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Comparison of Structural Efficiency in Relation to High Rise Structures

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Abstract: **The project aims to evaluate the design and construction of four distinct 35-storey commercial high-rise buildings, focusing on two Reinforced Concrete (RC). Each building will be scrutinized based on criteria including structural stability, efficiency, flooring systems, structural frames, economic viability, and construction time. Structural stability and efficiency will be assessed concerning resistance to lateral and vertical loads, material utilization, and overall robustness. Flooring systems and structural frames, such as flat plate systems for RC buildings and steel moment resisting frames for steel structures, will be compared in terms of construction complexity, layout flexibility, and long-term maintenance needs. Moreover, an economic analysis will scrutinize construction costs per unit area, including materials, labour, equipment, and long-term expenses. The overall stiffness of each structure and construction time for the superstructure will also be evaluated, providing comprehensive insights to aid engineers and developers in making informed decisions when designing and constructing high-rise buildings.**

By conducting a holistic assessment, this project seeks to offer valuable insights into the structural performance, economic feasibility, and construction efficiency of different high-rise building types. Through careful analysis of factors such as stability, efficiency, economic viability, and construction time, engineers and developers can make informed decisions when designing and constructing high-rise buildings in urban environments. This comprehensive approach aims to optimize building design and construction processes, ensuring the development of safe, cost-effective, and efficient structures suited to the demands of modern urban landscapes..

Keywords: **Structural efficiency, stability, cost effectiveness, sustainability.**

1. INTRODUCTION

This chapter gives an overview of the literature review done prior to the start of the project. This chapter also covers the objectives, and motivation.

1.1 Introduction

The mass the structure can support, divided by the mass of the structure itself, is known as structural efficiency. When we evaluate a structure's strength, stability, and load-bearing ability in relation to the materials and resources employed, we may declare any building to be structurally efficient. The most popular way to compute structural efficiency is to divide the maximum design load by the structure's weight. Beyond safety, structural efficiency is a critical factor in guaranteeing the dependability and durability of high-rise structures; hence, its computation is required. The structure of the high-rise building must be able to sustain tremendous loads, continuous use, and even adverse weather conditions without losing structural integrity [1].

High-rise structures are now a necessary component of modern cities' infrastructure. High rise structures first became popular with the general public because of their striking aesthetics, but they also became the talk of the town for structural engineers and architects, who saw in them new opportunities for invention and study.

The history of high-rise structures is not one that happened overnight. Every high-rise structure is the result of multiple technological advancements made over several decades. A new era began with the invention of the "Bessemer steel process" in the 1850s. This technique involved adding oxygen to extremely high-quality steel while it was still molten, burning off all of its imperfections. The steel industry was greatly impacted by this breakthrough, which allowed for the massive production of high-quality steel and, eventually, the creation of steel sections utilized in the construction of tall buildings (McNamara, 2019). Portland cement is another example of such an invention. It was created in 1824 and is credited to Joseph Aspdin of Leeds, United Kingdom. Over many years, this Portland cement underwent additional changes that resulted in the creation of modern cement. Furthermore, the patent for wrought iron bars as concrete reinforcement was granted in 1854 as the usage of unreinforced concrete for home construction became more widespread. In the years that followed, reinforced concrete bridges and industrial factories began to appear, along with the introduction of steel reinforcing technologies. The first multistory building was built in 1898 (Chang and Swenson, 2019) [2]. Even though multi-story buildings became common, the lack of a well-functioning elevator system limited occupants' access to higher floors. For instance, although buildings taller than eight stories could be built, climbing the eighth floor by staircase would be an exhausting undertaking. In the early 19th century, the first steam-powered elevator was created to move products in industries. The basis for the knowledge of electric elevators in multistory structures was thus established. Electric elevators were not utilized in multi-story structures until the late 1800s, towards the close of the 19th century (Bellis, 2019). The early 20th century saw the emergence of tall, thin structures that would later be known as high-rise buildings, painting the city skylines [3].

The present-day world offers structural engineers with a plethora of flooring systems, a range of different types of beams and columns along with an array of stability systems to ensure occupants comfort as well as stability and efficiency of structure. Structural Stability and efficiency of a high-rise building should not be looked at only through the prism of structure’s ability to withstand forces it is designed for. Moreover, stability and efficiency of a structure have several dimensions, such as economy, sustainability, and time of construction. The author compares the structural stability and efficiency of two types of high-rise buildings in this paper. This study throws light on the pros and cons of various structural systems that can be currently used to construct a high-rise building.

1.2 History of high-rise Building

Since the dawn of civilizations, tall buildings have served as a symbol of superior technical achievement. Built around 2325 B.C., the colossal pyramids of Egypt continue to display the riches and strength of the Egyptian monarchy at that time. Numerous historic buildings serve as proof of humanity's constant quest to expand the application of what is now known as structural engineering.

A number of reasons led to the creation of high-rise structures, including the 19th-century modern industrial revolution. However, in the 18th century, the industrial revolution had already started in England. Along with the massive influx of working-class people from rural areas into cities brought about by the Industrial Revolution came a host of other issues, including the housing crisis. Moreover, the First World War accelerated the pace of technological development. The fact that there were 164 cities in the world in 1871 with a population of more than a million, and 611 cities with a population of at least a million and 40 cities with a population of more than a million in 1930 indicates that the population of the world's major cities was trending upward (Anon, n.d.). There were 1205 cities in the world with a population of at least 100,000 in 1972; among these, 105 had a population of more than one million, 90 had a population of between 0.5 and one million, and 1010 had a population between 0.1 and 0.5 million.

As was noted, many technological advancements and inventions were required to make vertical living a reality. This extended beyond the building materials; to support vertical living, waste management, drainage, and water supply systems had to be established. Because of the building's increased height, elevators and emergency fire escapes were necessary. To withstand wind forces, high-rise buildings also required the development of various stabilizing devices.

Portland cement, created by mason Joseph Aspdin (1778–1855), was a significant invention. In the kitchen of his own home, he heated limestone and clay to generate Portland cement in 1824. He then crushed the mixture to produce a hydraulic cement, which solidified when water was added. Because of the product's resemblance in appearance to Portland stone, which was quarried on the Portland island off the coast of Britain, Aspdin termed it Portland cement (Anon, 2015). It was now the time for humans to begin combining the tensile strength of steel and the compressive strength of cement (or, initially, wrought iron) to build structures [4].

This all started in 1854 when Newcastle-upon-Tyne resident William B. Wilkinson built a modest two-story cottage employing iron bars for floor and roof reinforcement. Joseph Monier understood and patented this steel reinforcing at the tensile region of the beam in 1867, even though this represented the beginning of the usage of reinforcement in concrete. William E. Ward built the first reinforced concrete structure that became a landmark between 1871 and 1875. William was a mechanical engineer who researched the first technical studies of reinforced concrete and recorded them. In addition, German engineer G. A. Wayss acquired the patents for Joseph's research and started building reinforced concrete buildings all throughout Germany, Austria, and France .

The advent of monolithic frame construction marked the next stage in the development of high-rise structures. In order to increase the binding strength between the reinforcing bars and concrete, Ernest L. Ransom of San Francisco invented the usage of twisted square steel rods, which he utilized for the first time in 1877. The museum at the University of Stanford named Leland Stanford is among his most important creations. Using exposed aggregates, it was the first building of its kind. In the latter part of the 1870s, Francois Hennebique started constructing reinforced concrete homes in Paris. With the help of his own business network, he was clever enough to popularize and introduce this innovative construction technology. Auguste Perret encouraged the use of reinforced concrete, which quickly started to gain favor and spread like wildfire.

Many structures needed to be renovated in the years after World War II (after 1945) due to the damage inflicted by bombing cities. Cities started to become even more crowded as the population growth rate increased. The government turned to planners and architects for help in solving this issue because of the intense strain. While the government took its own action, the private sector was encouraged to seize this chance that the building industry had to give. In the 1950s and 1960s, the government started offering incentives for the building of residential blocks taller than eight floors. This had a significant effect on the housing crisis issue, reorganizing entire communities in line with contemporary town planning principles [5].

A variety of flooring solutions were developed as knowledge about using steel and concrete increased; by the middle of the 20th century, shear studs had been tested for the first time at the University of Illinois in the United States. As a result, the design formula was published in 1956; nevertheless, AISC did not recognize it until 1978. In Europe, "provisional regulations for the design of girders in the composite construction" were released in the 1950s at the same time. As a result, by the end of the 20th century, a new class of high-rise structures had emerged, featuring steel columns with composite floors and beams (Ahmed and Tsavdaridis, 2019) .

1.3 Literature Review

1.3.1 Structural efficiency of high-rise buildings:

We understand that the structural performance of high-rise buildings with various geometrical shapes under wind loads, comparing RCC and composite structures. It underscores the advantages of composite structures, including superior stiffness, stability, and strength against lateral wind loads and gravity loading. Using ETABS software, G+15 storey buildings with rectangular, triangular, and plus-shaped bases are modeled in both RCC and composite forms. Parameters such as maximum storey displacement, shear, and moment are analyzed. Results indicate that the composite structure with a plus-shaped base (Case 06) demonstrates the highest stability and wind load resistance. Moreover, composite structures prove more economical due to smaller steel beam sizes, quicker construction, and lower dead loads, highlighting their suitability for high rise buildings [6]. While at the same time high-rise buildings constructed with RC framed systems and shear wall systems, emphasizing structural performance under gravity and lateral loads, notably in seismic zones like Visakhapatnam. It references studies by Khushboo K. Soni et al. and Akash D. Shah, stressing the importance of structural configuration in coastal regions. Using ETABS software, the lateral displacement, storey drift, and base shear, showing shear wall systems outperform RC framed systems with lower displacement, reduced storey drift, and higher base shear resistance was analyzed. Shear walls' effectiveness is in ensuring stability and mitigating lateral loads [7].

A report on high-rise construction examines the shift in formwork systems from timber to steel and aluminum, considering factors like adaptability, duration, quality, cost, safety, and local conditions. The research includes literature reviews, expert interviews, and case studies of Conventional, Modern Conventional, Steel, and Mivan (Aluminum) systems. Data analysis shows aluminum formwork, despite higher initial costs, is cost-effective and efficient for mass construction due to its high repetition rate and lower labor costs. The report emphasizes selecting the appropriate formwork to optimize cost, duration, and quality based on project specifics [8]. also at the same time another report examines structural systems in high-rise buildings, tracing their evolution from traditional masonry to modern steel and reinforced concrete. It categorizes load-bearing systems into inner and outer, exploring rigid frames, crossed frames, tube systems, and diagrids. Iconic buildings like the Sears Tower and Turning Torso Tower illustrate structural and architectural implications. Core positioning, material selection, and system design are emphasized as crucial factors. The paper also discusses the trend of hybrid systems, combining steel and reinforced concrete for better flexibility and space utilization. It provides valuable insights into structural analysis and design in high-rise construction [9].

The paper examines diagrid systems in high-rise buildings, focusing on their economic and aesthetic benefits and superior lateral stiffness. Diagrid structures, with diagonal grids and horizontal rings, handle seismic loads better than traditional structures. Citing works by Revankar et al. (2014) and Kamath et al. (2015), it discusses structural stability, angle configurations, and load resistance. Using STAAD. Pro software, it models and analyzes seismic forces, comparing diagrid and non-diagrid structures. Results show diagrid systems reduce bending moments and lateral displacements in tall buildings. The paper provides insights into the structural efficiency and advantages of diagrid systems through detailed literature review and analysis [10]. While at the same time another paper offers a insight on the seismic behavior of different structural systems in tall buildings. These studies compare diagrid and shear wall structures, with findings suggesting that diagrids perform well in displacements while shear walls excel in reducing building acceleration. They also indicate that diagrid structures are more efficient, particularly in seismic zones. The literature review underscores the significance of structural systems like diagrids in enhancing the seismic performance of high-rise buildings, laying a solid groundwork for the comparative study presented in the paper [11].

A comparison between RC flat slab and shear wall systems with conventional framed structures in high-rise buildings shows that after evaluating these systems' behavior under lateral loads, considering parameters like building height, floor plate size, and shear wall location, we can offers a comprehensive review of structural systems' effectiveness in high-rise buildings, emphasizing the significance of shear walls and flat slabs in enhancing stability and lateral load resistance [12] . Also, a thorough examination of high-rise structures, covering definitions, safety, design challenges, and stability, historical evolution, emphasizing feasibility studies and modern stability requirements. Structural systems like framed tube and outriggers are assessed for lateral load resistance. Linear and nonlinear analysis concepts are explored, emphasizing material and geometric considerations. Wind loading's impact is highlighted, stressing accurate modeling. Pushover analysis methods, including modal and incremental response spectrum analysis, are discussion for seismic demands estimation. Simplified models and seismic energy dissipation in super-tall buildings are also explored. Overall, we can provide a comprehensive insight into high-rise design and analysis [13].

We can also come up with comparison of dynamic loads on high-rise structures across different international standard codes, which underscores seismic performance, design philosophy, and structural behavior under dynamic loads. The review highlights the importance of utilizing diverse international codes for structural analysis. Overall, we can establish the groundwork for the study's objectives and methodology, facilitating a comparative analysis of high-rise structures across various international codes [14]. while we have also explored the structural behavior of tall buildings employing hexagrid systems. Methodologically, the paper compared hexagrid module sizes and patterns under seismic forces, focusing on 15-storey buildings using STAAD Pro software. it analyzes parameters like moments, displacements, and shear forces. Overall, we observed insights into tall building structural performance with hexagrid systems, contributing to innovative solutions in modern architecture [15].

We can also investigate the influence of module-to-module (M2M) connection rotational stiffness on high-rise steel modular building structural performance. The study filled a gap in the literature concerning the insufficient exploration of M2M connection stiffness impact on internal force distribution. We come to learn about the stress accurate structural design for high-rise modular safety, Advantages of modular construction like productivity and sustainability alongside various connection types [16]. At the same time we were introduced to the method for stiffness analysis using OpenACC, targeting shear-deformable plate bending in high-rises. Boundary element method (BEM) aids accurate analysis, emphasizing structural floors. Traditional numerical methods' limitations prompt a new approach for super element stiffness matrix computation, integrating internal supports. OpenACC programming enables parallel processing on GPUs and multicore CPUs, enhancing computational efficiency. Numerical examples validate the method's feasibility and accuracy compared to conventional BEM approaches. The study advances computational methods for high-rise stiffness analysis, stressing precise modeling for structural engineering applications [17].

One of the paper focuses on system identification (SI) in high-rise buildings using a shear-bending model (SB model). It is proposed that a statistical model-updating approach to enhance the accuracy of shear and bending stiffness identification, incorporating floor rotation angle data. We also come to learn about SI evolution in structural health monitoring, highlighting challenges in parameter identification due to measurement constraints [18]. While at the same time some key factors are explored affecting the construction duration of high-rise buildings, focusing on formwork selection, vertical delivery challenges, and scheduling methods. We can underscore the impact of formwork systems on concrete activities and project progress, detailing parameters for optimal selection. [19].

1.3.2 Economic and time of construction comparison of high-rise buildings

A review on cost overruns in construction projects, focusing particularly on high-rise buildings in India. Drawing from studies in various countries like Malaysia, South Africa, and India, we identify key factors contributing to cost overruns, including material shortages, labor skill gaps, project management issues, design flaws, and fluctuating raw material prices. Methodologies such as the Relative Importance Index (RII), exploratory factor analysis, and Spearman's rank correlation test are discussed [20]. We also come to know about the cost and time overruns in high-rise construction in Pune, India, emphasizing timely and cost-effective project completion. Through surveys and interviews, it identifies 45 delay causes, calculating their Relative Importance Index (RII). Key factors include design changes, project complexity, and lack of skilled labor. The study highlights the interdependence of time and cost overruns, offering insights and mitigation strategies to address these challenges in high-rise construction [21].

A comparative study on composite member structures with RCC and steel structures, concluding that composite systems are more economical. developed models to assess seismic performance, finding shear wall buildings to be cost-effective. Emphasizing economic viability in seismic zones, it advocates for studies evaluating material consumption and costs to promote efficient systems like shear wall flat slab systems. Overall, the importance of economic analyses shall be underscored in advocating for shear wall systems in high-rise constructions within seismic zones [22]. Through a research article which examines examines cost overrun estimation in high-rise construction via a neuro-fuzzy inference model. It stresses the importance of accurate cost forecasting to ensure project success and minimize financial risks. Factors contributing to overruns, including poor performance and design changes, are identified. Methods like factor analysis and regression models are employed to predict cost deviations [23].

If we evaluate the cost effectiveness of three structural systems for tall buildings in Duhok: rigid frame, dual, and shear wall systems to identify the most economical system for buildings of varying heights (10, 20, and 30 floors) by assessing concrete and reinforcement quantities. Results compare concrete and reinforcement quantities, suggesting shear walls as the most economical for taller buildings [24]. At the same time another paper explores the economic aspects of green versus conventional building methods, using an Analytical Hierarchy Process to enhance green concrete with industrial waste. It highlights green buildings' energy efficiency and cost-effectiveness, especially in rebar and concrete costs. The study concludes with the long-term benefits of green building designs [25]. We are educated about preliminary design and cost analysis of a high-rise building with a braced shear wall core system, emphasizing early design stages in structural decision-making. Adhering to international codes, it highlights the importance of informed preliminary design for structural integrity and cost efficiency in high-rise projects [26].

We also come to know about the time and cost overruns in Penang's high-rise projects, emphasizing stakeholder impacts. We identify inadequate planning and design changes as key time overrun factors, and budget planning and material cost inflation as major cost overrun contributors, aiming to improve project management and reduce delays [27]. Another paper examines time overruns in tall building construction, emphasizing cost implications and global prevalence. We review factors affecting schedules, such as project scope and communication, and explore technologies like jump form systems and prefabrication. There shall be recommended tailored strategies and emerging tools to enhance efficiency and reduce construction time [28]. When investigating delays in high-rise building projects in Pune, the focus should be on poor planning, management, material shortages, communication gaps, and weather conditions [29].

At the same time of we address delays in high-rise construction, critical in urban settings, citing challenges like cost overruns and stakeholder dissatisfaction. We can pioneer Machine Learning for predicting delay times, noting the industry's shift towards Artificial Intelligence and Construction 4.0 [30]. A study on construction time performance (CTP) in Sri Lankan high-rise projects, emphasize timely completion's importance. Which highlighted project complexities, funding, permissions, and collaboration's roles. Through qualitative methods, we came to know about 49 significant factors impacting CTP, and the paper also offered insights to improve project performance and mitigate delays in Sri Lanka's high-rise construction [31]. While assessing the cost performance of high-rise hospital construction projects and scrutinizing factors impacting cost and schedule one of the papers identified design changes, poor management, financial constraints, and material shortages as key contributors to delays and cost escalations [32].

Another paper examines the factors influencing formwork system selection in high-rise buildings. Utilizing regression analysis and questionnaire surveys, we can assess factors like project duration, maintenance cost, and safety. We also come to know about the formwork materials and technological advancements, highlighting their impact on project success and aiding decision-making processes in high-rise construction [33]. While on the other hand a new method is presented to us for tracking high-rise construction progress using target detection technology, critiquing laser-based scanning for complexity and cost. The approach trains a detector with top-view construction site images, collected via drones. It emphasizes rough registration's role and advocates for larger datasets and real-time monitoring with video data [34].

1.3.3 Seismic and wind effect on high rise structures

On reading a comparative study on high-rise building designs under seismic forces, analyzing Indian and European standards, we come to know that Main focus was put on slab designs using IS codes and variables affecting structural demand, explore zone factors and international codes' influence on lateral load resisting systems [35]. At the same time another paper analyzed outrigger structural systems in tall buildings to enhance lateral stiffness, seismic resistance, and wind load mitigation. Through numerical simulations and structural modeling, it highlights the significance of outrigger systems in stability enhancement and load redistribution [36]. At the same time another paper compares bundled tube and moment resisting frame systems in high-rise buildings using Performance-Based Design. We came to know about structural systems like Moment Resisting Frame and Bundled Tube Systems, exploring seismic performance evaluation and nonlinear analysis techniques [37].

We also come to know about wind load challenges in tall building design, particularly relevant in populous countries like India, wind-induced vibrations and the importance of dynamic load management. Discussions encompass wind loading complexities, stability against overturning, uplift, and sliding, alongside structural component strength, a comprehensive insight into effectively designing tall buildings to withstand wind loads [38]. At the same time another paper examined wind load effects on tall buildings of diverse shapes, stressing the importance of assessing non-standard configurations beyond conventional standards. It advocates for computational fluid dynamics (CFD) and wind tunnel experiments [39].

We also come to know about technological advancements in high-rise building construction, focusing on structural and architectural aspects which highlights innovation in engineering and architectural studios' contributions, addressing challenges like spatial rigidity and wind effects with solutions such as vibration damping systems also review topics like geometric forms, materials, and energy efficiency, exploring advanced materials and technologies [40].

1.3.4 Sustainability comparison

We came to know about the analysis of the life-cycle cost (LCC) of a 12-story mass timber building versus a concrete alternative, emphasizing the cost-effectiveness and environmental benefits of mass timber, particularly cross-laminated timber (CLT). Methodology adhered to established standards, offered valuable insights into the economic and environmental aspects of mass timber in high-rise construction [41]. Another paper analyzed the development trends of high-rise buildings over 200 meters (about 656.17 ft) in China, the USA, and the UAE from 2000 to 2019, using data from the Council on Tall Buildings and Urban Habitat (CTBUH). It highlights a significant increase in completed high-rises since 2006, driven by social, economic, and political factors. The study also compares the number, distribution, and function of high-rises in these countries, discussing the influence of political and economic environments on their development. It also explores the relationship between high-rise construction and economic indicators like GDP growth rates, emphasizing the importance of sustainable development and collaboration for future growth [42].

We also come to know about the crucial role of sustainable conceptual design choices in reducing the construction industry's environmental impact, utilizing the Non-dominated Sorting Genetic Algorithm II tool, the paper illustrates how analyzing design solutions on a Pareto graph unveils sustainable alternatives. multi-objective optimization studies, advocating for a holistic approach for informed decision-making [43]. At the same time, another paper addresses challenges in tall building developments, emphasizing social, economic, and environmental sustainability, examining critiques like social isolation, economic hurdles, and environmental impacts. Stressing the need for sustainable solutions, it suggests innovations like energy-efficient features and eco-friendly materials, aiming to inform future research and practices in sustainable urban planning and architecture [44].

A comparative study on conventional and sustainable building construction, emphasizing sustainability's environmental, economic, and social dimensions also discusses the green building movement in India spearheaded by the Indian Green Building Council (IGBC) and highlights the economic benefits and environmental protection associated with sustainable construction. Overall, it provides a comprehensive overview of sustainability in the construction industry, advocating for its widespread adoption [45]. Another paper explores sustainable design solutions for tall buildings, specifically focusing on diagrid structural schemes. It emphasizes sustainability's significance in urban environments and compares traditional outrigger systems with diagrid configurations through FEM nonlinear analyses. Evaluating sustainability in terms of structural steel weight savings, it highlights steel's environmental advantages [46]. We also understand structural systems for tall timber buildings, emphasizing sustainability and height enhancement, the evolution of tall buildings and compare braced frames, CLT shear walls, and tube configurations using the Mjøstårnet case study. Steel-timber hybrids are a promising solution for structural efficiency and sustainability in tall timber construction [47].

We also come to know about sustainable design approaches in high-rise buildings, focusing on challenges posed by population density, benefits and drawbacks of high-rise living, emphasizing quality design for residential satisfaction and social cohesion. Structural aspects, including material selection and load-resisting structures, are explored, providing a comprehensive review of sustainable high-rise design principles [48]. While another paper emphasizes on sustainable development in Chinese high-rise buildings, targeting environmental, efficiency, and safety concerns. It advocates for eco-friendly designs combating consumption and pollution, stressing climate adaptation, energy efficiency, and architectural integration. It calls for a green high-rise building system to foster sustainability in Chinese urban development [49]. Another paper which advocates for sustainable design in tall buildings, promoting interdisciplinary approaches and technology transfer from aerospace. It proposes zero-energy designs, leveraging climate benefits and renewables, with case studies like Menara Mesiniaga and Swiss Reinsurance Headquarters showcasing green features. Stressing responsible energy use and waste reduction, it highlights the significance of sustainable architecture for environmental preservation [50]. One of the papers analyzed effective resource management in high-rise construction projects using Primavera Platform in Pune City. Data from "18 Latitude Construction of Commercial Building" illustrates resource allocation, highlighting Primavera's role in efficient planning [51].

At the same time we also come to know about automation and robotics advancements in high-rise construction, utilizing scientometric, critical literature, and market reviews to identify key research areas, evaluating academic research against practical applications, revealing developmental gaps and suggesting future research directions, thereby contributing significantly to the field's knowledge base [52]. We also come across another paper which explores skyscrapers' role in urbanization, emphasizing sustainable design's importance. It discusses green features within social, economic, and environmental contexts and advocates for balanced, resilient approaches amid climate change. Global case studies offer insights into future urban development, informing practitioners and policymakers and advancing sustainable high-rise construction discussions [53]. We also come to know about modular construction technology for high-rise buildings, emphasizing its advantages over traditional methods which discusses stacking approaches and technical challenges, like joining techniques and the absence of design guidelines, limiting its applications. Recent global developments and future research directions, including lightweight module development, are highlighted, offering valuable insights for professionals and researchers [54].

1.4 Literature Summary

Numerous studies comparing the costs of building high-rises have been conducted, as have analyses of the embodied carbon of different flooring and building types. Diverse individuals and institutions have also examined the sustainability aspects of different types of high-rise buildings.

These comparison studies are self-contained; for instance, studies comparing and evaluating building costs do not assess the relative sustainability of those structures within the purview of the publication.

With a more comprehensive approach that compares and weighs many variables of construction time, cost, and sustainability, we want to compare the structural stability and efficiency of high-rise buildings.

The literature reviews for the documents utilized in this study are included in the following sections, which are arranged in accordance with the subjects covered in this paper.

1.5 Motivation

This study compares the overall stiffness, structural stability and efficiency, and sustainability of high-rise buildings by designing two different types of high-rise buildings, evaluating and comparing embodied carbon dioxide emissions, and comparing lateral deflection due to wind and seismic effect. The goal is to understand the stability and efficiency of different types of high-rise buildings that can be constructed.

1.6 Objectives

Two different commercial high-rise building styles, each with the same floor plan and number of stories, are designed to house 4200 people.

- The structure's lateral displacement during severe wind and seismic conditions is analyzed.
- Comparing the sustainability of tall structures using the standards established by NBC.
- Comparing the construction cost for both the buildings.

1.7 Methodology

This report presents a comprehensive methodology for analysis of high-rise buildings, structural stability, efficiency, construction time, cost, and sustainability. Evaluating these variables enables a thorough comparison of structural integrity and performance. By considering construction time, cost-effectiveness, and environmental impact alongside stability, a holistic understanding of high-rise building efficiency emerges. This approach facilitates informed decision-making, balancing the demands of structural integrity with economic and environmental considerations. Ultimately, it ensures the development of sustainable, resilient, and efficient high-rise structures meeting contemporary architectural and societal needs.

1.8 Organisation of report

Chapter 1 – Introduction: This chapter provides insight into the project and its various aspects along with the motivation and literature review analyzed thoroughly for reference purpose and objectives of the project.

Chapter 2 – Structural behavior of high-rise buildings: This chapter provides a detailed description of the concepts involved in the project.

Chapter 3 – Methodology: Types of high-rise buildings, layout description, lift calculations and methodology for the proceeding of the project along with software usage are discussed in this chapter.

Chapter 4 – Results and Discussions: Various parameters such as deflection due to various load combinations, cost of construction, sustainability are discussed and compared in this chapter.

Chapter 5 – Conclusion: After obtaining the results from STAAD.pro software conclusions were drawn accordingly.

2. STRUCTURAL BEHAVIOUR OF HIGH-RISE BUILDINGS

This chapter delves into various methods and theories for analysis of structural behaviour of high-rise buildings and application of the study of structural efficiency and its importance in a high-rise structure.

2.1 Analysis of Structural behaviour for high rise buildings

There are several theories for the analysis of structural behaviour of high-rise buildings, including.

Elastic Theory: This is one of the simplest and most basic approaches to structural analysis. It assumes that materials behave elastically within their proportional limit. Tall buildings are often analysed using linear elasticity theory, where loads are applied, and the resulting stresses and strains are calculated. However, this theory may not fully capture the complex behaviour of high-rise structures under large deformations and nonlinear material properties.

Finite Element Method (FEM): FEM is a numerical technique used to analyse complex structures by breaking them down into smaller, simpler elements. It is widely used for the analysis of high-rise buildings due to its ability to handle non-linear behaviour and complex geometries. FEM can take material nonlinearity, large deformations, and geometric nonlinearities into account, so it is suitable for accurate analysis of high-rise structures.

Plasticity Theory: Plasticity theory deals with the behaviour of materials beyond their elastic limit, where permanent deformations occur. In high-rise buildings, plasticity theory is important for analysing structural members subjected to large loads, such as columns and beams. It helps in predicting failure modes and designing structures to resist yielding and collapse.

Limit State Design: This theory focuses on defining limit states, such as strength limit states and serviceability limit states, which a structure must satisfy to ensure its safety and functionality. High-rise buildings are designed to meet specific limit states under various loading conditions, including gravity loads, wind loads, and seismic forces.

Dynamic Analysis: Dynamic analysis is essential for evaluating the response of high-rise buildings to dynamic loads, such as wind and earthquakes. Methods like modal analysis, response spectrum analysis, and time-history analysis are used to predict the dynamic behaviour of structures and assess their performance under different loading scenarios.

Buckling Analysis: Buckling analysis is used to study the stability of structural members subjected to compressive loads. In high-rise buildings, columns, walls and other vertical elements can buckle, leading to structural instability. By considering the effects of buckling, engineers can

Theory of Composite Structures: In high-rise buildings, composite structures involving steel, concrete and other materials are often used to optimize structural performance. The theory of composite structures considers the interaction between different materials and analyses their combined behaviour under different loading conditions.

2.2 Application of Study of structural efficiency in high rise buildings

A critical part of their design, construction and operation is to study the effectiveness of building structures in high rise buildings to achieve the best balance between performance, cost effectiveness, sustainability, and safety. Structural efficiency refers to optimisation of a building's structure system. In this case, the study of structural efficiency in high-rise buildings offers several key applications:

Optimized Material Selection: High-rise buildings require large quantities of structural materials such as steel, concrete, and glass. By studying structural efficiency, engineers can select the most suitable materials that offer high strength-to-weight ratios, durability, and sustainability. For example, lightweight and high-strength materials can reduce the overall weight of the structure, leading to cost savings and improved seismic performance.

Innovative Structural Systems: The study of structural efficiency encourages the development of innovative structural systems that maximize space utilization, minimize material usage, and enhance performance. Examples include diagrid systems, bundled tube structures, and outrigger systems, which offer advantages such as increased stiffness, reduced wind-induced vibrations, and enhanced resistance to lateral loads.

Load Optimization: Structural efficiency involves optimizing the distribution of loads within the building to minimize stresses and deformations while ensuring structural integrity and safety. Through advanced analysis techniques such as finite element modelling and dynamic analysis, engineers can optimize load paths, design efficient lateral force resisting systems, and reduce the need for excessive reinforcement.

Energy Efficiency: High-rise buildings consume significant amounts of energy for heating, cooling, lighting, and ventilation. By integrating structural efficiency principles into the building design, engineers can optimize the building envelope, reduce thermal bridging, and enhance natural ventilation and daylighting. This not only improves energy efficiency but also reduces operational costs and environmental impact.

Sustainable Design: Structural efficiency is closely linked to sustainability, as it involves maximizing the performance of the building while minimizing resource consumption and environmental impact. By using recycled materials, employing efficient construction techniques, and designing for disassembly and reuse, high-rise buildings can achieve high levels of sustainability and contribute to a more resilient built environment.

Life Cycle Cost Analysis: Structural efficiency analysis includes considering the life cycle cost of the building, including initial construction costs, operational costs, maintenance costs, and potential retrofitting expenses. By conducting life cycle cost analysis, developers and owners can make informed decisions about design alternatives, materials selection, and maintenance strategies to optimize long-term performance and economic viability.

2.3. Summary

Structural efficiency in high-rise buildings refers to the optimal use of materials and design strategies to achieve a balance between performance, cost-effectiveness, sustainability, and safety. It involves selecting appropriate structural systems, materials, and construction techniques to maximize the building's strength, stability, and functionality while minimizing resource consumption and environmental impact. Structural efficiency considers factors such as load distribution, energy efficiency, resilience to hazards, and life cycle cost analysis. By prioritizing efficiency in design and construction, engineers can create high-rise buildings that are not only structurally sound and durable but also economically viable, environmentally sustainable, and resilient to future challenges.

3. METHODOLOGY

This chapter delves into both the types of high-rise buildings discussed in this paper, providing detailed layout descriptions and lift calculations. It outlines the methodology for project progression, emphasizing software utilization for efficiency. Through comprehensive analysis and planning, it addresses Cost comparisons, design specifications and sustainability comparison of various products used in the construction of such high-rise structures.

3.1 Types of High-Rise Buildings

The Two types of buildings under the scope of this paper are flat slab and two-way slab high rise building, the number of stories in the both the buildings is G + 35 . Both the buildings are Reinforced concrete buildings.

3.2 Layout Description

The reader will receive details in this section on the high-rise building's design, including the number of floors, stairs, elevator types, area of the core, and plot dimensions. Additionally, each high-rise building's individual structural member specifications and dimensions are listed in this section.

3.2.1 Layout description

A square plot with 42 meters on each side and a centrally positioned square core area with 18 meters on each side are selected, as seen in figure 3.1.

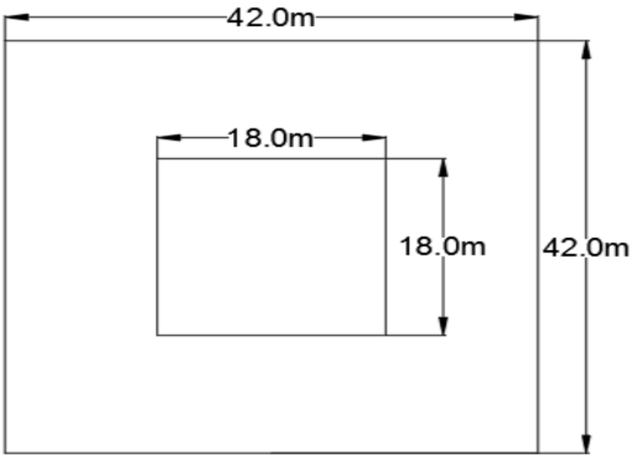

Fig 3.1 Layout of plot considered for the study

Workplace density shall not exceed 16.6 m^2 (NIA per person) in order to ensure that the NBC parameters for offices are met (General Building Regulations, Table 4.1 occupant Load).

Thus,

Area of core = $18 * 18 = 324$ m^2 (about the area of a tennis court)

Total area of the plot = $42 * 42 = 1764$ m^2

Net internal area (NIA) = $1764 - 324 = 1440$ m^2

It is anticipated that 120 people will need to be accommodated on each floor. Thus,

Workplace density = $1440/120 = 12 m^2$

The aforementioned dimensions are accepted since they meet the NBC's requirements for workplace density. In addition, to choose the number of floors:

Number. of floors = 4200/120 = 35 floors

Therefore, it is acknowledged that every high-rise structure that is designed needs to have a square core that is 18 meters in the centre of each side for a square plot size of 42 meters on each side, and that every high-rise building needs to be 35 stories tall.

Each side of the plot is divided into 7 bays of 6m each as shown in the fig 3.2.

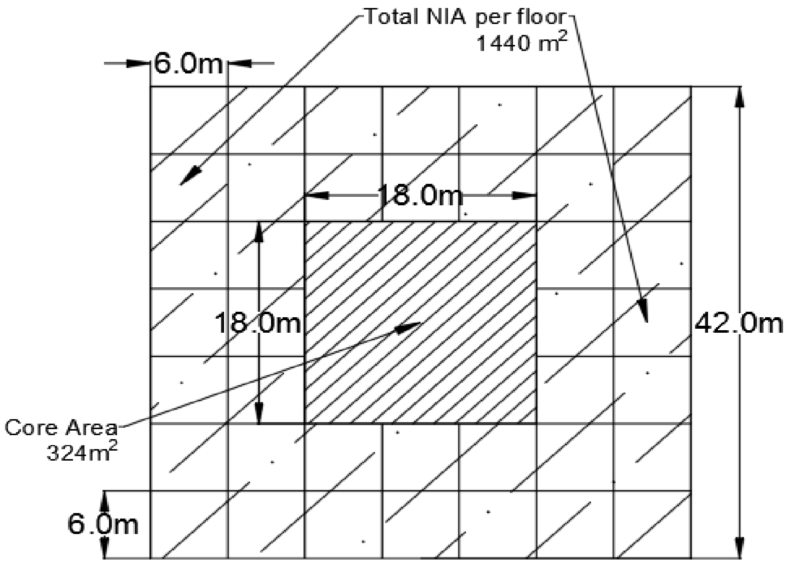

Fig 3.2 Core area and Net internal area per floor

3.2.2 Lift Calculation

Calculation for number of elevators:

(According to IS14665 (Part 2/ section 1) :2000)

Total core area: 18m X 18m = 324 m^2

Net internal area (NIA) = 1440 m^2

Total population of the building = 4200 persons

Total population on each floor = 120 persons

Capacity of lift car for a large building office = 1000 kg

Average weight per person = 70Kg

Average Number of persons in each lift (Q) = 12 persons

Round trip time (RTT) = 420 seconds

Assuming number of lifts (N) = 14

Waiting interval (T) = $\frac{RTT}{N} = \frac{420}{14}$ = 30 seconds

Hence, waiting interval (T) is classified as 'Good 'in terms of Quality of service according to IS 14665 (Part 2/ section 1) :2000.

Total population to be handled for peak morning period = 0.2 X 4200 = 840 persons

H = Handling capacity as percentage of the peak population handled during 5 min period

H = $\frac{300*Q*100}{T*P} = \frac{300*12*100}{30*840}$ = 14.28%

According to IS 14665 (Part 2/ section 1) :2000 for high rise office building value H should lie between 10% to 15%, Hence the obtained value of H is safe.

Therefore, the assumed value of the number of lifts is correct as shown in Figure 3.3.

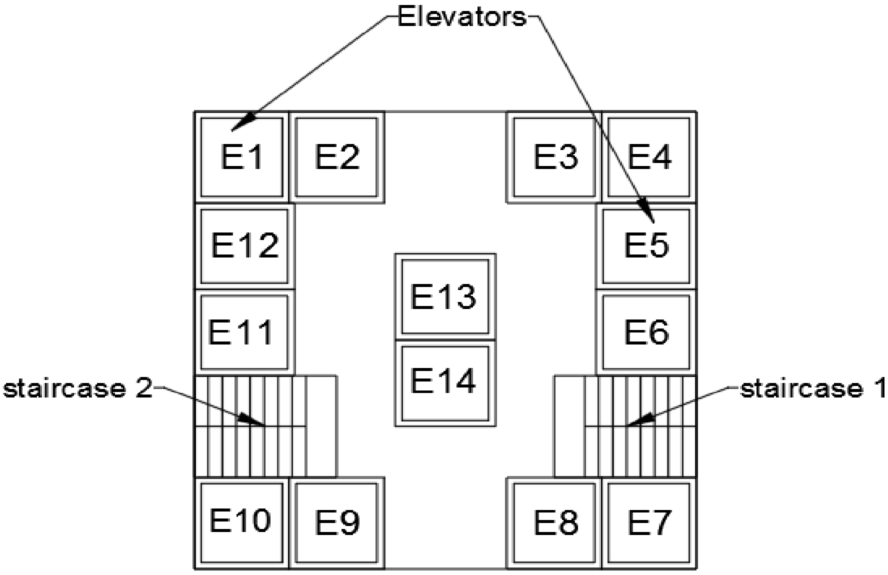

Fig 3.3 Arrangement of elevator and staircase in the core

3.2.3 Size of each elevator for 12 passenger capacity

A 13 passenger lift size is typically used in high traffic commercial buildings and large residential projects. However, this lift size has more extensive planning in the terms of shaft dimension and building design.

An elevator with a capacity for 13 pasengers or 1000Kg should ideally be 1600X1400mm as shown in Table 3.1.

The size of the shaft should be 2100x2000mm.

TABLE 3.1: Passenger lift size [56]

Passenger	Rated capacity (Kg)	Speed (m/s)	Car size (mm)	Shaft dimension (mm)
13	1000	1.5/1.6 1.75	AXB= 1600X1400 E= 900	CXD= 2100X2000

3.3 Design and Analysis of High-Rise Buildings

A high-rise building's foundation must be planned to securely disperse the weight of the structure to the earth. To choose the best foundation type, structural engineers take into account settlement analysis, bearing capability, and soil conditions.

3.3.1 Introduction:

Appendix 1 contains the design calculations and drawings for the two building types that are the subject of this article. STAAD Pro V 2023, a structural analysis tool, was used to do the research. The best grid for the kind of floor, columns, and beams served as the foundation for the structure. Because they are so site-specific, factors like landscaping and the layout of exterior construction have not been taken into account at all throughout the estimating process.

3.3.2 Design specifications:

The aim of these design calculations is to enable the estimation of material quantities to compare different characteristics of high-rise buildings covered in this work, as well as to estimate the size of structural components to model them for structural analysis in STAAD Pro V 2023. The details are not projected by these computations. The measurements of several structural members of the high-rise buildings covered by this research are shown in figures 3.4 and 3.5, respectively, for connections for any structural member:

Building 1: Flat slab floor, Reinforced concrete column.

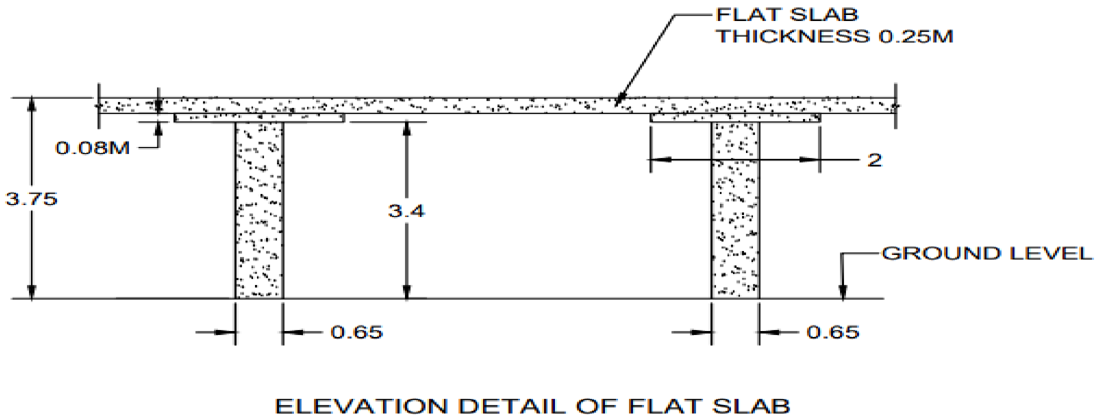

Fig 3.4: Flat slab dimensions

Size of flat slab: 6 m*6 m

Size of drop: 1.6 m*1.6 m*0.1 m

Column dimensions: h=0.75 m, b=0.65 m, column length= 3.4 m

Grid dimensions = 6 m*6 m

Building 2: Two-way slab floor, reinforced concrete beam, Reinforced concrete column.

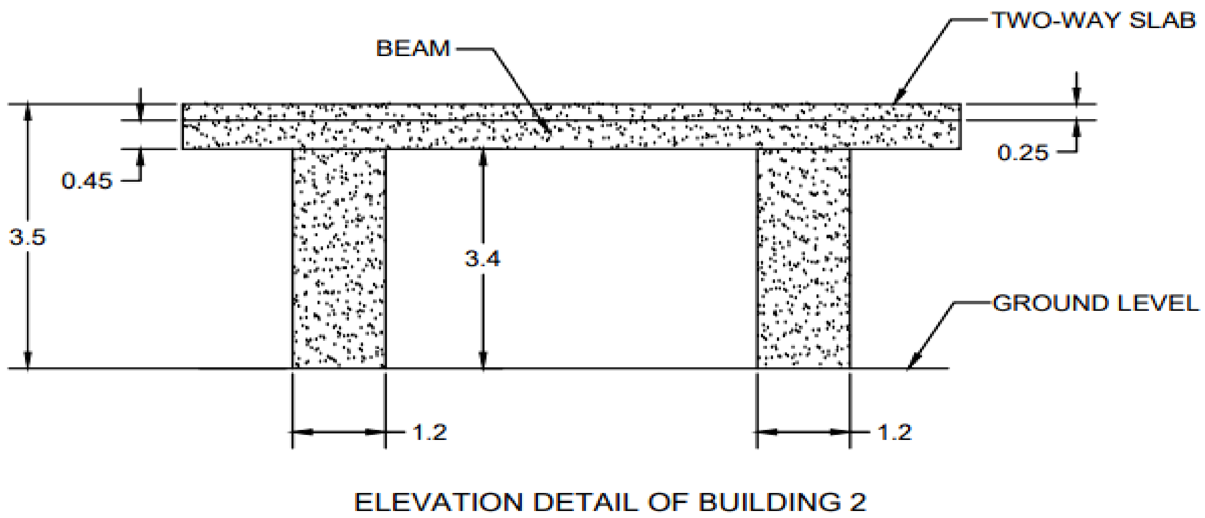

Fig 3.5 Two-way slab dimensions

Two-way slab:

Slab length = 42 m and Span of slab =6 m

depth of beam = 0.45 m,

Width of beam = 0.2 m

Column dimensions: h=1.35 m, b=1.25 m,

Length of column = 3.4 m

Grid dimensions = 6 m X 6 m

3.4 Cost comparison

Based on the design calculations completed in Appendix-1, the total amounts of steel and concrete in the high-rise buildings are determined. The following rates in table 3.2 for various items have been adopted from the Central Public Work Department schedule of rates for buildings in order to compare the cost of floor per m^2 and the total cost of high-rise building

TABLE 3.2: Rates as per CPWD schedule 2023

ITEMS	UNITS	RATES
Concrete in Walls	m^3	5500
Concrete in Column	m^3	2000
Concrete in Beam	m^3	4850
Reinforcement	Metric tonne	73620
Formwork of Walls	m^2	4850
Formwork of Beams	m^2	7700
Formwork of Columns	m^2	10000

3.5 Sustainability comparison

Historically, man has constructed his homes out of local resources like bamboo, wood, and earth stone. But as society has advanced, he has become more and more reliant on materials like steel, brick, and tiles because of their functionality and adaptability. He has been producing these materials with fuel energies since this transformation. While firewood was the traditional energy source, fossil fuel usage has increased dramatically due to industrialization.

While firewood was the traditional energy source, fossil fuel usage has increased dramatically due to industrialization. Significantly adding to carbon emissions are the embodied and operational energy energies that emerge from this. India currently holds the dubious distinction of being the world's third-largest carbon dioxide emitter.

Therefore, in order to determine which materials are most beneficial in lowering the energy consumption of fossil fuels, it is imperative that the various materials and processes that contribute to the embodied energy of building materials be analyzed.

In this paper we will only be looking into those factors which are influenced by the structural design of high-rise buildings. The key values of embodied embedded energy emissions are given in table below:

TABLE 3.3 embodied energy for various materials used [55].

TYPE OF MATARIAL	GRADE OF CONCRETE	ENERGY MJ/M3
CONCRETE OPC MANUAL	M20	1674.90
CONCRETE OPC MANUAL	M15	1364.26
CONCRETE OPC MANUAL	M10	1011.24
CONCRETE OPC MANUAL	M7.5	826.32
CONCRETE RMC MIX	M25	1940.23
CONCRETE RMC MIX	M20	1550.85
RMC CONCRETE 30% GGBS	M20	1212.85

AVERAGE EMBODIED ENERGY OF STEEL = 26.84MJ/Kg

4. RESULTS AND DISCUSSIONS

This chapter examines and contrasts multiple parameters including deflection under diverse load combinations, construction costs, and sustainability considerations. Through thorough analysis and comparison, it provides insights into optimizing high-rise building design for structural performance, economic feasibility, and environmental impact mitigation.

4.1 Overall Stiffness

Many structural elements make up high-rise buildings. Analyzing these structures to gather the information needed for designing different structural members by hand calculations is a laborious process that can lead to an accumulation of errors because of accuracy limitations and calculation errors. A variety of calculations incorporating the stiffness of members, the diaphragm action of floors, and the stiffness of columns are needed to estimate the deflection of structures under wind and earthquake loading. Thus, STAAD Pro V 2023 is used to do the structure's finite element analysis.

This section of the article will provide light on how tall buildings behave in windy situations. comprehensive instructions on building a modal in STAAD. Pro V 2023 is outside the purview of this essay. We must comprehend the total stiffness of a structure in order to comprehend the several aspects impacting the stability and efficiency that are taken into consideration in this research. An understanding of the structure's overall stiffness can be gained by examining the building's entire deflection under wind loading.

The behaviour of the high-rise buildings that are modeled in this study will be examined in three different configurations: bracings, with and without concrete core installation. Every building is designed to withstand a dead load of 1KN/m2 from moveable partitions and a wind speed of 52 Km/h. It is also subject to zone 5 seismic loading. Every area part was given a live load of 3KN/m2. Since this study does not examine the pressures acting on the substructure or its effectiveness, all buildings have a fixed base.

4.1.1 Overall stiffness comparison

Regarding each building, the layout of the slab, beams, columns, and core is the same for every floor. Therefore, it is reasonable to infer that the building's vertical plane has an equal distribution of structural stiffness. Since each floor is 3.4 meters high, ASCE 7 states that the maximum allowable inter-story drift due to wind load is H/400, where H is the height of each floor. That being said, the maximum drift between storeys is determined by:

$$\frac{H}{400} = \frac{3400}{400} = 8.5\text{mm}$$

With each floor having a height of 3.4 meters, the maximum displacement of the 35-story building, assuming that all of the floors are experiencing maximum inter-story drift, is as follows:

35 x 8.5 = 297.5 mm

The highest displacements possible for each of the six varieties of tall buildings in the absence of core and bracings are tabulated and reported in table 4.1 in this work.

TABLE 4.1: Deviation from deflection limit

Building type	Lateral deflection (mm)	Allowable deflection (mm)	Deviation from deflection limit (mm)
Flat Slab	1728	297.5	1430.5
Two Way Slab	961	297.5	663.5

Table 4.1 makes it clear that, in comparison to other flat slabs, the two-way slab has the least amount of deflection. The departure of the deflection values from the maximum permitted deflection is also shown in Table 4.1. The need for a stability system is determined by a structure's rigidity. Although bracings or a reinforced concrete shear wall core are required for both buildings, this data can be utilized to compare the total stiffness of the selected structural systems.

The construction is made more rigid by the slabs, columns, and beams. The overall deflection of buildings is significantly influenced by the diaphragm action of slabs under wind loads. In proportion to their size, columns and beams give the structure rigidity and stiffness. Below is a summary of the "deviation from deflection limit" in Figure 4.1 statistics to help you better understand the overall stiffness of the structure.

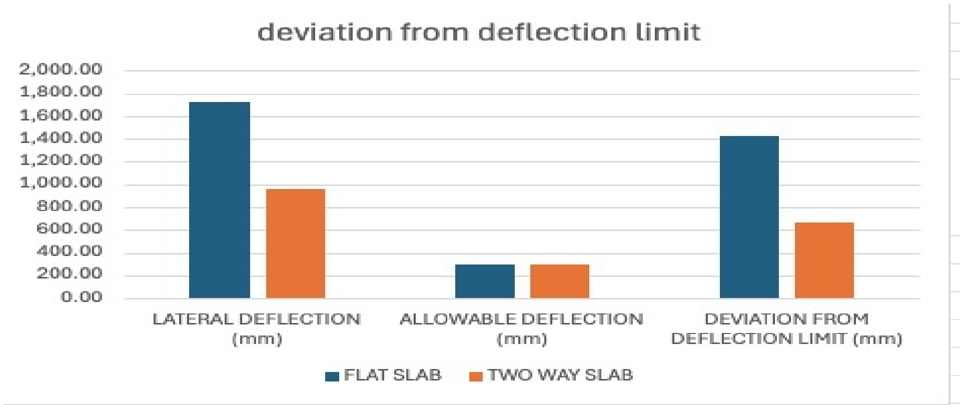

Fig 4.1: Deviation from deflection limit comparison

4.1.2 Selection of stability system:

Like all high-rise buildings, the two buildings covered by this study require stabilizing mechanisms, such as bracings or a reinforced concrete shear wall core, as was indicated in the preceding section. The choice of stabilizing system type will depend on a number of things. The structural stability of the system is the most important factor, and the stabilizing system that is chosen must, within ASCE 7's bounds, lessen the inter story deflection of structures. Both reinforced concrete buildings can have a shear wall core made of reinforced concrete.

4.2 Cost comparison

Every high-rise building project's financial aspect is influenced by a number of variables, including the flooring system, stabilizing system, and building frame section types. These elements also affect the kind of floor finishing, the building's ventilation, heating, and cooling systems, and the kind of curtain walls that should be utilized, all of which have an additional effect on the building's operating and maintenance costs. Since the two high-rise structures under consideration in this study have the same reinforced concrete shear wall core, the cost of the core has not been included in the estimation of the building's overall construction costs.

4.2.1 Cost comparison of reinforced concrete buildings

Building costs per square meter of floor:

The cost of building each story per square meter is contrasted in the table below. Steel, concrete, and formwork costs are all included in this estimate. Since floor finishes are decided upon by the client or the architect and can differ from building to building, their cost has not been included in the Figure 4.2.

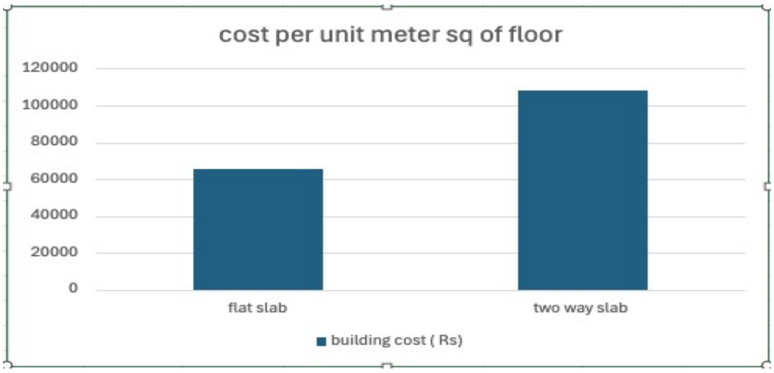

Fig 4.2: Cost of construction of R.C. flooring systems

It is evident that the most cost-effective choice for high-rise reinforced concrete structures is the flat slab floor. To guarantee that the slab is safe for punching shear, reinforced concrete flat slabs are constructed with drops of 80 mm at each column. This somewhat increases the volume of concrete utilized in the building of the slabs. The economics of slab construction is determined by the quantity of steel reinforcement used in the slab. Of the two reinforced concrete flooring alternatives, two-way slab is the most expensive for high-rise building floors because it requires the most steel reinforcement.

Two-way slabs are 65.95% more expensive than flat slabs. Comparing flooring system construction costs is critical since it affects how much a high-rise structure will ultimately cost to develop.

For reinforced concrete buildings, the weight of the structure affects the cost of the columns. Lighter constructions require smaller columns, whereas heavier structures require larger columns. Lighter structures will therefore cost less to create the building's frame as seen in figure 4.3.

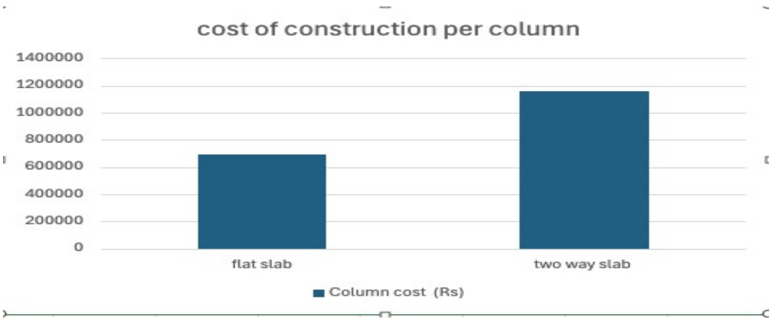

Fig 4.3: Cost of construction of columns in reinforced concrete high-rise buildings

Appendix-A contains the design calculations for each structure listed in the column below. The least expensive construction per column is found in flat slab floors, whereas the most expensive construction per column is found in two-way slab floors. This is because, unlike two-way slabs, which need beams at all four sides to support them, flat slabs do not need beams at any of their edges. When there are no beams in a flat slab floor, the structure's overall weight is decreased simultaneously. Because two-way slab floors must sustain the weight of beams as well, the structure's overall weight will increase, resulting in greater dimensions and a higher cost per unit column.

4.2.2 Total cost comparison

The Figure 4.4 shows the overall cost of construction for the high-rise structures covered by this article. The total cost of construction based on the materials used has been computed in Appendix-2.

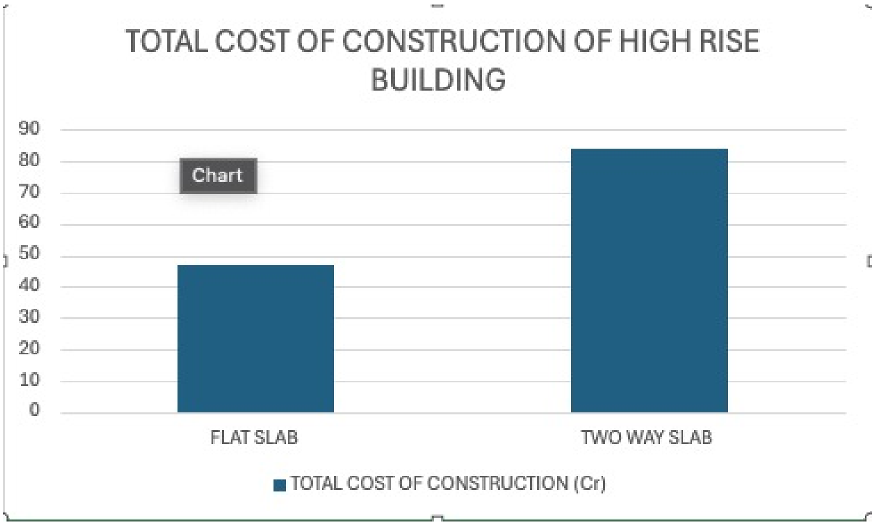

Fig 4.4: Comparison of total cost of construction of high-rise buildings

It is discovered that the cost of creating a two-way slab structure is substantially more than that of a flat slab. The primary cause of this is the additional expense of beams, which are not needed in flat slabs, and the greater column size needed in two-way slabs.

4.3 Sustainability comparison of high-rise buildings:

4.3.1 Total embodied carbon dioxide emissions of high-rise buildings

The Figures 4.5 and 4.6 makes it evident that flat slab high-rise structures have comparatively lower embodied carbon emissions per unit area of floor than two-way slab high-rise buildings. This is explained by the flat slab's absence of beams and its high embodied carbon dioxide emissions (26.84MJ/Kg) per kilogram of reinforcement steel. It is assumed that the concrete in the figure below is regular RMC mixed concrete. (1940.23 MJ/kg)

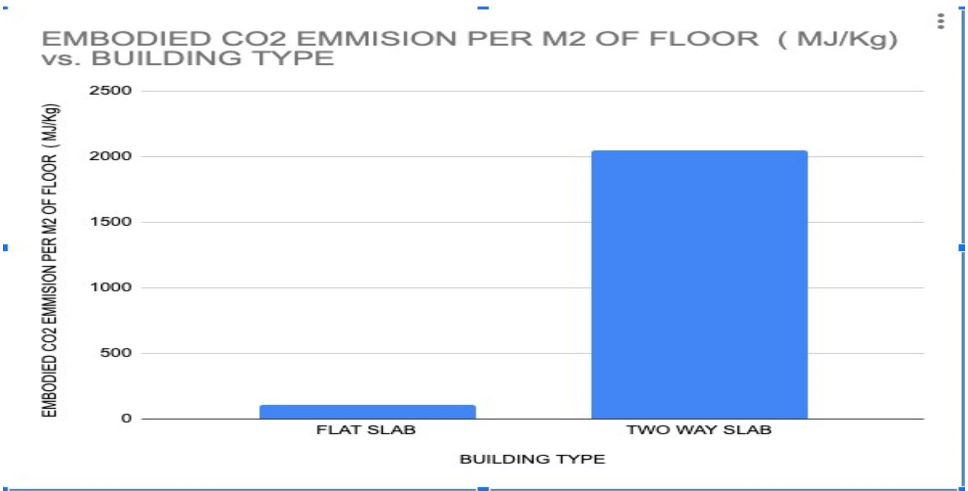

Fig 4.5: Embodied carbon dioxide emission per unit area of floor

Fig 4.6: Total embodied carbon dioxide emission of high-rise buildings

4.4 Preliminary outcome

In order to create a summary, the study's section on findings presents them in a comparative manner.

4.4.1 Overall stiffness

It was stated that the shear wall cores of both structures are made of reinforced concrete. The buildings were graded according to lateral deflection, and 3-D models of high-rise buildings were made. The greatest displacement measured at 1430.5 mm. The high-rise building scored as "1" has the highest structural stiffness because the goal is to identify the building system with the highest stiffness.

TABLE 4.2: Ranking of overall stiffness of high-rise buildings

Rank	Building type	Lateral deflection
1	Two-way slab	663.5mm
2	Flat slab	1430.5mm

4.4.2 Cost comparison of high-rise buildings

This document's section 4.2 analyzes high-rise buildings based on two key economic parameters: the overall cost of building the structure and the cost of construction per unit area (cost per m2). Finding the least expensive flooring system out of all the possibilities is the goal here, so it is ranked as option number one. The several flooring systems that were employed during the course of this investigation are ranked in the following table:

TABLE 4.3: Ranking of flooring systems in high-rise buildings

Rank	Building type	Cost per m^2 of floor (₹)
1	Flat slab floor	65320
2	Two-way slab floor	108400

The goal of comparing high-rise building construction costs overall is to identify the most cost-effective solution. As a result, the most affordable part is placed first in the following table:

TABLE 4.4: Ranking of total cost of high-rise buildings

Rank	Building type	Total cost of construction (₹)
1	Flat slab floor	47,47,53,696
2	Two-way slab floor	84,93,09,199

4.4.3 Embodied Carbon dioxide Emissions

In order to determine how sustainable each flooring system is, this study also compares the sustainability of high-rise buildings and the embodied carbon dioxide emission per ft2 of floor for different flooring systems. Therefore, in the accompanying table, the flooring system ranked "1" has the lowest embodied carbon dioxide emission.

TABLE 4.5: Sustainability ranking of flooring systems in high-rise buildings.

Rank	Building type	Embodied Carbon Dioxide Emissions per m^2 of floor
1	Flat slab floor	104.926 MJ/Kg
2	Two-way slab floor	2044.176 MJ/Kg

ln order to identify the most sustainable high-rise building structural system in terms of embodied carbon dioxide energy and to gain an understanding of the contribution of other structural parts. The high-rise buildings are ranked in Table 5.5 from lowest to highest embodied carbon dioxide emissions.

TABLE 4.6: Sustainability ranking of high-rise buildings.

Rank	Building type	Total embodied carbon dioxide emissions (KgCo2e)
1	Flat slab floor	38452058.4 MJ/Kg
2	Two-way slab floor	47111756.7 MJ/kg

5. CONCLUSIONS

By designing two distinct types of commercial (office) high-rise buildings, the aforementioned study examines the structural stability and efficiency of high-rise structures. A number of factors, including the economics, sustainability, and structural stability, were compared.

1. The most cost-effective choice was determined to be the flat slab floor (Building 1) in the comparative analysis regarding floor cost per unit area. After evaluating the overall construction costs of several high-rise structures, Building 1 (Flat slab floor) was determined to be the most cost-effective choice.

2. Additionally, embodied carbon dioxide emissions for each structure were compared based on the quantity of steel and concrete needed per unit area of floor. According to the findings, the least amount of carbon dioxide was embodied in flat slab floors. Similarly, a comparison of the total embodied carbon dioxide emissions of high-rise buildings revealed that the lowest carbon dioxide emissions were found on flat slab floors.

3. The results indicate that while all buildings have a reinforced concrete shear wall core to guarantee that they are all within the lateral deflection restrictions, two-way slab floors have the highest overall stiffness and flat slab floors have the least overall stiffness.

Other elements that significantly impact the structural stability and effectiveness of the project over its lifetime include financial flow, variations in the cost of building materials, site location, operational costs of the structure, and meteorological conditions. This article suggests that when designing high-rise structures, two-way slab floors with reinforced concrete frames be used. Other flooring and framework solutions must be employed, nevertheless, if the client's requests and the architectural goals cannot be satisfied by the competitive options already stated.

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APPENDIX – 1

(Slab design calculations, estimation of cost and embodied Carbon Dioxide)

FLAT SLAB DESIGN					
ASSUMING THAT THE FLAT SLAB IS SUPPORTED AT THE CENTER OF THE SUPPORT , A DROP OF 2000mm X 2000mm X 80mm is provided between the slab and the column					
minimum size of drop pannel as per **clause 31.2.2** of IS 456:2000 should not be less than span/3 m , Hence Assumed value is safe .					
Center to center distance between the supports = 6m					
Middle strip (Ln)= 6-2/2 -2/2 =	4	m			
Fck	30	N/mm/mm			
Fy	500	N/mm/mm			
D	250	mm	0.25	m	
upper cover	25	mm	0.025	m	
Lower cover	20	mm	0.02	m	
effective deapth =	D- upper cover - lower cover				
d =	205	mm			
Thickness of drop =	80	mm			
Cover of drop =	20	mm			
D(drop)	330	mm			
Hence OK					
Effective deapth of slab with drop =	D (drop)- upper cover of slab - cover of drop				
	285	mm			
STEP 1: LOAD CALCULATIONS					
DEAD LOADS :					
self Weight of slab	6.25	KN/m/m	225	KN	
self weight of drop	2	KN/m/m	5.12	KN	
Floor finish	1.5	KN/m/m	54	KN	
Movable partiton load	1	KN/m/m	36	KN	
Total dead load	10.75	KN/m/m	320.12	KN	
LIVE LOADS :					
live load	3	KN/m/m	108	KN	
TOTAL DESIGN LOAD (W)	13.75	KN/m/m	428.12	KN	
FACTORED DESIGN LOAD (Wu)	20.625	KN/m/m	642.18	KN	
STEP2 : MOMENT CALCULATIONS					
Mu = (Wu*Ln/8)	321.09	KN m			IS 456:2000 Clause 31.4.2.2

INTERIOR SPAN :			IS 456:2000 Clause 31.4.3.2
Negetive Design Moment (0.65* Mu)	208.7085	KN m	
Positive Design moment (0.35*Mu)	112.3815	KN m	
END SPAN :			IS 456:2000 Clause 31.4.3.3
Effective length of column (Lcc)	3.4	m	
length of side of column	0.65	m	
Relative stiffness of column (Kc)	0.004375153186	m^4	
Relative stiffness of Slab (Ks)	0.001302083333	m^4	
α,c	6.720235294		
imposed load / dead load	0.2790697674		IS 456:2000 Clause 31.4.6
SINCE RATIO IS < 0.5 WE HAVE TO USE LENGTH RATIO			
L2/L1	1		
α,c,min	0.7		IS 456:2000 Clause 31.4.6, table 17
HENCE STIFFNESS IS SUFFICIENT			
α	1.148804314		
INTERIOR NEGETIVE DESIGN MOMENT	212.8675701	KNm	IS 456:2000 Clause 31.4.3.3
POSITIVE DESIGN MOMENT	124.0268964	KNm	IS 456:2000 Clause 31.4.3.3
EXTERIOR NEGETIVE DESIGN MOMENT	181.6745442	KNm	IS 456:2000 Clause 31.4.3.3

STEP 4 : DISTRIBUTION TABLE — IS 456:2000 Clause 31.5.5

INTERIOR PANEL	Column strip	M/bd*d	Pt (SP 6)	Ast (mm*mm)	Middle strip	M/bd*d	Pt (SP 6)	Ast (mm*mm)
negetive moment	156.531375	3.724720405	1.046	2144.3	52.177125	1.241573468	0.303	621.15
positive moment	67.4289	1.604494943	0.394	315.2	44.9526	1.069663296	0.255	522.75
OUTER PANEL								
negetive at interior support	159.6506776	3.798945332	1.063	2179.15	53.21689253	1.266315111	0.316	647.8
negetive at exterior support	181.6745442	4.323011164	1.118	2291.9	0	0		0
positive at panel	74.41613782	1.770758782	0.448	918.4	49.61075854	1.180505855	0.29	594.5

STEP 5 : REINFORECEMENT CALCULATIONS

Minimum reinforcement (0.0012X b X D)	1200	mm*mm
INTERIOR SUPPORT OF OUTER PANEL COLUMN STRIP		
Ast	2179.15	mm*mm
Diameter of bars	12	
Area of bars	113.1428571	mm*mm
Number of bars	19.26016414	
Rounding up	20	
Spacing	155.7619124	
Rounding	155	
OUTER SUPPORT AT TOP		
Ast	2291.9	mm*mm
Diameter of bars	12	
Area of bars	113.1428571	mm*mm
Number of bars	20.25669192	
Rounding up	21	
Spacing	148.0992065	
Rounding	148	
MIDDLE SUPPORT AT BOTTOM		
Ast	918.4	mm*mm
Diameter of bars	12	
Area of bars	113.1428571	mm*mm
Number of bars	8.117171717	
Rounding up	9	
Spacing	369.5868591	
Rounding	369	
INNER SUPPORT AT TOP		
Ast	2144.3	mm*mm
Diameter of bars	12	
Area of bars	113.1428571	mm*mm
Number of bars	18.95214646	
Rounding up	19	
Spacing	158.2934158	
Rounding	158	

STEP 6 : CHECK FOR PUNCHING SHEAR

Critical shear plane is at a distance d/2 from the face of column

Perimeter of critical section (4(a+d))	822.6	mm	
Shear force on this plane (Vu)	727.4226094	KN	
Nominal shear stress (Tv)	0.8871007431	N/mm/mm	
Shear strength			IS 456:2000 Clause 31.6.3
Ks	1		
Tc	1.369306394	N/mm/mm	
Ks X Tc	1.369306394	N/mm/mm	

NO shear reinforcement requiered

STEP 7 : CHECK FOR ONE WAY SHEAR

The maximum shear force occurs at a distance of effective deapth from the face of support

Vu = Wu (0.5*L-d)	57.646875	KN
Tv	0.2812042683	N/mm/mm

NO shear reinforcement is requiered in drop pannel

Two way slab calculations				
Two adjacent edges discontinous				
CHECK FOR ONE WAY AND TWO WAY SLAB				
Lx	6	m		
Ly	6	m		
Lx/Ly	1			
Hence Two Way Slab				IS 456:2000 , Annex D , D1.11
STEP 2				
DETERMING THE DEPTH OF SLAB				
Given : Fck	30	N/mm/mm		
Given: Fy	500	N/mm/mm		
Minimum Thickness of Slab	200	mm		
Minimum Clear Cover	25	mm		
Minimum Lower Clear Cover	20	mm		
Assumed D	250	mm		
Effective Depth (d)	205	mm		
STEP 3				
LOAD CALCULATIONS:				
For Slab b=	1000	mm		IS 456:2000 , Annex D
DEAD LOAD				
SELF WEIGHT	25*b*D			
	6.25	KN/m/m		
Floor Finish	1.25	KN/m/m		
Partition Load	1	KN/m/m		
Total Dead Load	8.5			
Total Live Load	3	KN/m/m		
Total Load on Slab	11.5	KN/m/m		
Total Factored Load	17.25			
STEP 4				
MOMENT CALCULATION:				
αx,-ve	0.047			
αx,+ve	0.035			
αy,-ve	0.047			
αy,+ve	0.035			IS 456:2000, ANNEX D , TABLE 26
Mx,-ve	29.187	KNm		
Mx,+ve	21.735	KNm		
My,-ve	29.187	KNm		
My,+ve	21.735	KNm		IS 456:2000 , ANNEX D 1.1 , Mx= αx*W*l*l, My= αy*W*l*l
maximum Moment	29.187	KNm		
Mx,-ve/b*d*d	0.69451517	N/mm/mm		
Corresponding Pt value	0.166			SP 6 , Table 4 , Pg 50
STEP 5				
Check For Effective Depth of Slab				

Provided d	205	mm		
Required d	85.52799304	mm		SP 6 , Table c , Pg 10
Pass for effective depth of slab				
STEP 6				
Reinforcement Calculation:				
Ast Required	340.3	mm*mm		
Diameter of bar	8	mm		
Area of bar	50.28571429	mm*mm		
No of bar	6.767329545			
Rounding	7			
Ast Provided	352			
Spacing	14.28571429			
Rounding	14	mm		
STEP 7				
Check For Reinforcement				
Minimum reinforcement	300	mm*mm		IS 456:2000 , Clause 26.5.2.1,
Pass for reinforcement				
therefore new Ast provided	300	mm*mm		
STEP 8				
Check for Shear				
Vu	51.75	KN		
Nominal Factored Shear Stress (Tv)	0.252439024	N/mm/mm		IS 456:2000 , clause 40.1
Design Shear stress of concrete (Tc)	0.8	N/mm/mm		IS 456:2000 , Table 19
Maximum shear stress(Tcmax)	3.5	N/mm/mm		IS 456:2000 , Table 20
Pass For Shear				IS 456:2000 , Clause 40.5.3
STEP 9.				
Check For Deflection				
l/d provided	29.26829268			
Fs	280.3607955			IS 456:2000 Pg 38 ,Fig 4
Pt	0.166			
MF	1.6			IS 456:2000 Pg 38 ,Fig 4
base value	26			IS 456:2000 , Clause 23.2.1
l/d max	41.6			
Safe For Deflection				

(ESTIMATION OF COST AND EMBODIED CARBON DIOXIDE)

FLAT SLAB, R.C COLUMN

For slab

Slab dimensions: 6m*6m.

Thickness of concrete: 0.25m

Density of concrete = 25KN/$\boldsymbol{m^3}$ =2500 Kg/$\boldsymbol{m^3}$

Thus,

Volume of concrete per $\boldsymbol{m^2}$= $\frac{\boldsymbol{thckness\ of\ slab * Area}}{\boldsymbol{Area}} = \frac{\mathbf{0.25 * 36}}{\mathbf{36}}$ = 0.25 m^3/m^2

Calculation of reinforcement steel:

For middle strip:

No. of top bars= 14(Dia 10mm)

No. of bottom bars= 8(Dia 10mm)

Thus,

Total length of 10mm bars in middle strip= (14+8) *4= 88m

Mass per unit length (Kg/m) for 10 mm bars = 0.616 Kg/m

Mass of steel in middle strip= 88*0.616= 54.208Kg

For column strip:

No. of top bars= 10(Dia 10mm)

No. of bottom bars= 8(Dia 12mm)

Thus,

Length of column strip = 6 m

Total length of 10mm bars in column strip= 10*6= 60m

Total length of 12mm bars in column strip= 8*6= 48m

Mass per unit length (Kg/m) for 10 mm bars = 0.616 Kg/m

Mass per unit length (Kg/m) for 12 mm bars = 0.888 Kg/m

Mass of 10mm bars= 60*0.616= 39.96Kg

Mass of 12mm bars= 48*0.888= 42.624Kg

Thus,

Total steel in slab = 54.208+ 39.96 + 42.62 = 136.788kg

Now,

Mass of steel per $\boldsymbol{m^2}$ of slab = $\frac{\mathbf{136.788}}{\mathbf{6*6}}$ = 3.79kg

For column –

Length of column = 3.4 m, b= 0.65m, h=0.75m

volume of concrete = $3.4 * 0.65 * 0.75 = 1.6575$ $\boldsymbol{m^3}$

Calculation for steel reinforcement in column:

Dia of main bar= 40 mm

No. of bars =16

Mass per unit length (Kg/m) for 40 mm bars = 9.864 kg/m

Total length of main bar = $16 * 3.4m = 54.4\ m$

Thus,

Total mass of main bar= $54.4 * 9.864 = 536.6016$Kg

Similarly, mass of links was calculated and found out to be 51.73 kg.

Total steel mass per column = 536.6016+51.731=588.3326kg

Since quantities of steel and concrete are known the cost estimation and estimation of embodied carbon are carried out below.

Cost calculations:

Density of concrete = 25 KN/m3
= 2500 kg/m3

Area of each floor = 1440$\boldsymbol{m^2}$

No. of floors = 35

No. of columns in each floor= 60

FOR FLAT SLAB

Volume of concrete per $\boldsymbol{m^2}$= 0.25 $\boldsymbol{m^3}$

Mass of steel per $\boldsymbol{m^2}$ of slab = 3.9503 KG
= 0.0039503 Tonne

For RC column

Volume of concrete per $\boldsymbol{m^2}$= 1.6575 $\boldsymbol{m^3}$

Mass of steel per column = 588.326 KG
= 0.588326 Tonne

Cost of slab per m2 = 65318.252Rs

Cost of flooring in building = 32,92,03,990.1 Rs

Cost per column = 69,309.384 Rs

Per floor = 41,58,563.04 Rs

Cost of column for building = 14,55,49,706.4 Rs

Total cost of construction = 47,47,53,696 Rs

EMBODIED CARBON CALCULATIONS:

Mass of concrete per $\boldsymbol{m^2}$ = 625 kg = 0.284 $\boldsymbol{m^3}$

Mass of steel per m2 of slab = 3.9503 kg

Embodied carbon per m2 of slab = 104.926 MJ/kg

Embodied carbon for flooring in building = 5288270.4 MJ/ kg

For column

Mass of concrete per of column = 4143.75 kg = 1.883$\boldsymbol{m^3}$

Mass of steel per column = 588.326 kg

Embodied carbon per column = 15792.28 MJ/kg

Embodied carbon in building due to columns = 33163788 MJ/kg

Total embodied carbon of building = 38452058.4 MJ/kg

TWO WAY SLAB, RC COLUMN, RC SLAB:

Two-way slab:

Density of concrete = 25 kN/$\boldsymbol{m^3}$

= 2500 kg/m3

Area of each floor = 1440 $\boldsymbol{m^2}$

No. of floors = 35

No. of columns in each floor = 60

ESTIMATION –

For two-way slab –

Volume of concrete per m^2 = 0.25 m3
Mass of steel per m^2 of slab = 55.265 kg
= 0.055265 tonne

For RC column –

Volume of concrete per column = 5.525 m3
Mass of steel per column = 588.326 kg
= 0.588326 tonne

For RC beam

Volume of concrete per beam = 1.08 m^3
Mass of steel per column = 184.992 kg
= 0.184992 tonne
No. of beam per slab = 4
No of beams per floor = 60
Cost of slab per m^2 = 10,842.26 Rs
Cost of flooring in building= 54,64,49,904 Rs
Cost per column = 1,15,719.384 Rs
Per floor column cost= 69,43,163.04 Rs
Cost per beam = 28,499.328 Rs
Cost of beams per floor = 17,09,959.68 Rs
Cost of beam for building = 5,98,48,588.8 Rs
Cost of column for building = 24,30,10,706 Rs
Total cost of construction = 84,93,09,199 Rs

EMBODIED CARBON

For two-way slab

Mass of concrete per m^2 = 625 kg
Mass of steel per m^2 of slab = 55.265 kg
Embodied carbon per m^2 of slab = 2044.176 MJ/kg
Embodied carbon for flooring in building = 2943614 MJ/kg

For column

Mass of concrete per of column = 13812.5 kg
Mass of steel per column= 588.326 kg
Embodied carbon per column = 27971.78 MJ/kg
Embodied carbon in building due to columns = 28740751.75 MJ/kg

For beam

Mass of concrete per beam = 2700 kg
Mass of steel per beam = 184.992 kg
Embodied carbon per beam= 7346.37 MJ/kg
No. of beam per slab 2
No of beams per floor 60
Embodied carbon in building due to beams = 15427390.95 MJ/kg
Total embodied carbon of building = 47111756.7 MJ/kg

APPENDIX – 2
(Drawings and STAAD. PRO results)

Flat slab-

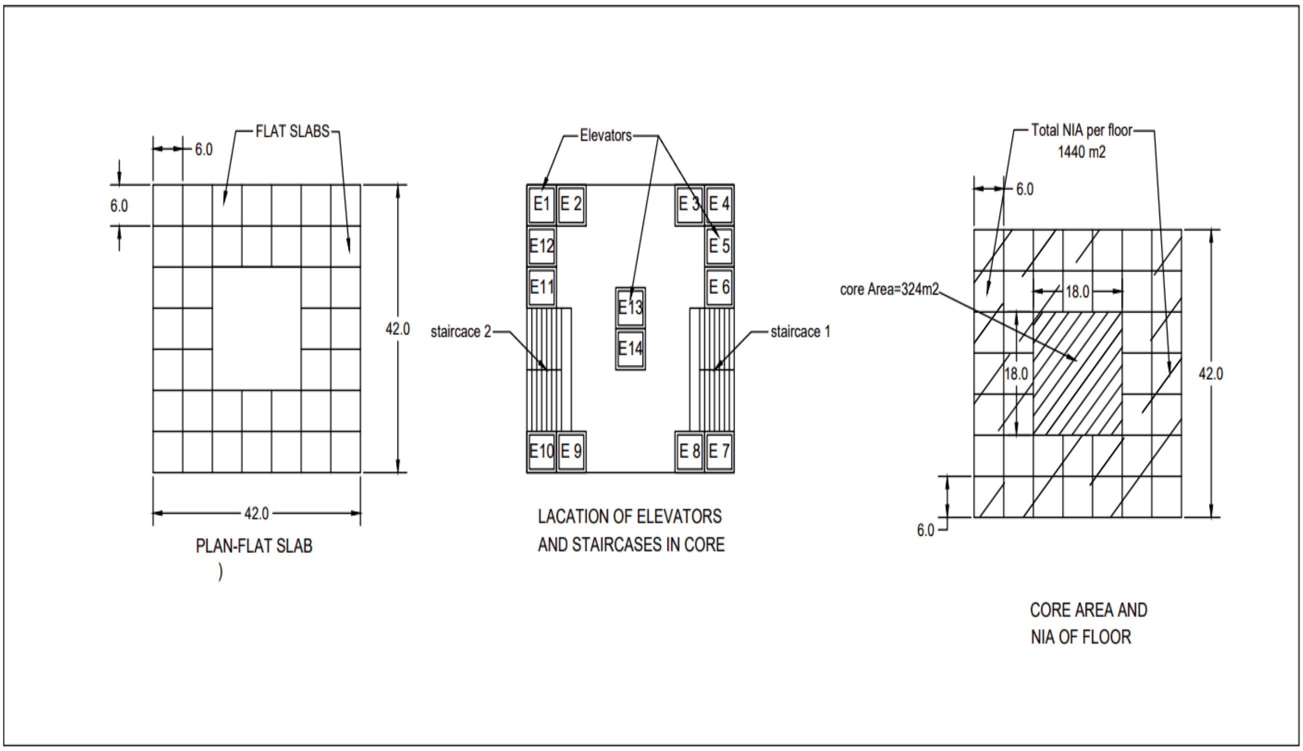

Figure A2.1 : Floor plan , location of elevators, core area and net internal area for flat slab

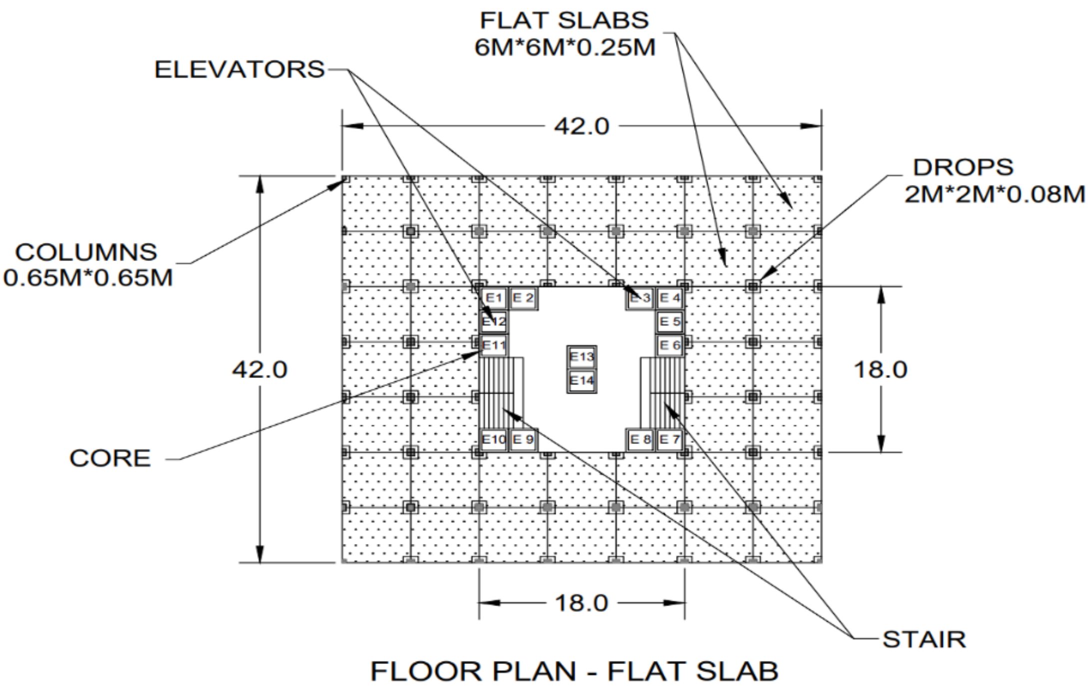

Figure A2.2: Floor plan of flat slab

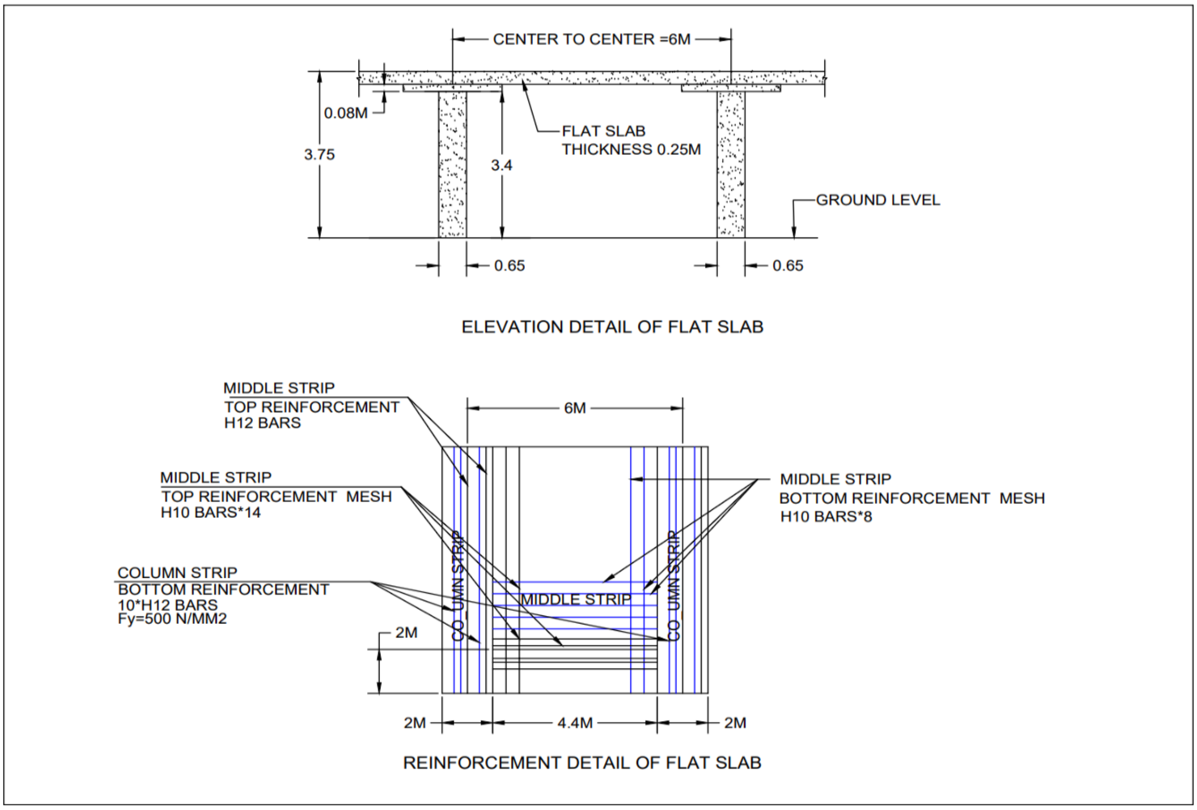

Figure A2.3: Reinforcement in flat slab

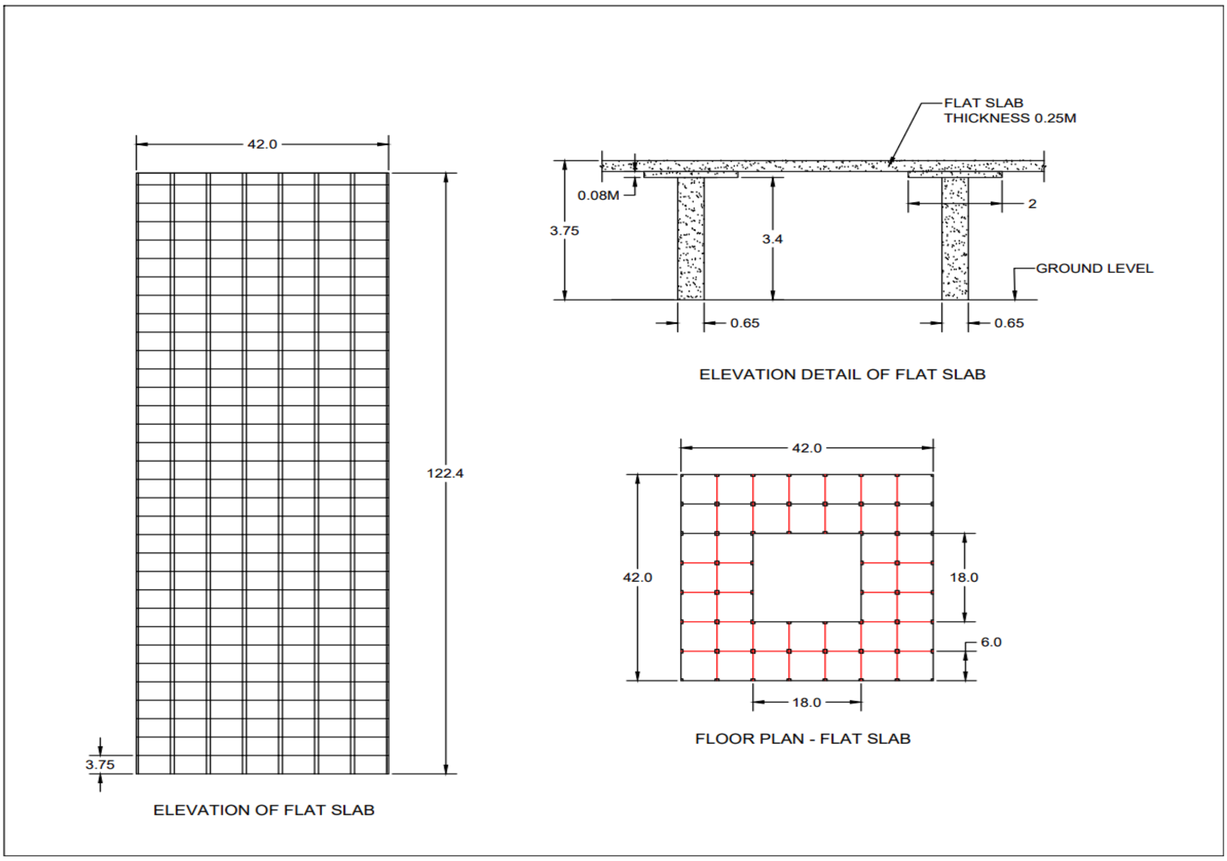

Figure A2.4 Floor height and location of columns in flat slab

Two-way slab-

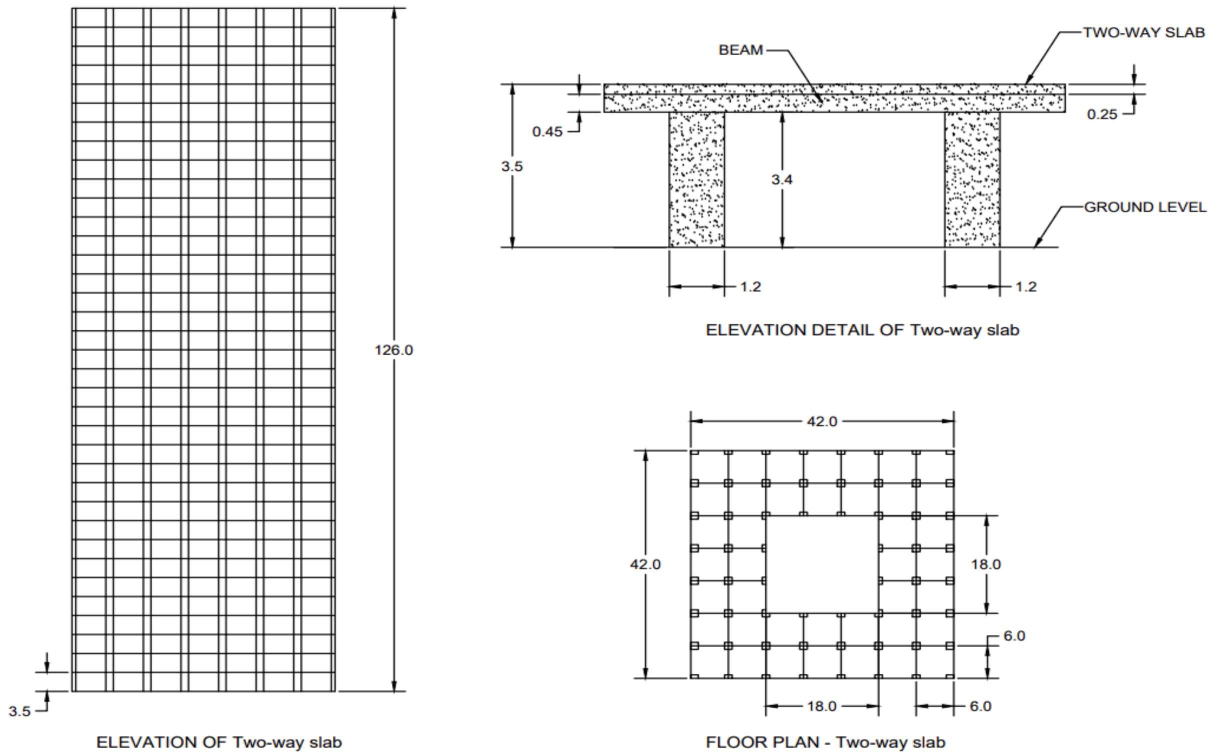

Figure A2.5: Floor height and location of columns for two way slab

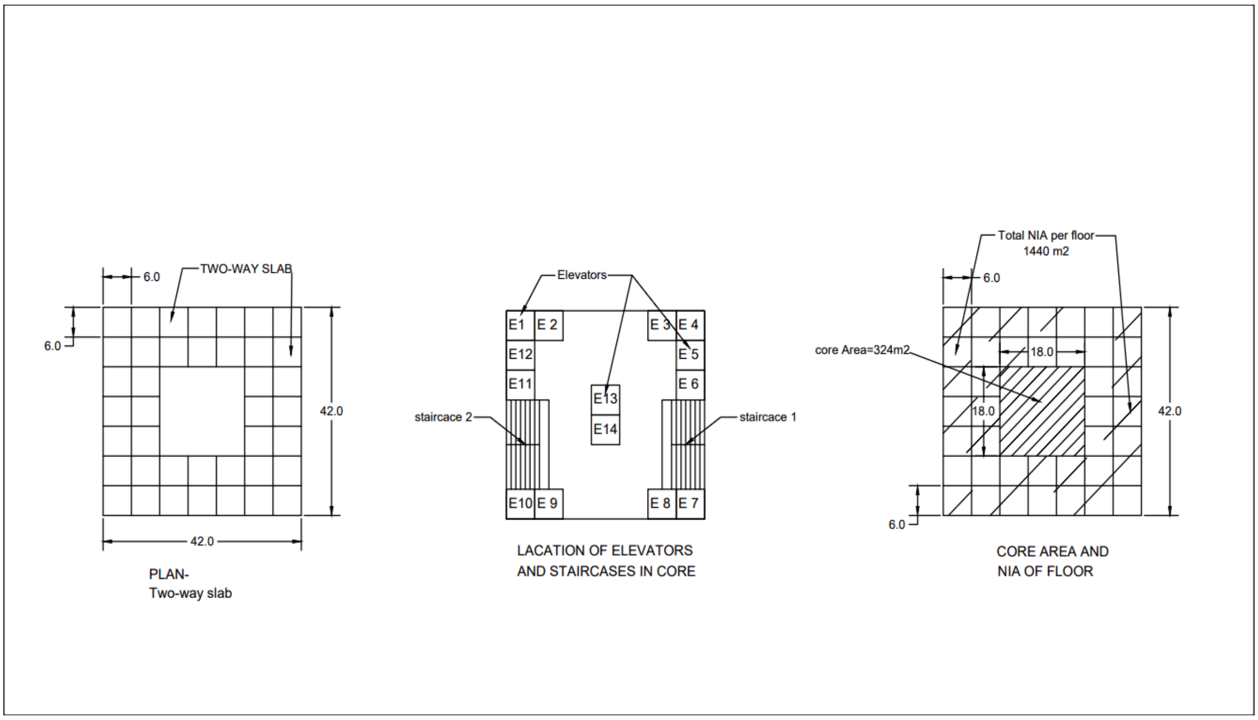

Figure A2.6: Plan, location of elevators, core and net internal area for two way slab

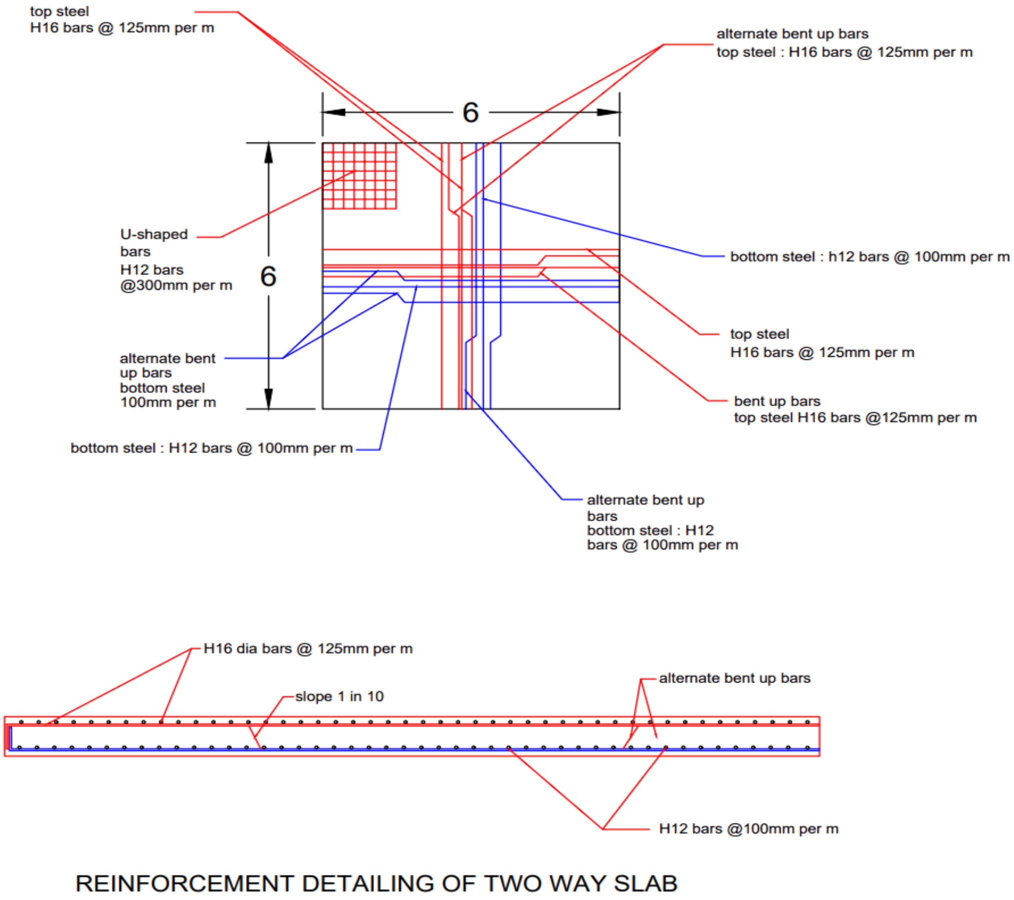

Figure A2.7: Reinforcement in two way slab

STAAD. Pro images

FLAT SLAB -

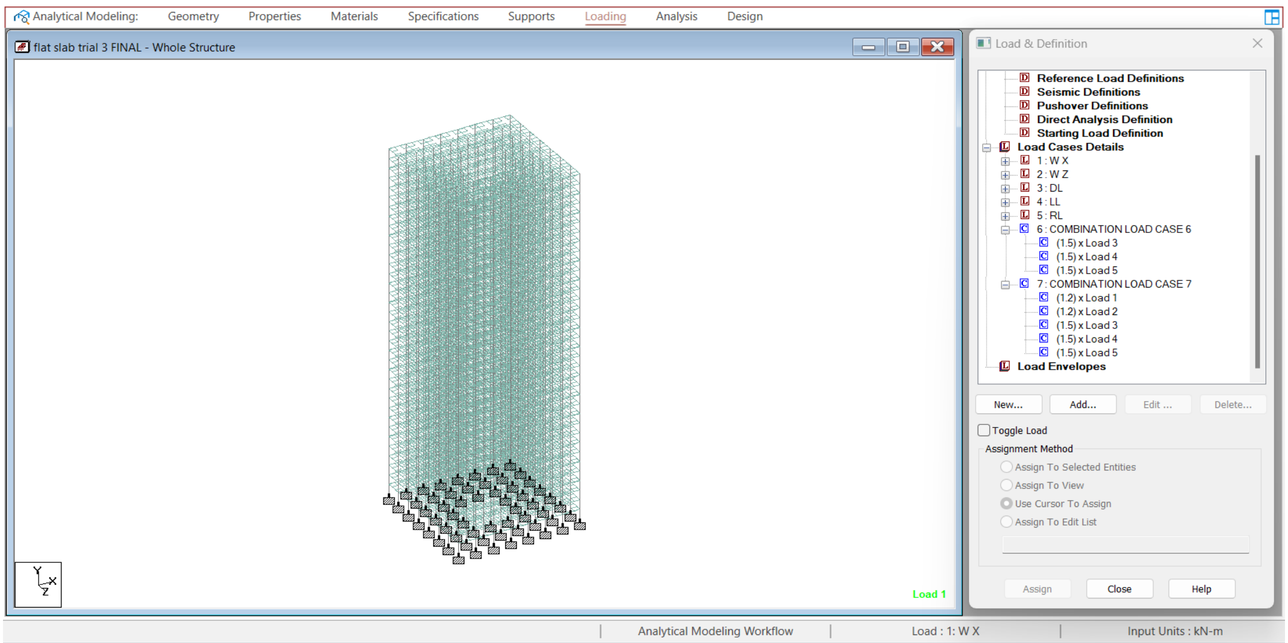

Figure A2.8: Support and loading in flat slab

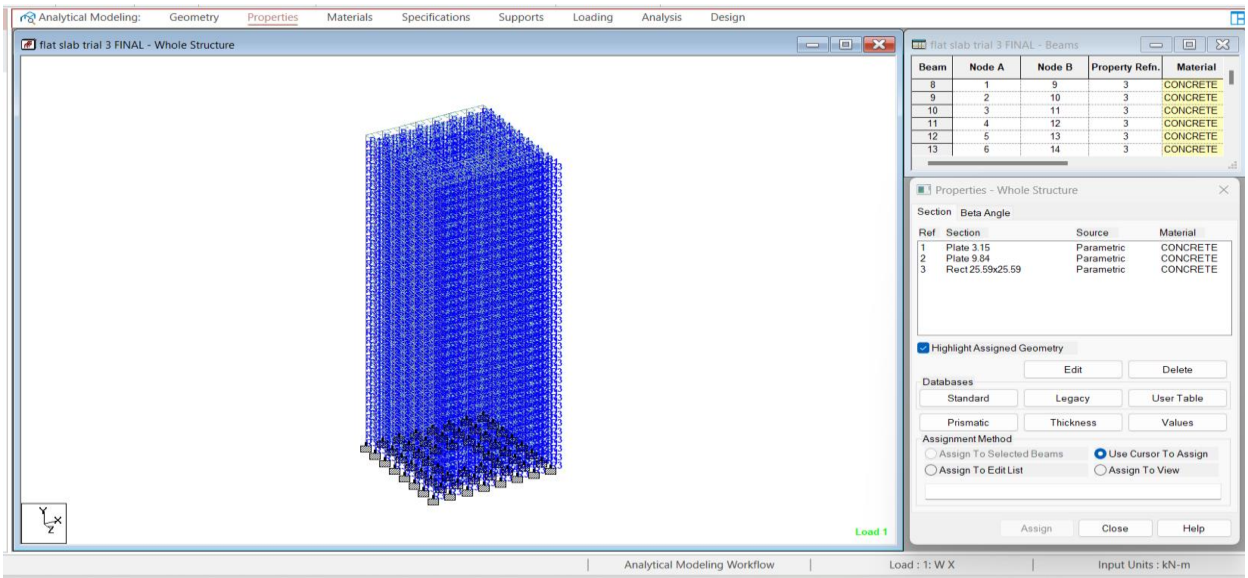

Figure A2.9: material specifications

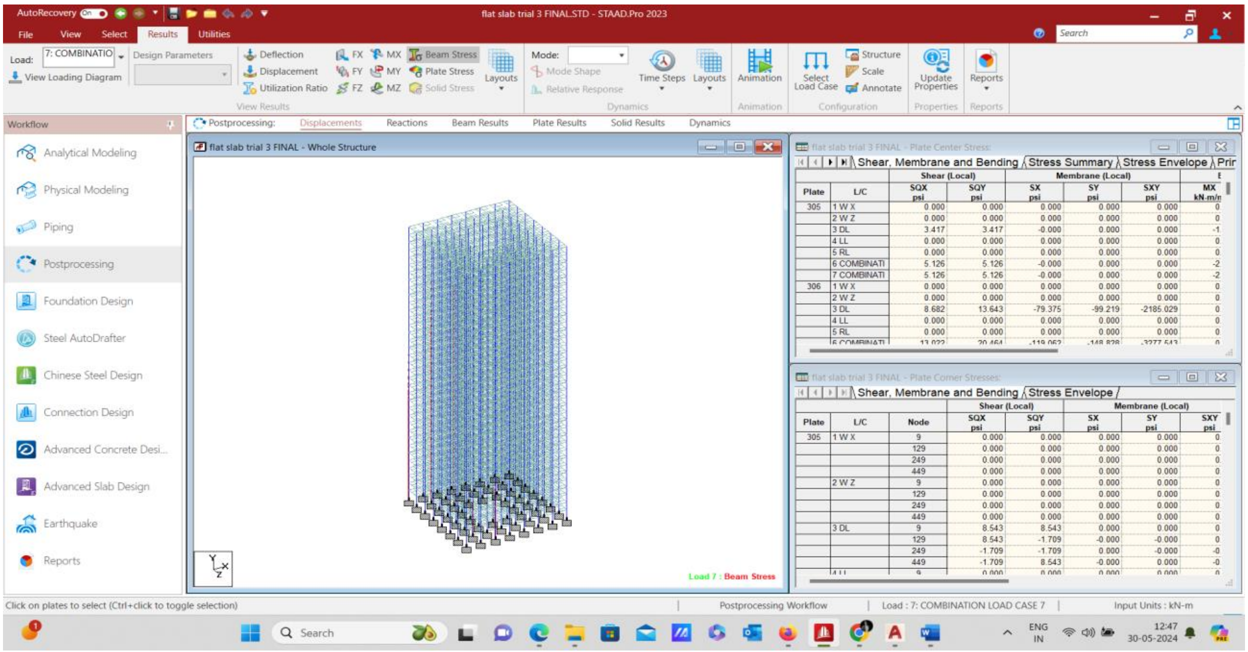

Figure A2.10: Beam stresses in flat slab

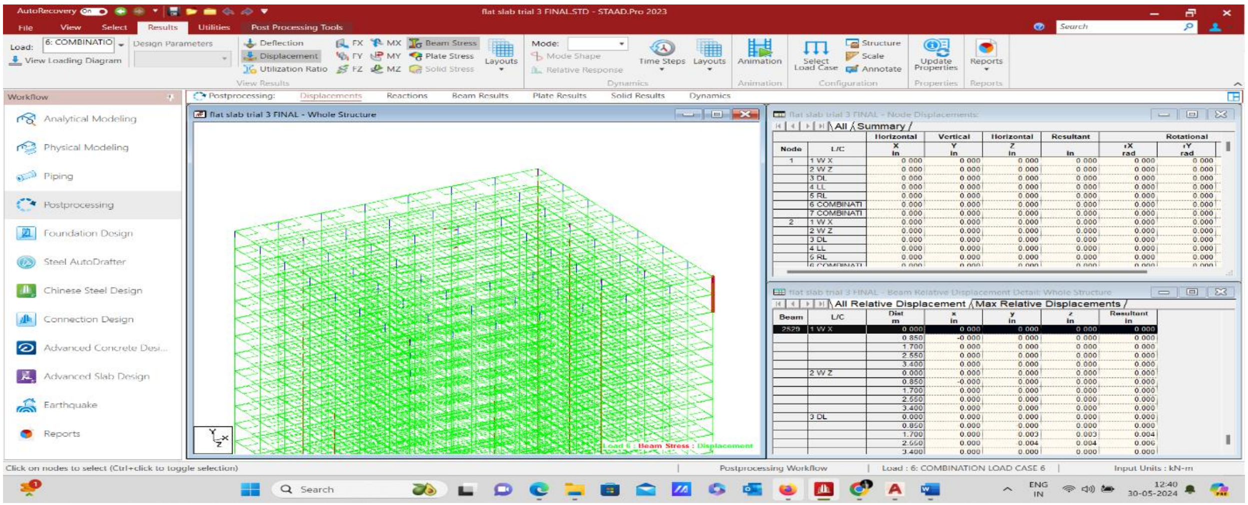

Figure A2.11: beam displacements

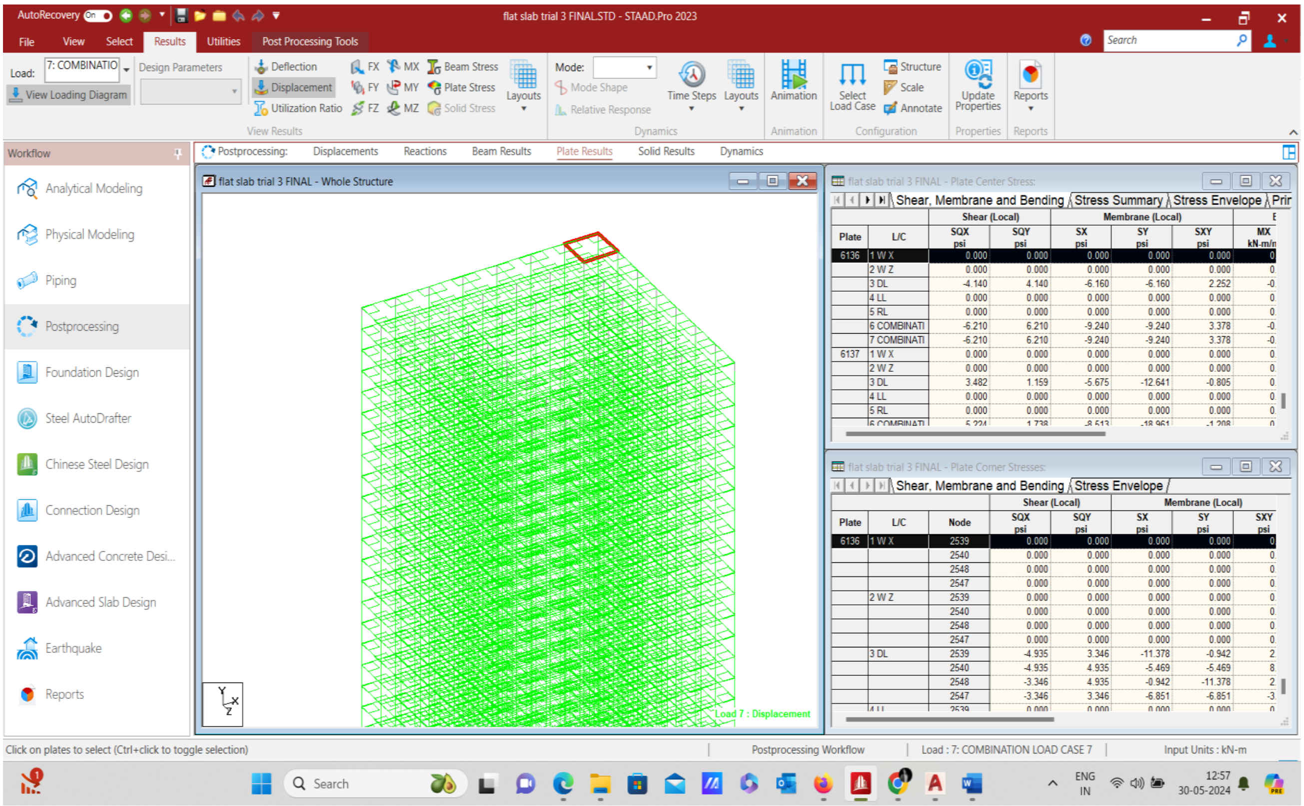

Figure A2.12: plate stresses

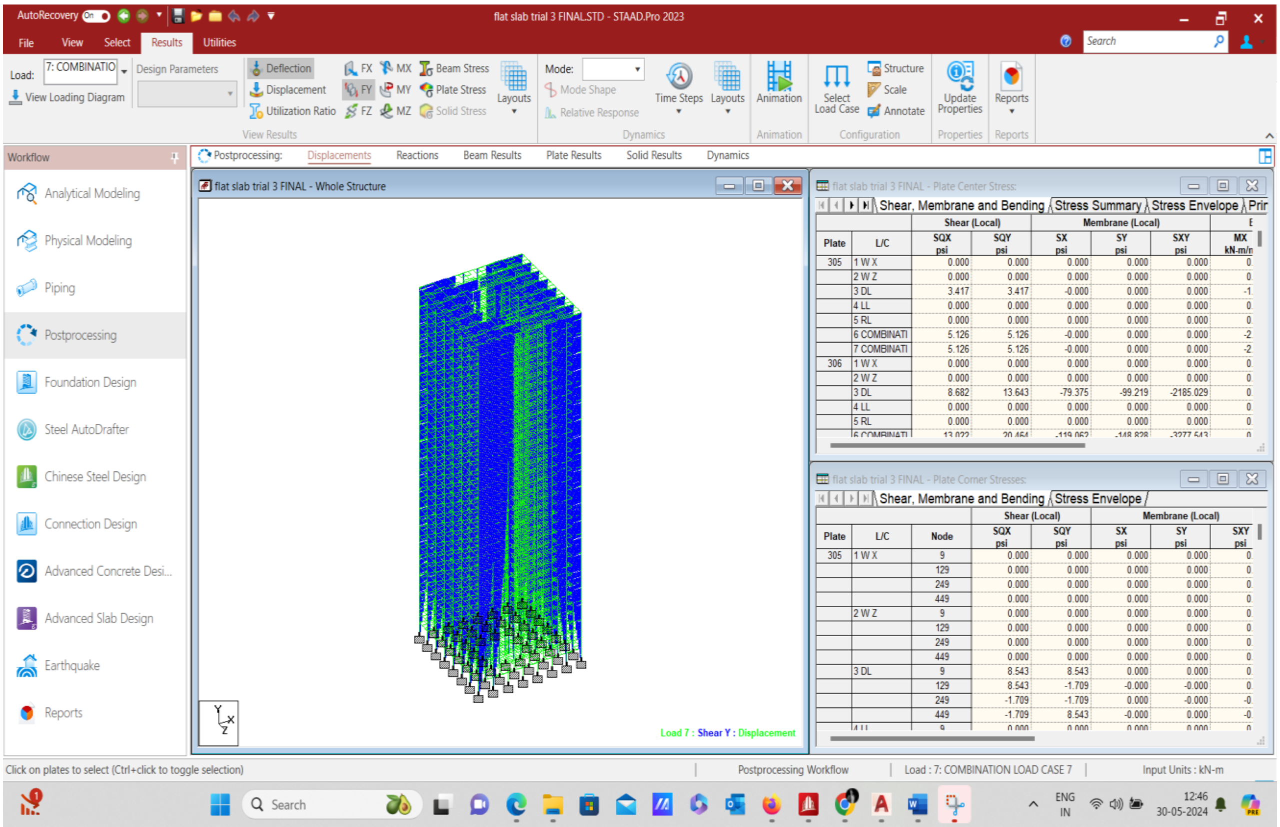

Figure A2.13: deflection

TWO WAY SLAB -

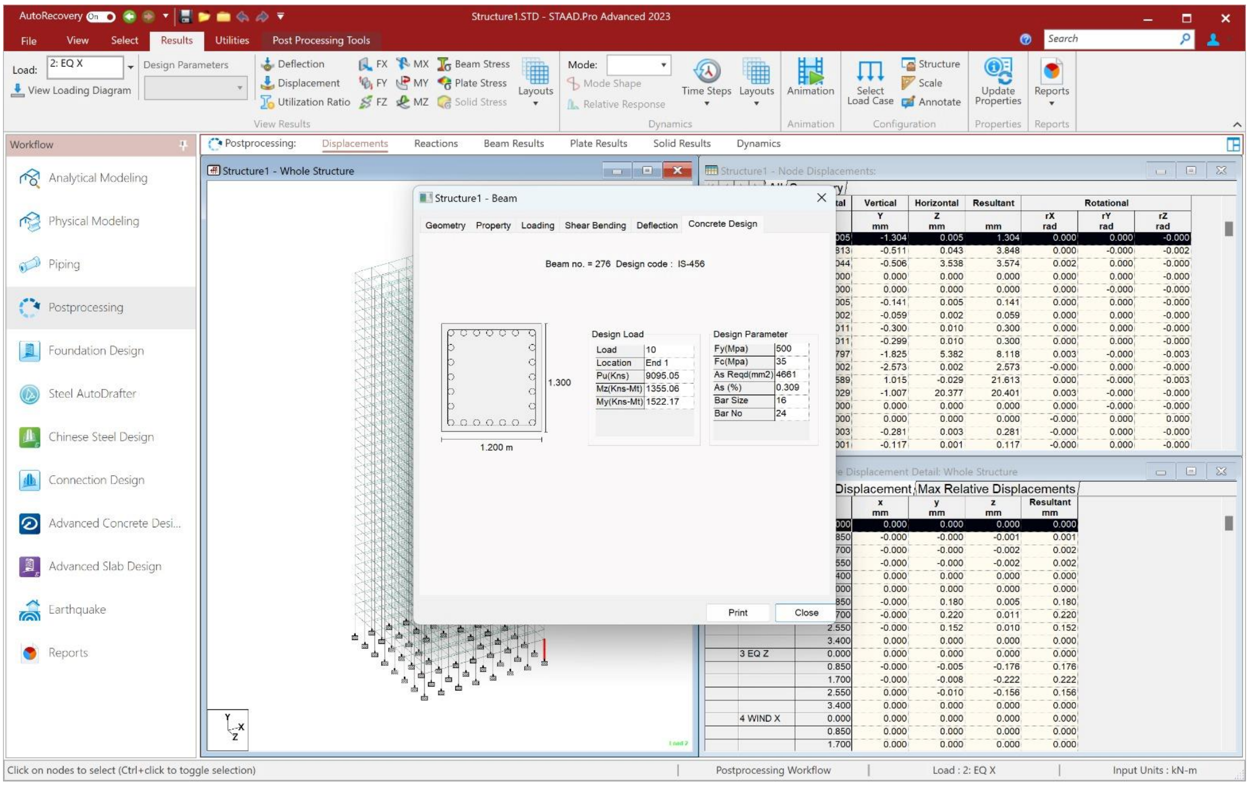

Figure A2.14: bottom beam reinforcement

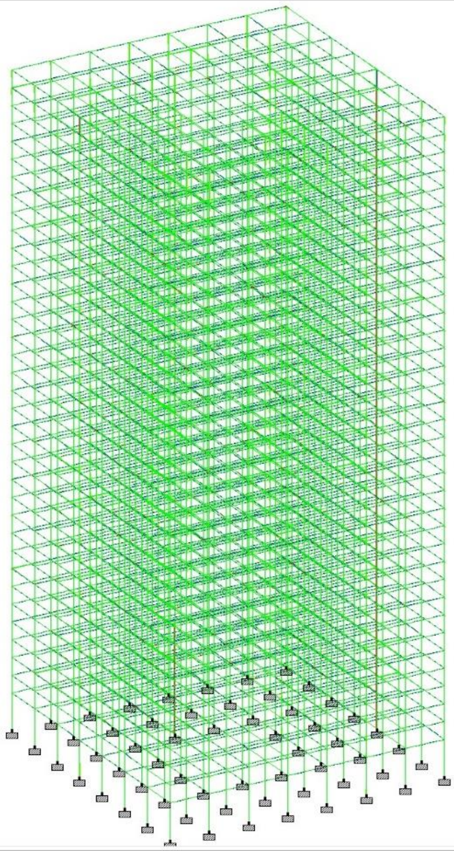

Figure A2.15: Beam stress distribution

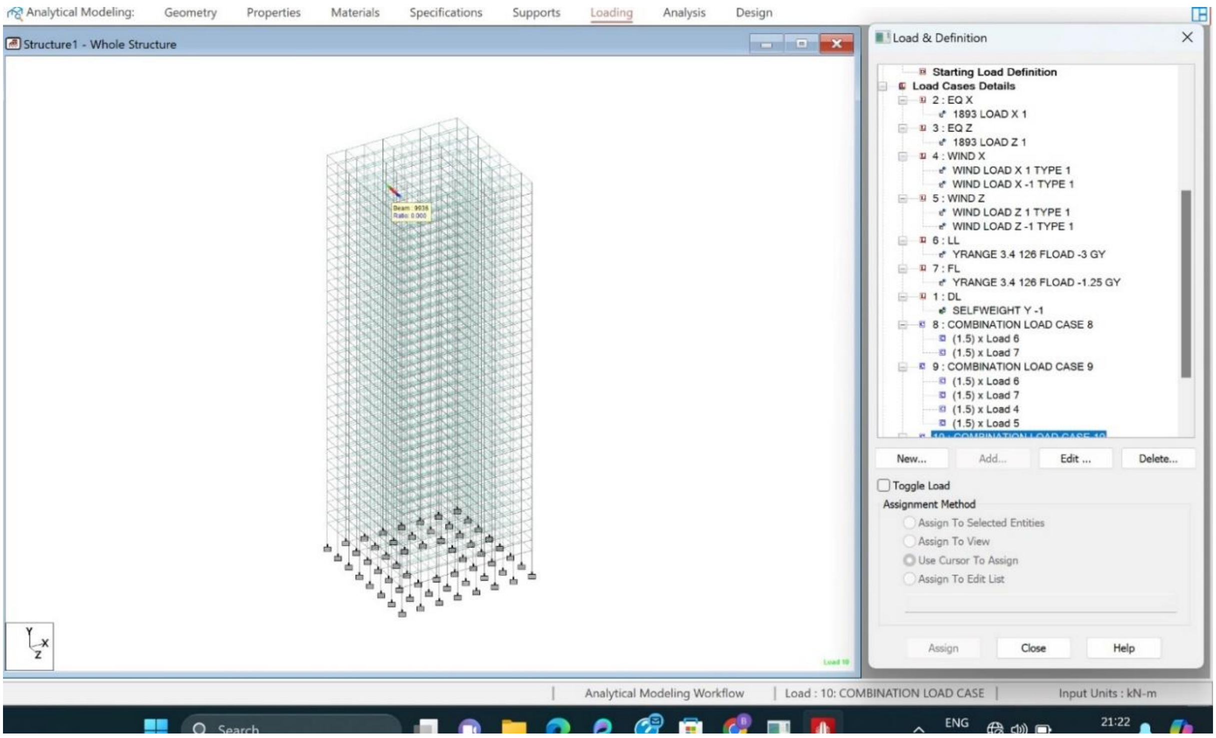

Figure A2.16: Load combination details

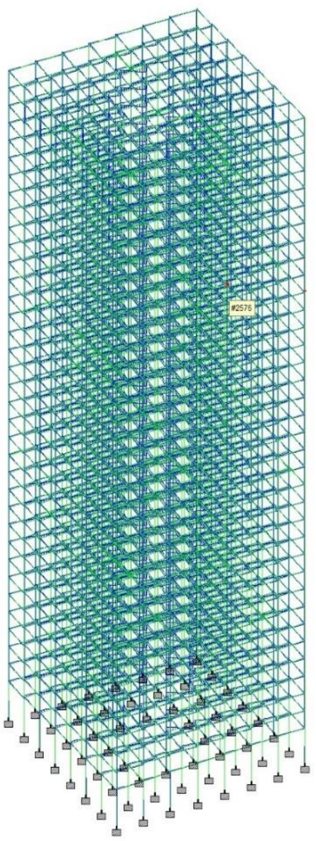

Figure A2.17: Deflection diagram

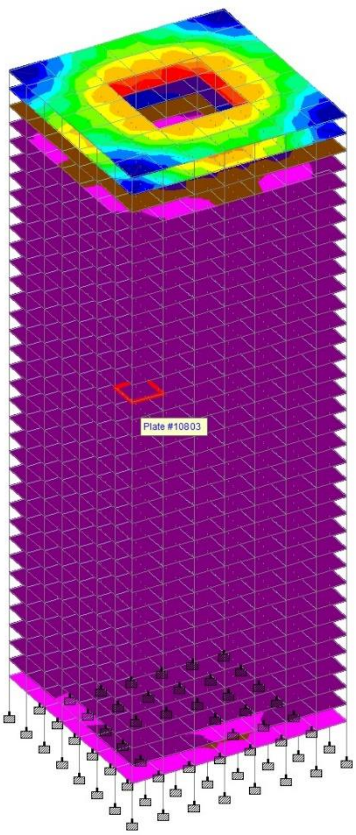

Figure A2.18: Plate Stress distribution

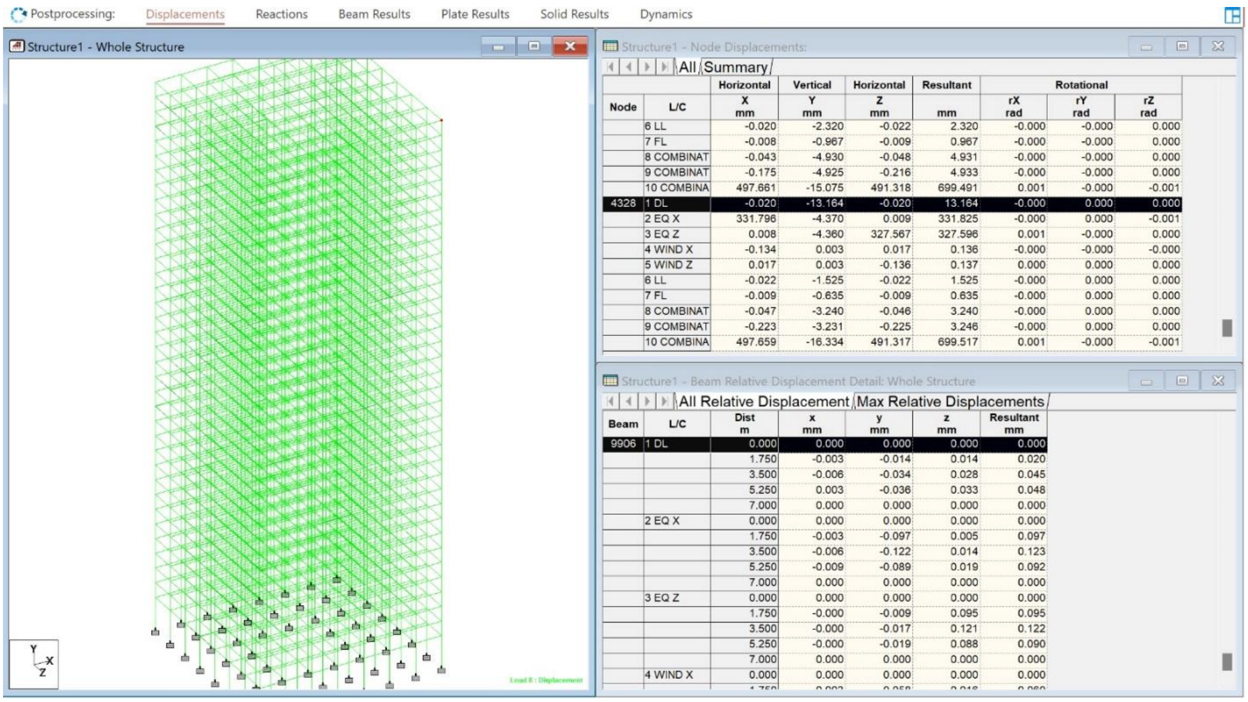

Figure 2.19: Max Deflection Node