000121

11 Nx	3	Free Nodes (Max)	5.139610	0.151040	0.000121
11 Nx	3	Free Nodes (Min)	0.000000	0.151040	0.000121
12 Ny	3	Free Nodes (Average)	0.000000	4.988595	-0.000003
12 Ny	3	Free Nodes (Max)	0.003550	4.992140	-0.000003
12 Ny	3	Free Nodes (Min)	0.000000	4.992140	-0.000003
13 Wx	3	Free Nodes (Average)	0.000000	0.000000	0.000000
13 Wx	3	Free Nodes (Max)	0.000000	0.000000	0.000000
13 Wx	3	Free Nodes (Min)	0.000000	0.000000	0.000000
14 Wy	3	Free Nodes (Average)	0.000000	0.000000	0.000000
14 Wy	3	Free Nodes (Max)	0.000000	0.000000	0.000000
14 Wy	3	Free Nodes (Min)	0.000000	0.000000	0.000000
1 G	4	Free Nodes (Average)	-0.059058	-0.058865	0.000000
1 G	4	Free Nodes (Max)	-0.059681	-0.059486	0.000000
1 G	4	Free Nodes (Min)	0.000000	-0.059486	0.000000

2 GP11	4	Free Nodes (Average)	-0.224188	-0.661208	0.000000
2 GP11	4	Free Nodes (Max)	-0.224690	-0.661670	0.000000
2 GP11	4	Free Nodes (Min)	0.000000	-0.661670	0.000000
3 GP12	4	Free Nodes (Average)	-0.224188	-0.661208	0.000000
3 GP12	4	Free Nodes (Max)	-0.224680	-0.661670	0.000000
3 GP12	4	Free Nodes (Min)	0.000000	-0.661670	0.000000
4 GP21	4	Free Nodes (Average)	0.165168	0.602383	0.000000
4 GP21	4	Free Nodes (Max)	0.165530	0.602820	0.000000
4 GP21	4	Free Nodes (Min)	0.000000	0.602820	0.000000
5 GP22	4	Free Nodes (Average)	0.165173	0.602383	0.000000
5 GP22	4	Free Nodes (Max)	0.165590	0.602770	0.000000
5 GP22	4	Free Nodes (Min)	0.000000	0.602770	0.000000
6 Q	4	Free Nodes (Average)	-1.895538	-1.889545	0.000000
6 Q	4	Free Nodes (Max)	-1.904100	-1.898110	0.000000

6 Q	4	Free Nodes (Min)	0.000000	-1.898110	0.000000
7 QP11	4	Free Nodes (Average)	-4.149680	-6.188295	0.000000
7 QP11	4	Free Nodes (Max)	-4.156700	-6.194970	0.000000
7 QP11	4	Free Nodes (Min)	0.000000	-6.194970	0.000000
8 QP12	4	Free Nodes (Average)	-4.149680	-6.188295	0.000000
8 QP12	4	Free Nodes (Max)	-4.156700	-6.194970	0.000000
8 QP12	4	Free Nodes (Min)	0.000000	-6.194970	0.000000
9 QP21	4	Free Nodes (Average)	2.254143	4.298750	0.000000
9 QP21	4	Free Nodes (Max)	2.255660	4.300090	0.000000
9 QP21	4	Free Nodes (Min)	0.000000	4.300090	0.000000
10 QP22	4	Free Nodes (Average)	2.254143	4.298750	0.000000
10 QP22	4	Free Nodes (Max)	2.255660	4.300090	0.000000
10 QP22	4	Free Nodes (Min)	0.000000	4.300090	0.000000
11 Nx	4	Free Nodes (Average)	6.735080	0.000005	0.000164

11 Nx	4	Free Nodes (Max)	6.940320	0.205320	0.000164
11 Nx	4	Free Nodes (Min)	0.000000	0.205320	0.000164
12 Ny	4	Free Nodes (Average)	0.000003	6.735080	-0.000004
12 Ny	4	Free Nodes (Max)	0.004830	6.739900	-0.000004
12 Ny	4	Free Nodes (Min)	0.000000	6.739900	-0.000004
13 Wx	4	Free Nodes (Average)	0.000000	0.000000	0.000000
13 Wx	4	Free Nodes (Max)	0.000000	0.000000	0.000000
13 Wx	4	Free Nodes (Min)	0.000000	0.000000	0.000000
14 Wy	4	Free Nodes (Average)	0.000000	0.000000	0.000000
14 Wy	4	Free Nodes (Max)	0.000000	0.000000	0.000000
14 Wy	4	Free Nodes (Min)	0.000000	0.000000	0.000000
1 G	5	D5-1	-0.093218	-0.092793	0.000000
2 GP11	5	D5-1	-0.361230	-1.054490	0.000000
3 GP12	5	D5-1	-0.361240	-1.054490	0.000000
4 GP21	5	D5-1	0.268450	0.962150	0.000000
5 GP22	5	D5-1	0.268450	0.962150	0.000000

6 Q	5	D5-1	-3.017290	-3.005830	0.000000
7 QP11	5	D5-1	-6.631790	-9.876480	0.000004
8 QP12	5	D5-1	-6.631790	-9.876480	0.000004
9 QP21	5	D5-1	3.614510	6.870640	-0.000004
10 QP22	5	D5-1	3.614510	6.870640	-0.000004
11 Nx	5	D5-1	8.071710	-0.001134	0.000198
12 Ny	5	D5-1	0.000003	8.070570	-0.000005
13 Wx	5	D5-1	0.000000	0.000000	0.000000
14 Wy	5	D5-1	0.000000	0.000000	0.000000
1 G	6	Free Nodes (Average)	-0.101850	-0.101418	0.000000
1 G	6	Free Nodes (Max)	-0.129430	-0.129100	0.000000
1 G	6	Free Nodes (Min)	0.000000	-0.129100	0.000000
2 GP11	6	Free Nodes (Average)	-0.401253	-1.156238	0.000000
2 GP11	6	Free Nodes (Max)	-0.421080	-1.183700	0.000002
2 GP11	6	Free Nodes (Min)	0.000000	-1.183700	0.000002
3 GP12	6	Free Nodes (Average)	-0.401263	-1.156230	0.000000
3 GP12	6	Free Nodes (Max)	-0.420450	-1.184330	0.000002
3 GP12	6	Free Nodes	0.000000	-1.184330	0.000002

		(Min)			
4 GP21	6	Free Nodes (Average)	0.299990	1.055403	0.000000
4 GP21	6	Free Nodes (Max)	0.321220	1.080970	-0.000002
4 GP21	6	Free Nodes (Min)	0.000000	1.080970	-0.000002
5 GP22	6	Free Nodes (Average)	0.299993	1.055395	0.000000
5 GP22	6	Free Nodes (Max)	0.321310	1.080890	-0.000002
5 GP22	6	Free Nodes (Min)	0.000000	1.080890	-0.000002
6 Q	6	Free Nodes (Average)	-3.312278	-3.299445	0.000000
6 Q	6	Free Nodes (Max)	-3.498180	-3.485060	0.000006
6 Q	6	Free Nodes (Min)	0.000000	-3.485060	0.000006
7 QP11	6	Free Nodes (Average)	-7.314725	-10.833590	0.000005
7 QP11	6	Free Nodes (Max)	-7.415760	-11.028410	0.000024
7 QP11	6	Free Nodes (Min)	0.000000	-11.028410	0.000024
8 QP12	6	Free Nodes (Average)	-7.314725	-10.833590	0.000005

8 QP12	6	Free Nodes (Max)	-7.415760	-11.028410	0.000024
8 QP12	6	Free Nodes (Min)	0.000000	-11.028410	0.000024
9 QP21	6	Free Nodes (Average)	4.002445	7.534145	-0.000005
9 QP21	6	Free Nodes (Max)	4.065940	7.624470	-0.000017
9 QP21	6	Free Nodes (Min)	0.000000	7.624470	-0.000017
10 QP22	6	Free Nodes (Average)	4.002445	7.534145	-0.000005
10 QP22	6	Free Nodes (Max)	4.065940	7.624470	-0.000017
10 QP22	6	Free Nodes (Min)	0.000000	7.624470	-0.000017
11 Nx	6	Free Nodes (Average)	8.174618	0.000077	0.000198
11 Nx	6	Free Nodes (Max)	8.720800	0.545310	0.000199
11 Nx	6	Free Nodes (Min)	0.000000	0.545310	0.000199
12 Ny	6	Free Nodes (Average)	0.000064	8.174625	-0.000005
12 Ny	6	Free Nodes (Max)	0.012777	8.187450	-0.000005
12 Ny	6	Free Nodes (Min)	0.000000	8.187450	-0.000005

13 Wx	6	Free Nodes (Average)	0.000000	0.000000	0.000000
13 Wx	6	Free Nodes (Max)	0.000000	0.000000	0.000000
13 Wx	6	Free Nodes (Min)	0.000000	0.000000	0.000000
14 Wy	6	Free Nodes (Average)	0.000000	0.000000	0.000000
14 Wy	6	Free Nodes (Max)	0.000000	0.000000	0.000000
14 Wy	6	Free Nodes (Min)	0.000000	0.000000	0.000000

4.2 Internal Force Diagram

Internal force diagrams are graphical representations of the forces developed within structural members when subjected to applied loads. These forces include axial force (N), shear force (V), and bending moment (M). They are essential in structural design because they illustrate the magnitude and distribution of forces along beams, columns, and other members. By analyzing these diagrams, the designer can identify critical sections where maximum tension, compression, or shear occurs. The obtained values are then used to determine appropriate member dimensions and reinforcement in accordance with relevant design codes such as Eurocode 2.

Figure 4.1 presents the internal force diagrams generated from ProtaStructures for the 20 m reinforced concrete elevated water tank tower. The diagrams show the distribution of shear forces, bending moments, and axial forces in all structural members under the governing load combinations. From the results, higher bending moments are observed at beam-column connections, while significant axial forces occur in the columns due to the combined effects of self-weight, water load, and imposed loads. Shear forces are more pronounced near supports and joint regions. These internal force results formed the basis for the detailed reinforcement design of the beams, columns, and slabs, ensuring that the structure satisfies both strength and serviceability requirements.

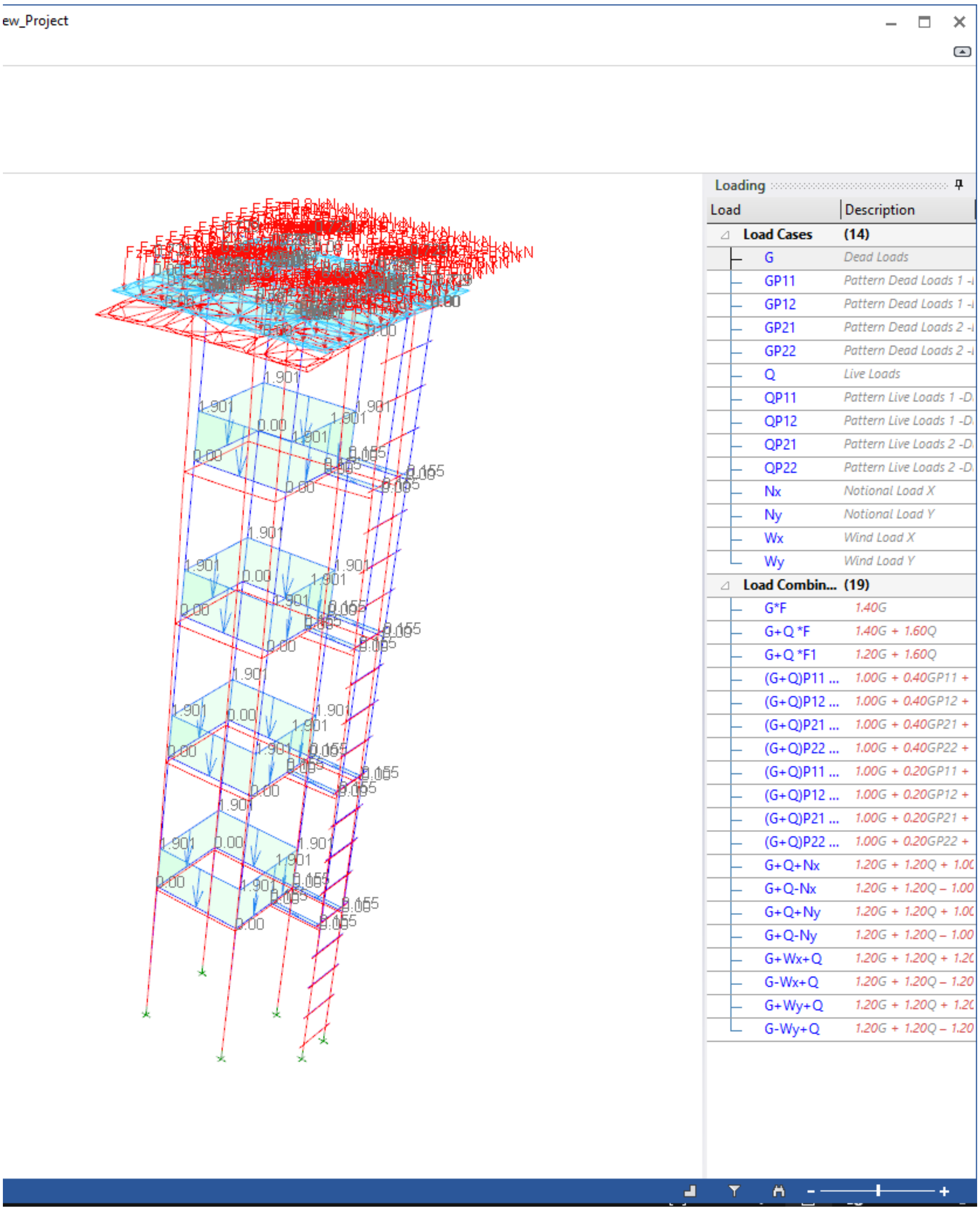


Figure 4.1: ProtaStructures design showing internal force diagrams (shear, bending moment, and axial load) for all structural members

4.3 ProtaStructure Structural Design Detailing and Modeling

Structural design detailing and modelling are critical stages in reinforced concrete construction. After analysis and internal force determination, detailed drawings are prepared to translate analytical results into practical construction information. These drawings show member sizes, reinforcement arrangements, dimensions, and connectivity between structural elements. Modelling software such as ProtaStructures is used to simulate the behaviour of the structure under different load combinations, ensuring that all members meet strength and serviceability requirements before construction.

Figure 4.2 presents the structural detailed plan of the storey, showing the layout of beams, slabs, and columns within the grid system. The plan indicates the positioning of structural members, span dimensions, and reinforcement distribution across the floor system. This layout ensures proper load transfer from slabs to beams and subsequently to columns and foundations.

Figure 4.3 further illustrates the 2D plan layout with the 3D structural model of the tank walls (shear walls) generated using ProtaStructure Software. The model provides a spatial representation of the structural framework, showing tank walls (shear walls), which serve as the primary water-retaining elements, and successfully designed as 250 mm thick reinforced concrete walls. These walls were reinforced using high-yield steel bars (Grade 500) with 12 mm diameter bars spaced at 250 mm centers in both vertical and horizontal directions (H12-250) on both faces of the wall.

Additionally, the design status on Figure 4.4 highlights the performance evaluation of structural members after analysis. The colour-coded indicators show whether members passed, required modification, or were satisfactory under the applied load combinations. This verification process ensures that all structural components comply with the requirements of relevant design standards. These figures demonstrate the transition from analytical modelling to practical structural detailing, confirming that the proposed elevated water tank tower is structurally adequate, stable, and ready for construction documentation.

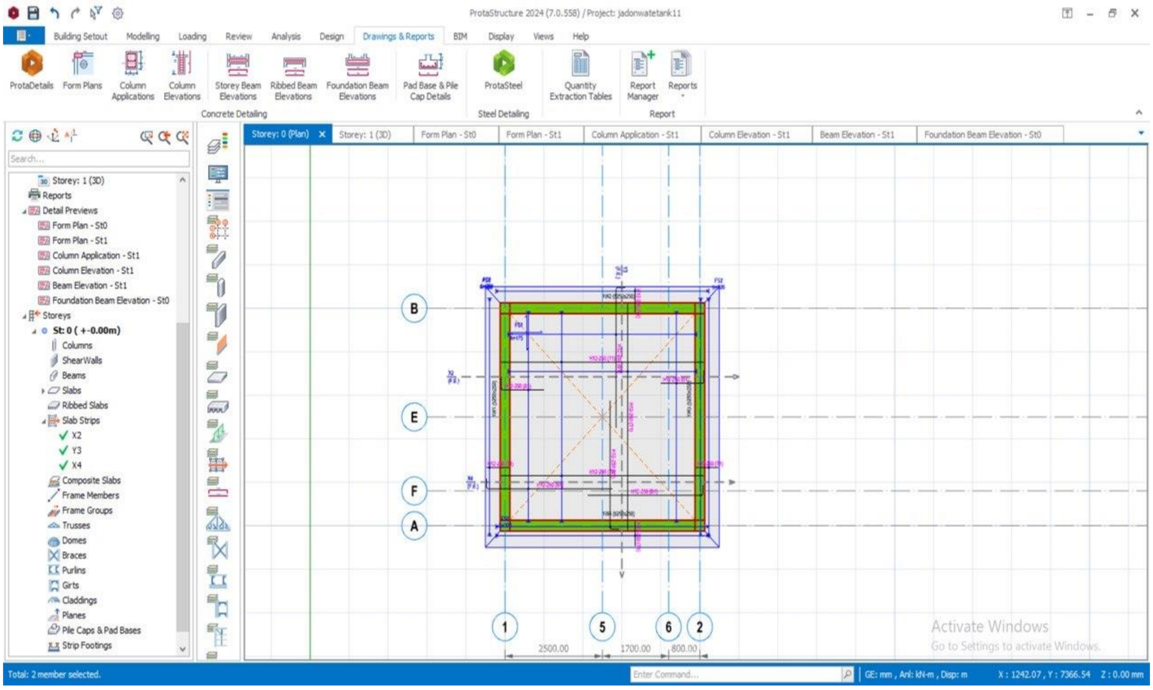


Figure 4.2: ProtaStructures Design Showing Structural Detailed Plan for Storey 5

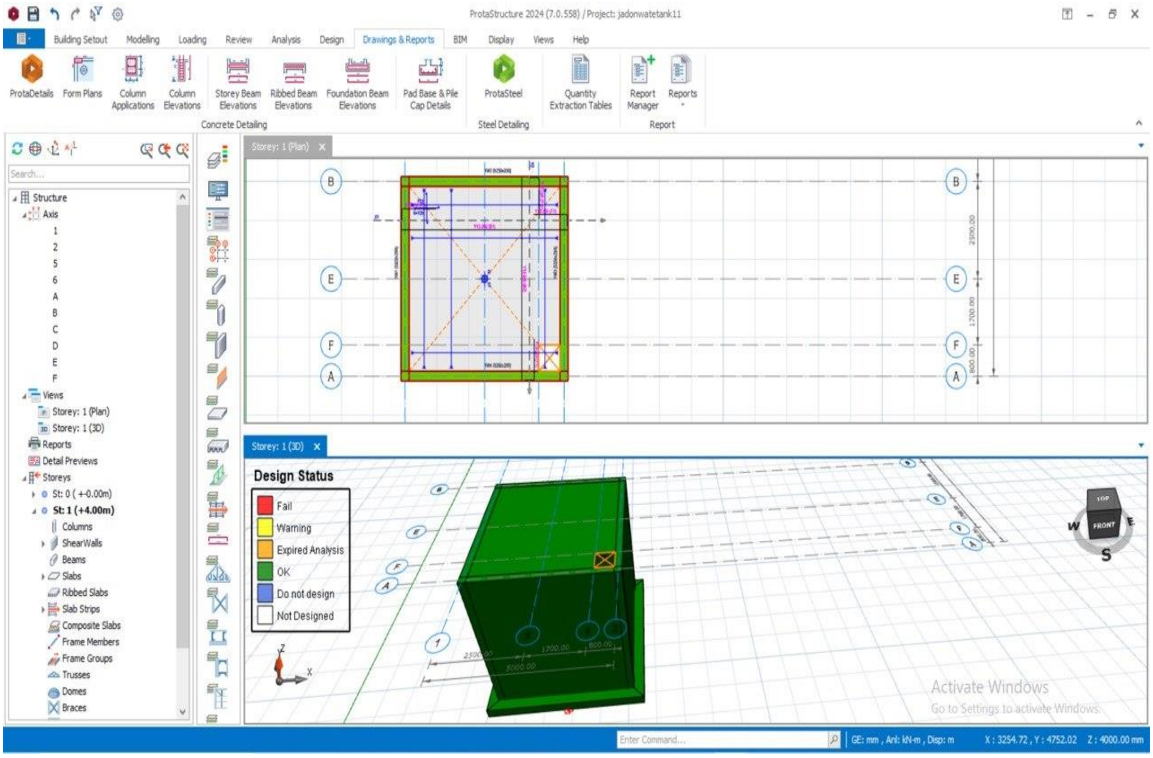


Figure 4.3: ProtaStructures Design Showing 3D Model For 20m Water Tank

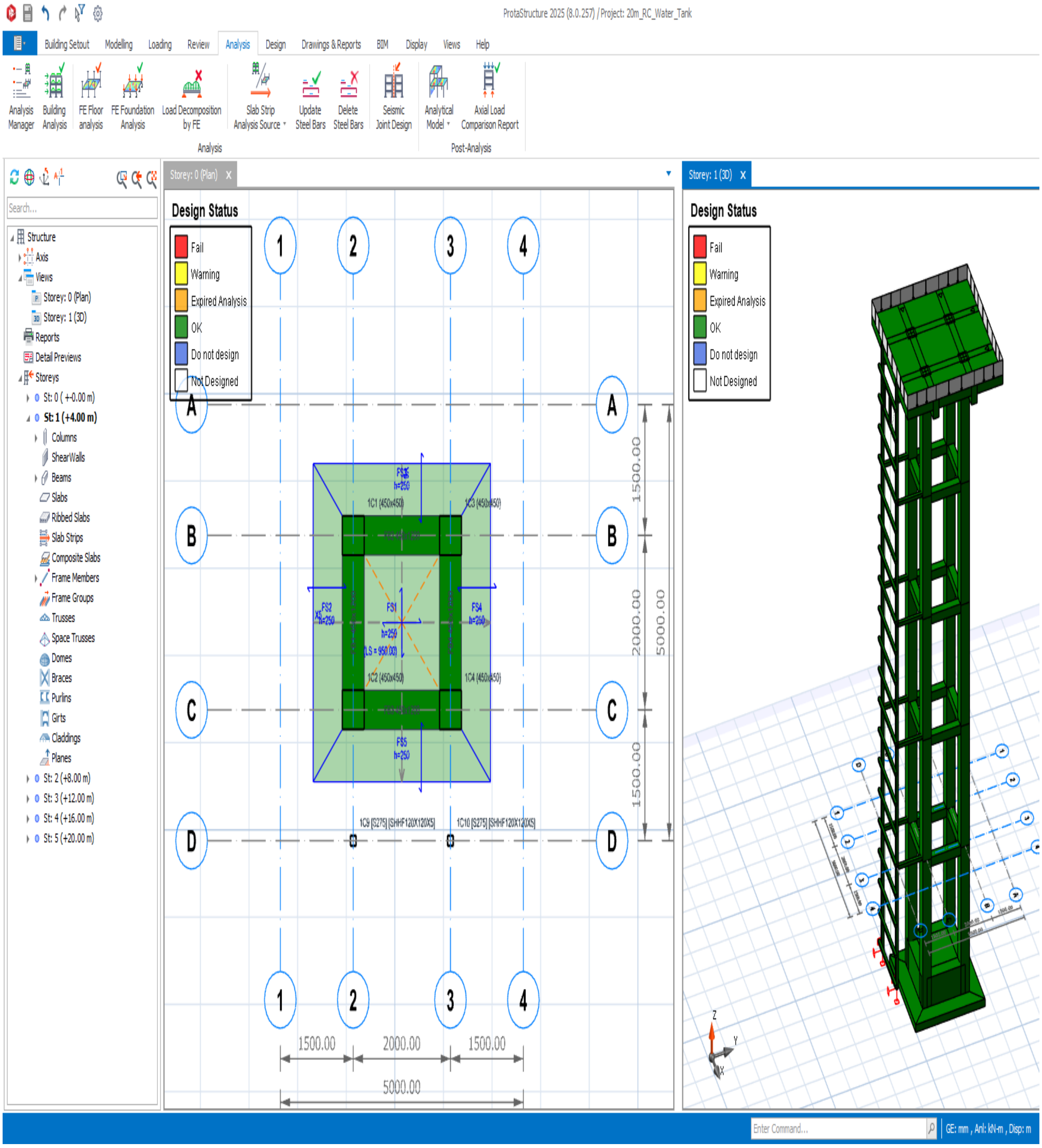


Figure 4.4: ProtaStructures Design Showing Design Status in Structural Plan And 3D Model For 20m Water Tank Tower

4.4 Architectural Representation and Three-Dimensional Visualization of the Elevated Water Tank

Architectural and visual representations are essential components of structural design documentation. While structural analysis ensures safety and stability, plan, elevation, and 3D views provide a clear graphical understanding of the geometry, proportions, and spatial configuration of the structure. These drawings enhance interpretation, coordination, and communication of the design intent.

Figure 4.5 presents the plan and elevation views of the proposed 100 m³ reinforced concrete elevated water tank. The plan view illustrates the layout and dimensions of the tank and supporting structure, while the elevation view shows the vertical arrangement, including the 20 m tower height, bracing levels, and tank positioning. These views provide a clear understanding of the structural configuration and dimensional relationships of the components.

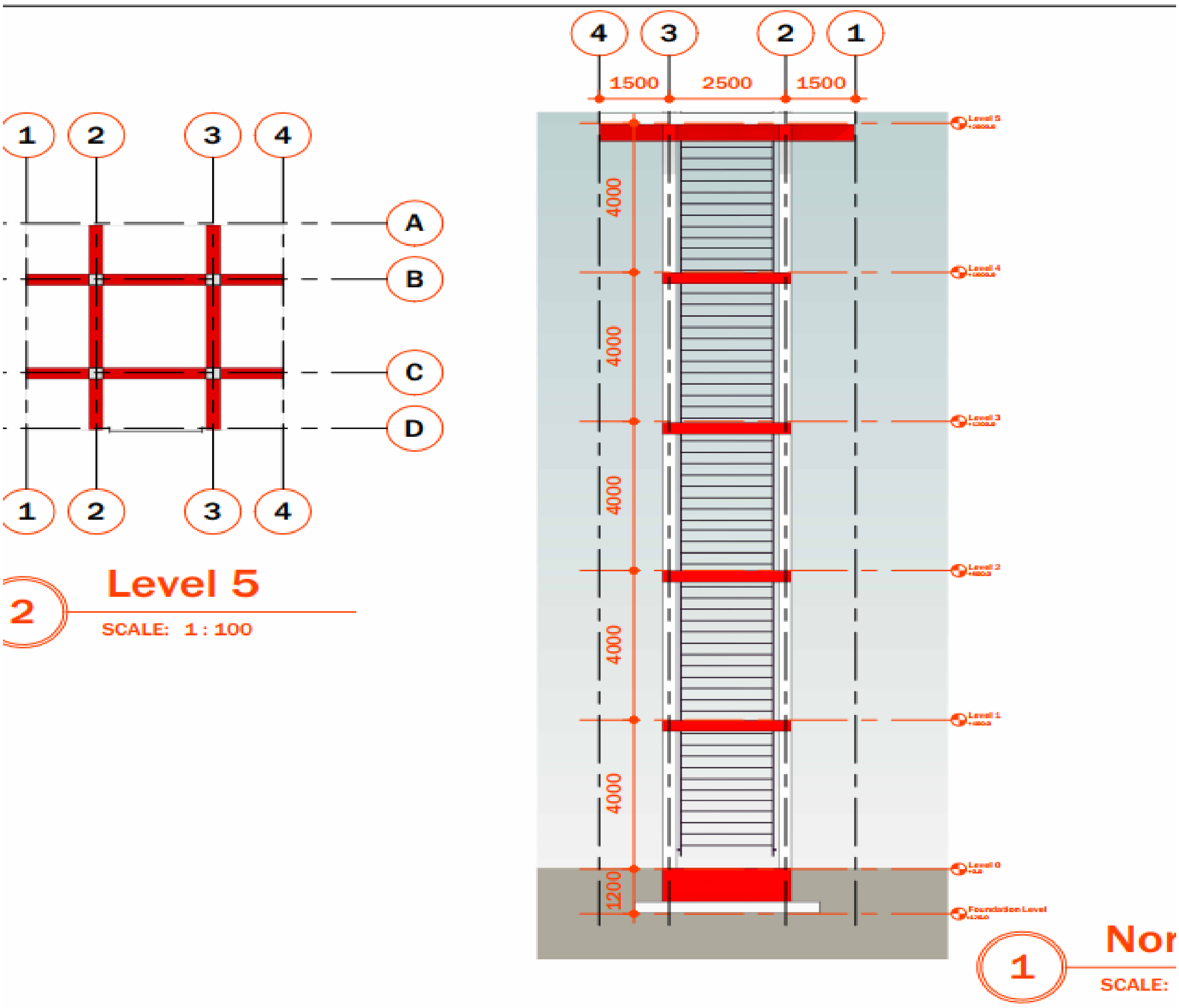


Figure 4.5: Plan and Elevation of the Tank

4.5 Foundation Selection

Figure 4.6 presents the detailed reinforcement layout for the tank base slab, which serves as a raft foundation for the 20 m elevated water tank tower. A raft footing was adopted for this design because the four tower columns are spaced only 2 m apart; providing isolated pad footings would have resulted in overlapping foundations and uneven stress distribution. The use of a single reinforced concrete raft foundation ensures that loads from the columns are uniformly distributed across a larger soil area.

The reinforcement detailing shown in the figure includes bottom and top steel layers arranged in orthogonal directions to resist bending moments induced by column loads, water weight, and wind effects. The raft foundation improves overall stability by reducing differential settlement, increasing resistance to overturning, and enhancing structural rigidity. It also simplifies construction compared to multiple combined footings.

This foundation solution is structurally efficient, economical, and fully compliant with geotechnical and reinforced concrete design principles for elevated water tank systems.

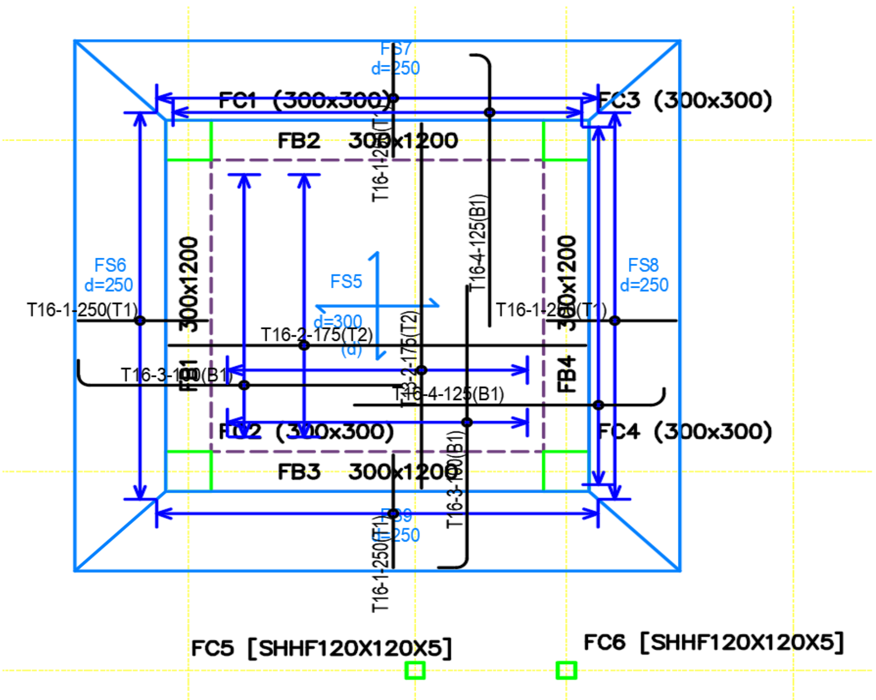


Figure 4.6: Detailed reinforcement layout for tank base slab

4.6 Detailed Reinforcement Layout for Foundation Beams

Figure 4.7 presents the detailed reinforcement layout for the 300 × 1200 mm reinforced concrete foundation beams (FB1–FB4). These beams serve as critical load-transfer members, connecting the columns to the raft foundation and distributing structural loads safely to the substructure.

Each beam section incorporates T10 links at 300 mm spacing, provided throughout the beam depth to resist shear forces and ensure confinement of the longitudinal reinforcement. The main longitudinal reinforcement varies depending on the beam type, with top bars such as 2T25, 2T20, or 2T20, and bottom reinforcement including 2T20–2B (1) supplemented with 2 × 3T16.3 bars to enhance flexural capacity.

The selected bar sizes and arrangement were determined based on the bending moments and shear forces obtained from structural analysis. The reinforcement configuration ensures adequate strength, stiffness, and crack control, thereby providing a stable and reliable foundation system capable of safely supporting the 20 m elevated water tank tower.

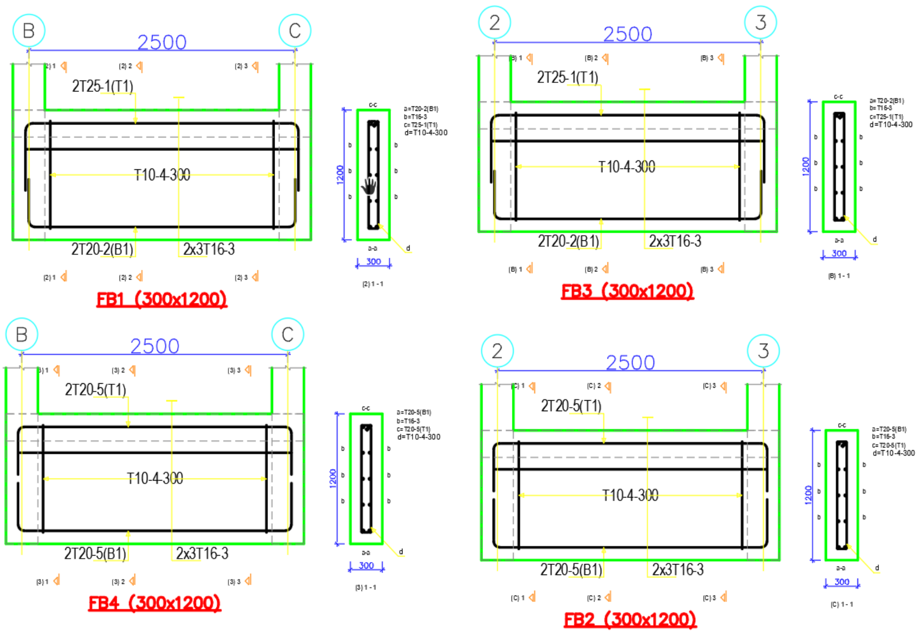


Figure 4.7: Detailed Reinforcement Layout for Foundation Beams

4.7 Detailed Reinforcement Layout for Storey Beams

Figures 4.8 and 4.9 present the detailed reinforcement layouts for the reinforced concrete (RC) storey beams supporting the elevated water tank structure. These beams play a crucial role in transferring loads from the tank platform and bracing levels to the supporting columns while maintaining overall structural stability.

The drawings show the longitudinal reinforcement consisting of 2T16 top bars and 3T16 bottom bars, arranged according to the beam dimensions, which vary between 300 × 300 mm and 300 × 450 mm. The top reinforcement primarily resists negative bending moments at beam-column junctions, while the bottom reinforcement resists positive bending moments at mid-span.

Shear reinforcement is provided using T10 stirrups spaced at 200 mm intervals, ensuring adequate shear capacity and crack control along the beam length. The reinforcement configuration was determined from the internal force analysis results, ensuring that the beams satisfy both flexural and shear design requirements under the applied load combinations. Overall, the detailing ensures structural strength, serviceability, and durability of the storey beams within the 20 m elevated water tank tower system.

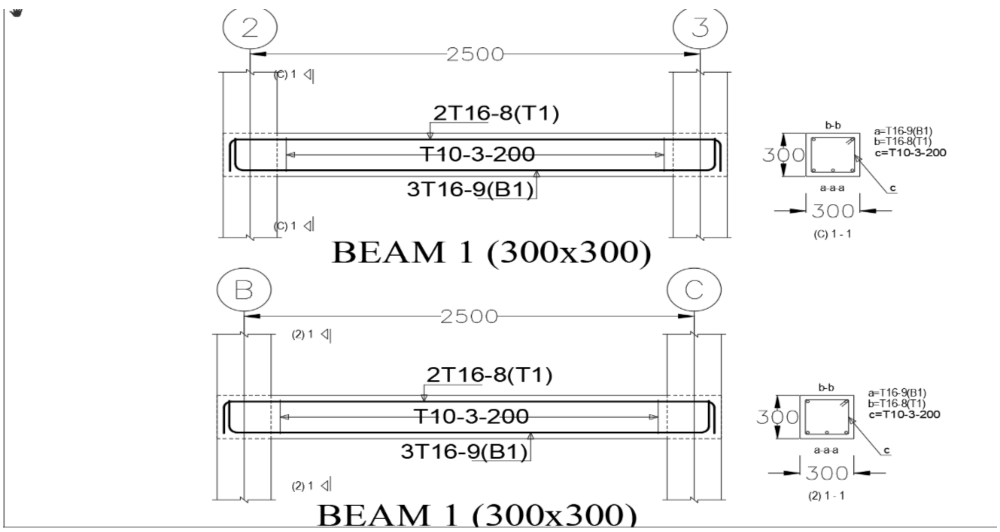


Figure 4.8: Detailed Reinforcement Layout for RC Storey Beams

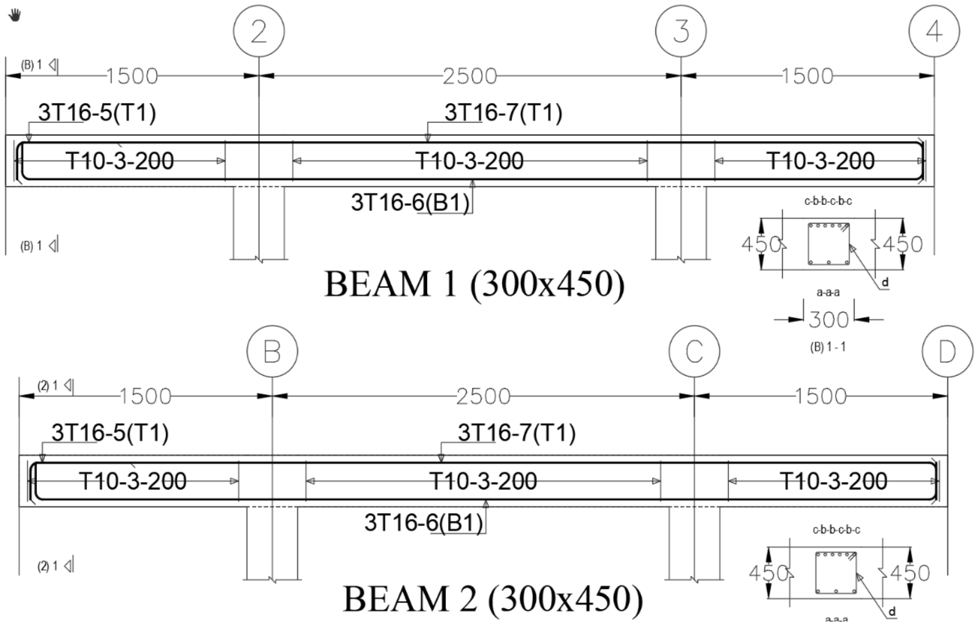


Figure 4.9: Detailed Reinforcement Layout for RC Storey Beams

4.8 Detailed Reinforcement Layout for RC Columns

Figure 4.10 presents the detailed reinforcement layout for the reinforced concrete (RC) columns of the elevated water tank tower. The columns are reinforced with 4Y25 longitudinal bars, placed continuously along the full height to resist axial compression and bending moments induced by gravity and wind loads.

Lateral reinforcement is provided using Y10 ties spaced at 225 mm intervals, arranged as closed stirrups to ensure proper confinement of the longitudinal bars. These ties enhance shear resistance, prevent buckling of the main reinforcement, and improve ductility of the columns under load.

The drawing also indicates the kicker levels at each storey, which facilitate proper alignment during construction and ensure accurate positioning of vertical members. The reinforcement arrangement ensures that the columns possess sufficient strength, stability, and durability to safely support the 20 m elevated water tank structure.

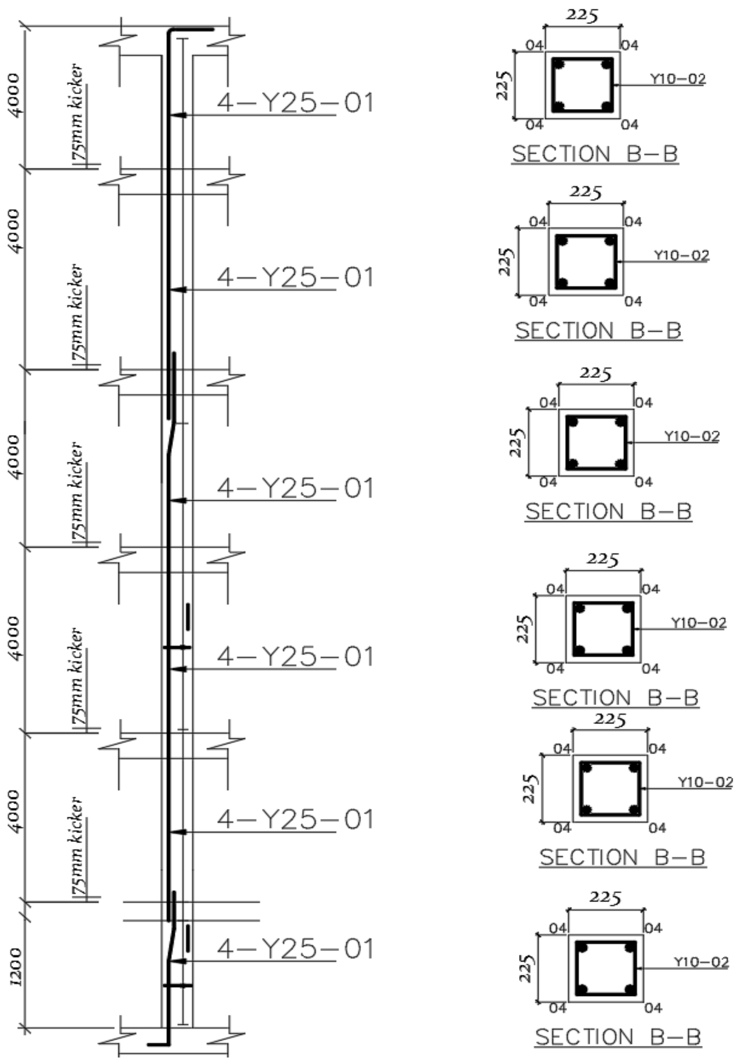


Figure 4.10: Detailed Reinforcement Layout for RC Columns

4.9 Structural Design Calculations

This section presents the detailed structural design calculations for the elevated water tank and tower system. The design was carried out in accordance with the relevant provisions of BS 8110 and Eurocode 2 for reinforced concrete structures, ensuring both structural safety and serviceability. The design was performed using a combination of manual calculations and software tools including AutoCAD for drafting and ProtaStructures for structural modelling and analysis.

4.9.1 Tank Load Calculations

Weight of Water (W):

$$W = \rho \cdot V = 9.81 \left\{\frac{kN}{m}\right\}^3 \times 100 \{m\}^3 = 981 \{kN\}$$

Self-Weight of Tank (Assumed 4 kN/m² over 30 m²):

$$W_{\{\{tank\}\}} = 4 \times 30 = 120 \{kN\}$$

Live Load (Maintenance):

$$W_{\{\{live\}\}} = 1.5 \times 30 = 45 \{kN\}$$

Total Factored Load:

$$W_{\{\{total\}\}} = 1.4\left(W_{\{\{tank\}\}} + W_{\{\{water\}\}}\right) + 1.6\left(W_{\{\{live\}\}}\right)$$

$$= 1.4(120 + 981) + 1.6(45) = 1.4(1101) + 72 = 1541.4 + 72$$

$$= 1613.4 \{kN\}$$

4.9.1.1 Column Design

Assume 4 columns carrying the load equally:

Load per Column $= \frac{1613.4}{4} = 403.35$KN

Column Design Using Eurocode (Short Column, Axial Load Only)

Effective height, $L = 12$ m$L = 12$ m, assumed square section of 300×300 mm

Check capacity:

$NRd = 0.35fckAc + 0.67fyAsN_{Rd} = 0.35\, F_{ck}\, A_c + 0.67\, F_y Z_s$

assuming 4 Y20 bars ($A_s = 1256\, mm^2$), and $A_c = 300 \times 300 = 90000\, mm^2$:

$N_{Rd} = 0.35 \times 25 \times 90000 + 0.67 \times 460 \times 1256 = 787500 + 386015.2 =$

$1173515.2\,\mathrm{N} = 1173.5\,\mathrm{kN}$

Hence, each column is adequate (403.35 kN < 1173.5 kN)

4.9.1.2 Slab and Beam Design (Support Platform)

Assume Slab Thickness = 150 mm

Live Load + Water Load = 10 kN/m² (distributed)

Design moment (Simply supported):

$$M = \frac{wL^2}{8} = \frac{10\times4^2}{8} = 20\,\mathrm{kNm/m}$$

Use $f_{ck} = 25\,\mathrm{MPa}, f_y = 460\,\mathrm{MPa}$, design for moment capacity:

$M_{Rd} = 0.138 f_{ck} b d^2$

$b = 1000\,\mathrm{mm}, d = 120\,\mathrm{mm}$, solve for MRd $\approx 49.68\,\mathrm{kNm/m} M_{Rd} \approx 49.68\,\mathrm{kNm/m}$

Since $M < M_{Rd}$, the slab is safe.

4.9.2 Tank Load Software Calculations

All Tables below were Obtained from Prota structure Software Analysis

4.9.2.1 Column Design

Table 4.2: Column Reinforcement Design

1C1	(**C-2**)		(300/300)
(C25/30 / Grade 460 (Type 2))			
No	**$N_{Top/Bot}$ (kN)**	**$M_{11\ Top/Bot}$ (kN.m)**	**$M_{22\ Top/Bot}$ (kN.m)**
1	1269.8, 1281.9	-1.0, -0.2	0.1, -0.7
2	760.2, 772.3	-1.9, -1.1	-0.4, -1.2
3	760.2, 772.3	-1.9, -1.1	-0.4, -1.2
4	700.6, 712.7	0.5, 1.2	0.8, 0.3
5	700.6, 712.7	0.7, 1.1	0.9, 0.3
6	946.7, 957.0	-0.6, -0.3	-3.7, 5.5
7	1006.4, 1016.8	-0.9, 0.1	4.0, -6.6
8	1006.4, 1016.8	-4.8, 6.2	0.1, -0.5
9	946.6, 957.0	3.2, -6.4	0.1, -0.6
10	976.5, 986.9	-0.8, -0.1	0.1, -0.5
11	976.5, 986.9	-0.8, -0.1	0.1, -0.5
12	976.5, 986.9	-0.8, -0.1	0.1, -0.5
13	976.5, 986.9	-0.8, -0.1	0.1, -0.5

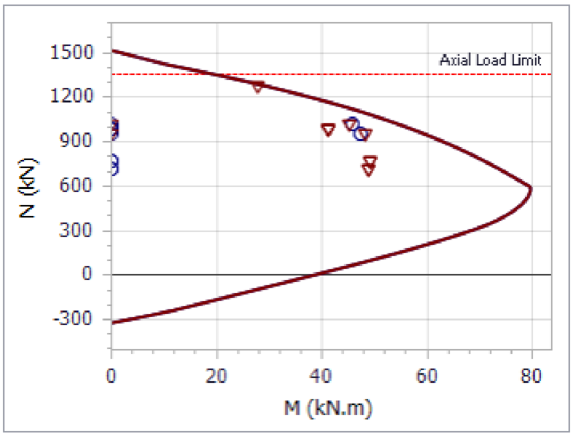


Table 4.3: Column Critical Loading Design

Critical Loading: 1 - (G*F)								
		min	Design					
N	1281.9	-	1281.9	kN				
M_{11}	-1.0	-19.2	-27.8	kN.m				
M_{22}	-0.7	-19.2	0.0	kN.m				
N_{max}	1080.0							
Concrete Cover = 25.0 mm								
BS8110-Cl.3.8.4.5								
N/bhFcu =	0.475							
Beta =	0.45							
$V_{d(1/2)}$ =	0.1 / 0.1	kN	Slender Column...			As (Req):	%0.88	789.51 mm^2
$v_{c'(1/2)}$ =	0.78 / 0.73	N/mm^2	L_{e1}/b_1 =	16.5 ≥ 10.0		As (Sup):	%0.89	804.25 mm^2
$v_{(1/2)}$ =	0.00 / 0.00	N/mm^2	L_{e2}/b_2 =	16.5 ≥ 10.0				
			$M_{add(1/2)}$ =	15.0 / 15.0	kN.m	**4T16**		
Links = T10-175								

Table 4.4: Column Reinforcement Design

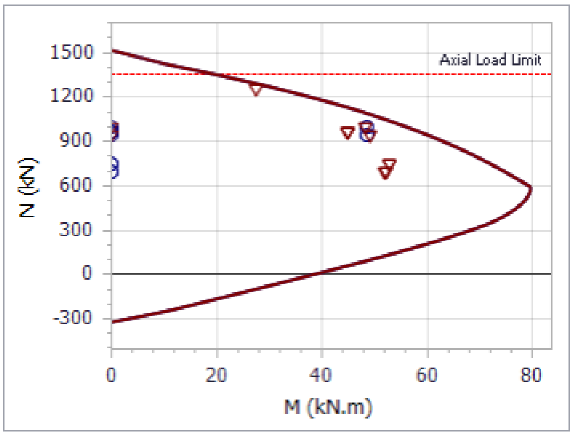
2C1 (**C-2**) (300/300) (C25/30 / Grade 460 (Type 2))				
No	**$N_{Top/Bot}$ (kN)**	**$M_{11\ Top/Bot}$ (kN.m)**	**$M_{22\ Top/Bot}$ (kN.m)**	
1	1250.5, 1262.6	-1.4, 0.4	0.5, -1.3	
2	741.0, 753.1	-2.3, -0.6	-0.1, -1.7	
3	741.0, 753.1	-2.3, -0.6	-0.1, -1.7	
4	682.8, 694.9	0.3, 1.6	1.0, 0.0	
5	682.8, 694.9	0.5, 1.4	1.1, -0.1	
6	937.3, 947.6	-0.9, 0.2	-4.0, 3.7	
7	982.9, 993.2	-1.2, 0.5	4.9, -5.7	
8	982.9, 993.3	-5.7, 5.3	0.4, -1.0	
9	937.2, 947.6	3.5, -4.5	0.4, -1.0	
10	960.1, 970.4	-1.1, 0.4	0.4, -1.0	
11	960.1, 970.4	-1.1, 0.4	0.4, -1.0	
12	960.1, 970.4	-1.1, 0.4	0.4, -1.0	
13	960.1, 970.4	-1.1, 0.4	0.4, -1.0	

Table 4.5: Column Critical Loading Design

Critical Loading: 1 - (G*F)					
		min	Design		
N	1262.6	-	1262.6	kN	
M_{11}	-1.4	-18.9	-27.6	kN.m	
M_{22}	-1.3	-18.9	0.0	kN.m	
N_{max}	1080.0				
Concrete Cover = 25.0 mm					
BS8110- Cl.3.8.4.5					
N/bhFcu =	0.468				
Beta =	0.46				

$V_{d(1/2)}$ =	0.2 / 0.2	kN	Slender Column...			As (Req):	%0.81	729.46 mm^2
$v_{c'(1/2)}$ =	0.89 / 0.80	N/mm^2	L_{e1}/b_1 =	17.0 ≥ 10.0		As (Sup):	%0.89	804.25 mm^2
$v_{(1/2)}$ =	0.00 / 0.00	N/mm^2	L_{e2}/b_2 =	17.0 ≥ 10.0				
			$M_{add(1/2)}$ =	16.9 / 16.9	kN.m	**4T16**		
Links = T10-175								

Table 4.6: Column Reinforcement Design

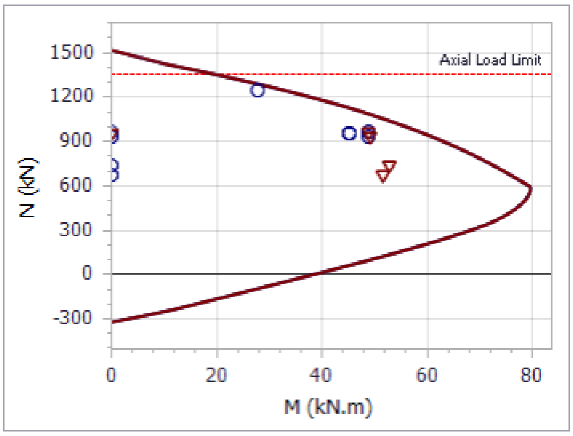
3C1 (C-2) (300/300) (C25/30 / Grade 460 (Type 2))				
No	**$N_{Top/Bot}$ (kN)**	**$M_{11\ Top/Bot}$ (kN.m)**	**$M_{22\ Top/Bot}$ (kN.m)**	
1	1230.7, 1242.8	-0.9, 0.3	0.0, -1.2	
2	721.3, 733.4	-2.0, -0.6	-0.2, -1.7	
3	721.3, 733.4	-2.0, -0.6	-0.2, -1.7	
4	664.9, 677.0	0.7, 1.4	0.6, 0.2	
5	664.9, 677.0	0.8, 1.3	0.7, 0.1	
6	927.6, 937.9	-0.6, 0.1	-4.1, 3.2	
7	958.9, 969.2	-0.9, 0.4	4.2, -5.1	
8	958.9, 969.3	-5.0, 4.6	0.1, -0.9	
9	927.5, 937.9	3.6, -4.1	0.1, -0.9	
10	943.2, 953.6	-0.7, 0.3	0.1, -0.9	
11	943.2, 953.6	-0.7, 0.3	0.1, -0.9	
12	943.2, 953.6	-0.7, 0.3	0.1, -0.9	
13	943.2, 953.6	-0.7, 0.3	0.1, -0.9	

Table 4.7: Column Critical Loading Design

Critical Loading: 1 - (G*F)					
		min	Design		
N	1242.8	-	1242.8	kN	
M_{11}	-0.9	-18.6	0.0	kN.m	
M_{22}	-1.2	-18.6	-27.7	kN.m	
N_{max}	1080.0				
Concrete Cover = 25.0 mm					
BS8110- Cl.3.8.4.5					
N/bhFcu =	0.460				
Beta =	0.46				

$V_{d(1/2)}$ =	0.1 / 0.1	kN	Slender Column...			As (Req):	%0.75	672.74 mm^2
$v_{c'(1/2)}$ =	0.79 / 0.71	N/mm^2	L_{e1}/b_1 =	17.0 ≥ 10.0		As (Sup):	%0.89	804.25 mm^2
$v_{(1/2)}$ =	0.00 / 0.00	N/mm^2	L_{e2}/b_2 =	17.0 ≥ 10.0				
			$M_{add(1/2)}$ =	17.8 / 17.8	kN.m	**4T16**		
Links = T10-175								

Table 4.8: Column Reinforcement Design

4C1 (**C-2**) (300/300)

(C25/30 / Grade 460 (Type 2))

No	$N_{Top/Bot}$ (kN)	$M_{11\ Top/Bot}$ (kN.m)	$M_{22\ Top/Bot}$ (kN.m)
1	1210.3, 1222.4	-4.6, 1.7	3.5, -2.5
2	701.0, 713.1	-4.5, 0.3	1.5, -2.5
3	701.0, 713.1	-4.5, 0.3	1.5, -2.5
4	647.0, 659.1	-1.1, 2.1	2.9, -0.6
5	647.0, 659.1	-0.9, 1.9	3.1, -0.7
6	916.8, 927.2	-3.4, 1.2	-1.1, 1.7
7	935.1, 945.4	-3.7, 1.5	6.6, -5.7
8	935.1, 945.5	-7.5, 5.2	2.8, -2.0
9	916.7, 927.1	0.5, -2.5	2.8, -2.0
10	925.9, 936.3	-3.5, 1.3	2.8, -2.0
11	925.9, 936.3	-3.5, 1.3	2.8, -2.0
12	925.9, 936.3	-3.5, 1.3	2.8, -2.0
13	925.9, 936.3	-3.5, 1.3	2.8, -2.0

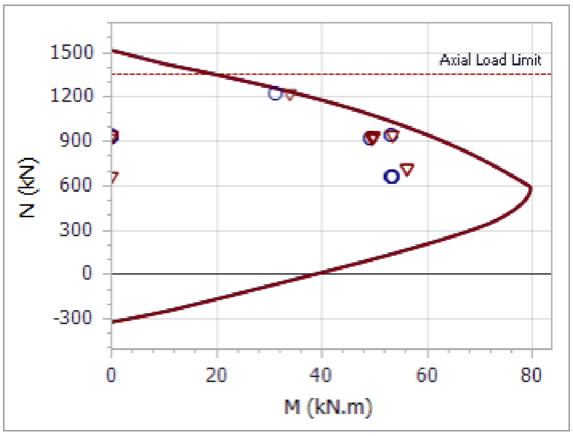


Table 4.9: Column Critical Loading Design

Critical Loading: 1 - (G*F)					
		min	Design		
N	1222.4	-	1222.4	kN	
M_{11}	-4.6	-18.3	-33.9	kN.m	
M_{22}	3.5	18.3	0.0	kN.m	
N_{max}	1080.0				
Concrete Cover = 25.0 mm					
BS8110-Cl.3.8.4.5					
N/bhFcu =	0.453				
Beta =	0.47				

$V_{d(1/2)}$ =	0.9 / 1.2	kN	Slender Column...			As (Req):	%0.82	737.61 mm^2
$v_{c'(1/2)}$ =	0.94 / 0.92	N/mm^2	L_{e1}/b_1 =	17.0 ≥ 10.0		As (Sup):	%0.89	804.25 mm^2
$v_{(1/2)}$ =	0.01 / 0.01	N/mm^2	L_{e2}/b_2 =	17.0 ≥ 10.0				
			$M_{add(1/2)}$ =	18.8 / 18.8	kN.m	**4T16**		
Links = T10-175								

Table 4.10: Column Reinforcement Design

5C1 (C-2) (300/300) (C25/30 / Grade 460 (Type 2))			
No	**$N_{Top/Bot}$ (kN)**	**$M_{11\ Top/Bot}$ (kN.m)**	**$M_{22\ Top/Bot}$ (kN.m)**
1	1189.0, 1201.1	13.8, -4.7	-14.3, 3.3
2	680.0, 692.1	6.8, -4.3	-6.9, -0.3
3	680.0, 692.1	6.8, -4.3	-6.9, -0.3
4	628.8, 640.9	9.1, -0.7	-9.5, 4.0
5	628.8, 640.9	9.1, -0.9	-9.5, 3.9
6	904.3, 914.7	10.8, -3.7	-15.0, 5.2
7	911.6, 922.0	10.4, -3.4	-7.0, -0.2
8	911.6, 922.0	6.4, -0.7	-11.0, 2.5
9	904.2, 914.6	14.8, -6.4	-11.0, 2.5
10	907.9, 918.3	10.6, -3.6	-11.0, 2.5
11	907.9, 918.3	10.6, -3.6	-11.0, 2.5
12	907.9, 918.3	10.6, -3.6	-11.0, 2.5
13	907.9, 918.3	10.6, -3.6	-11.0, 2.5

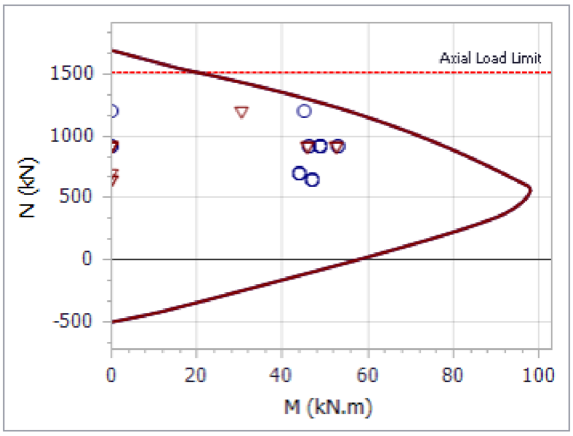


Table 4.11: Column Critical Loading Design

Critical Loading: 1 - (G*F)					
		min	Design		
N	1201.1	-	1201.1	kN	
M_{11}	13.8	18.0	0.0	kN.m	
M_{22}	-14.3	-18.0	-45.1	kN.m	
N_{max}	1080.0				
Concrete Cover = 25.0 mm					
BS8110- Cl.3.8.4.5					
N/bhFcu =	0.445				
Beta =	0.48				

$V_{d(1/2)}$ =	1.6 / 2.5	kN	Slender Column...			As (Req):	%1.00	901.74 mm^2
$v_{c'(1/2)}$ =	0.98 / 0.99	N/mm^2	L_{e1}/b_1 =	13.6 ≥ 10.0		As (Sup):	%1.40	1256.64 mm^2
$v_{(1/2)}$ =	0.02 / 0.03	N/mm^2	L_{e2}/b_2 =	13.6 ≥ 10.0				
			$M_{add(1/2)}$ =	16.3 / 16.3	kN.m	**4T20**		
Links = T10-225								

Table 4.12: Column Reinforcement Design

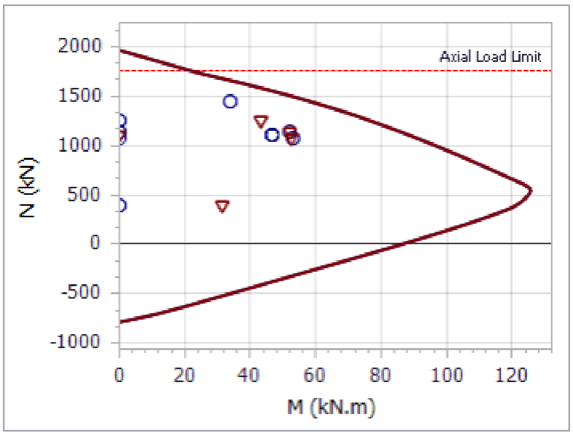
1C2 (**B-2**) (300/300) (C25/30 / Grade 460 (Type 2))				
No	**$N_{Top/Bot}$ (kN)**	**M_{11} Top/Bot (kN.m)**	**M_{22} Top/Bot (kN.m)**	
1	1431.5, 1443.6	-0.1, -0.6	-0.1, -0.6	
2	1245.1, 1257.2	-1.1, -1.5	-0.6, -1.1	
3	1245.1, 1257.2	-1.1, -1.5	-0.6, -1.1	
4	380.7, 392.8	1.4, 0.8	0.8, 0.4	
5	380.7, 392.8	1.3, 0.8	0.9, 0.3	
6	1068.4, 1078.7	0.1, -0.7	-4.2, 6.0	
7	1128.3, 1138.6	-0.2, -0.2	4.1, -6.9	
8	1068.4, 1078.8	-4.0, 5.8	0.0, -0.5	
9	1128.2, 1138.6	3.9, -6.7	-0.1, -0.4	
10	1098.3, 1108.7	-0.1, -0.4	-0.1, -0.4	
11	1098.3, 1108.7	-0.1, -0.4	-0.1, -0.4	
12	1098.3, 1108.7	-0.1, -0.4	-0.1, -0.4	
13	1098.3, 1108.7	-0.1, -0.4	-0.1, -0.4	

Table 4.13: Column Critical Loading Design

Critical Loading: 1 - (G*F)					
		min	Design		
N	1443.6	-	1443.6	kN	
M_{11}	-0.6	-21.7	0.0	kN.m	
M_{22}	-0.6	-21.7	-33.9	kN.m	
N_{max}	1080.0				
Concrete Cover = 25.0 mm					
BS8110- Cl.3.8.4.5					
N/bhFcu =	0.535				
Beta =	0.38				

$V_{d(1/2)}$ =	0.1 / 0.1	kN	Slender Column...			As (Req):	%1.43	1288.21 mm^2
$v_{c'(1/2)}$ =	0.91 / 0.87	N/mm^2	L_{e1}/b_1 =	16.5 ≥ 10.0		As (Sup):	%2.18	1963.50 mm^2
$v_{(1/2)}$ =	0.00 / 0.00	N/mm^2	L_{e2}/b_2 =	16.5 ≥ 10.0				
			$M_{add(1/2)}$ =	24.1 / 24.1	kN.m	**4T25**		
Links = T10-300								

Table 4.14: Column Reinforcement Design

2C2 (B-2) (300/300) (C25/30 / Grade 460 (Type 2))			
No	**$N_{Top/Bot}$ (kN)**	**$M_{11\ Top/Bot}$ (kN.m)**	**$M_{22\ Top/Bot}$ (kN.m)**
1	1413.3, 1425.4	0.0, -0.9	0.0, -0.9
2	1226.8, 1238.9	-1.0, -1.8	-0.6, -1.4
3	1226.8, 1238.9	-1.0, -1.8	-0.6, -1.4
4	362.9, 375.0	1.6, 0.4	0.9, 0.1
5	362.9, 375.0	1.4, 0.5	1.1, -0.1
6	1059.8, 1070.2	0.2, -0.9	-4.7, 4.3
7	1105.5, 1115.9	-0.1, -0.5	4.8, -5.7
8	1059.8, 1070.2	-4.5, 4.2	0.0, -0.7
9	1105.5, 1115.8	4.6, -5.6	0.0, -0.7
10	1082.6, 1093.0	0.0, -0.7	0.0, -0.7
11	1082.6, 1093.0	0.0, -0.7	0.0, -0.7
12	1082.6, 1093.0	0.0, -0.7	0.0, -0.7
13	1082.6, 1093.0	0.0, -0.7	0.0, -0.7

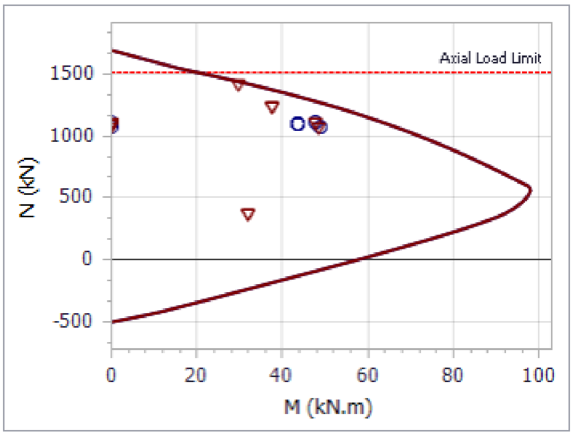


Table 4.15: Column Critical Loading Design

Critical Loading: 1 - (G*F)					
		min	Design		
N	1425.4	-	1425.4	kN	
M_{11}	-0.9	-21.4	-29.6	kN.m	
M_{22}	-0.9	-21.4	0.0	kN.m	
N_{max}	1080.0				
Concrete Cover = 25.0 mm					
BS8110- Cl.3.8.4.5					
N/bhFcu =	0.528				
Beta =	0.39				

$V_{d(1/2)}$ =	0.2 / 0.2	kN	Slender Column...			As (Req):	%1.36	1222.65 mm^2
$v_{c'(1/2)}$ =	0.85 / 0.80	N/mm^2	L_{e1}/b_1 =	17.0 ≥ 10.0		As (Sup):	%1.40	1256.64 mm^2
$v_{(1/2)}$ =	0.00 / 0.00	N/mm^2	L_{e2}/b_2 =	17.0 ≥ 10.0				
			$M_{add(1/2)}$ =	16.5 / 16.5	kN.m	**4T20**		
Links = T10-225								

Table 4.16: Column Reinforcement Design

3C2 (**B-2**) (300/300) (C25/30 / Grade 460 (Type 2))			
No	**$N_{Top/Bot}$ (kN)**	**M_{11} Top/Bot (kN.m)**	**M_{22} Top/Bot (kN.m)**
1	1395.6, 1407.7	-0.9, -0.4	-0.9, -0.4
2	1209.0, 1221.1	-1.6, -1.5	-1.1, -1.0
3	1209.0, 1221.1	-1.6, -1.5	-1.1, -1.0
4	345.2, 357.3	1.2, 0.6	0.5, 0.3
5	345.2, 357.3	1.1, 0.7	0.7, 0.1
6	1051.6, 1062.0	-0.4, -0.5	-5.1, 4.1
7	1083.1, 1093.4	-0.8, -0.2	3.9, -4.8
8	1051.7, 1062.0	-4.9, 4.0	-0.6, -0.4
9	1083.0, 1093.4	3.7, -4.7	-0.6, -0.4
10	1067.4, 1077.7	-0.6, -0.4	-0.6, -0.4
11	1067.4, 1077.7	-0.6, -0.4	-0.6, -0.4
12	1067.4, 1077.7	-0.6, -0.4	-0.6, -0.4
13	1067.4, 1077.7	-0.6, -0.4	-0.6, -0.4

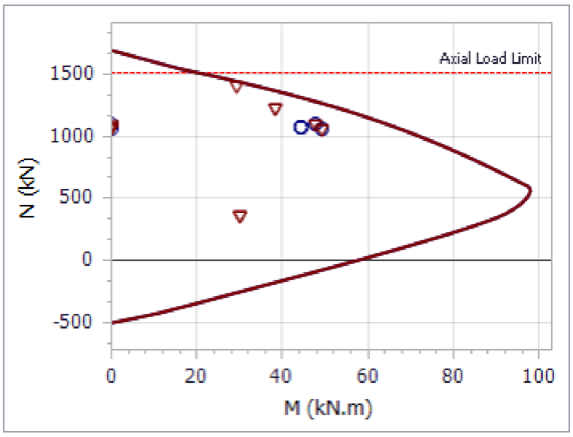


Table 4.17: Column Critical Loading Design

Critical Loading: 1 - (G*F)					
		min	Design		
N	1407.7	-	1407.7	kN	
M_{11}	-0.9	-21.1	-29.4	kN.m	
M_{22}	-0.9	-21.1	0.0	kN.m	
N_{max}	1080.0				
Concrete Cover = 25.0 mm					
BS8110-Cl.3.8.4.5					
N/bhFcu =	0.521				
Beta =	0.39				

$V_{d(1/2)}$ =	0.0 / 0.1	kN	Slender Column...			As (Req):	%1.30	1170.97 mm²
$v_{c'(1/2)}$ =	0.73 / 0.75	N/mm²	L_{e1}/b_1 =	17.0 ≥ 10.0		As (Sup):	%1.40	1256.64 mm²
$v_{(1/2)}$ =	0.00 / 0.00	N/mm²	L_{e2}/b_2 =	17.0 ≥ 10.0				
			$M_{add(1/2)}$ =	17.3 / 17.3	kN.m	**4T20**		
Links = T10-225								

Table 4.18: Column Reinforcement Design

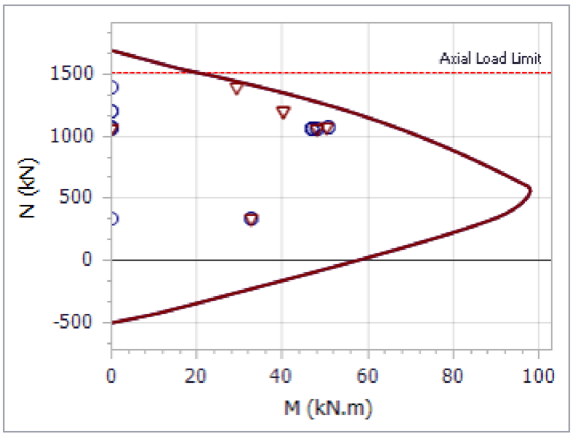
4C2 (B-2) (300/300) (C25/30 / Grade 460 (Type 2))				
No	**$N_{Top/Bot}$ (kN)**	**M_{11} Top/Bot (kN.m)**	**$M_{22\ Top/Bot}$ (kN.m)**	
1	1378.4, 1390.5	2.4, -1.4	2.4, -1.4	
2	1191.8, 1203.9	0.4, -2.1	0.5, -1.5	
3	1191.8, 1203.9	0.4, -2.1	0.5, -1.5	
4	327.6, 339.7	3.0, 0.0	2.8, -0.5	
5	327.6, 339.7	2.8, 0.2	3.0, -0.6	
6	1043.3, 1053.7	2.1, -1.3	-2.2, 2.9	
7	1061.7, 1072.1	1.8, -1.0	6.1, -5.1	
8	1043.3, 1053.7	-2.1, 2.7	1.9, -1.1	
9	1061.7, 1072.0	6.0, -5.0	1.9, -1.1	
10	1052.5, 1062.9	1.9, -1.1	1.9, -1.1	
11	1052.5, 1062.9	1.9, -1.1	1.9, -1.1	
12	1052.5, 1062.9	1.9, -1.1	1.9, -1.1	
13	1052.5, 1062.9	1.9, -1.1	1.9, -1.1	

Table 4.19: Column Critical Loading Design

Critical Loading: 1 - (G*F)					
		min	Design		
N	1390.5	-	1390.5	kN	
M_{11}	2.4	20.9	29.2	kN.m	
M_{22}	2.4	20.9	0.0	kN.m	
N_{max}	1080.0				
Concrete Cover = 25.0 mm					
BS8110-Cl.3.8.4.5					
N/bhFcu =	0.515				
Beta =	0.40				

$V_{d(1/2)}$ =	0.8 / 0.7	kN	Slender Column...			As (Req):	%1.25	1122.40 mm^2
$v_{c'(1/2)}$ =	0.87 / 0.83	N/mm^2	L_{e1}/b_1 =	17.0 ≥ 10.0		As (Sup):	%1.40	1256.64 mm^2
$v_{(1/2)}$ =	0.01 / 0.01	N/mm^2	L_{e2}/b_2 =	17.0 ≥ 10.0				
			$M_{add(1/2)}$ =	18.1 / 18.1	kN.m	**4T20**		
Links = T10-225								

Table 4.20: Column Reinforcement Design

5C2 (**B-2**) (300/300)

(C25/30 / Grade 460 (Type 2))

No	$N_{Top/Bot}$ (kN)	$M_{11\ Top/Bot}$ (kN.m)	$M_{22\ Top/Bot}$ (kN.m)
1	1362.0, 1374.1	-17.8, 5.4	-17.8, 5.4
2	1174.6, 1186.7	-13.6, 2.0	-10.4, 1.8
3	1174.6, 1186.7	-13.6, 2.0	-10.4, 1.8
4	310.6, 322.7	-6.3, 3.8	-9.6, 4.1
5	310.6, 322.7	-6.4, 3.9	-9.6, 4.0
6	1034.4, 1044.8	-13.4, 4.0	-18.0, 7.1
7	1041.9, 1052.2	-13.8, 4.3	-9.2, 1.1
8	1034.4, 1044.8	-17.8, 7.0	-13.6, 4.1
9	1041.8, 1052.2	-9.4, 1.3	-13.7, 4.1
10	1038.1, 1048.5	-13.6, 4.1	-13.6, 4.1
11	1038.1, 1048.5	-13.6, 4.1	-13.6, 4.1
12	1038.1, 1048.5	-13.6, 4.1	-13.6, 4.1
13	1038.1, 1048.5	-13.6, 4.1	-13.6, 4.1

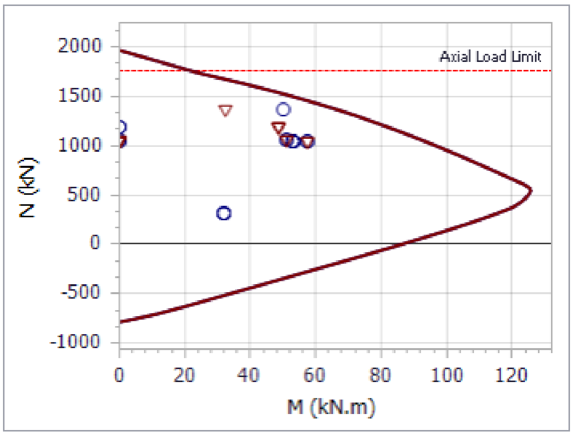


Table 4.21: Column Critical Loading Design

Critical Loading: 1 - (G*F)					
		min	Design		
N	1374.1	-	1374.1	kN	
M_{11}	-17.8	-20.6	0.0	kN.m	
M_{22}	-17.8	-20.6	-50.0	kN.m	
N_{max}	1080.0				
Concrete Cover = 25.0 mm					
BS8110-Cl.3.8.4.5					
N/bhFcu =	0.509				
Beta =	0.41				

$V_{d(1/2)}$ =	3.4 / 2.5	kN	Slender Column...			As (Req):	%1.61	1452.34 mm^2
$v_{c'(1/2)}$ =	1.01 / 1.03	N/mm^2	L_{e1}/b_1 =	13.6 ≥ 10.0		As (Sup):	%2.18	1963.50 mm^2
$v_{(1/2)}$ =	0.04 / 0.03	N/mm^2	L_{e2}/b_2 =	13.6 ≥ 10.0				
			$M_{add(1/2)}$ =	17.7 / 17.7	kN.m	**4T25**		
Links = T10-300								

Table 4.22: Column Reinforcement Design

1C3 (C25/30 / Grade 460 (Type 2))		(C-3)	(300/300)
No	$N_{Top/Bot}$ (kN)	$M_{11\ Top/Bot}$ (kN.m)	$M_{22\ Top/Bot}$ (kN.m)
1	1148.0, 1160.1	-0.7, -0.3	-0.7, -0.3
2	470.3, 482.4	-1.7, -1.3	-1.2, -0.8
3	470.3, 482.4	-1.7, -1.3	-1.2, -0.8
4	866.6, 878.7	0.6, 1.2	0.2, 0.6
5	866.6, 878.7	0.7, 1.1	0.1, 0.7
6	914.8, 925.1	-0.7, 0.0	-4.4, 5.9
7	855.0, 865.4	-0.4, -0.4	3.3, -6.3
8	914.8, 925.2	-4.6, 6.1	-0.6, -0.2
9	855.0, 865.4	3.4, -6.5	-0.6, -0.2
10	884.9, 895.3	-0.6, -0.2	-0.6, -0.2
11	884.9, 895.3	-0.6, -0.2	-0.6, -0.2
12	884.9, 895.3	-0.6, -0.2	-0.6, -0.2
13	884.9, 895.3	-0.6, -0.2	-0.6, -0.2

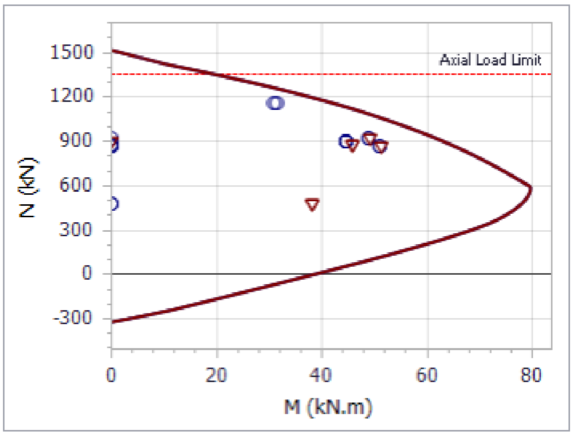


Table 4.23: Column Critical Loading Design

Critical Loading: 1 - (G*F)					
		min	Design		
N	1160.1	-	1160.1	kN	
M_{11}	-0.7	-17.4	0.0	kN.m	
M_{22}	-0.7	-17.4	-31.6	kN.m	
N_{max}	1080.0				
Concrete Cover = 25.0 mm					
BS8110-Cl.3.8.4.5					
N/bhFcu =	0.430				
Beta =	0.50				

$V_{d(1/2)}$ =	0.1 / 0.0	kN	Slender Column...			As (Req):	%0.47	424.04 mm^2
$v_{c'(1/2)}$ =	0.68 / 0.63	N/mm^2	L_{e1}/b_1 =	16.5 ≥ 10.0		As (Sup):	%0.89	804.25 mm^2
$v_{(1/2)}$ =	0.00 / 0.00	N/mm^2	L_{e2}/b_2 =	16.5 ≥ 10.0				
			$M_{add(1/2)}$ =	20.4 / 20.4	kN.m	**4T16**		
Links = T10-175								

Table 4.24: Column Reinforcement Design

2C3 (C25/30 / Grade 460 (Type 2))	(C-3)		(300/300)
No	**$N_{Top/Bot}$ (kN)**	**$M_{11\ Top/Bot}$ (kN.m)**	**$M_{22\ Top/Bot}$ (kN.m)**
1	1129.8, 1141.9	-0.8, 0.0	-0.8, 0.0
2	452.0, 464.1	-1.7, -1.0	-1.3, -0.5
3	452.0, 464.1	-1.7, -1.0	-1.3, -0.5
4	848.8, 860.9	0.3, 1.6	0.0, 0.9
5	848.8, 860.9	0.5, 1.4	-0.1, 1.1
6	892.0, 902.4	-0.8, 0.2	-5.1, 4.8
7	846.4, 856.8	-0.5, -0.1	3.8, -4.6
8	892.0, 902.4	-5.3, 4.9	-0.7, 0.1
9	846.4, 856.8	3.9, -4.8	-0.7, 0.1
10	869.2, 879.6	-0.7, 0.1	-0.7, 0.1
11	869.2, 879.6	-0.7, 0.1	-0.7, 0.1
12	869.2, 879.6	-0.7, 0.1	-0.7, 0.1
13	869.2, 879.6	-0.7, 0.1	-0.7, 0.1

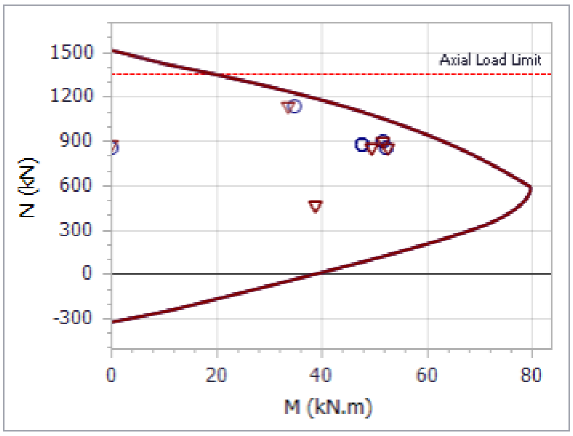


Table 4.25: Column Critical Loading Design

Critical Loading: 8 - ((G+Q)P11 *F2)					
		min	Design		
N	902.4	-	902.4	kN	
M_{11}	-5.3	-13.5	-51.6	kN.m	
M_{22}	-0.7	-13.5	0.0	kN.m	
N_{max}	1080.0				
Concrete Cover = 25.0 mm					
BS8110- Cl.3.8.4.5					
N/bhFcu =	0.334				
Beta =	0.61				

$V_{d(1/2)}$ =	0.2 / 0.2	kN	Slender Column...			As (Req):	%0.43	386.11 mm²
$v_{c'(1/2)}$ =	0.72 / 0.69	N/mm²	L_{e1}/b_1 =	17.0 ≥ 10.0		As (Sup):	%0.89	804.25 mm²
$v_{(1/2)}$ =	0.00 / 0.00	N/mm²	L_{e2}/b_2 =	17.0 ≥ 10.0				
			$M_{add(1/2)}$ =	28.5 / 28.5	kN.m	**4T16**		
Links = T10-175								

Table 4.26: Column Reinforcement Design

No	$N_{Top/Bot}$ (kN)	$M_{11\ Top/Bot}$ (kN.m)	$M_{22\ Top/Bot}$ (kN.m)
3C3 (C25/30 / Grade 460 (Type 2))	(C-3)		(300/300)
1	1112.1, 1124.2	0.0, -0.4	0.0, -0.4
2	434.3, 446.4	-1.3, -1.3	-0.8, -0.8
3	434.3, 446.4	-1.3, -1.3	-0.8, -0.8
4	831.1, 843.2	0.9, 1.3	0.5, 0.7
5	831.1, 843.2	1.0, 1.2	0.3, 0.9
6	869.6, 880.0	-0.2, -0.1	-4.2, 3.9
7	838.3, 848.6	0.1, -0.4	4.1, -4.5
8	869.6, 880.0	-4.4, 4.0	-0.1, -0.3
9	838.2, 848.6	4.2, -4.6	-0.1, -0.3
10	853.9, 864.3	-0.1, -0.3	-0.1, -0.3
11	853.9, 864.3	-0.1, -0.3	-0.1, -0.3
12	853.9, 864.3	-0.1, -0.3	-0.1, -0.3
13	853.9, 864.3	-0.1, -0.3	-0.1, -0.3

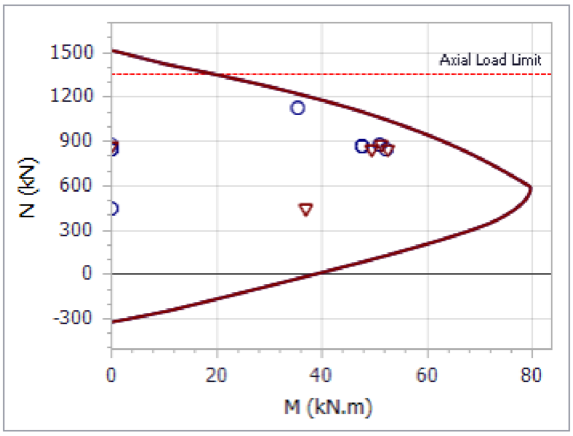


Table 4.27: Column Critical Loading Design

Critical Loading: 8 - ((G+Q)P11 *F2)					
		min	Design		
N	880.0	-	880.0	kN	
M_{11}	-4.4	-13.2	-51.2	kN.m	
M_{22}	-0.3	-13.2	0.0	kN.m	
N_{max}	1080.0				
Concrete Cover = 25.0 mm					
BS8110- Cl.3.8.4.5					
N/bhFcu =	0.326				
Beta =	0.62				

$V_{d(1/2)}$ =	0.0 / 0.0	kN	Slender Column...			As (Req):	%0.40 (min)	360.00 mm^2
$v_{c'(1/2)}$ =	0.61 / 0.61	N/mm^2	L_{e1}/b_1 =	17.0 ≥ 10.0		As (Sup):	%0.89	804.25 mm^2
$v_{(1/2)}$ =	0.00 / 0.00	N/mm^2	L_{e2}/b_2 =	17.0 ≥ 10.0				
			$M_{add(1/2)}$ =	28.8 / 28.8	kN.m	**4T16**		
Links = T10-175								

Table 4.28: Column Reinforcement Design

4C3	**(C-3)**		(300/300)
(C25/30 / Grade 460 (Type 2))			
No	**$N_{Top/Bot}$ (kN)**	**$M_{11\ Top/Bot}$ (kN.m)**	**$M_{22\ Top/Bot}$ (kN.m)**
1	1095.0, 1107.1	-3.2, 0.5	-3.2, 0.5
2	417.2, 429.3	-2.4, -1.1	-2.3, -0.5
3	417.2, 429.3	-2.4, -1.1	-2.3, -0.5
4	813.4, 825.5	-1.8, 2.3	-1.8, 1.5
5	813.4, 825.5	-1.6, 2.1	-2.0, 1.7
6	848.2, 858.6	-2.7, 0.6	-6.4, 4.1
7	830.0, 840.3	-2.3, 0.3	1.3, -3.2
8	848.3, 858.6	-6.5, 4.3	-2.5, 0.4
9	829.9, 840.3	1.5, -3.4	-2.5, 0.4
10	839.1, 849.5	-2.5, 0.4	-2.5, 0.4
11	839.1, 849.5	-2.5, 0.4	-2.5, 0.4
12	839.1, 849.5	-2.5, 0.4	-2.5, 0.4
13	839.1, 849.5	-2.5, 0.4	-2.5, 0.4

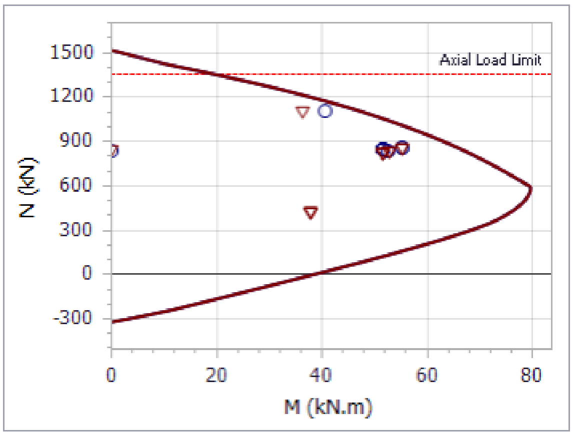


Table 4.29: Column Critical Loading Design

Critical Loading: 1 - (G*F)					
		min	Design		
N	1107.1	-	1107.1	kN	
M_{11}	-3.2	-16.6	0.0	kN.m	
M_{22}	-3.2	-16.6	-40.6	kN.m	
N_{max}	1080.0				
Concrete Cover = 25.0 mm					
BS8110-Cl.3.8.4.5					
N/bhFcu =	0.410				
Beta =	0.52				

$V_{d(1/2)}$ =	0.4 / 0.3	kN	Slender Column...			As (Req):	%0.54	488.81 mm^2
$v_{c'(1/2)}$ =	0.74 / 0.70	N/mm^2	L_{e1}/b_1 =	17.0 ≥ 10.0		As (Sup):	%0.89	804.25 mm^2
$v_{(1/2)}$ =	0.01 / 0.00	N/mm^2	L_{e2}/b_2 =	17.0 ≥ 10.0				
			$M_{add(1/2)}$ =	23.5 / 23.5	kN.m	**4T16**		
Links = T10-175								

Table 4.30: Column Reinforcement Design

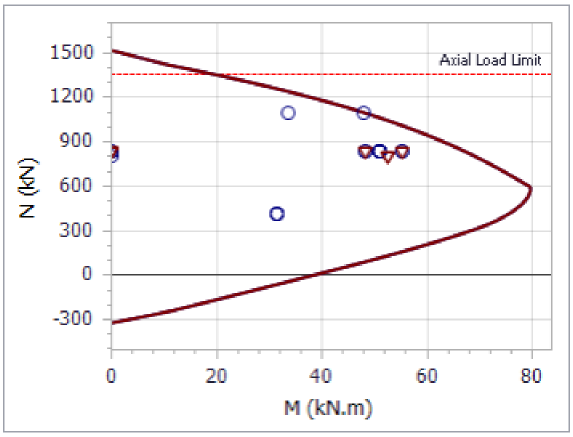
5C3 (C25/30 / Grade 460 (Type 2))		**(C-3)**	(300/300)	
No	**$N_{Top/Bot}$ (kN)**	**$M_{11\ Top/Bot}$ (kN.m)**	**$M_{22\ Top/Bot}$ (kN.m)**	
1	1079.0, 1091.1	15.9, -6.4	15.9, -6.4	
2	401.6, 413.7	4.4, -4.4	6.7, -4.3	
3	401.6, 413.7	4.5, -4.4	6.6, -4.3	
4	795.2, 807.3	13.6, -2.4	11.4, -2.6	
5	795.2, 807.3	13.6, -2.5	11.4, -2.5	
6	828.8, 839.2	12.0, -4.7	8.2, -2.1	
7	821.5, 831.8	12.4, -5.0	16.2, -7.5	
8	828.8, 839.2	8.0, -2.0	12.2, -4.8	
9	821.4, 831.8	16.4, -7.7	12.2, -4.8	
10	825.1, 835.5	12.2, -4.8	12.2, -4.8	
11	825.1, 835.5	12.2, -4.8	12.2, -4.8	
12	825.1, 835.5	12.2, -4.8	12.2, -4.8	
13	825.1, 835.5	12.2, -4.8	12.2, -4.8	

Table 4.31: Column Critical Loading Design

Critical Loading: 1 - (G*F)					
		min	Design		
N	1091.1	-	1091.1	kN	
M_{11}	15.9	16.4	0.0	kN.m	
M_{22}	15.9	16.4	48.0	kN.m	
N_{max}	1080.0				
Concrete Cover = 25.0 mm					
BS8110-Cl.3.8.4.5					
N/bhFcu =	0.404				
Beta =	0.53				

$V_{d(1/2)}$ =	2.7 / 2.2	kN	Slender Column...			As (Req):	%0.88	796.27 mm^2
$v_{c'(1/2)}$ =	0.89 / 0.94	N/mm^2	L_{e1}/b_1 =	13.6 ≥ 10.0		As (Sup):	%0.89	804.25 mm^2
$v_{(1/2)}$ =	0.03 / 0.03	N/mm^2	L_{e2}/b_2 =	13.6 ≥ 10.0				
			$M_{add(1/2)}$ =	15.5 / 15.5	kN.m	**4T16**		
Links = T10-175								

Table 4.32: Column Reinforcement Design

1C4	**(B-3)**		(300/300)
(C25/30 / Grade 460 (Type 2))			
No	**$N_{Top/Bot}$ (kN)**	**$M_{11\ Top/Bot}$ (kN.m)**	**$M_{22\ Top/Bot}$ (kN.m)**
1	1269.3, 1281.4	0.1, -0.7	-1.0, -0.2
2	916.8, 928.9	-0.9, -1.7	-1.5, -0.7
3	916.8, 928.9	-0.9, -1.7	-1.5, -0.7
4	543.6, 555.7	1.4, 0.8	0.2, 0.6
5	543.6, 555.7	1.3, 0.8	0.1, 0.7
6	1006.1, 1016.5	0.0, -0.3	-4.9, 6.4
7	946.3, 956.6	0.3, -0.8	3.4, -6.6
8	946.3, 956.7	-3.9, 5.7	-0.8, -0.1
9	1006.1, 1016.5	4.1, -6.8	-0.8, -0.1
10	976.2, 986.6	0.1, -0.5	-0.8, -0.1
11	976.2, 986.6	0.1, -0.5	-0.8, -0.1
12	976.2, 986.6	0.1, -0.5	-0.8, -0.1
13	976.2, 986.6	0.1, -0.5	-0.8, -0.1

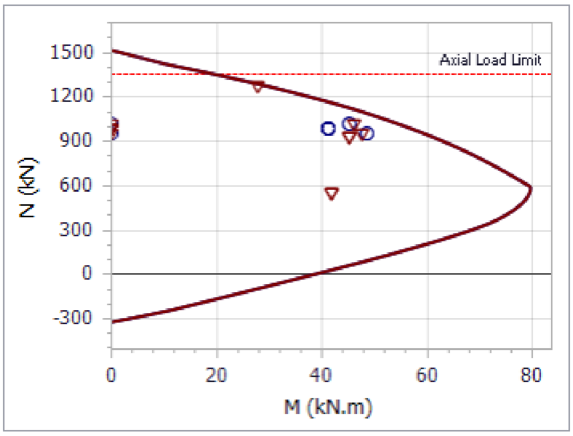


Table 4.33: Column Critical Loading Design

Critical Loading: 1 - (G*F)					
		min	Design		
N	1281.4	-	1281.4	kN	
M_{11}	-0.7	-19.2	-27.8	kN.m	
M_{22}	-1.0	-19.2	0.0	kN.m	
N_{max}	1080.0				
Concrete Cover = 25.0 mm					
BS8110- Cl.3.8.4.5					
N/bhFcu =	0.475				
Beta =	0.45				

$V_{d(1/2)}$ =	0.1 / 0.1	kN	Slender Column...			As (Req):	%0.88	788.19 mm^2
$v_{c'(1/2)}$ =	0.77 / 0.69	N/mm^2	L_{e1}/b_1 =	16.5 ≥ 10.0		As (Sup):	%0.89	804.25 mm^2
$v_{(1/2)}$ =	0.00 / 0.00	N/mm^2	L_{e2}/b_2 =	16.5 ≥ 10.0				
			$M_{add(1/2)}$ =	15.0 / 15.0	kN.m	**4T16**		
Links = T10-175								

Table 4.34: Column Reinforcement Design

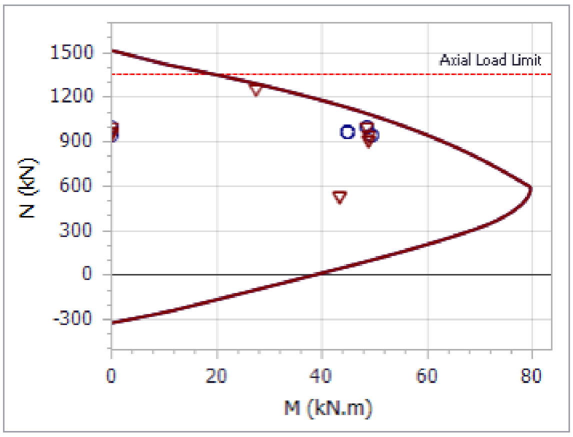
2C4 (B-3) (300/300) (C25/30 / Grade 460 (Type 2))				
No	**$N_{Top/Bot}$ (kN)**	**$M_{11\ Top/Bot}$ (kN.m)**	**$M_{22\ Top/Bot}$ (kN.m)**	
1	1250.1, 1262.2	0.5, -1.3	-1.4, 0.4	
2	897.6, 909.7	-0.5, -2.2	-1.8, -0.1	
3	897.6, 909.7	-0.5, -2.2	-1.8, -0.1	
4	525.7, 537.8	1.6, 0.3	0.0, 1.0	
5	525.7, 537.8	1.5, 0.5	-0.2, 1.1	
6	982.6, 993.0	0.3, -0.9	-5.8, 5.4	
7	936.9, 947.3	0.6, -1.2	3.7, -4.6	
8	936.9, 947.3	-4.1, 3.8	-1.1, 0.4	
9	982.6, 992.9	5.0, -5.9	-1.1, 0.4	
10	959.7, 970.1	0.4, -1.0	-1.1, 0.4	
11	959.7, 970.1	0.4, -1.0	-1.1, 0.4	
12	959.7, 970.1	0.4, -1.0	-1.1, 0.4	
13	959.7, 970.1	0.4, -1.0	-1.1, 0.4	

Table 4.35: Column Critical Loading Design

Critical Loading: 1 - (G*F)					
		min	Design		
N	1262.2	-	1262.2	kN	
M_{11}	-1.3	-18.9	-27.6	kN.m	
M_{22}	-1.4	-18.9	0.0	kN.m	
N_{max}	1080.0				
Concrete Cover = 25.0 mm					
BS8110-Cl.3.8.4.5					
N/bhFcu =	0.467				
Beta =	0.46				

$V_{d(1/2)}$ =	0.2 / 0.2	kN	Slender Column...			As (Req):	%0.81	728.16 mm^2
$v_{c'(1/2)}$ =	0.83 / 0.75	N/mm^2	L_{e1}/b_1 =	17.0 ≥ 10.0		As (Sup):	%0.89	804.25 mm^2
$v_{(1/2)}$ =	0.00 / 0.00	N/mm^2	L_{e2}/b_2 =	17.0 ≥ 10.0				
			$M_{add(1/2)}$ =	16.9 / 16.9	kN.m	**4T16**		
Links = T10-175								

Table 4.36: Column Reinforcement Design

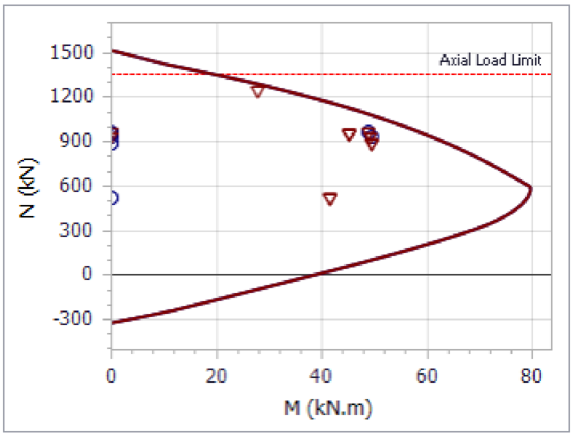
3C4 (B-3) (300/300) (C25/30 / Grade 460 (Type 2))				
No	**N Top/Bot (kN)**	**M11 Top/Bot (kN.m)**	**M22 Top/Bot (kN.m)**	
1	1230.3, 1242.4	0.0, -1.2	-0.9, 0.3	
2	877.8, 889.9	-0.6, -2.2	-1.6, -0.1	
3	877.8, 889.9	-0.6, -2.2	-1.6, -0.1	
4	507.9, 520.0	1.1, 0.5	0.4, 0.8	
5	507.9, 520.0	1.0, 0.7	0.3, 0.9	
6	958.6, 969.0	-0.1, -0.8	-5.2, 4.8	
7	927.2, 937.5	0.2, -1.1	3.8, -4.2	
8	927.2, 937.6	-4.2, 3.4	-0.7, 0.3	
9	958.6, 968.9	4.4, -5.3	-0.7, 0.3	
10	942.9, 953.3	0.1, -0.9	-0.7, 0.3	
11	942.9, 953.3	0.1, -0.9	-0.7, 0.3	
12	942.9, 953.3	0.1, -0.9	-0.7, 0.3	
13	942.9, 953.3	0.1, -0.9	-0.7, 0.3	

Table 4.37: Column Critical Loading Design

Critical Loading: 1 - (G*F)					
		min	Design		
N	1242.4	-	1242.4	kN	
M_{11}	-1.2	-18.6	-27.7	kN.m	
M_{22}	-0.9	-18.6	0.0	kN.m	
N_{max}	1080.0				
Concrete Cover = 25.0 mm					
BS8110- Cl.3.8.4.5					
N/bhFcu =	0.460				
Beta =	0.46				

$V_{d(1/2)}$ =	0.1 / 0.1	kN	Slender Column...			As (Req):	%0.75	671.44 mm^2
$v_{c'(1/2)}$ =	0.71 / 0.67	N/mm^2	L_{e1}/b_1 =	17.0 ≥ 10.0		As (Sup):	%0.89	804.25 mm^2
$v_{(1/2)}$ =	0.00 / 0.00	N/mm^2	L_{e2}/b_2 =	17.0 ≥ 10.0				
			$M_{add(1/2)}$ =	17.9 / 17.9	kN.m	**4T16**		
Links = T10-175								

Table 4.38: Column Reinforcement Design

4C4	(B-3)		(300/300)
(C25/30 / Grade 460 (Type 2))			

No	$N_{Top/Bot}$ (kN)	$M_{11\ Top/Bot}$ (kN.m)	$M_{22\ Top/Bot}$ (kN.m)
1	1209.9, 1222.0	3.5, -2.5	-4.6, 1.7
2	857.5, 869.6	0.7, -2.9	-3.6, 0.6
3	857.5, 869.6	0.7, -2.9	-3.6, 0.6
4	490.0, 502.1	3.9, -0.4	-1.8, 1.6
5	490.0, 502.1	3.7, -0.2	-2.0, 1.8
6	934.8, 945.2	2.6, -1.8	-7.7, 5.3
7	916.4, 926.8	2.9, -2.1	0.6, -2.6
8	916.4, 926.8	-1.2, 1.9	-3.5, 1.3
9	934.8, 945.1	6.8, -5.8	-3.5, 1.4
10	925.6, 936.0	2.8, -2.0	-3.5, 1.3
11	925.6, 936.0	2.8, -2.0	-3.5, 1.3
12	925.6, 936.0	2.8, -2.0	-3.5, 1.3
13	925.6, 936.0	2.8, -2.0	-3.5, 1.3

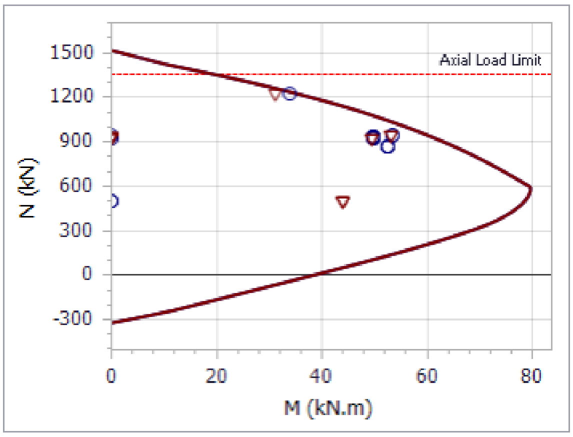


Table 4.39: Column Critical Loading Design

Critical Loading: 1 - (G*F)					
		min	Design		
N	1222.0	-	1222.0	kN	
M_{11}	3.5	18.3	0.0	kN.m	
M_{22}	-4.6	-18.3	-33.9	kN.m	
N_{max}	1080.0				
Concrete Cover = 25.0 mm					
BS8110-Cl.3.8.4.5					
N/bhFcu =	0.453				
Beta =	0.47				

$V_{d(1/2)}$ =	0.9 / 1.0	kN	Slender Column...			As (Req):	%0.82	737.34 mm^2
$v_{c'(1/2)}$ =	1.00 / 0.82	N/mm^2	L_{e1}/b_1 =	17.0 ≥ 10.0		As (Sup):	%0.89	804.25 mm^2
$v_{(1/2)}$ =	0.01 / 0.01	N/mm^2	L_{e2}/b_2 =	17.0 ≥ 10.0				
			$M_{add(1/2)}$ =	18.8 / 18.8	kN.m	**4T16**		
Links = T10-175								

Table 4.40: Column Reinforcement Design

5C4 (**B-3**) (300/300)

(C25/30 / Grade 460 (Type 2))

No	**$N_{Top/Bot}$ (kN)**	**$M_{11\ Top/Bot}$ (kN.m)**	**$M_{22\ Top/Bot}$ (kN.m)**
1	1188.6, 1200.7	-14.3, 3.2	13.8, -4.7
2	836.3, 848.4	-5.9, -1.5	5.1, -2.8
3	836.3, 848.4	-5.9, -1.5	5.1, -2.8
4	472.1, 484.2	-10.5, 5.1	10.9, -2.4
5	472.1, 484.2	-10.5, 5.2	10.8, -2.3
6	911.4, 921.7	-11.2, 2.6	6.2, -0.6
7	903.9, 914.2	-10.7, 2.3	15.0, -6.5
8	903.9, 914.3	-15.2, 5.3	10.6, -3.6
9	911.3, 921.7	-6.8, -0.4	10.6, -3.6
10	907.6, 918.0	-11.0, 2.5	10.6, -3.6
11	907.6, 918.0	-11.0, 2.5	10.6, -3.6
12	907.6, 918.0	-11.0, 2.5	10.6, -3.6
13	907.6, 918.0	-11.0, 2.5	10.6, -3.6

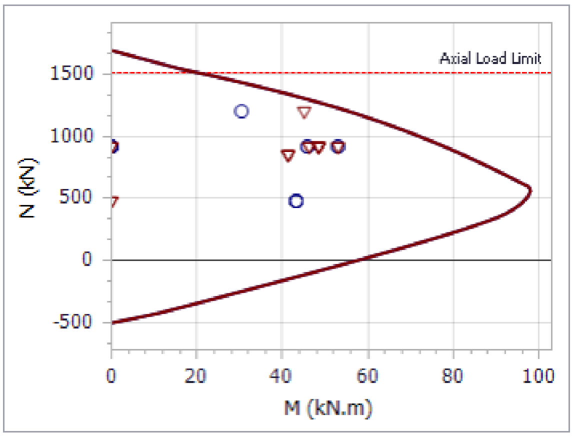


Table 4.41: Column Critical Loading Design

Critical Loading: 1 - (G*F)					
		min	Design		
N	1200.7	-	1200.7	kN	
M_{11}	-14.3	-18.0	-45.1	kN.m	
M_{22}	13.8	18.0	0.0	kN.m	
N_{max}	1080.0				
Concrete Cover = 25.0 mm					
BS8110- Cl.3.8.4.5					
N/bhFcu =	0.445				
Beta =	0.48				

$V_{d(1/2)}$ =	3.3 / 1.1	kN	Slender Column...			As (Req):	%1.00	899.69 mm^2
$v_{c'(1/2)}$ =	0.95 / 0.96	N/mm^2	L_{e1}/b_1 =	13.6 ≥ 10.0		As (Sup):	%1.40	1256.64 mm^2
$v_{(1/2)}$ =	0.04 / 0.01	N/mm^2	L_{e2}/b_2 =	13.6 ≥ 10.0				
			$M_{add(1/2)}$ =	16.3 / 16.3	kN.m	**4T20**		
Links = T10-225								

4.9.2.2 Slab and Beam Design (Support Platform)

4.9.2.2.1 Beam Reinforcement Design

Table 4.42: Beam Design Result

Beam 1 Materials: C25/30 / Grade 460 (Type 2) (Links: Grade 460 (Type 2))

	5B9		L= 1500mm	**5B4**		L= 2500mm	**5B6**		L= 1500mm
B_w x H (mm)	300 x 300			300 x 300			300 x 300		
Flange B_f x H_f	---			---			---		
Bending (Top Edge) ...									
M (kN.m)	0.0	16.7	20.4	30.6	16.8	20.2	22.0	13.7	0.0
d (mm)		259.0	257.0	257.0	257.0	257.0	257.0	259.0	259.0
K/K'	257.0	259.0	259.0	257.0	259.0	259.0	257.0	259.0	259.0
x (mm)	257.0	259.0	259.0	257.0	259.0	259.0	257.0	259.0	259.0
A_s (mm^2)		169.21	208.57	317.50	172.09	206.98	225.14	139.05	0.27
A_s' (mm^2)		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$A_{s,min}$ (mm^2)	0.00	132.84	132.84	132.84	132.84	132.84	132.84	132.84	0.00
Bending (Bottom Edge) ...									
M (kN.m)	11.5	2.3	0.0	0.0	0.6	1.1	0.0	2.8	5.9
d (mm)	240.0	257.0			257.0	240.0		257.0	240.0
K/K'		257.0	240.0		257.0	240.0		257.0	240.0
x (mm)		257.0	240.0		257.0	240.0		257.0	240.0
A_s (mm^2)	126.25	23.12			5.81	12.21		28.35	64.37
A_s' (mm^2)	0.00	0.00			0.00	0.00		0.00	0.00
$A_{s,min}$ (mm^2)	0.00	132.84	132.84	132.84	132.84	132.84	132.84	132.84	0.00

Shear And Torsion Design ...									
V_d (kN)	28.1		107.5	81.9		35.6	94.5		23.8
v (MPa)	0.36		1.39	1.06		0.46	1.23		0.31
v_c (MPa)	0.66		0.66	0.66		0.66	0.66		0.66
v_{max} (MPa)	4.38		4.38	4.38		4.38	4.38		4.38
V_{nom} (kN)		118.7			141.2			118.7	
T_d (kN.m)		0.1			0.0			0.1	
v_t (MPa)		0.00			0.00			0.00	
$v_{t,min}$ (MPa)		0.00			0.00			0.00	
$b_{support}$ (mm)	0.0		0.0	0.0		0.0	0.0		0.0
Links			**1T10-200**	**1T10-200**	**1T10-200**	**1T10-200**	**1T10-200**		
Deflection Check ...									
L/d		5.84 ≤ 16.9 √			9.73 ≤ 62.76 √			5.84 ≤ 16.9 √	
Supplied Steel Areas ... (mm^2)									
Top Edge	402.12	**X** 0.00	603.19	603.19	603.19	603.19	603.19	**X** 0.00	**X** 0.00
Bottom Edge	603.19	603.19	603.19	603.19	603.19	603.19	603.19	603.19	603.19
Steel Bars ...									
Top Bars					**3T16**				
Top.Sup.Bars	**2T16**		**3T16**	**3T16**		**3T16**	**3T16**		
Top.Sup.Bars									
Bottom Bars		**3T16**			**3T16**			**3T16**	
Bottom Bars									
Bot.Sup.Bars									
Side Bars									

Table 4.43: Beam Design Result

Beam 2 Materials: C25/30 / Grade 460 (Type 2) (Links: Grade 460 (Type 2))

	5B10		L= 1500mm	**5B2**		L= 2500mm	**5B5**		L= 1500mm
B_w x H (mm)	300 x 300			300 x 300			300 x 300		
Flange B_f x H_f	---			---			---		
Bending (Top Edge) ...									
M (kN.m)	0.0	17.2	21.2	31.1	16.9	20.8	24.8	15.5	0.0
d (mm)		259.0	257.0	257.0	257.0	257.0	257.0	259.0	
K/K'	257.0	259.0		257.0	259.0		257.0	259.0	
x (mm)	257.0	259.0		257.0	259.0		257.0	259.0	
A_s (mm^2)		174.92	217.14	322.29	172.76	212.85	254.27	157.03	
A_s' (mm^2)		0.00	0.00	0.00	0.00	0.00	0.00	0.00	
$A_{s,min}$ (mm^2)	0.00	132.84	132.84	132.84	132.84	132.84	132.84	132.84	0.00
Bending (Bottom Edge) ...									
M (kN.m)	13.3	3.1	0.0	0.0	0.0	0.0	0.0	2.9	6.6
d (mm)	240.0	257.0						257.0	240.0
K/K'		257.0	240.0		257.0	240.0		257.0	240.0
x (mm)		257.0	240.0		257.0	240.0		257.0	240.0
A_s (mm^2)	146.04	31.74						30.04	72.91
A_s' (mm^2)	0.00	0.00						0.00	0.00
$A_{s,min}$ (mm^2)	0.00	132.84	132.84	132.84	132.84	132.84	132.84	132.84	0.00
Shear And Torsion Design ...									
V_d (kN)	30.4		110.1	41.5		30.5	104.1		27.0
v (MPa)	0.39		1.43	0.54		0.40	1.35		0.35

v_c (MPa)	0.66		0.66	0.66		0.66	0.66		0.66
v_{max} (MPa)	4.38		4.38	4.38		4.38	4.38		4.38
V_{nom} (kN)		118.7			141.2			118.7	
T_d (kN.m)		0.1			0.0			0.1	
v_t (MPa)		0.00			0.00			0.00	
$v_{t,min}$ (MPa)		0.00			0.00			0.00	
$b_{support}$ (mm)	0.0		0.0	0.0		0.0	0.0		0.0
Links			**1T10-200**	**1T10-200**	**1T10-200**	**1T10-200**	**1T10-200**		
Deflection Check ...									
L/d		5.84 ≤ 16.9 √			9.73 ≤ 59.7 √			5.84 ≤ 16.02 √	
Supplied Steel Areas ... (mm^2)									
Top Edge	402.12	**X** 0.00	603.19	603.19	603.19	603.19	603.19	**X** 0.00	0.00
Bottom Edge	603.19	603.19	603.19	603.19	603.19	603.19	603.19	603.19	603.19
Steel Bars ...									
Top Bars					**3T16**				
Top.Sup.Bars	**2T16**		**3T16**	**3T16**		**3T16**	**3T16**		
Top.Sup.Bars									
Bottom Bars		**3T16**			**3T16**			**3T16**	
Bottom Bars									
Bot.Sup.Bars									
Side Bars									

Table 4.44: Beam Design Result

Beam 3 Materials: C25/30 / Grade 460 (Type 2) (Links: Grade 460 (Type 2))

	5B11	L=	1500mm	**5B3**	L=	2500mm	**5B8**	L=	1500mm
B_w x H (mm)	300 x 300			300 x 300			300 x 300		
Flange B_f x H_f	---			---			---		
Bending (Top Edge) ...									
M (kN.m)	0.0	17.2	21.2	31.1	16.9	20.7	24.8	15.4	0.0
d (mm)		259.0	257.0	257.0	257.0	257.0	257.0	259.0	
K/K'	257.0	259.0		257.0	259.0		257.0	259.0	
x (mm)	257.0	259.0		257.0	259.0		257.0	259.0	
A_s (mm^2)		174.76	217.14	322.83	172.79	211.87	253.62	156.57	
A_s' (mm^2)		0.00	0.00	0.00	0.00	0.00	0.00	0.00	
$A_{s,min}$ (mm^2)	0.00	132.84	132.84	132.84	132.84	132.84	132.84	132.84	0.00
Bending (Bottom Edge) ...									
M (kN.m)	13.3	3.1	0.0	0.0	2.2	0.0	0.0	2.9	6.6
d (mm)	240.0	257.0			257.0			257.0	240.0
K/K'		257.0	240.0		257.0	240.0		257.0	240.0
x (mm)		257.0	240.0		257.0	240.0		257.0	240.0
A_s (mm^2)	146.20	31.89			22.25			30.08	72.91
A_s' (mm^2)	0.00	0.00			0.00			0.00	0.00
$A_{s,min}$ (mm^2)	0.00	132.84	132.84	132.84	132.84	132.84	132.84	132.84	0.00
Shear And Torsion Design ...									
V_d (kN)	30.4		110.1	37.7		21.0	104.0		26.9

v (MPa)	0.39		1.43	0.49		0.27	1.35		0.35
v_c (MPa)	0.66		0.66	0.66		0.66	0.66		0.66
v_{max} (MPa)	4.38		4.38	4.38		4.38	4.38		4.38
V_{nom} (kN)		118.7			141.2			118.7	
T_d (kN.m)		0.1			0.0			0.1	
v_t (MPa)		0.00			0.00			0.00	
$v_{t,min}$ (MPa)		0.00			0.00			0.00	
$b_{support}$ (mm)	0.0		0.0	0.0		0.0	0.0		0.0
Links			**1T10-200**	**1T10-200**	**1T10-200**	**1T10-200**	**1T10-200**		
Deflection Check ...									
L/d		5.84 ≤ 16.9 √			9.73 ≤ 62.76 √			5.84 ≤ 16.04 √	
Supplied Steel Areas ... (mm^2)									
Top Edge	402.12	**X** 0.00	603.19	603.19	603.19	603.19	603.19	**X** 0.00	0.00
Bottom Edge	603.19	603.19	603.19	603.19	603.19	603.19	603.19	603.19	603.19
Steel Bars ...									
Top Bars					**3T16**				
Top.Sup.Bars	**2T16**		**3T16**	**3T16**		**3T16**	**3T16**		
Top.Sup.Bars									
Bottom Bars		**3T16**			**3T16**			**3T16**	
Bottom Bars									
Bot.Sup.Bars									
Side Bars									

Table 4.45: Beam Design Result

Beam 4 Materials: C25/30 / Grade 460 (Type 2) (Links: Grade 460 (Type 2))

	5B12		L= 1500mm	**5B1**		L= 2500mm	**5B7**		L= 1500mm
B_w x H (mm)	300 x 300			300 x 300			300 x 300		
Flange B_f x H_f	---			---			---		
Bending (Top Edge) ...									
M (kN.m)	0.3	16.6	22.3	30.8	16.9	19.0	22.0	13.7	0.0
d (mm)	257.0	259.0	257.0	257.0	257.0	257.0	257.0	259.0	
K/K'	257.0	259.0		257.0	259.0		257.0	259.0	
x (mm)	257.0	259.0		257.0	259.0		257.0	259.0	
A_s (mm^2)	2.81	169.15	228.46	319.19	172.79	194.33	224.97	138.89	
A_s' (mm^2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
$A_{s,min}$ (mm^2)	0.00	132.84	132.84	132.84	132.84	132.84	132.84	132.84	0.00
Bending (Bottom Edge) ...									
M (kN.m)	11.5	2.6	0.0	0.0	0.0	0.9	0.0	2.6	5.8
d (mm)	240.0	257.0				240.0		257.0	240.0
K/K'		257.0	240.0		257.0	240.0		257.0	240.0
x (mm)		257.0	240.0		257.0	240.0		257.0	240.0
A_s (mm^2)	126.34	26.12				9.58		26.22	63.08
A_s' (mm^2)	0.00	0.00				0.00		0.00	0.00
$A_{s,min}$ (mm^2)	0.00	132.84	132.84	132.84	132.84	132.84	132.84	132.84	0.00
Shear And Torsion Design ...									
V_d (kN)	28.1		123.6	38.6		41.8	94.4		23.8

v (MPa)	0.36		1.60	0.50		0.54	1.22		0.31
v_c (MPa)	0.66		0.66	0.66		0.66	0.66		0.66
v_{max} (MPa)	4.38		4.38	4.38		4.38	4.38		4.38
V_{nom} (kN)		118.7			141.2			118.7	
T_d (kN.m)		0.1			0.0			0.1	
v_t (MPa)		0.00			0.00			0.00	
$v_{t,min}$ (MPa)		0.00			0.00			0.00	
$b_{support}$ (mm)	0.0		0.0	0.0		0.0	0.0		0.0
Links			**1T10-200**	**1T10-200**	**1T10-200**	**1T10-200**	**1T10-200**		
Deflection Check ...									
L/d		5.84 ≤ 16.9 √			9.73 ≤ 59.7 √			5.84 ≤ 16.9 √	
Supplied Steel Areas ... (mm^2)									
Top Edge	603.19	**X** 0.00	603.19	603.19	603.19	603.19	603.19	**X** 0.00	0.00
Bottom Edge	603.19	603.19	603.19	603.19	603.19	603.19	603.19	603.19	603.19
Steel Bars ...									
Top Bars					**3T16**				
Top.Sup.Bars	**3T16**		**3T16**	**3T16**		**3T16**	**3T16**		
Top.Sup.Bars									
Bottom Bars		**3T16**			**3T16**			**3T16**	
Bottom Bars									
Bot.Sup.Bars									
Side Bars									

4.9.2.2.2 Slab Reinforcement Design

Table 4.46: Slab Design Legend

Notation	Definitions
d	Slab's Effective Depth
h	Slab Total Depth
q.max	Maximum Load Combination
L_1	Width of the Slab Along the Strip Direction
L_2	Width of the Slab Perpendicular to the Strip Direction
C	Moment Coefficient ($M=Cp / L^2$)
M	Ultimate Moment
As	Reinforcement Area

Table 4.47: Slab Design Result for Slab Strip X1 -- Storey (1)

Materials: C25/30 / Grade 460 (Type 2)

Slab	h/d (mm)	q.max (kN/m^2)	L_1 L_2 (mm)	M_{sup} (kN.m	As_{left}/ Sup (mm^2)	As_{span}/ Sup (mm^2)	As_{right}/ Sup (mm^2)	Steel Bars
1S1	120/89	1.25SG	5000 4750	0.0240	143.95 **530.93**	195.19 **530.93**	143.95 **530.93**	Y13-250 (T_1) Y13-250 (B_1)

Table 4.48: Slab Design Result for Slab Strip Y2 - Storey 1

Materials: C25/30/Grade 410 (Type 2)

Slab	h/d (mm)	q.max (kN/m^2)	L_1 L_2 (mm)	M_{sup} (kN.m	As_{left}/ Sup (mm^2)	As_{span}/ Sup (mm^2)	As_{right}/ Sup (mm^2)	Steel Bars
1S1	120/76	1.25SG	5000 4750	0.0240	122.81 **589.92**	195.19 **554.21**	122.81 **589.92**	Y13-225 (T_2) Y13-240 (B_2)

Table 4.49: Slab Design Result for Slab Strip X2 -- Storey 0 (FE Strip)

Materials: C25/30/Grade 500 (Type 2)

Slab	h/d (mm)	q.max (kN/m^2)	L_1 L_2 (mm)	M_{sup} (kN.m	As_{left}/ Sup (mm^2)	As_{span}/ Sup (mm^2)	As_{right}/ Sup (mm^2)	Steel Bars
FS1 	129/75	6.9 7.8	5000 5000	0.0240	172.06 452.39	233.41 452.39	172.06 452.39	H12-250 (T_1) H12-250 (B_1)

Table 4.50: Slab Design Result for Slab Strip Y3 -- Storey 0 (FE Strip)

Materials: C25/30/Grade 500 (Type 2)

Slab	h/d (mm)	q.max (kN/m^2)	L_1 L_2 (mm)	M_{sup} (kN.m	As_{left}/ Sup (mm^2)	As_{span}/ Sup (mm^2)	As_{right}/ Sup (mm^2)	Steel Bars
FS3	120/89	1.25SG	5000 5000	0.0240	143.95 530.93	195.19 530.93	143.95 530.93	H12-250 (T_1) H12-200 (B_1)
FS1	254/300	0.0 5.0	5000 5000	0.0 8.0	0.00 452.39	400.13 565.49	338.78 452.39	H12-250 (T_1) H12-200 (B_1)
FS5	129/175	0.0 8.0	5000 5000	0.0 8.3	338.78 452.39	233.41 452.39	338.78 452.39	H12-250 (T_1) H12-200 (B_1)

Table 4.51: Slab Design Result for Slab Strip X4 -- Storey 0 (FE Strip)

Materials: C25/30/Grade 500 (Type 2)

Slab	h/d (mm)	q.max (kN/m²)	L_1 L_2 (mm)	M_{sup} (kN.m	As_{left}/ Sup (mm²)	As_{span}/ Sup (mm²)	As_{right}/ Sup (mm²)	Steel Bars
FS4	254/300	1.25SG	5000 5625	0.0240	0.00 **452.39**	400.13 **565.49**	338.78 **452.39**	H12-250 (T_1) H12-200 (B_1)
FS1	129/175	0.0 5.0	5000 5000	0.0 8.0	338.78 **452.39**	233.41 **452.39**	338.78 **452.39**	H12-250 (T_1) H12-200 (B_1)
FS2	254/300	0.0 8.0	5000 5625	0.0 8.3	338.78 **452.39**	400.13 **565.49**	0.00 **452.39**	H12-250 (T_1) H12-200 (B_1)

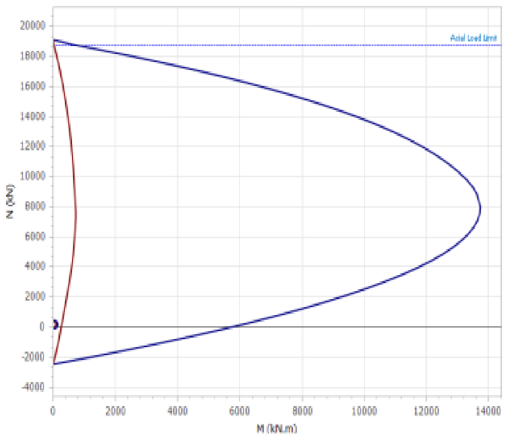
4.10 Wall Reinforcement Design

Materials: C25/30 / Grade 410 (Type 2) Web: Grade 410 (Type 2) (Links: Grade 410 (Type 2))

Section

Combinations

Table 4.52: Wall Design Result for 1W1 (A-1) (5250/250)

No	N_{Top} (kN)	$M_{22\ Top}$ (kN.m)	$M_{33\ Top}$ (kN.m)	N_{Bot} (kN)	$M_{22\ Bot}$ (kN.m)	$M_{33\ Bot}$ (kN.m)	Interaction Diagram
2	38.2	-0.2	7.2	202.2	0.6	-12.9	
3	38.2	-0.2	7.2	202.2	0.6	-12.9	
4	34.0	-0.2	7.2	198.0	0.6	-12.9	
5	38.2	-0.2	7.2	202.2	0.6	-12.9	
6	34.0	-0.2	7.2	198.0	0.6	-12.9	
7	38.2	-0.2	7.2	202.2	0.6	-12.9	
8	38.2	-0.2	7.2	202.2	0.6	-12.9	
9	34.0	-0.2	7.2	198.0	0.6	-12.9	
10	38.2	-0.2	7.2	202.2	0.6	-12.9	
11	34.0	-0.2	7.2	198.0	0.6	-12.9	
12	38.2	-0.2	7.2	202.2	0.6	-12.9	
13	38.2	-0.2	7.2	202.2	0.6	-12.9	
14	34.0	-0.2	7.2	198.0	0.6	-12.9	
15	38.2	-0.2	7.2	202.2	0.6	-12.9	
16	34.0	-0.2	7.2	198.0	0.6	-12.9	
17	38.2	-0.2	7.2	202.2	0.6	-12.9	
18	38.2	-0.2	7.2	202.2	0.6	-12.9	
19	34.0	-0.2	7.2	198.0	0.6	-12.9	
20	34.0	-0.2	7.2	198.0	0.6	-12.9	

Critical Loading:
2 - (G+Q+Qr)

		Min	Design	
N	202.2	-	202.2	kN
M_{22}	0.6	4.0	4.0	kN.m
M_{33}	-12.9	-35.4	-35.4	kN.m

Concrete Cover = 25.0 mm
Neutral Axis: 278.1 mm / 13.08 ^{O}

Table 4.53: Wall Shear Design Result for 1W1 (A-1) (5250/250)

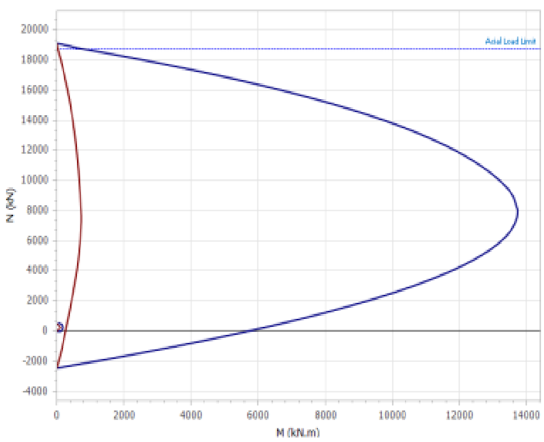
Shear						**Rebars**		
$V_{Ed(1/2)}$ =	5.0 / 0.2	kN	Short Column...			As (Req):	%0.20 $_{(min)}$	2625.00 mm^2
v_{Ed} =	0.00 / 0.00	N/mm^2	λ_1/Lim$_1$ =	3.2 < 338.2	√	As (Sup):	%0.53	6902.06 mm^2
v_{Rdc} =	0.27 / 0.49	N/mm^2	λ_2/Lim$_2$ =	42.1 < 104.7	√			
$v_{Rd\ Max}$ =	0.00 / 0.00	N/mm^2	$M_{Add(1)/2)}$ =	0.0 / 0.0	kN.m	**52Y13**		
Lat. Steel = Y8-150								

Materials: C25/30 / Grade 410 (Type 2) Web: Grade 410 (Type 2) (Links: Grade 410 (Type 2))
Section

Combinations

Table 4.54: Wall Design Result for 1W2 (B-1) (5250/250)

No	**N_{Top} (kN)**	**$M_{22\ Top}$ (kN.m)**	**$M_{33\ Top}$ (kN.m)**	**N_{Bot} (kN)**	**$M_{22\ Bot}$ (kN.m)**	**$M_{33\ Bot}$ (kN.m)**	**Interaction Diagram**
2	51.0	0.0	-43.3	215.1	0.1	77.3	
3	51.0	0.0	-43.3	215.1	0.1	77.3	
4	46.8	0.0	-43.3	210.9	0.1	77.3	
5	51.0	0.0	-43.3	215.1	0.1	77.3	
6	46.8	0.0	-43.3	210.9	0.1	77.3	
7	51.0	0.0	-43.3	215.1	0.1	77.3	
8	51.0	0.0	-43.3	215.1	0.1	77.3	
9	46.8	0.0	-43.3	210.9	0.1	77.3	
10	51.0	0.0	-43.3	215.1	0.1	77.3	
11	46.8	0.0	-43.3	210.9	0.1	77.3	
12	51.0	0.0	-43.3	215.1	0.1	77.3	
13	51.0	0.0	-43.3	215.1	0.1	77.3	
14	46.8	0.0	-43.3	210.9	0.1	77.3	
15	51.0	0.0	-43.3	215.1	0.1	77.3	
16	46.8	0.0	-43.3	210.9	0.1	77.3	
17	51.0	0.0	-43.3	215.1	0.1	77.3	
18	51.0	0.0	-43.3	215.1	0.1	77.3	
19	46.8	0.0	-43.3	210.9	0.1	77.3	
20	46.8	0.0	-43.3	210.9	0.1	77.3	



Critical Loading:
2 - (G+Q+Qr)

		Min	Design	
N	215.1	-	215.1	kN
M_{22}	0.1	4.3	4.3	kN.m
M_{33}	77.3	37.6	78.9	kN.m

Concrete Cover = 25.0 mm
Neutral Axis: 14.4 mm / 0.03 ^{O}

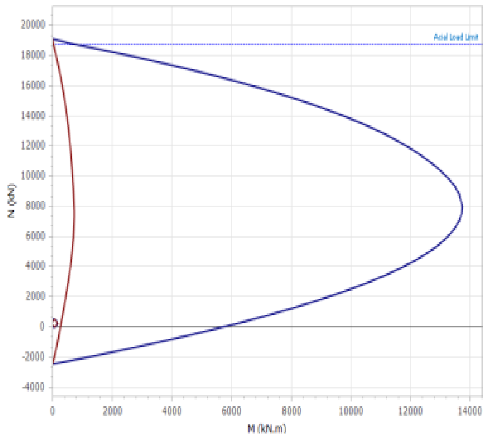
Table 4.55: Wall Shear Design Result for 1W2 (B-1) (5250/250)

Shear						**Rebars**		
$V_{Ed(1/2)}$ =	30.1 / 0.0	kN	Short Column...			As (Req):	%0.20 $_{(min)}$	2625.00 mm^2
v_{Ed} =	0.02 / 0.00	N/mm^2	λ_1/Lim_1 =	3.2 < 101.6	√	As (Sup):	%0.53	6902.06 mm^2
v_{Rdc} =	0.27 / 0.49	N/mm^2	λ_2/Lim_2 =	42.1 < 327.9	√			
$v_{Rd\ Max}$ =	0.00 / 0.00	N/mm^2	$M_{Add(1)/2)}$ =	0.0 / 0.0	kN.m	**52Y13**		
Lat. Steel = Y8-150								

Materials: C25/30 / Grade 410 (Type 2) Web: Grade 410 (Type 2) (Links: Grade 410 (Type 2))
Section

Combinations

Table 4.56: Wall Design Result for 1W3 (A-2) (5250/250)

No	**N_{Top} (kN)**	**$M_{22\ Top}$ (kN.m)**	**$M_{33\ Top}$ (kN.m)**	**N_{Bot} (kN)**	**$M_{22\ Bot}$ (kN.m)**	**$M_{33\ Bot}$ (kN.m)**	**Interaction Diagram**
2	68.3	11.4	7.2	232.4	69.6	-12.9	
3	68.3	11.4	7.2	232.4	69.6	-12.9	
4	64.1	11.4	7.2	228.2	69.6	-12.9	
5	68.3	11.4	7.2	232.4	69.6	-12.9	
6	64.1	11.4	7.2	228.2	69.6	-12.9	
7	68.3	11.4	7.2	232.4	69.6	-12.9	
8	68.3	11.4	7.2	232.4	69.6	-12.9	
9	64.1	11.4	7.2	228.2	69.6	-12.9	
10	68.3	11.4	7.2	232.4	69.6	-12.9	
11	64.1	11.4	7.2	228.2	69.6	-12.9	
12	68.3	11.4	7.2	232.4	69.6	-12.9	
13	68.3	11.4	7.2	232.4	69.6	-12.9	
14	64.1	11.4	7.2	228.2	69.6	-12.9	
15	68.3	11.4	7.2	232.4	69.6	-12.9	
16	64.1	11.4	7.2	228.2	69.6	-12.9	
17	68.3	11.4	7.2	232.4	69.6	-12.9	
18	68.3	11.4	7.2	232.4	69.6	-12.9	
19	64.1	11.4	7.2	228.2	69.6	-12.9	
20	64.1	11.4	7.2	228.2	69.6	-12.9	

Critical Loading: 2 - (G+Q+Qr)

		Min	Design	
N	232.4	-	232.4	kN
M_{22}	69.6	4.6	72.5	kN.m
M_{33}	-12.9	-40.7	-40.7	kN.m

Concrete Cover = 25.0 mm
Neutral Axis: 2110.5 mm / 88.06 ^{O}

Table 4.57: Wall Shear Design Result for 1W3 (A-2) (5250/250)

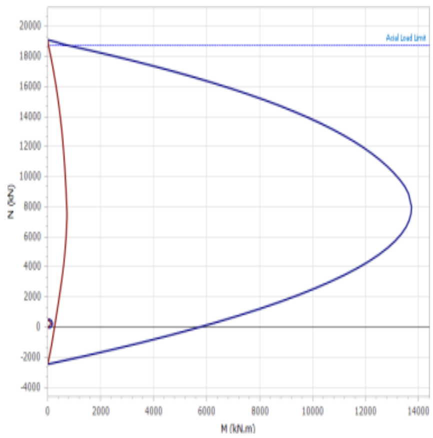
Shear						**Rebars**		
$V_{Ed(1/2)}$ =	5.0 / 89.6	kN	Short Column...			As (Req):	%0.20 $_{(min)}$	2625.00 mm^2
v_{Ed} =	0.00 / 0.07	N/mm^2	λ_1/Lim$_1$ =	3.2 < 315.5	√	As (Sup):	%0.53	6902.06 mm^2
v_{Rdc} =	0.28 / 0.51	N/mm^2	λ_2/Lim$_2$ =	42.1 < 97.7	√			
$v_{Rd\ Max}$ =	0.00 / 0.00	N/mm^2	$M_{Add(1)/2)}$ =	0.0 / 0.0	kN.m	**52Y13**		
Lat. Steel = Y8-150								

Materials: C25/30 / Grade 410 (Type 2) Web: Grade 410 (Type 2) (Links: Grade 410 (Type 2))

Section

Combinations

Table 4.58: Wall Design Result for 1W4 (A-1) (5250/250)

No	N_{Top} (kN)	$M_{22\ Top}$ (kN.m)	$M_{33\ Top}$ (kN.m)	N_{Bot} (kN)	$M_{22\ Bot}$ (kN.m)	$M_{33\ Bot}$ (kN.m)	Interaction Diagram
2	56.0	1.9	-43.3	220.1	11.6	77.3	
3	56.0	1.9	-43.3	220.1	11.6	77.3	
4	51.8	1.9	-43.3	215.9	11.6	77.3	
5	56.0	1.9	-43.3	220.1	11.6	77.3	
6	51.8	1.9	-43.3	215.9	11.6	77.3	
7	56.0	1.9	-43.3	220.1	11.6	77.3	
8	56.0	1.9	-43.3	220.1	11.6	77.3	
9	51.8	1.9	-43.3	215.9	11.6	77.3	
10	56.0	1.9	-43.3	220.1	11.6	77.3	
11	51.8	1.9	-43.3	215.9	11.6	77.3	
12	56.0	1.9	-43.3	220.1	11.6	77.3	
13	56.0	1.9	-43.3	220.1	11.6	77.3	
14	51.8	1.9	-43.3	215.9	11.6	77.3	
15	56.0	1.9	-43.3	220.1	11.6	77.3	
16	51.8	1.9	-43.3	215.9	11.6	77.3	
17	56.0	1.9	-43.3	220.1	11.6	77.3	
18	56.0	1.9	-43.3	220.1	11.6	77.3	
19	51.8	1.9	-43.3	215.9	11.6	77.3	
20	51.8	1.9	-43.3	215.9	11.6	77.3	

Critical Loading:
2 - (G+Q+Qr)

		Min	Design	
N	220.1	-	220.1	kN
M_{22}	11.6	4.4	14.3	kN.m
M_{33}	77.3	38.5	78.9	kN.m

Concrete Cover = 25.0 mm
Neutral Axis: 14.5 mm / 0.03 ^{O}

Table 4.59: Wall Shear Design Result for 1W4 (A-1) (5250/250)

Shear						**Rebars**		
$V_{Ed(1/2)}$ =	30.1 / 14.9	kN	Short Column...			As (Req):	%0.20 $_{(min)}$	2625.00 mm^2
v_{Ed} =	0.02 / 0.01	N/mm^2	λ_1/Lim$_1$ =	3.2 < 100.4	√	As (Sup):	%0.53	6902.06 mm^2
v_{Rdc} =	0.28 / 0.51	N/mm^2	λ_2/Lim$_2$ =	42.1 < 324.2	√			
$v_{Rd\ Max}$ =	0.00 / 0.00	N/mm^2	$M_{Add(1)/2)}$ =	0.0 / 0.0	kN.m	**52Y13**		
Lat. Steel = Y8-150								

4.10.1 Axial Load Comparison Report

TOTAL LOADS (Based On Slabs Loads):

Table 4.60: G - Dead Loads

Storey	Column	Wall	Beam	Slab	Ribbed Slab	Total (kN)
1 (+4.00m)	0.0	525.0	0.0	124.7	0.0	649.7
Total						**649.7**

Table 4.61: Q - Live Loads

Storey	Column	Wall	Beam	Slab	Ribbed Slab	Total (kN)
1 (+4.00m)	0.0	0.0	0.0	36.8	0.0	36.8
Total						**36.8**

TOTAL LOADS (Decomposed to Beams):

Table 4.62: G - Dead Loads

Storey	Column	Wall	Beam	Slab	Ribbed Slab	Total (kN)
1 (+4.00m)	0.0	650.8	0.0	0.0	0.0	650.8
Total						**650.8**

Table 4.63: Q - Live Loads

Storey	Column	Wall	Beam	Slab	Ribbed Slab	Total (kN)
1 (+4.00m)	0.0	37.5	0.0	0.0	0.0	37.5
Total						**37.5**

Table 4.64: Building Analysis Column and Wall Axial Loads

Storey	G (kN)	Delta G (kN)	Q (kN)	Delta Q (kN)
1 (+4.00m)	650.8	650.8	37.5	37.5
Total		**650.8**		**37.5**

Total Base Reactions: G = 650.8 kN Q = 37.5 kN

2.10.2 Formwork Design

Table 4.65: Formwork Design Notation

Notation	Definitions
f_{el}	Bending Strength of the Plates
f_{kl}	Shear Strength of the Plates
E_l	Elastic Modulus of the Plates
S_l	Section Modulus of the Plates
I_l	Moment of Inertia of the Plates
f_{ebk}	Bending Strength of the Joists
f_{kbk}	Shear Strength of the Joists
E_{bk}	Elastic Modulus of the Joists
S_{bk}	Section Modulus of the Joists
I_{bk}	Moment of Inertia of the Joists
f_{eik}	Bending Strength of the Stringers
f_{kik}	Shear Strength of the Stringers
E_{ik}	Elastic Modulus of the Stringers
S_{ik}	Section Modulus of the Stringers
I_{ik}	Moment of Inertia of the Stringers
p	Total Load Acting on Formwork
N_d	Axial Load Capacity of Tie Rod or Shore
W	Wind Load
GK	Safety Factor

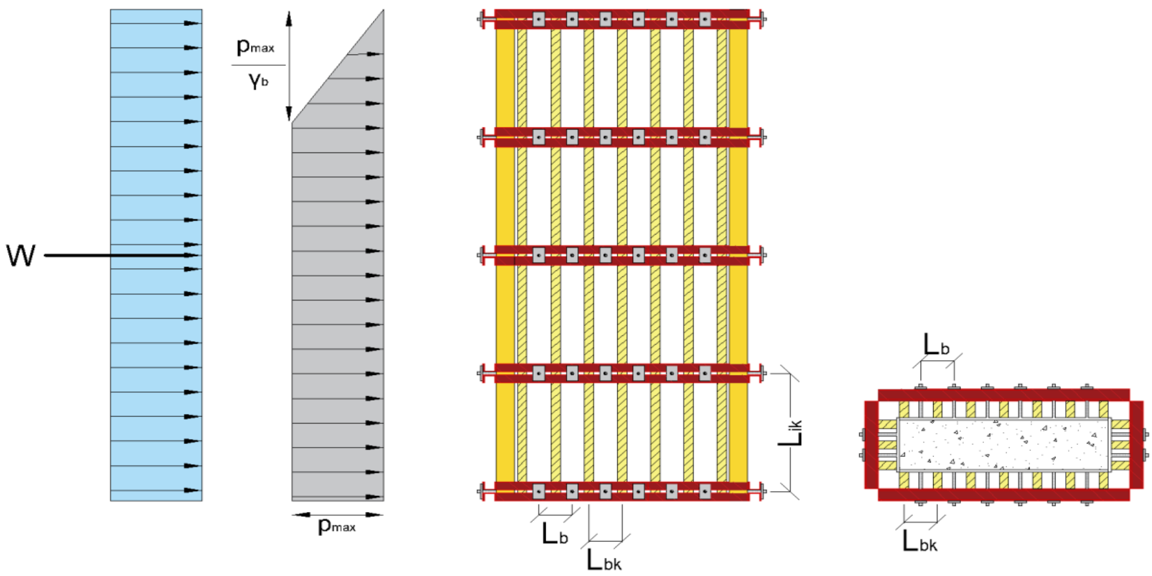


Figure 4.11: Detailed Reinforcement Layout for Shear Wall Formwork

Table 4.66: Shear Wall Formwork Summary Table

Type	Surface	Loads		Joist (mm)			Stringer (mm)			Tie Rod (mm)			Brace (kN)	
H (mm)	**(Width) (mm)**	**p kN/m²**	**W kN**	**n**	**Req Spacing**	**Prov Spacing**	**n**	**Req Spacing**	**Prov Spacing**	**n**	**Req Spacing**	**Prov Spacing**	**n**	**Capacity**
	1 (5250)	58.5	21.4	22	253.0	248.0	7	923.8	833	27	205.2	201.9	1×3	29.1.≥ W
F1	2 (250)	58.5	1.0	2	253.0	200.0	7	923.8	833	3	205.2	125	1×1	9.7.≥ W
5100	3 (5250)	58.5	21.4	22	253.0	248.0	7	923.8	833	27	205.2	201.9	-	-
	4 (250)	58.5	1.0	2	253.0	200.0	7	923.8	833	3	205.2	125.0	-	-
	1 (5250)	58.5	21.4	22	253.0	248.0	7	923.8	833	27	205.2	201.9	1×3	29.1.≥ W
F2	2 (250)	58.5	1.0	2	253.0	200.0	7	923.8	833	3	205.2	125.0	1×1	9.7.≥ W
5100	3 (5250)	58.5	21.4	22	253.0	248.0	7	923.8	833	27	205.2	201.9	-	-
	4 (250.0)	58.50	1.0	2	253.0	200.0	7	923.8	833.0 √	3	205.2	125.0	-	-

Formwork Type	**Storey** : ShearWalls
F1	Storey 1 : 1W1 - 1W3
F2	Storey 1 : 1W2 - 1W4

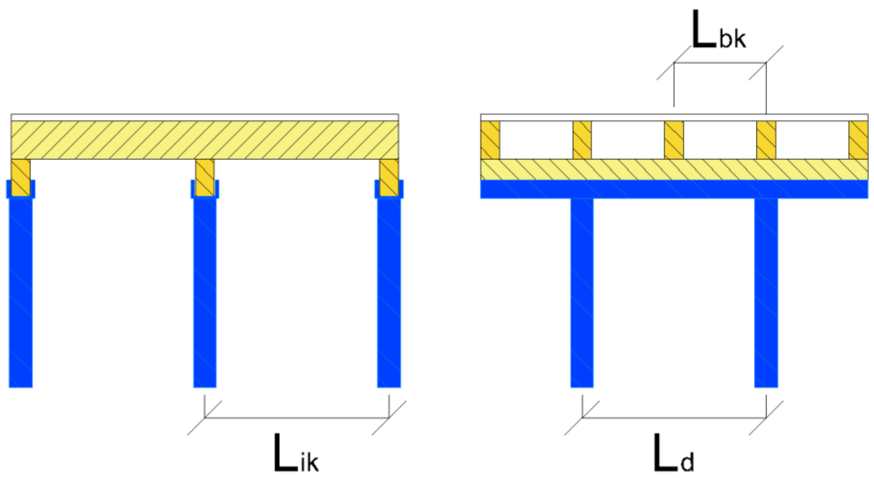


Figure 4.12: Detailed Reinforcement Layout for Slab Formwork

Table 4.67: Slab Formwork Summary Table

Type	Loads		Joist	(mm)		Stringer	(mm)		Shore	(mm)	
(Thickness) (mm)	**p (kN/m²)**	**p_d (kN/m²)**	**n**	**Required Spacing**	**Provided Spacing**	**n**	**Required Spacing**	**Provided Spacing**	**n**	**Required Spacing**	**Provided Spacing**
F3 (h=120.0)	5.90	9.30	10	543.6	522.0 √	4	1799.6	1567.0 √	7	605.1	594.0 √

Formwork Type	**Storey** : Slabs
F3	Storey 1 : 1S1

Shear Wall Formworks

Shear Wall Formwork : F1

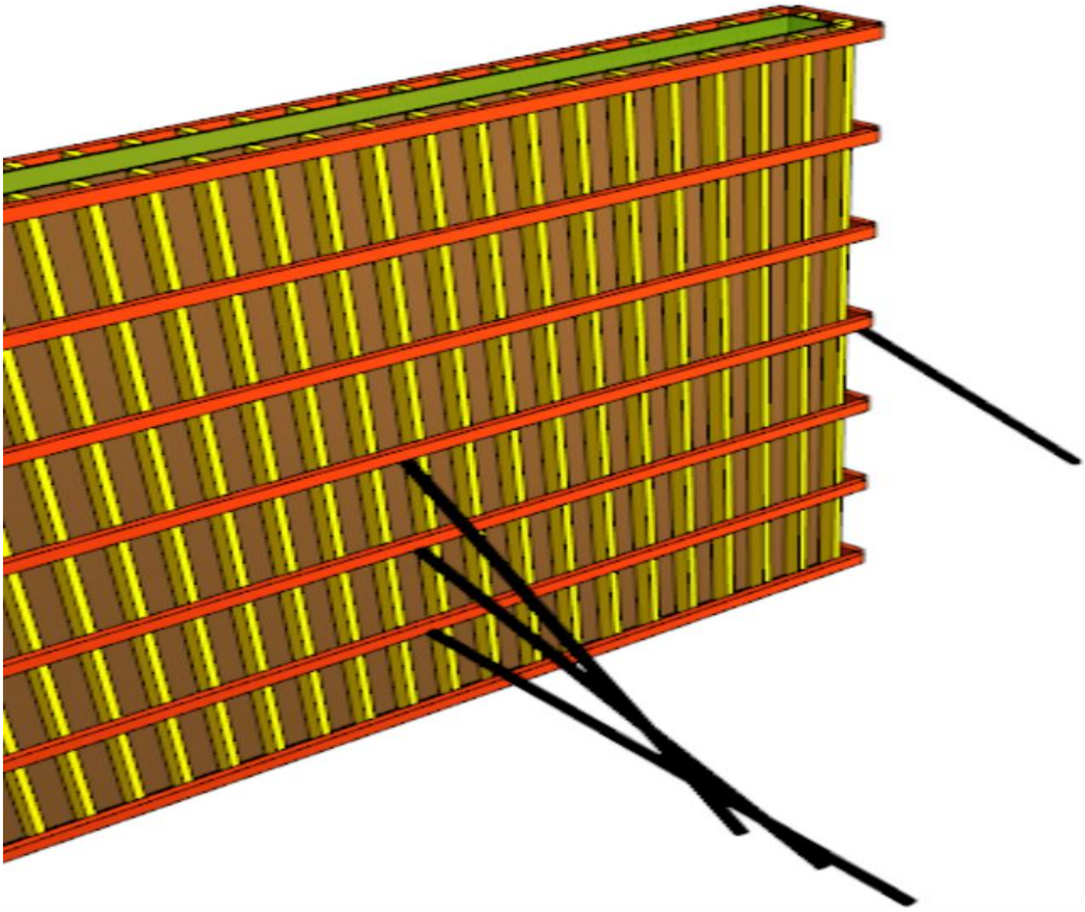


Figure 4.13: Detailed Reinforcement Layout for Shear Wall Formwork (F1)

Table 4.68: Shear Wall Formwork Joist Spacing F1

f_{el} (N/mm²)	f_{kl} (N/mm²)	E_l (N/mm²)	S_l (m³)	I_l (m⁴)	A_l (m²)	GK
20.00	5.00	3350.0	0.000	0.000000	0.018	2.0

ShearWalls	Storey 1 : 1W1 - 1W3
Spacing Limit from Bending Strength	$L_{bk\text{-}Limit\ 1} = 3.16 \sqrt{(f_{el} S_l / (p\ b_l\ GK))} = 303.6$ mm
Spacing Limit from Elastic Modulus	$L_{bk\text{-}Limit\ 2} = 0.835 (E_l I_l / (p\ b_l))^{1/3} = 253.0$ mm
Spacing Limit from Shear Strength	$L_{bk\text{-}Limit\ 3} = f_{kl} A_l / (0.9\ p\ b_l\ GK) = 854.7$ mm
Calculated Spacing	$L_{bk} = \min[L_{bk\text{-}Limit\ 1}, L_{bk\text{-}Limit\ 2}, L_{bk\text{-}Limit\ 3}] = 253.0$ mm

....**Surface No :1**

Quantity of Member	$n = 22$
Edge Space	$\ell_{edge} = 0.0$ mm
Effective Surface Length	$\ell = 5250.0$ mm
Section Width	$b = 50.0$ mm
Provided Spacing	$L_{bk,provided} = (\ell - 2\ \ell_{edge} - b) / (n - 1) = 248.0$ mm
	$L_{bk} \geq L_{bk,provided}$ √

....**Surface No :2**

Quantity of Member — $n = 2$

Edge Space — $\ell_{edge} = 0.0$ mm

Effective Surface Length — $\ell = 250.0$ mm

Section Width — $b = 50.0$ mm

Provided Spacing — $L_{bk,provided} = (\ell - 2\ \ell_{edge} - b) / (n - 1) = 200.0$ mm

$L_{bk}.\geq.L_{bk,provided}$ √

....**Surface No :3**

Quantity of Member — $n = 22$

Edge Space — $\ell_{edge} = 0.0$ mm

Effective Surface Length — $\ell = 5250.0$ mm

Section Width — $b = 50.0$ mm

Provided Spacing — $L_{bk,provided} = (\ell - 2\ \ell_{edge} - b) / (n - 1) = 248.0$ mm

$L_{bk}.\geq.L_{bk,provided}$ √

....**Surface No :4**

Quantity of Member — $n = 2$

Edge Space — $\ell_{edge} = 0.0$ mm

Effective Surface Length — $\ell = 250.0$ mm

Section Width — $b = 50.0$ mm

Provided Spacing — $L_{bk,provided} = (\ell - 2\ \ell_{edge} - b) / (n - 1) = 200.0$ mm

$L_{bk}.\geq.L_{bk,provided}$ √

Table 4.69: Stringer Spacing

f_{ebk} (N/mm^2)	f_{kbk} (N/mm^2)	E_{bk} (N/mm^2)	S_{bk} (m^3)	I_{bk} (m^4)	A_{bk} (m^2)	GK
24.00	4.00	7400.0	0.000	0.000004	0.005	2.0

ShearWalls	Storey 1 : 1W1 - 1W3
Spacing Limit from Bending Strength	$L_{ik\text{-}Limit\ 1} = 3.16 \sqrt{(f_{ebk} S_{bk} / (p L_{bk} GK))} = 923.8$ mm
Spacing Limit from Elastic Modulus	$L_{ik\text{-}Limit\ 2} = 0.835 (E_{bk} I_{bk} / (p L_{bk}))^{1/3} = 1153.4$ mm
Spacing Limit from Shear Strength	$L_{ik\text{-}Limit\ 3} = f_{kbk} A_{bk} / (0.9\ p L_{bk} GK) = 949.7$ mm
Calculated Spacing	$L_{ik} = \min[L_{ik\text{-}Limit\ 1} , L_{ik\text{-}Limit\ 2} , L_{ik\text{-}Limit\ 3}] = 923.8$ mm

....**Surface No : 1 - 2 - 3 - 4**

Quantity of Member — $n = 7$

Edge Space — $\ell_{edge} = 0.0$ mm

Effective Surface Length — $\ell = 5100.0$ mm

Section Width — $b = 100.0$ mm

Provided Spacing — $L_{ik,provided} = (\ell - 2\ \ell_{edge} - b) / (n - 1) = 833.0$ mm

$L_{ik}.\geq.L_{ik,provided}$ √

Table 4.70: Tie Rod Spacing

f_{eik} (N/mm^2)	f_{kik} (N/mm^2)	E_{ik} (N/mm^2)	S_{ik} (m^3)	I_{ik} (m^4)	N_d (kN)	A_{ik} (m^2)	GK
24.00	4.00	7400.0	0.000	0.000004	22.00	0.005	2.0

ShearWalls	Storey 1 : 1W1 - 1W3
Spacing Limit from Bending Strength	$L_{b\text{-Limit }1} = 3.16 \sqrt{ (f_{eik} S_{ik} / (p L_{ik} GK)) } = 452.7$ mm
Spacing Limit from Elastic Modulus	$L_{b\text{-Limit }2} = 0.835 (E_{ik} I_{ik} / (p L_{ik}))^{1/3} = 716.8$ mm
Spacing Limit from Shear Strength	$L_{b\text{-Limit }3} = f_{kik} A_{ik} / (0.9 p L_{ik} GK) = 228.0$ mm
Spacing Limit from Axial Load Capacity	$L_{b\text{-Limit }4} = N_d / (1.1 p L_{ik} GK) = 205.2$ mm
Calculated Spacing	$L_b = \min[L_{b\text{-Limit }1}, L_{b\text{-Limit }2}, L_{b\text{-Limit }3}, L_{b\text{-Limit }4}] = 205.2$ mm

....**Surface No :1**

Quantity of Member — $n = 27$

Effective Surface Length — $\ell = 5250.0$ mm

Provided Spacing — $L_{b,provided} = \ell / (n - 1) = 201.9$ mm

$L_b . \geq . L_{b,provided}$ √

....**Surface No :2**

Quantity of Member — $n = 3$

Effective Surface Length — $\ell = 250.0$ mm

Provided Spacing — $L_{b,provided} = \ell / (n - 1) = 125.0$ mm

$L_b . \geq . L_{b,provided}$ √

....**Surface No :3**

Quantity of Member — $n = 27$

Effective Surface Length — $\ell = 5250.0$ mm

Provided Spacing — $L_{b,provided} = \ell / (n - 1) = 201.9$ mm

$L_b . \geq . L_{b,provided}$ √

....**Surface No :4**

Quantity of Member — $n = 3$

Effective Surface Length — $\ell = 250.0$ mm

Provided Spacing — $L_{b,provided} = \ell / (n - 1) = 125.0$ mm

$L_b . \geq . L_{b,provided}$ √

Brace Capacity Calculation

Brace Axial Load Capacity — $N_{Brace} = 19.40$ kN

....**Surface No :1**

Brace Quantity In Horizontal Direction — $n_{Horizontal} = 1$

........*Brace No :1*

Brace Angle $\alpha = 60.00°$

Brace Capacity In Horizontal Direction $N_1 = N_{Brace} \cos(\alpha)\, n_{Horizontal} = 9.70$ kN

........*Brace No :2*

Brace Angle $\alpha = 60.00°$

Brace Capacity In Horizontal Direction $N_2 = N_{Brace} \cos(\alpha)\, n_{Horizontal} = 9.70$ kN

........*Brace No :3*

Brace Angle $\alpha = 60.00°$

Brace Capacity In Horizontal Direction $N_3 = N_{Brace} \cos(\alpha)\, n_{Horizontal} = 9.70$ kN

Total Wind Load $W = 21.4$ kN

Total Brace Capacity In Horizontal Direction $N_{Brace,Horizontal} = N_1 + N_2 + N_3 = 29.10$ kN

$N_{Brace,Horizontal} \geq W$ √

....**Surface No :2**

Brace Quantity In Horizontal Direction $n_{Horizontal} = 1$

........*Brace No :1*

Brace Angle $\alpha = 60.00°$

Brace Capacity In Horizontal Direction $N_1 = N_{Brace} \cos(\alpha)\, n_{Horizontal} = 9.70$ kN

Total Wind Load $W = 1.0$ kN

$N_1 \geq W$ √

....**Surface No :3**

Brace Quantity In Horizontal Direction $n_{Horizontal} = 0$

Total Wind Load $W = 21.4$ kN

There is another brace present at the same axis but on a different surface. The total capacity equals to sum of all braces at the same axes.

Total Brace Capacity $N_{Brace,Total\ Horizontal} = 29.10$ kN

$N_{Brace,Total\ Horizontal} \geq W$ √

....**Surface No :4**

Brace Quantity In Horizontal Direction $n_{Horizontal} = 0$

Total Wind Load $W = 1.0$ kN

There is another brace present at the same axis but on a different surface. The total capacity equals to sum of all braces at the same axes.

Total Brace Capacity $N_{Brace,Total\ Horizontal} = 9.70$ kN

$N_{Brace,Total\ Horizontal} \geq W$ √

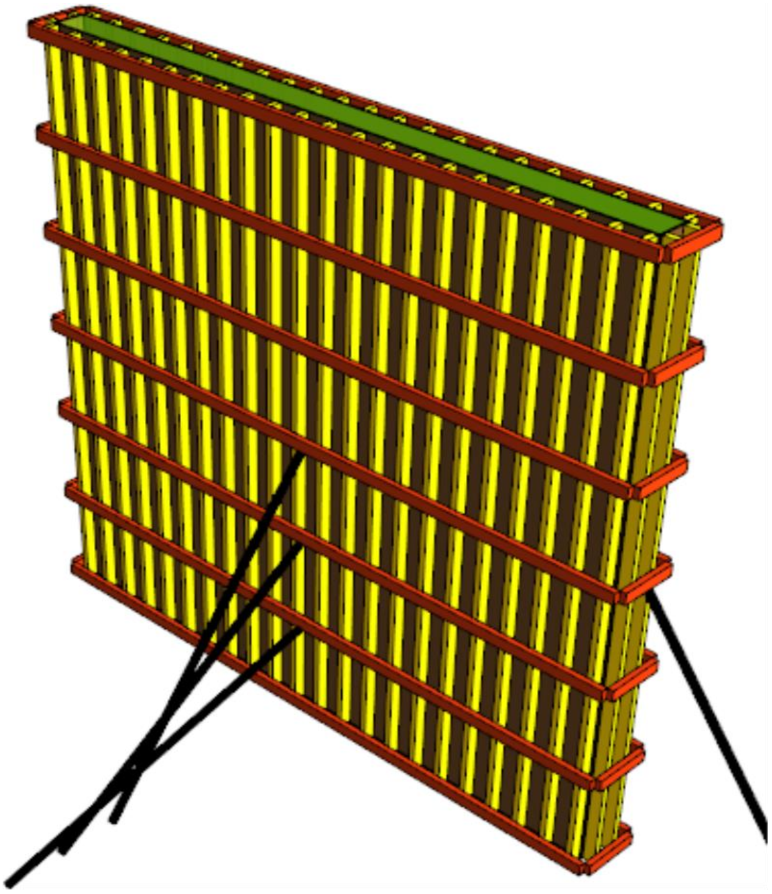


Figure 4.14: Detailed Reinforcement Layout for Shear Wall Formwork (F2)

Table 4.71: Shear Wall Formwork Joist Spacing F2

f_{el} (N/mm^2)	f_{kl} (N/mm^2)	E_l (N/mm^2)	S_l (m^3)	I_l (m^4)	A_l (m^2)	GK
20.00	5.00	3350.0	0.000	0.000000	0.018	2.0

ShearWalls	Storey 1 : 1W2 - 1W4
Spacing Limit from Bending Strength	$L_{bk\text{-}Limit\ 1} = 3.16 \sqrt{(f_{el} S_l / (p\ b_l\ GK))} = 303.6$ mm
Spacing Limit from Elastic Modulus	$L_{bk\text{-}Limit\ 2} = 0.835 (E_l I_l / (p\ b_l))^{1/3} = 253.0$ mm
Spacing Limit from Shear Strength	$L_{bk\text{-}Limit\ 3} = f_{kl} A_l / (0.9\ p\ b_l\ GK) = 854.7$ mm
Calculated Spacing	$L_{bk} = \min[L_{bk\text{-}Limit\ 1}, L_{bk\text{-}Limit\ 2}, L_{bk\text{-}Limit\ 3}] = 253.0$ mm

....**Surface No :1**

Quantity of Member	$n = 22$
Edge Space	$\ell_{edge} = 0.0$ mm
Effective Surface Length	$\ell = 5250.0$ mm
Section Width	$b = 50.0$ mm
Provided Spacing	$L_{bk,provided} = (\ell - 2\ \ell_{edge} - b) / (n - 1) = 248.0$ mm
	$L_{bk} \geq L_{bk,provided}$ √

....**Surface No :2**

Quantity of Member	$n = 2$
Edge Space	$\ell_{edge} = 0.0$ mm
Effective Surface Length	$\ell = 250.0$ mm
Section Width	$b = 50.0$ mm
Provided Spacing	$L_{bk,provided} = (\ell - 2\ \ell_{edge} - b) / (n - 1) = 200.0$ mm
	$L_{bk} . \geq . L_{bk,provided}$ √

....**Surface No :3**

Quantity of Member	$n = 22$
Edge Space	$\ell_{edge} = 0.0$ mm
Effective Surface Length	$\ell = 5250.0$ mm
Section Width	$b = 50.0$ mm
Provided Spacing	$L_{bk,provided} = (\ell - 2\ \ell_{edge} - b) / (n - 1) = 248.0$ mm
	$L_{bk} . \geq . L_{bk,provided}$ √

....**Surface No :4**

Quantity of Member	$n = 2$
Edge Space	$\ell_{edge} = 0.0$ mm
Effective Surface Length	$\ell = 250.0$ mm
Section Width	$b = 50.0$ mm
Provided Spacing	$L_{bk,provided} = (\ell - 2\ \ell_{edge} - b) / (n - 1) = 200.0$ mm
	$L_{bk} . \geq . L_{bk,provided}$ √

Table 4.72: Stringer Spacing

f_{ebk} (N/mm^2)	f_{kbk} (N/mm^2)	E_{bk} (N/mm^2)	S_{bk} (m^3)	I_{bk} (m^4)	A_{bk} (m^2)	GK
24.00	4.00	7400.0	0.000	0.000004	0.005	2.0

ShearWalls	Storey 1 : 1W2 - 1W4
Spacing Limit from Bending Strength	$L_{ik\text{-}Limit\ 1} = 3.16 \sqrt{ (f_{ebk} S_{bk} / (p L_{bk} GK)) } = 923.8$ mm
Spacing Limit from Elastic Modulus	$L_{ik\text{-}Limit\ 2} = 0.835 (E_{bk} I_{bk} / (p L_{bk}))^{1/3} = 1153.4$ mm
Spacing Limit from Shear Strength	$L_{ik\text{-}Limit\ 3} = f_{kbk} A_{bk} / (0.9\ p L_{bk} GK) = 949.7$ mm
Calculated Spacing	$L_{ik} = \min[L_{ik\text{-}Limit\ 1} , L_{ik\text{-}Limit\ 2} , L_{ik\text{-}Limit\ 3}] = 923.8$ mm

….**Surface No : 1 – 2 – 3 – 4**

Quantity of Member	$n = 7$
Edge Space	$\ell_{edge} = 0.0$ mm
Effective Surface Length	$\ell = 5100.0$ mm
Section Width	$b = 100.0$ mm
Provided Spacing	$L_{ik,provided} = (\ell - 2\ \ell_{edge} – b) / (n – 1) = 833.0$ mm
	$L_{ik} . \geq . L_{ik,provided}$ √

Table 4.73: Tie Rod Spacing

f_{eik} (N/mm^2)	f_{kik} (N/mm^2)	E_{ik} (N/mm^2)	S_{ik} (m^3)	I_{ik} (m^4)	N_d (kN)	A_{ik} (m^2)	GK
24.00	4.00	7400.0	0.000	0.000004	22.00	0.005	2.0

Spacing Limit from Bending Strength — $L_{b\text{-Limit }1} = 3.16 \sqrt{(f_{eik} S_{ik} / (p L_{ik} GK))} = 452.7$ mm

Spacing Limit from Elastic Modulus — $L_{b\text{-Limit }2} = 0.835 (E_{ik} I_{ik} / (p L_{ik}))^{1/3} = 716.8$ mm

Spacing Limit from Shear Strength — $L_{b\text{-Limit }3} = f_{kik} A_{ik} / (0.9 p L_{ik} GK) = 228.0$ mm

Spacing Limit from Axial Load Capacity — $L_{b\text{-Limit }4} = N_d / (1.1 p L_{ik} GK) = 205.2$ mm

Calculated Spacing — $L_b = \min[L_{b\text{-Limit }1} , L_{b\text{-Limit }2} , L_{b\text{-Limit }3} , L_{b\text{-Limit }4}] = 205.2$ mm

....**Surface No :1**

Quantity of Member — $n = 27$

Effective Surface Length — $\ell = 5250.0$ mm

Provided Spacing — $L_{b,provided} = \ell / (n - 1) = 201.9$ mm

$L_b . \geq . L_{b,provided}$ √

....**Surface No :2**

Quantity of Member — $n = 3$

Effective Surface Length — $\ell = 250.0$ mm

Provided Spacing — $L_{b,provided} = \ell / (n - 1) = 125.0$ mm

$L_b . \geq . L_{b,provided}$ √

....**Surface No :3**

Quantity of Member — $n = 27$

Effective Surface Length — $\ell = 5250.0$ mm

Provided Spacing — $L_{b,provided} = \ell / (n - 1) = 201.9$ mm

$L_b . \geq . L_{b,provided}$ √

....**Surface No :4**

Quantity of Member — $n = 3$

Effective Surface Length — $\ell = 250.0$ mm

Provided Spacing — $L_{b,provided} = \ell / (n - 1) = 125.0$ mm

$L_b . \geq . L_{b,provided}$ √

Brace Capacity Calculation

Brace Axial Load Capacity — $N_{Brace} = 19.40$ kN

....**Surface No :1**

Brace Quantity In Horizontal Direction — $n_{Horizontal} = 1$

........*Brace No :1*

Brace Angle — $\alpha = 60.00°$

Brace Capacity In Horizontal Direction — $N_1 = N_{Brace} \cos(\alpha)\, n_{Horizontal} = 9.70$ kN

........*Brace No :2*

Brace Angle — $\alpha = 60.00°$

Brace Capacity In Horizontal Direction — $N_2 = N_{Brace} \cos(\alpha)\, n_{Horizontal} = 9.70$ kN

........*Brace No :3*

Brace Angle — $\alpha = 60.00°$

Brace Capacity In Horizontal Direction — $N_3 = N_{Brace} \cos(\alpha)\, n_{Horizontal} = 9.70$ kN

Total Wind Load — $W = 21.4$ kN

Total Brace Capacity In Horizontal Direction — $N_{Brace,Horizontal} = N_1 + N_2 + N_3 = 29.10$ kN

$N_{Brace,Horizontal}.\geq.W$ √

....**Surface No :2**

Brace Quantity In Horizontal Direction — $n_{Horizontal} = 1$

........*Brace No :1*

Brace Angle — $\alpha = 60.00°$

Brace Capacity In Horizontal Direction — $N_1 = N_{Brace} \cos(\alpha)\, n_{Horizontal} = 9.70$ kN

Total Wind Load — $W = 1.0$ kN

$N_1.\geq.W$ √

....**Surface No :3**

Brace Quantity In Horizontal Direction — $n_{Horizontal} = 0$

Total Wind Load — $W = 21.4$ kN

There is another brace present at the same axis but on a different surface. The total capacity equals to sum of all braces at the same axes.

Total Brace Capacity — $N_{Brace,Total\ Horizontal} = 29.10$ kN

$N_{Brace,Total\ Horizontal}.\geq.W$ √

....**Surface No :4**

Brace Quantity In Horizontal Direction — $n_{Horizontal} = 0$

Total Wind Load — $W = 1.0$ kN

There is another brace present at the same axis but on a different surface. The total capacity equals to sum of all braces at the same axes.

Total Brace Capacity — $N_{Brace,Total\ Horizontal} = 9.70$ kN

$N_{Brace,Total\ Horizontal}.\geq.W$ √

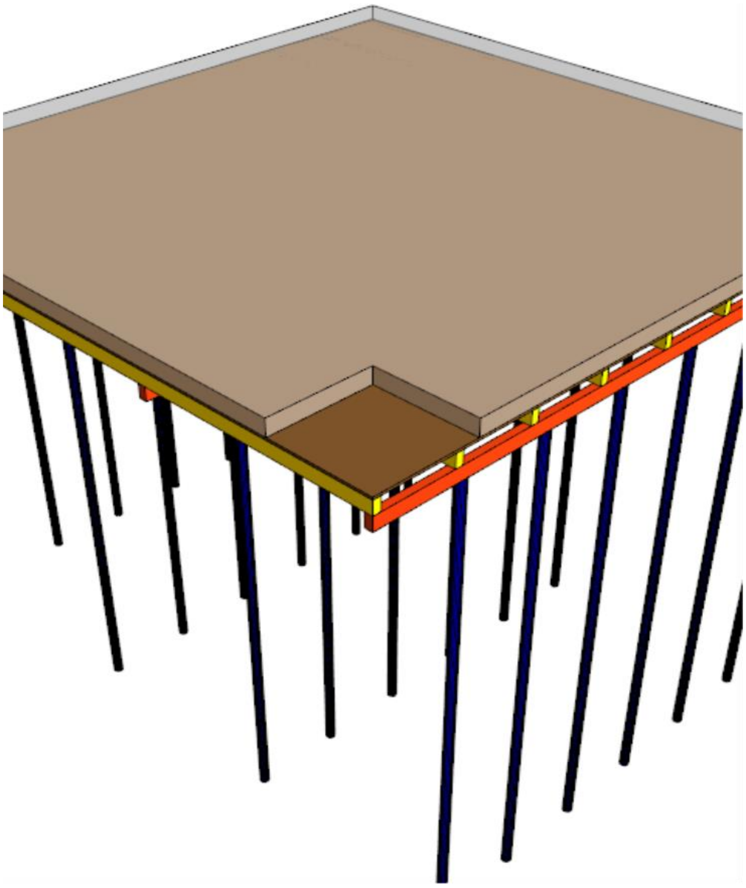


Figure 4.15: Detailed Reinforcement Layout for Slab Formwork (F3)

Table 4.74: Slab Formwork: F3Joist Spacing

f_{el} (N/mm^2)	f_{kl} (N/mm^2)	E_l (N/mm^2)	S_l (m^3)	I_l (m^4)	A_l (m^2)	GK
20.00	5.00	3350.0	0.000	0.000000	0.018	2.0

Slabs	Storey 1 : 1S1
Spacing Limit from Bending Strength	$L_{bk\text{-}Limit\ 1} = 3.16 \sqrt{(f_{el}\ S_l / (p\ b_l\ GK))} = 956.0$ mm
Spacing Limit from Elastic Modulus	$L_{bk\text{-}Limit\ 2} = 0.835 (E_l\ I_l / (p\ b_l))^{1/3} = 543.6$ mm
Spacing Limit from Shear Strength	$L_{bk\text{-}Limit\ 3} = f_{kl}\ A_l / (0.9\ p\ b_l\ GK) = 8474.6$ mm
Calculated Spacing	$L_{bk} = \min[L_{bk\text{-}Limit\ 1} , L_{bk\text{-}Limit\ 2} , L_{bk\text{-}Limit\ 3}] = 543.6$ mm
Quantity of Member	$n = 10$
Edge Space	$\ell_{edge} = 0.0$ mm
Effective Surface Length	$\ell = 4750.0$ mm
Section Width	$b = 50.0$ mm
Provided Spacing	$L_{bk,provided} = (\ell - 2\ \ell_{edge} - b) / (n - 1) = 522.0$ mm
	$L_{bk} \geq L_{bk,provided}$ √

Table 4.75: Stringer Spacing

f_{ebk} (N/mm^2)	f_{kbk} (N/mm^2)	E_{bk} (N/mm^2)	S_{bk} (m^3)	I_{bk} (m^4)	A_{bk} (m^2)	GK
24.00	4.00	7400.0	0.000	0.000004	0.005	2.0

Slabs	Storey 1 : 1S1
Spacing Limit from Bending Strength	$L_{ik\text{-}Limit\ 1} = 3.16 \sqrt{(f_{ebk} S_{bk} / (p L_{bk} GK))} = 1800.6$ mm
Spacing Limit from Elastic Modulus	$L_{ik\text{-}Limit\ 2} = 0.835 (E_{bk} I_{bk} / (p L_{bk}))^{1/3} = 1799.6$ mm
Spacing Limit from Shear Strength	$L_{ik\text{-}Limit\ 3} = f_{kbk} A_{bk} / (0.9 p L_{bk} GK) = 3607.7$ mm
Calculated Spacing	$L_{ik} = \min[L_{ik\text{-}Limit\ 1} , L_{ik\text{-}Limit\ 2} , L_{ik\text{-}Limit\ 3}] = 1799.6$ mm
Quantity of Member	$n = 4$
Edge Space	$\ell_{edge} = 0.0$ mm
Effective Surface Length	$\ell = 4750.0$ mm
Section Width	$b = 50.0$ mm
Provided Spacing	$L_{ik,provided} = (\ell - 2 \ell_{edge} - b) / (n - 1) = 1567.0$ mm
	$L_{ik} \geq L_{ik,provided}$ √

Table 4.76: Shore Spacing

f_{eik} (N/mm^2)	f_{kik} (N/mm^2)	E_{ik} (N/mm^2)	S_{ik} (m^3)	I_{ik} (m^4)	N_d (kN)	A_{ik} (m^2)	GK
24.00	4.00	7400.0	0.000	0.000004	19.40	0.005	2.0

Slabs	Storey 1 : 1S1
Spacing Limit from Bending Strength	$L_{d\text{-}Limit\ 1} = 3.16 \sqrt{(f_{eik} S_{ik} / (p_d L_{ik} GK))} = 827.8$ mm
Spacing Limit from Elastic Modulus	$L_{d\text{-}Limit\ 2} = 0.835 (E_{ik} I_{ik} / (p_d L_{ik}))^{1/3} = 1072.0$ mm
Spacing Limit from Shear Strength	$L_{d\text{-}Limit\ 3} = f_{kik} A_{ik} / (0.9 p_d L_{ik} GK) = 762.4$ mm
Spacing Limit from Axial Load Capacity	$L_{d\text{-}Limit\ 4} = N_d / (1.1 p_d L_{ik} GK) = 605.1$ mm
Calculated Spacing	$L_d = \min[L_{d\text{-}Limit\ 1} , L_{d\text{-}Limit\ 2} , L_{d\text{-}Limit\ 3} , L_{d\text{-}Limit\ 4}] = 605.1$ mm
Quantity of Member	$n = 7$
Effective Surface Length	$\ell = 4750.0$ mm
Provided Spacing	$L_{d,provided} = (\ell - 2 \ell_{edge}) / (n + 1) = 594.0$ mm
	$L_d \geq L_{d,provided}$ √

4.11 Bill of Engineering Measurement and Evaluation (BEME) Discussion

The Bill of Engineering Measurement and Evaluation (BEME) for the reinforced concrete shear wall structure provides a comprehensive summary of the materials, quantities, and estimated costs required for the execution of the proposed design. The detailed BEME table is presented above, while this section highlights the key cost components and their relative contributions based on the structural design outputs and quantity take-off results.

The Concrete Works section comprises the structural elements including shear walls at both foundation and superstructure levels, the foundation slab (FS elements), and the suspended slab (1S1). The total concrete volume is 37.158 m^3, corresponding to a subtotal cost of ₦4,830,540. This component represents a significant portion of the project due to the dominance of shear walls in the structural system, which are essential for load transfer, lateral stability, and overall rigidity of the structure.

The Reinforcement Works account for an estimated steel quantity of 4.83 tonnes, derived using an average reinforcement ratio of 130 kg/m^3 appropriate for shear wall systems. This section includes the supply of TMT reinforcement bars, cutting, bending, fixing, binding wire, and transportation. With a subtotal cost of ₦6,271,755, reinforcement constitutes the largest cost component of the project. This is expected, as shear wall structures typically require substantial steel content to resist axial loads, bending moments, and lateral forces such as wind effects.

The Formwork and Finishes section includes the cost of shuttering for all structural elements and selected surface treatments. The total formwork area is approximately 314.60 m^2, covering both vertical (walls) and horizontal (slabs) elements. This results in a subtotal of ₦914,000. Formwork is critical for achieving the desired geometry, surface finish, and dimensional accuracy of the concrete elements, particularly for vertical shear walls which demand careful alignment and stability during casting.

The Ancillary Works consist of provisional allowances for services and minor installations, captured as a lump sum of ₦250,000. This provides flexibility for site-specific requirements such as fittings, handling, and minor adjustments during construction.

A 5% Contingency/VAT allowance amounting to ₦672,123 is included to accommodate uncertainties such as material price fluctuations, minor design changes, or unforeseen site conditions. This ensures that the overall cost estimate remains robust and practical for real-world implementation.

Bringing all components together, the Total Estimated Cost for all works (A–E) is ₦19,114,573. This consolidated estimate reflects the structural characteristics of the design, where reinforcement and shear wall construction dominate the cost distribution. The BEME therefore serves as a reliable tool for cost planning, budgeting, and decision-making, while also providing a transparent breakdown of resource allocation for the project.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.0 Conclusion

This study focused on the structural analysis and design of an elevated reinforced concrete water tank and its supporting tower structure using a combination of manual calculations, code provisions (BS 8110 and Eurocode 2), and software-based modelling using ProtaStructures software.

From the displacement analysis under different loading conditions gravity, live, and wind it was observed that the structure remained stable with negligible torsional rotation and well-contained lateral displacements. The maximum displacement occurred at the topmost storey (9.87 mm), which is within the acceptable limits for multi-storey frame systems according to Eurocode EN 1991-1-4: Maximum horizontal displacement $\leq \frac{H}{500}$.

Design outputs revealed that each structural component columns, beams, slabs, and the water tank base was adequately sized and reinforced to resist both vertical and lateral forces. Manual design calculations of tank loads and column capacity were validated through software simulations, with detailed reinforcement schedules and moment distribution results confirming safety margins. Columns carried design axial loads significantly less than their ultimate capacity (1173.5 kN < 1443.6 kN), confirming adequate factor of safety.

Furthermore, both service and ultimate limit state checks were satisfied for all structural members. The structural detailing, including concrete grades (C25/30), reinforcement bars (mainly T16-25 for tension and compression and T10–T12 for links), and slab thickness (300 mm), ensured compliance with code-based structural integrity requirements.

5.1 Recommendations

Based on the analysis and design results, the following recommendations were made:

1. Engineers should incorporate use of other structural software like staadPRO, TEKLA or eTABS in both preliminary and detailed design phases for comparison and to avoid human error.
2. Engineers should make consideration for seismic loads for projects in regions prone to higher seismic activity.
3. Engineers should make comprehensive geotechnical survey to ensure accurate foundation design, which was assumed in this project.

REFERENCES

American Concrete Institute (2013). Code Requirements for Environmental Engineering Concrete Structures (ACI 350-13). Farmington Hills: American Concrete Institute.

American Concrete Institute (2016). Guide for the Analysis, Design, and Construction of Elevated Concrete and Composite Steel-Concrete Water Storage Tanks. Farmington Hills: American Concrete Institute.

American Society of Civil Engineers (2016). Minimum Design Loads and Associated Criteria for Buildings and Other Structures (ASCE 7-16). Reston: ASCE.

Bowles, J.E. (1996). Foundation Analysis and Design. 5th edn. New York: McGraw Hill.

British Standards Institution (2005). BS 8110: Structural Use of Concrete. London: BSI.

British Standards Institution (2004). BS EN 1991-1-4: Eurocode 1 – Actions on Structures – Wind Actions. London: BSI.

British Standards Institution (2004). BS EN 1992-1-1: Eurocode 2 – Design of Concrete Structures. London: BSI.

British Standards Institution (2006). BS EN 1997-1: Eurocode 7 – Geotechnical Design. London: BSI.

Chopra, A.K. (2012). Dynamics of Structures: Theory and Applications to Earthquake Engineering. 4th edn. New Jersey: Pearson.

Das, B.M. (2015). Principles of Foundation Engineering. 8th edn. Stamford: Cengage Learning.

Gambhir, M.L. (2013). Design of Reinforced Concrete Structures. New Delhi: PHI Learning.

Hibbeler, R.C. (2017). Structural Analysis. 10th edn. Harlow: Pearson.

MacGregor, J.G. and Wight, J.K. (2012). Reinforced Concrete: Mechanics and Design. 6th edn. Boston: Pearson.

Neville, A.M. (2011). Properties of Concrete. 5th edn. Harlow: Pearson.

Nilson, A.H., Darwin, D. and Dolan, C.W. (2010). Design of Concrete Structures. 14th edn. New York: McGraw-Hill.

Pillai, S.U. and Menon, D. (2017). Reinforced Concrete Design. New Delhi: Tata McGraw-Hill.

Prota Software Inc. (2023). ProtaStructure User Manual and Technical Guide. Istanbul: Prota Software Inc.

Salmon, C.G., Johnson, J.E. and Malhas, F.A. (2009). Steel Structures: Design and Behavior. 5th edn. Upper Saddle River: Pearson.

Timoshenko, S. and Gere, J.M. (2009). Theory of Elastic Stability. 2nd edn. New York: McGraw-Hill.

Wang, C.K. and Salmon, C.G. (2007). Reinforced Concrete Design. 6th edn. New York: HarperCollins.

World Health Organization (2017). Guidelines for Drinking-Water Quality. 4th edn. Geneva: WHO.

APPENDIX

BILL OF ENGINEERING MEASUREMENT AND EVALUATION (BEME) for 100 m³ RC Water Tank & 20 m Tower

Item No.	Description of Work	Unit	Qty	Unit Rate (₦)	Amount (₦)	Notes / Measurement Basis
A. Concrete Works						
A1	Shear walls (Foundation level) – 4 Nos	m³	5.775	130,000	750,750	From quantity take-off
A2	Foundation slab (all FS elements combined)	m³	7.675	130,000	997,750	Sum of FS1–FS5
A3	Shear walls (Storey 1) – 4 Nos @ 4.0 m height	m³	21.000	130,000	2,730,000	5250×250×4000 mm × 4
A4	Suspended slab (1S1)	m³	2.708	130,000	352,040	22.563 m² × 0.12 m
A1	Shear walls (Foundation level) – 4 Nos	m³	5.775	130,000	750,750	From quantity take-off
A2	Foundation slab (all FS elements combined)	m³	7.675	130,000	997,750	Sum of FS1–FS5
Subtotal A	**Concrete Works**		**37.158**		**4,830,540**	
B. Reinforcement Works						
B1	Reinforcement steel: supply of TMT bars (all elements)	tonne	4.83	1,200,000	5,796,000	Estimated from 130 kg/m³
B2	Cutting, bending & fixing of reinforcement	tonne	4.83	30,000	144,900	Fabrication cost
B3	Binding wire :1% of steel weight	kg	48.3	850	41,055	1% of steel
B4	Transport & handling of reinforcement	%	—	—	289,800	5% of steel cost
Subtotal B	**Reinforcement Works**				**6,271,755**	
C. Formwork & Finishes						
C1	Formwork/shuttering to columns, beams, slabs, walls	m²	314.60	2,500	786,500	Total shuttering area
C2	Internal cementitious walls + base	m²	224.40	2,500	561,000	Walls (80 m²) + base (25 m²)
C3	Internal surface treatment / waterproofing (optional)	m²	50.00	1,500	75,000	Assumed partial treatment
Subtotal C	**Formwork & Finishes**				**914,000**	
D. Ancillary Works						
D1	Plumbing & valves: inlet, outlet, overflow, float valve, fittings & installation	LS	1	250,000	250,000	Provisional lump sum
E. Contingency / VAT						
E1	Contingency / VAT allowance (5% of A–D)	%			672,123	5% × ₦19,442,450
TOTAL	**ALL WORKS (A–E)**				**19,114,573**	