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STRUCTURAL DESIGN AND ANALYSIS OF A 20-STORY MIXED-USE HIGH-RISE RESIDENTIAL AND COMMERCIAL BUILDING IN DHAKA: SEISMIC AND WIND LOAD CONSIDERATIONS

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ABSTRACT

This study, conducted in the Department of Civil Engineering at Stamford University Bangladesh, focuses on the structural design and analysis of a 20-story mixed-use high-rise building in Dhaka, accommodating both residential and commercial functions. The objective of the study is to gain insights into the design and analysis of an intermediate moment-resisting frame that addresses the specific challenges posed by seismic and wind loads in a dense urban environment. A commercial building, defined as a structure primarily dedicated to business activities, requires specialized design considerations that extend beyond residential construction, including the need for larger beams, increased floor space, and accommodation for various commercial functions. In high-density urban areas, like Dhaka, the design of multi-story commercial buildings, such as shopping malls and office complexes, presents additional challenges related to space constraints, vertical shopping preferences, and the high cost of land. The study emphasizes the importance of creating a structural design that balances rentable space, aesthetics, cost, safety, and comfort, while addressing the lateral forces caused by wind and seismic activity. This analysis aims to assist engineers and architects in meeting the growing demand for multifunctional high-rise structures, ensuring both safety and functionality in the face of complex environmental and structural factors.

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1 Introduction

Shelter is one of the fundamental needs of human existence, and in today's technological era, there is a growing demand for cost-effective, durable homes that can withstand environmental stresses. Reinforced Concrete Structural (RCC) frame building systems have emerged as a preferred solution to meet this need, particularly in urban environments where land is limited, and the demand for high-rise buildings is increasing. RCC structures offer strength, longevity, and resilience, making them an ideal choice for both residential and commercial buildings. The design and construction of such structures require specialized expertise, particularly from structural engineers whose primary responsibility is to ensure the integrity and safety of the buildings through optimal planning and design (Hassan et al., 2020). Effective structural planning not only considers the functionality of the building but also ensures its safety against potential environmental hazards, such as seismic activity and strong wind loads.

The importance of structural design in high-rise buildings, particularly in urban centers like Dhaka, cannot be overstated. Before construction begins, it is essential to conduct a comprehensive survey of the site to assess its suitability and to consider the building's resistance to external forces such as earthquakes and wind. Earthquake-resistant design is particularly critical in earthquake-prone regions, as the failure to account for seismic loads can result in catastrophic structural damage and loss of life. In areas like Dhaka, where the population density is high, and the demand for vertical development is increasing, it is crucial that high-rise structures are designed to withstand the forces generated by seismic activity. This study seeks to address these design challenges by focusing on the structural analysis of a 20-story mixed-use residential and commercial building (Chopra, 2021).

Earthquakes have the potential to cause significant loss of life and damage to infrastructure, particularly in urban areas where buildings, bridges, and other structures are concentrated. The most severe earthquakes generate seismic waves that reach the Earth's surface, causing devastating effects in densely populated regions. For this reason, structural designers and researchers have adopted the "strong column, weak beam" philosophy in seismic design. This approach aims to ensure that beams yield in flexure before columns during an earthquake, which is considered a preferable failure mode, as it prevents total collapse. This principle is embedded in seismic design codes globally and plays a critical role in safeguarding structures against earthquake-induced failures (Paulay & Priestley, 1992).

Bangladesh, due to its geographic location and susceptibility to earthquakes, is particularly vulnerable to seismic activity. Dhaka, the capital, faces additional challenges as one of the fastest-growing cities in the world, with rapid urbanization leading to an increasing number of high-rise buildings. These structures must be designed with advanced engineering techniques to ensure their ability to withstand seismic and wind forces. The high land values in Dhaka make vertical development more feasible, but it also necessitates that these buildings are structurally sound to mitigate the effects of natural disasters. Advanced design techniques, including the careful detailing of structural components such as beams, columns, and connections, play a pivotal role in achieving this goal. Additionally, the incorporation of shear walls is critical for reducing lateral forces caused by wind and seismic loads, further enhancing the stability of the structure (Hassan et al., 2020).

This study seeks to comprehensively analyze and design a 20-story mixed-use commercial and residential building in Dhaka, with a particular focus on addressing the challenges posed by seismic and wind loads. The research aims to develop detailed architectural plans and elevations that reflect the structural demands of high-rise buildings in an urban environment prone to seismic activity. A key objective is to analyze and visualize the effects of both wind and earthquake forces on the building's structural integrity, thereby ensuring it can withstand these environmental pressures. Furthermore, the study will assess the critical role of shear walls in resisting lateral loads, emphasizing how these structural components contribute to the overall stability of high-rise buildings during seismic events.

Additionally, the research will explore the methodologies and analytical approaches involved in conducting structural analysis for such buildings, providing insights into best practices in high-rise construction. Finally, the study will focus on learning and applying advanced design techniques and seismic detailing methods that ensure structural members, such as beams and columns, are capable of withstanding both wind and seismic loads, enhancing the building's resilience and safety in a dynamic environmental context.

The scope of this study involves the collection of essential data regarding residential buildings in Dhaka, which serves as the foundation for the architectural and structural planning of the proposed 20-story mixed-use building. The research applies the Ultimate Strength Design (USD) method, in accordance with the guidelines set forth by the American Concrete Institute (ACI) and the Bangladesh National Building Code (BNBC), to ensure that the building is designed to meet international safety and performance standards. Additionally, the study includes the detailed analysis and design of a ten-story residential and commercial building, serving as a reference model to assess the structure's ability to resist both wind and earthquake loads. This comprehensive approach allows for the development of resilient building designs that are capable of withstanding the environmental challenges specific to urban areas like Dhaka, ensuring the safety and durability of high-rise structures in earthquake-prone regions.

2 Literature Review

The literature review serves as a critical component of any research study, offering a comprehensive overview of existing knowledge and research related to the subject. This section synthesizes relevant theories, frameworks, and empirical findings from prior studies to provide context and support for the research. By analyzing key developments, trends, and gaps within the field, the literature review not only helps to establish the foundation for the research but also highlights areas where further investigation is necessary. Furthermore, this review allows the researcher to evaluate the strengths and limitations of previous work, thereby situating the current study within the broader academic discourse. Through an in-depth analysis of relevant literature, the study aims to draw connections between existing knowledge and the research objectives, ensuring that the proposed study is both grounded in scholarly work and contributes to ongoing debates and advancements within the field.

A Reinforced Concrete (RCC) framed structure comprises key structural elements such as slabs, beams, columns, and footings, which are interconnected to function as a unified system. The primary purpose of these structures is to transfer loads efficiently from the slabs to the beams, then to the columns, and finally to the foundation, which disperses the loads into the soil. These structural elements work in tandem to maintain the building's integrity under various load conditions. In RCC structures, external and partition walls are generally considered non-structural components and do not contribute to load-bearing, except for their self-weight (ACI 318-19, 2019). The design of such a structural system requires careful consideration by structural engineers to ensure that the system is cost-effective, strong, and maintains serviceability under regular usage and external stresses, such as wind and seismic loads (BNBC, 2020; Yahia et al. 2024).

2.1 Reinforced Concrete Frame Structure

A concrete frame structure typically consists of interconnected vertical and horizontal members that form a rigid, load-bearing framework, often referred to as a "frame structure." According to the Bangladesh National Building Code (BNBC), frame structures are classified into two types based on height: high-rise and low-rise buildings. High-rise buildings are defined as structures exceeding 10 stories, and their design must account for lateral loads, including those from wind and seismic forces, to ensure structural stability. In contrast, low-rise buildings, typically below 10 stories or less than 72 feet in height, are not required to be designed for lateral loads under the same stringent conditions (BNBC, 2020). These classifications guide engineers in determining the appropriate design considerations for each building type.

2.1.1 Slab

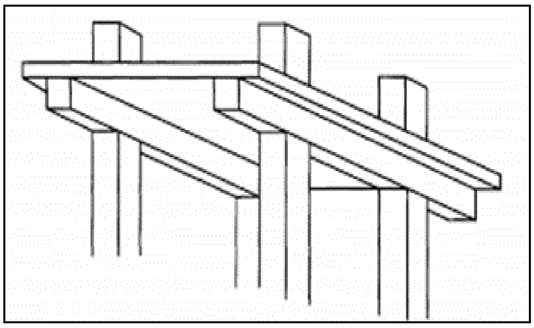
Slabs in RCC structures are flat, reinforced concrete plates that rest on beams, playing a critical role in the load-bearing system. Slabs transfer loads to the beams and, ultimately, to the columns and foundation. Slabs can be categorized based on their shape and support mechanisms. One common type is the flat plate slab, which is a reinforced concrete slab without beams and is directly supported by columns, providing a clean, monolithic appearance. In contrast, the flat slab, though similar in function, may include drop panels for additional support, particularly in areas with higher loads (Hossain & Islam, 2018). Another type is the edge (beam) supported slab, where the slab is supported by beams on both sides, causing it to bend into a dish-like shape under load. Depending on the ratio of the slab's length to width (L/B), slabs are further classified into one-way and two-way slabs. One-way slabs transfer most of the load in the shorter direction, while two-way slabs distribute loads more evenly across both directions, bending into a dish-like form (Chopra, 2021).

Figure 1: Reinforced concrete flat plate system

Figure 2: Reinforced concrete flat slab system

Figure 3: Reinforced concrete beam-supported slab system

Figure 4: One-way slab system slab system



2.1.2 Beam

Beams are horizontal structural members that support loads transferred from slabs and walls. All horizontal reinforced concrete members are generally classified as beams, which serve to transfer these loads to the vertical columns. Beams can be categorized into three main types: singly reinforced, doubly reinforced, and T-beams. Singly reinforced beams feature reinforcement only in the tension zone to resist tensile forces, while doubly reinforced beams have reinforcements in both the tension and compression zones to manage higher compressive forces. T-beams, characterized by a T-shaped compression zone, provide additional strength and stiffness, especially in floor systems where the slab contributes to the beam's compressive resistance (ACI 318-19, 2019). Beams may also vary in their support configurations, including simply supported beams, fixed support beams, and overhanging beams, each providing different structural responses to loads (Hassan et al., 2020).

2.1.3 Column

Columns are vertical structural members that primarily bear compressive loads from the beams and slabs above, transferring these loads to the foundation. In RCC structures, columns play a crucial role in maintaining the building's stability and are essential components in resisting both vertical and horizontal loads. Columns are subjected to compression forces and must be designed to accommodate the combined effects of axial loads and moments caused by lateral forces, such as those from wind or seismic events (Paulay & Priestley, 1992). There are several types of columns, including tied, spiral, composite, combination, and steel pipe columns, each with distinct characteristics and applications depending on the building's structural needs. Columns are critical in ensuring the overall stability of the building, as they act as the primary load-bearing elements (BNBC, 2020).

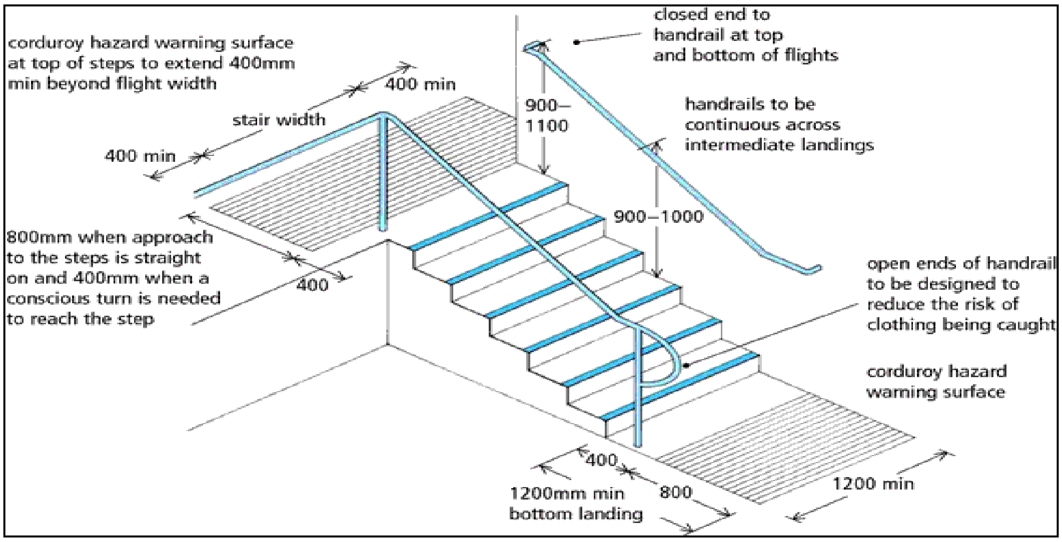
2.1.4 Foundation

The foundation is the lowest part of a building's structural system and plays an integral role in transferring the total load of the structure to the soil. Foundations are classified based on their depth as shallow or deep and are further categorized by their load distribution method. Common types of foundations include individual footings (square or rectangular), combined footings (rectangular or trapezoidal), strap footings, mat footings, pile foundations, and wall footings (Hossain & Islam, 2018). Each type is designed to address specific soil conditions and load-bearing requirements. For high-rise buildings, the choice of foundation is critical, as it must support the structure's weight and ensure stability against lateral forces such as wind and seismic activities. Proper foundation design is essential for minimizing settlement and ensuring the longevity of the building (Chopra, 2021).

2.1.5 Staircase

Staircases serve as a vital means of vertical circulation within buildings, providing access between floors. A staircase consists of a series of steps, known as treads and risers, and must be carefully designed for both functionality and safety. The placement of the staircase within a building requires careful consideration, particularly in residential buildings where it is often located near the main entrance for ease of access. In addition to providing access, staircases must be adequately lit and ventilated to ensure user comfort and safety (Hossain & Islam, 2018). The design of staircases must comply with safety standards, ensuring that they are structurally sound and capable of supporting the loads imposed by frequent use.

***Figure 3: Reinforced concrete beam supported* slab system**



2.2 Design Code and Specifications

The design of reinforced concrete structural members must adhere to established guidelines to ensure that safety, deformation, and crack criteria are met. In Bangladesh, the design process is primarily guided by the *Bangladesh National Building Code (BNBC)*, with supplementary references to the *American Concrete Institute (ACI) Code*. These codes provide comprehensive standards for structural design, ensuring that the building is capable of withstanding various loads throughout its lifecycle while maintaining structural integrity. The BNBC and ACI codes outline detailed specifications for materials, design methods, and load calculations, particularly focusing on safety factors that minimize risks related to excessive deformation, cracking, or catastrophic failure under normal service conditions or extreme events such as wind and seismic activity (ACI 318-19, 2019; BNBC, 2020). These guidelines form the foundation for the structural analysis and design of high-rise buildings in Bangladesh, ensuring compliance with international best practices.

2.2.1 Material

The materials used in reinforced concrete structures are primarily concrete and steel, which are combined to form a robust composite material capable of handling both compressive and tensile forces. Concrete is composed of coarse aggregates (such as stone chips), fine aggregates (typically sand), bonding materials (Portland cement), and water, which together form a durable and resilient matrix. Steel reinforcement bars (rebars) are embedded within the concrete to resist tensile forces, as concrete alone is weak in tension. The quality of both concrete and steel is critical to the overall strength and durability of the structure. Concrete's compressive strength and the yield strength of the steel reinforcement must be carefully considered during the design process to ensure that the structure meets the

Table 1: The different types of loads acting on a structure

Load Type	**Description**	**Key Considerations**
Dead Loads	Constant in magnitude and location throughout the structure's lifespan. Includes the weight of the structure itself and any permanently attached components, such as floors, beams, ceilings, roofs, pipes, ventilation ducts, and windows.	Dead loads provide a predictable baseline for design and must ensure that the structure can support its own weight and any permanent fixtures without excessive deformation or failure.
Live Loads	Variable in magnitude and location. Includes movable objects such as furniture, vehicles, equipment, and people.	Live loads fluctuate based on the building's use and occupancy, especially in commercial spaces, requiring flexibility in design to accommodate varying loads without exceeding the structure's capacity.
Lateral Loads	External forces that act horizontally, typically caused by wind or seismic activity. Lateral loads are dynamic, changing in magnitude and location over time.	High-rise buildings, particularly slender structures, are more susceptible to lateral loads. Design must account for changing forces to prevent excessive lateral movement or failure.
Wind Loads	Wind pressure acting horizontally on the building, including sustained wind velocity and fluctuating gusts. For tall, slender buildings, wind-induced vibrations can increase the overall wind load effects.	Wind load calculations depend on the building's height, exposure to wind, and geographic location. Design must incorporate the effects of both sustained and gust wind pressures, as well as any additional effects due to wind-induced vibrations.

load-bearing requirements specified in the BNBC and ACI codes (Chopra, 2021). The correct proportioning of these materials is vital for achieving the desired structural performance, especially in high-rise buildings that are subject to significant vertical and lateral forces.

2.2.2 Loads

The loads acting on a structure are classified into three main categories: dead loads, live loads, and lateral loads. Each type of load has a distinct impact on the structure's design and must be carefully accounted for to ensure structural safety and stability.

2.3 Method of Wind Load Calculation

The calculation of wind loads on buildings and structures is essential for ensuring safety, stability, and longevity, especially in areas prone to high wind velocities. The minimum design wind load on buildings, structures, and their components must be calculated within the scope and limitations of the design codes, taking into account various factors such as wind pressure, building height, exposure conditions, and structural importance. The calculation method typically follows national building standards, such as the Bangladesh National Building Code (BNBC) and the American Concrete Institute (ACI) Code (BNBC, 2020).

2.3.1 Sustained Wind Pressure

The sustained wind pressure on a building surface at any given height is calculated using the following formula:

The sustained wind pressure *(Q_z)* on a building surface at any given height *(z)* is calculated using the following formula:

$$Q_z = C_c \times C_i \times C_z \times V_b^2$$

Where:
Q_z = Sustained wind pressure at height z (KN/m²)

C_c = Velocity-to-pressure conversion factor

C_i = Structural importance coefficient

C_z = Combined height and exposure coefficient

V_b = Basic wind speed (Km/h)

This equation accounts for the effects of sustained wind pressure at varying heights and the importance of the structure, which impacts the structural design, especially in high-wind areas.

2.3.2 Design Wind Pressure

The design wind pressure (P_z) is the equivalent static pressure due to wind, including gusts, and is used to determine wind loads on a building. The design wind pressure is given by:

$$P_z = C_g \times C_p \times Q_z$$

Where:
P_z = Design wind pressure at height z (KN/m²)

C_g = Gust coefficient

C_p = Pressure coefficient for structures or components

Q_z = Sustained wind pressure

Design wind pressure is applied perpendicular to the building surface and includes the dynamic effects of gusts and other wind variations. This pressure calculation ensures that the building design takes into account wind-induced forces, which are critical in preventing structural deformation or failure.

Table 2: The important terms and descriptions related to wind load calculation

Term	**Description**
Basic Wind Speed (V_b)	The fastest-mile wind speed measured at a height of 10 meters above the ground, usually expressed in kilometers per hour (km/h), and applicable to the design of structures.
Design Wind Pressure (P)	The equivalent static pressure due to wind, including gusts, applied in determining wind loads. This pressure is assumed to act in a direction normal to the building's surface (BNBC, 2020).

Openings	Apertures or holes in the building exterior walls, such as doors or windows, which may impact the wind load distribution.
Structure Importance Coefficient (C_i)	A factor accounting for the hazard posed to human life and property damage, used to adjust wind load calculations based on the building's criticality and occupancy.
Sustained Wind Pressure (Q_z)	The effective wind pressure exerted on a building surface at any height above ground level. Sustained pressure is crucial for designing structural components to withstand long-term wind forces.
Exposure A	Urban and suburban areas with obstructions like trees, hills, or other structures covering at least 20% of the area. These obstructions must extend at least 500 meters from the site or 10 times the height of the structure, whichever is greater.
Exposure B	Open terrain with scattered obstructions, generally less than 10 meters in height, extending 800 meters or more in any full quadrant from the site. This includes airfields, open parklands, outskirts of towns, and flat open areas like grasslands (BNBC, 2020).
Exposure C	Flat, unobstructed open terrain, such as coastal areas, riversides, or regions facing large bodies of water, with a width of 1.5 kilometers or more. The exposure category extends inland up to 400 meters or 10 times the height of the structure. These areas are prone to more severe wind loads due to their lack of natural barriers (Hassan et al., 2020).

2.4 Earthquake Load:

The earthquake load on a structure is typically calculated using the equivalent static force method, which simplifies the seismic response of a building into a static force for design purposes. The primary $V = \frac{ZICW}{R}$ parameter in this method is the *design base shear (V)*, which represents the total lateral force or shear at the base of the structure due to seismic activity. The base shear is calculated using the following formula:

Where:

- *Z* is the seismic zone coefficient, representing the seismic hazard level of a particular geographic location.
- *I* is the structure importance coefficient, which accounts for the importance of the building, particularly in terms of hazard to life or property.
- *R* is the response modification coefficient, which adjusts for the energy-dissipating capacity of the structural system.
- *W* is the total seismic dead load of the building, including the weight of permanent partitions and other applicable portions of load.

The numeric coefficient *C*, which affects the base shear, is defined as:

$$C = \frac{1.25 \times S}{T^{2/3}}$$

Where:

- SSS is the site coefficient, which accounts for soil characteristics at the building site.
- TTT is the fundamental period of vibration of the structure in seconds, calculated as:

$$T = Ct \times (h_n)^{3/4}$$

Where:

- C_t is a constant that varies depending on the structural system: 0.083 for steel moment-resisting frames, 0.073 for reinforced concrete moment-resisting frames and eccentric braced steel frames, and 0.049 for other structural systems.

- h_n is the height of the structure in meters from the base to the topmost level.

The seismic dead load W encompasses the total weight of the building, including the permanent partitions and other applicable loads.

2.5 Vertical Distribution of Lateral Force:

Once the base shear V is calculated, the lateral forces acting on each story of the building need to be distributed along the height of the structure. In the absence of a more rigorous procedure, the total lateral force, represented by the base shear V, is distributed according to the following equation:

$$V = F_t + \sum F_i$$

Where:

- F_i is the lateral force applied at story level iii.
- F_t is the concentrated lateral force considered at the top of the building, in addition to the force F_n, and is given by:

$$F_t = 0.070TV \leq 0.25V \quad \text{when } T > 0.70 \text{ seconds}$$

This approach ensures that the lateral forces, which arise due to seismic activity, are properly distributed across the height of the building, ensuring the stability and resilience of the structure under earthquake conditions.

3 Method

This chapter outlines the detailed procedures followed to complete the structural analysis and design for the 20-story mixed-use building. The study was conducted in several phases, starting with the selection and planning of the structure. The building was divided into two functional parts—commercial and residential—with modern amenities such as escalators, passenger lifts, observation lifts, stairs, and ramps incorporated into the design. Material properties and loading conditions, based on the design codes of ACI and BNBC, were carefully selected, including the compressive strength of concrete, yield stress of steel, unit weight of concrete, and other building materials such as brick and soil. The structure was designed following the Ultimate Strength Design (USD) method, ensuring it met the criteria for high-rise building design. The study also incorporated calculations for wind and earthquake loads, following the guidelines provided by the BNBC and ACI codes, ensuring that the structure could withstand lateral forces from these natural events. The study was carried out based on specific design data and load calculations, following established guidelines. Wind and earthquake loads were calculated according to the BNBC and ACI design codes, with various load cases applied. Dead load calculations were carried out for both commercial and residential areas, considering factors like the self-weight of slabs, floor finish, and partition wall loads. Similarly, live loads were calculated for different areas, with higher live loads assigned to commercial spaces. Seismic loads were computed based on the height of the building, seismic zone coefficient, site coefficient, and response modification factors. Wind loads were also calculated based on the building's dimensions, exposure conditions, and wind pressure in Dhaka. For instance, the building's design accounted for a wind speed of 210 km/h, and both wind and seismic loads were analyzed using ETABS-2013 software in compliance with UBC-94 and BNBC code specifications. These load calculations were crucial in determining the structural resilience of the building, ensuring it meets safety standards and performs effectively under varying environmental conditions.

Table 3: Summary of the Design Considerations and Specification of the Study

Items	Description
Design code	• American Concrete Institute (*ACI*) Building design code, 2014. • Bangladesh National Building Code (*BNBC*), 1993.
Building components	• Column type = Tied • Footing type = Mat foundation. • Thickness of all partition walls = 5 *inch.*

Material properties	• Yield strength of reinforcing bars, f_y = 60,000 *psi.* • Concrete compressive strength, f'_c = 3,000 *psi.* • Normal density concrete having w_c = 150 *pcf.* • Unit weight of brick, w_b = 120 *pcf.*

Table 4: Overall Load Calculations

Category	**Item**	**Value/Formula**	**Notes**
Load Cases			
	1.40xDL		
	1.00xDL + 1.00xLL		
	1.40xDL + 1.70xLL		
	0.90xDL + 1.30xWL (L-R) long side		
	0.90xDL + 1.30xWL (R-L) long side		
	0.90xDL + 1.30xWL (L-R) short side		
	0.90xDL + 1.30xWL (R-L) Short side		
	1.05xDL + 1.275xWL (L-R) long + 1.275xLL		
	1.05xDL + 1.275xWL (R-L) long + 1.275xLL		
	1.05xDL + 1.275xWL (L-R) Short + 1.275xLL		
	1.05xDL + 1.275xWL (R-L) short + 1.275xLL		
	1.40xDL + 1.40xEQ(L-R) long + 1.40xLL		
	1.40xDL + 1.40xEQ(R-L) long + 1.40xLL		
	1.40xDL + 1.40xEQ (L-R) short + 1.40xLL		
	1.40xDL + 1.40xEQ (R-L) short + 1.40xLL		
	0.90xDL + 1.43xEQ (L-R) long		
	0.90xDL + 1.43xEQ (R-L) long		
	0.90xDL + 1.43xEQ (L-R) short		
	0.90xDL + 1.43xEQ (R-L) short		
Dead Loads (psf)			
Commercial	Slab self-weight	62.5	
	Floor finish	30	
	Partition wall (GF)	53 (assumed)	
	Partition wall (1st to 5th)	55 (assumed)	

	Partition wall (6th to 10th)	83 (assumed)	
	Total DL (GF)	145.5	
	Total DL (1st to 5th)	147.5	
	Total DL (6th to 10th)	175.5	
Residential	Slab self-weight	62.5	
	Floor finish	30	
	Partition wall	83 (assumed)	
	Total DL	175.5	
Other	Floor finish (water tanks)	10	
	Floor finish (ramp)	10	
	Floor finish (parking)	10	
	Floor finish (stairs)	25	
Live Loads (psf)	Commercial	120	
	Residential	40	
	Stairs	100	
	Basement	10	
	Ramp	10	
	Water tanks	10	
	Car	50	
Seismic Load Parameters	Building height	226 ft (69.0 m)	
	Seismic zone coefficient (Z)	0.15	Dhaka, Zone II
	Site coefficient (S)	1.5	
	Special moment resisting frame (R)	9	
	Importance coefficient (I)	1.25	Hazardous facilities
	Ct	0.049	
	Vibration period (T)	1.19	
	Story range	Basement to Roof Top	

Wind Load Parameters	Building length (L)	84.14 m	
	Building width (B)	69.21 m	
	Building height (H)	69.0 m	
	Exposure condition	A	
	Wind pressure (Vb)	210 km/h	Dhaka city
	Importance coefficient (I)	1.25	Hazardous facilities
	Story range	Ground Level to Top	
Additional Notes		Wind and earthquake loads calculated using ETABS-2013	UBC-94 and BNBC codes

Dead Load (DL) Calculation

Dead load (DL) consists of the self-weight of the structure and any permanent fixtures, such as partitions and finishes.

Total Dead Load (DL):

$$\text{Total DL} = \text{Self-Weight of Slab} + \text{Floor Finish} + \text{Partition Wall Load}$$

For the **Ground Floor (Commercial)**:

$$\text{Total DL} = 62.5\ \text{psf} + 30\ \text{psf} + 53\ \text{psf} = 145.5\ \text{psf}$$

For the **Residential Floors**:

$$\text{Total DL} = 62.5\ \text{psf} + 30\ \text{psf} + 83\ \text{psf} = 175.5\ \text{psf}$$

4 Findings

The findings of this study provide an in-depth analysis and comprehensive insight into the structural design and engineering of a 20-story mixed-use high-rise building. This building, designed to accommodate both residential and commercial functions, has been meticulously crafted to adhere to modern safety standards and established building codes, such as the American Concrete Institute (ACI) and Bangladesh National Building Code (BNBC). The structural layout of the building includes a basement for parking, commercial spaces spanning from the ground to the ninth floor, and residential apartments occupying the 10th to 19th floors. The design successfully integrates essential facilities such as high-speed passenger lifts, capsule lifts, and multiple staircases. These features are engineered to ensure smooth vertical and horizontal circulation throughout the building. The inclusion of these elements contributes significantly to ease of access and movement within the structure, highlighting the building's functionality and comfort. Moreover, the design includes provisions for critical utilities such as emergency power generation systems, ensuring the continuity of essential services, even during power outages. This attention to detail in utility planning enhances the building's operational reliability and long-term serviceability. The commercial floors within the building, offering expansive shop areas, are configured to accommodate a wide variety of business activities. In contrast, the residential floors feature a broad range of apartment sizes, catering to diverse market needs, from smaller units to larger, family-sized flats. This careful balance between commercial and residential functions demonstrates the study's success in designing a multifunctional high-rise structure, combining modern amenities with safety and efficiency.

In terms of structural design methodology, the study emphasizes the critical importance of selecting appropriate material properties and load calculations to ensure the building's integrity and durability. The use of

Ultimate Strength Design (USD), a widely accepted method in structural engineering, allowed the design to incorporate both wind and seismic load considerations effectively. One of the key aspects of the material selection was the concrete compressive strength, set at 3,500 psi, which provided the necessary resistance to compressive forces. Similarly, the reinforcing bars, with a yield strength of 60,000 psi, were chosen to ensure optimal performance under tensile stresses. These specifications ensured that the building could withstand the expected loads and meet performance criteria under various loading conditions, including those imposed by natural forces such as wind and earthquakes. Another important feature of the structural design is the careful consideration given to partition walls and lateral loads. The integration of earthquake and wind load considerations into the overall design framework further reinforces the building's resilience against these forces. In particular, the slabs were designed as two-way slabs, which are capable of distributing loads in two directions, thus providing superior structural support. The use of appropriate reinforcement in the slabs, including shrinkage and temperature reinforcement, ensured that they could carry the anticipated loads without experiencing excessive deformation or cracking. These design choices are critical in maintaining the long-term structural integrity of the building, especially in a high-rise environment where loads are often more complex and dynamic.

The study also delves deeply into the design of beams and columns, which are fundamental structural components that must meet stringent safety and stability requirements. Using advanced software such as ETABS, the study was able to model and analyze the bending moments and shear forces in the beams, ensuring that these elements were designed with the appropriate levels of reinforcement. The analysis took into account the effects of both static and dynamic loads, allowing for precise calculations of the reinforcement required to prevent structural failure. Furthermore, the study incorporated the use of seismic ties and splicing in the reinforcement of beams and columns, a technique that is particularly effective in enhancing the building's ability to resist seismic activity. These features are crucial in ensuring the building's stability in the face of lateral forces, which can be especially challenging in high-rise structures. The columns, which are responsible for carrying the vertical loads from the building's upper floors down to the foundation, were designed with specific attention to axial forces and bending moments. By ensuring that the columns were sufficiently reinforced, the study achieved a design that could effectively handle both the gravitational forces from the building's weight and the lateral forces resulting from wind and seismic events. The incorporation of special moment-resisting frames further enhanced the building's capacity to resist these forces. These frames provide added rigidity to the structure, ensuring that the building remains stable under the expected environmental conditions. The reinforcement calculations demonstrated that the design of these structural elements was well within the safety limits set by the relevant building codes, further validating the overall approach taken in the study.

In addition to the primary structural elements, the design of secondary components, such as staircases and torsional reinforcement, was another significant focus of the study. The staircases, designed with appropriate tread and rise dimensions, were engineered to provide both functionality and structural support. The study ensured that the staircases could comfortably accommodate both residents and commercial users, including the transport of furniture and other large items. This attention to detail is particularly important in high-rise buildings, where the staircases serve as a vital means of vertical circulation, especially during emergencies. The design of torsional reinforcement in beams, which accounts for potential twisting forces and lateral loads, was another important finding. By addressing the potential for torsion in the design phase, the study added a layer of stability to the overall structural system, ensuring that the beams could resist not only bending and shear forces but also the twisting forces that might occur during seismic events or under uneven load distribution. Moreover, the application of lapping ties in the columns played a crucial role in managing the distribution of forces throughout the building. These ties ensure that the load transfer between the columns and other structural elements is consistent, preventing localized failures and enhancing the overall robustness of the building.

The findings also highlight the thoroughness of the design and calculation processes, ensuring that the building is capable of withstanding both static and dynamic loads. The study demonstrates that the building, with its combination of advanced engineering techniques, modern amenities, and compliance with international building codes, is not only structurally sound but also provides a safe and comfortable environment for its occupants. By adhering to the Ultimate Strength Design method and carefully calculating the loads on each structural element, the study ensures that the building meets all necessary safety standards. The use of advanced design software, such as ETABS, allowed for the precise modeling and analysis of the building's structural components, further validating the accuracy and effectiveness of the design. Overall, the study provides a detailed roadmap for the design of high-rise mixed-use buildings, offering valuable insights for both engineers and architects. The integration of modern amenities, the consideration of lateral forces, and the use of high-strength materials all contribute to the creation of a building that is not only functional but also resilient in the face of environmental challenges.

5 Discussion

The structural design and analysis of a 20-story mixed-use building presented in this study reveal several critical insights into the complexities of high-rise construction, particularly when addressing the distinct functional needs of residential and commercial spaces. One of the most prominent findings is the notable difference in service load requirements between these two types of spaces. Commercial areas typically experience higher loads due to increased foot traffic, the use of heavy equipment, and large gatherings. As a result, thicker slabs are necessary in these spaces to accommodate the added weight, whereas residential spaces, which experience lighter loads, can rely on thinner slabs. This conclusion aligns with earlier research by Gupta et al. (2017), who emphasized the need for differentiated slab designs in mixed-use buildings to manage varying load distributions effectively. The increased slab thickness in commercial areas helps distribute heavier loads, ensuring the building's stability and longevity. The study also reinforces the recommendation by Rahman and Islam (2015) that commercial floors in mixed-use buildings should be placed on lower levels to reduce torsional effects, as doing so enhances stability by lowering the center of gravity and improving resistance to lateral forces.

In high-rise design, accounting for lateral loads, such as wind and seismic forces, is a critical consideration, particularly in regions like Dhaka, Bangladesh, where these forces are prevalent. The findings of this study emphasize the importance of managing lateral forces to ensure the safety and resilience of tall buildings. The study's focus on lateral load calculations supports earlier research by Ali and Moon (2007), who discussed the necessity of designing high-rise buildings to withstand lateral forces, especially in wind-prone and seismically active regions. The study's calculations, which account for wind speeds exceeding 210 km/h in Dhaka, reflect the importance of precise engineering and structural planning in preventing excessive sway and structural failure. By adhering to established codes such as the Bangladesh National Building Code (BNBC) and the American Concrete Institute (ACI) standards, the study builds upon previous work to ensure the design is robust enough to handle extreme environmental conditions. This application of the Ultimate Strength Design (USD) method in this context emphasizes the necessity of balancing local environmental factors with global best practices in structural design to create buildings that are both resilient and safe.

Material verification is another key area of focus in this study, which highlights the importance of ensuring that all materials used in construction meet required strength and durability standards before building begins. Haque and Kabir (2016) have previously pointed out the risks of material variability, particularly in concrete and steel, and the significant impact such variability can have on a building's structural performance. This study's emphasis on verifying material strength—particularly the compressive strength of concrete and the yield strength of reinforcing bars—underscores the critical role of rigorous material testing and quality control. Ensuring that materials meet the specified design standards is not just a technical requirement but a necessary step in preventing potential structural failures. The study's reliance on high-strength materials, including 60,000 psi yield strength reinforcing bars and 3,500 psi compressive strength concrete, echoes previous research by Chopra (2021), which emphasized the importance of material selection in enhancing the overall load-bearing capacity and durability of high-rise structures. This finding reinforces the argument that the proper selection and verification of materials are crucial to the long-term success and safety of high-rise buildings, particularly in environments subject to significant lateral forces.

Despite the study's thorough approach to load management and material verification, a notable gap is the omission of detailed beam-to-column joint design, a critical element in the structural integrity of high-rise buildings. Previous research, including studies by Fintel (2019) and Paulay and Priestley (1992), has emphasized the importance of robust beam-to-column joints, particularly in buildings located in seismic zones. These joints are crucial stress points that experience high levels of strain during seismic events, and their failure can lead to disproportionate structural damage. The current study's focus on general load management without detailed attention to these joints suggests that future research should prioritize joint design to ensure that high-rise buildings can withstand seismic forces without significant damage. The findings of this study would be further strengthened by incorporating detailed joint design analyses, which would provide a more comprehensive approach to seismic resilience, particularly in a region like Dhaka, where earthquakes pose a serious risk to structural integrity.

Another area that the study touches on but does not explore in depth is the control of sway and deflection, which are essential for both the structural performance of high-rise buildings and the comfort of their occupants. Previous research by Mendis et al. (2015) highlighted the importance of controlling sway in tall buildings to ensure both occupant comfort and long-term structural health. Excessive sway, even if it does not lead to immediate structural failure, can cause discomfort for occupants and lead to cumulative damage over time. The current study's general approach to managing lateral loads could be enhanced by incorporating more detailed strategies for sway control, such as the use of tuned mass dampers, which are widely recognized in tall building design for reducing oscillations caused by wind and seismic activity. Future studies could expand on this by integrating advanced sway control measures into the design of high-rise buildings, providing a more holistic approach that ensures both safety and comfort.

The findings of this study also shed light on the importance of torsional reinforcement in beams and the strategic use of staircases to support both structural integrity and occupant movement within high-rise buildings. The design of torsional reinforcement in this study ensures that beams are equipped to handle potential twists caused by lateral forces, thus improving the overall stability of the structure. This aspect of the design aligns with the work of Hassan et al. (2020), who emphasized the need for reinforced beams to counteract torsional effects, particularly in high-rise structures exposed to wind and seismic forces. Additionally, the study's design of staircases, with appropriate tread and rise dimensions, not only facilitates ease of movement but also contributes to the structural performance of the building by providing consistent load transfer across different floors. The integration of staircases into the overall structural design reflects a growing trend in modern high-rise construction, where functional elements like staircases are also considered critical structural components.

The application of lapping ties in columns, another significant finding of the study, helps manage the distribution of forces and ensures consistent load transfer throughout the building. The use of seismic ties and splicing in reinforcement plays a crucial role in enhancing the building's capacity to withstand seismic forces, a design approach supported by the work of Fintel (2019). The implementation of these reinforcement techniques, which are designed to resist seismic-induced stresses, further supports the building's overall stability. This detailed attention to reinforcement, particularly in the context of high-rise buildings in seismically active regions, demonstrates the importance of combining traditional reinforcement techniques with modern design strategies to create buildings that are resilient to both everyday loads and extreme events.

Finally, while the study's findings provide a solid foundation for understanding the structural design and analysis of a 20-story mixed-use building, there are several opportunities for further research. In addition to the need for more detailed joint design and sway control, future studies could explore the impact of foundation design on the overall stability of high-rise buildings. The foundation is a critical component that supports the entire structure, and ensuring that it is adequately designed to handle both vertical and lateral loads is essential. Studies by Hossain and Islam (2018) have emphasized the importance of foundation design in high-rise buildings, particularly in urban environments where soil conditions can vary significantly. A more detailed analysis of foundation design in future studies could provide further insights into the best practices for ensuring the stability and resilience of high-rise buildings, especially in regions prone to seismic and wind activity.

In sum, the study provides valuable insights into the design and analysis of a high-rise mixed-use building, with a particular focus on load distribution, material verification, and lateral load management. However, areas such as beam-to-column joint design, sway control, and foundation analysis offer opportunities for further research to enhance the resilience and safety of high-rise structures in complex urban environments. By addressing these additional considerations, future studies can build on the findings of this research to develop more comprehensive and effective strategies for high-rise building design, particularly in regions like Dhaka, where environmental conditions pose significant challenges.

6 Conclusion

The study successfully planned and designed a 20-story mixed-use residential and commercial building in accordance with ACI and BNBC codes, with particular attention given to lateral load considerations. The analysis highlighted several key findings. First, the service load requirements for residential spaces differ significantly from commercial spaces, necessitating the use of thicker floor slabs in commercial areas to support the higher loads. Additionally, placing commercial spaces on the lower floors, as in this project (Ground to 10th floors), helps to reduce torsional effects, improving the building's stability. It was also emphasized that material strength properties should be thoroughly checked before construction to ensure that the structure meets the necessary design strength. Moreover, the study underscored the importance of understanding the computational methods employed by structural analysis software, as this knowledge is crucial for developing accurate structural models. For future research, it is recommended that particular attention be given to the design of beam-to-column joints, which are critical in high-rise buildings but were not covered in this study. Foundation design also requires detailed focus, as it plays a fundamental role in the stability of high-rise structures. Furthermore, incorporating sway and deflection control in both the analysis and design stages would enhance the structural resilience of future buildings. These recommendations serve as vital points for further studies to address areas that were outside the scope of this research but are essential for the comprehensive design of high-rise buildings.

6.1 Recommendations for future research

Future research on the structural design and analysis of high-rise mixed-use buildings should focus on several critical areas that were not fully addressed in this study. First, there is a need for detailed exploration of beam-to-column joint design, which plays a vital role in ensuring the structural integrity of high-rise buildings, particularly in seismic zones. Developing advanced design techniques for these joints will help prevent structural failures during earthquakes. Additionally, more research is needed on the incorporation of sway and deflection control measures, such as tuned mass dampers, which can significantly improve occupant comfort and reduce long-term structural stress. The study also highlights the importance of foundation design, particularly in urban environments with varying soil conditions; future studies should explore advanced foundation techniques to ensure both vertical and lateral stability under diverse loading conditions. Furthermore, integrating innovative materials and reinforcement methods, such as fiber-reinforced polymers or smart materials, could provide enhanced durability and load-carrying capacity for high-rise buildings in extreme environments. Finally, future research could benefit from a more in-depth analysis of the role of sustainability in high-rise construction, particularly with respect to the use of energy-efficient designs and renewable materials, ensuring that the structural solutions not only meet safety standards but also contribute to environmental goals. By addressing these areas, future studies can contribute to the ongoing development of safer, more resilient, and environmentally sustainable high-rise buildings.

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