ANALYSIS AND DESIGN OF RCC STRUCTURE WITH LIGHT WEIGHT BRICKS USING ETABS

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A thesis submitted to the Department of Civil Engineering in partial fulfillment
for the degree of Bachelor of Science in Civil Engineering



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Semester - Spring-2025

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Dedicated

to

" Our Respectful Teachers & parents"

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ABSTRACT

This study aims to analyze and design a reinforced cement concrete (RCC) structure using light weight bricks and compare its performance with that of a conventional RCC structure using standard clay bricks, utilizing ETABS software as the primary tool for structural modeling and analysis. The use of lightweight bricks, such as autoclaved aerated concrete (AAC) blocks, has gained popularity in modern construction due to their reduced density, thermal insulation properties, and potential to decrease overall structural dead load. This research investigates the impact of incorporating lightweight bricks on the structural behavior of a multi-storied building, focusing on key parameters such as base shear, storey drift, displacement, and member forces. The results of the analysis reveal significant differences in structural performance between the two models. The use of light weight bricks leads to a notable reduction in base shear and member forces due to decreased dead load, resulting in improved seismic performance and potential cost savings in foundation design. Storey drift and displacement are also analyzed to ensure serviceability and safety under lateral loads.

Overall, this study highlights the structural, economic, and sustainability benefits of using lightweight bricks in RCC construction. The findings provide valuable insights for engineers, architects, and developers, encouraging the adoption of light weight materials in structural design to enhance building performance while adhering to national code requirements. This study's contributes to the ongoing efforts to optimize construction practices and promote safer, more efficient, and environmentally conscious urban infrastructure in Bangladesh and similar regions worldwide.

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CHAPTER 01

INTRODUCTION

1.1 Introduction & Background

The construction industry is increasingly focusing on sustainable practices and efficient material usage. One such advancement is the incorporation of lightweight bricks in building design, offering benefits like reduced weight, better thermal insulation, and cost efficiency. When integrated into Reinforced Cement Concrete (RCC) structures, these bricks can reduce the overall dead load of a building, thus minimizing the load on foundations and structural elements. However, to fully realize the benefits of lightweight bricks, a comprehensive understanding of their behavior in RCC systems is necessary.

This thesis aims to analyze and design RCC structure using lightweight bricks, employing ETABS software for structural analysis. ETABS is a powerful tool that allows for detailed modeling and analysis of buildings, ensuring that they meet the required safety and performance standards. By evaluating the impact of lightweight bricks on the structural design, this research seeks to optimize the use of these materials for more sustainable and cost-effective construction.

The shift toward sustainable construction materials has led to the widespread use of lightweight bricks made from materials such as aerated concrete, fly ash, and expanded aggregates. These bricks reduce building weight and improve energy efficiency by enhancing thermal insulation. However, they also present challenges, such as lower compressive strength compared to conventional materials, which requires careful consideration during structural design.

The use of ETABS allows engineers to model and analyze RCC structures with light weight bricks, simulating their behavior under various load conditions. This thesis will explore how the use of lightweight bricks affects the structural performance, safety, and cost-efficiency of RCC buildings, contributing valuable insights for future construction projects that aim to balance sustainability with structural integrity.

BNBC 2020 refers to the Bangladesh National Building Code (BNBC) 2020, which

serves as a comprehensive set of guidelines for designing, constructing and maintaining buildings in Bangladesh. It is the primary standard for ensuring safety, structural integrity and sustainability in the built environment. The BNBC is updated periodically to reflect new research, materials, technologies, and evolving international best practices.

The BNBC 2020 introduces several important updates and revisions to address modern challenges in construction. These updates include enhanced provisions for earthquake-resistant design, considering Bangladesh's susceptibility to seismic activities, improved fire safety regulations, and sustainability guidelines to promote energy efficiency and environmentally-friendly construction practices. The code also emphasizes accessibility standards, ensuring that buildings are more inclusive for people with disabilities.

1 .2 Research Objectives

The objectives of the study are:

- Design and analyze a multi-storied RCC building model with ETABS.
- Perform structural analysis and assess the impact of lightweight bricks.
- Compare structural performance of lightweight vs. conventional brick structures.

1.3 General Approach

- Getting an architectural design of a RCC Residential Ten-storied building.
- Project on RCC Residential Building in Dhaka.
- To establish the structural system for the ground and typical floors of the building.
- Selection of lightweight bricks as a key building material.
- Analysis of building, wind resisting system, and type of foundations
- Designs, Analyses and Recommendations will strictly adhere to the BNBC 2020.

1.4 Organization of the thesis :

Chapter-1: Introduction and Objectives: An engineer supplies plans you need in order to build as opposed to an architect who supplies plans on the look and dimensions, you will need all to work together to archive quality results.

Chapter-2: Literature Review: This chapter related to the theme of the study. The analysis and design of structure is based on trial and error processes, until the convergence of structural models and defines and designs the various elements that make it up .

Chapter-3: Methodology: The methodologies will include areas such as the location of the study, research design, sampling and sample size, types of data, data collection method and its management.

Chapter-4: Results and Discussion: This chapter provides the main concept of the thesis. The comparison between light weight concrete block building and Conventional building.

Chapter-5: Conclusions and Future Work.: The ultimate goal of preparing this report is to making out the difference between theoretical knowledge and practical design of a RCC building. We have done the analysis for this project by ETABS.

CHAPTER 02

LITERATURE REVIEW

2.1 Introduction

The growing demand for sustainable and cost-effective building materials has led to significant research into the use of light weight bricks in the construction of Reinforced Cement Concrete (RCC) structures**.** The use of light weight materials, particularly in non-load bearing and load-bearing walls, offers multiple advantages such as reduced overall weight, improved thermal insulation, and better resistance to earthquakes due to lower dead load. However, the performance of RCC structures incorporating lightweight bricks under various loads (seismic, wind, and dead loads) needs careful evaluation. Researchers have done some different comparison with these topic, their result is discussed below.

2.2 Previous Background of the Study

Traditionally, burnt clay bricks have been the most commonly used masonry material in Bangladesh and many South Asian countries due to their availability, durability, and ease of use. However, the manufacturing of clay bricks requires the extraction of fertile topsoil and the burning of large amounts of coal or wood, leading to severe environmental degradation, air pollution, and carbon emissions. According to the World Bank (2018), the brick sector in Bangladesh accounts for a significant portion of urban air pollution and contributes heavily to CO_2 emissions.

With growing awareness of sustainable development and green construction practices, lightweight concrete blocks such as AAC (Autoclaved Aerated Concrete) and CLC (Cellular Lightweight Concrete) have emerged as viable alternatives. These blocks are made using fly ash, cement, lime, and aluminum powder (for AAC) or foam agents (for CLC), and are known for their low density, high thermal insulation, sound resistance, and fireproofing properties. More importantly, they reduce the dead load of a structure by 25–40%, which significantly affects the design of RCC members such as beams, columns, and footings.

Several studies have been conducted both internationally and locally. In India, Patil and Sayyed (2017) and Kolarkar and Tande (2015) found that AAC blocks improve construction efficiency and reduce structural cost. In Bangladesh, research by Hasan and Kabir (2019) highlighted the cost and structural performance of lightweight blocks in comparison with clay bricks in low-rise buildings. Reports by HBRI (Housing and Building Research Institute) and UNDP (2019) have also promoted the adoption of AAC and CLC blocks for environmentally sustainable housing projects.

Despite these findings, a detailed structural comparison using advanced design software such as ETABS between lightweight blocks and conventional bricks in the context of multi storey RCC buildings is still limited in Bangladesh. This study aims to fill that gap by analyzing and designing a G+9 residential RCC structure using both types of bricks to quantify differences in member sizing, reinforcement, and structural behavior.

2.3 Methods for Analyzing a Frame Structure

Analyzing a frame structure involves determining the internal forces, displacements, stresses, and moments that occur due to applied loads such as dead loads, live loads, wind loads, and seismic forces. This analysis is essential for the safe and economical design of structural members in reinforced concrete buildings.

There are two main categories of analysis methods used in civil engineering:

1. Manual Analytical Methods
2. Computer-Aided Methods

1. **Manual Analytical Methods:** Manual methods are typically used for simple, smaller structures and involve hand calculations. Common techniques include:

i. Moment distribution method
ii. Slope displacements methods (iterative methods)
iii. Portal method
iv. Cantilever method
v. Matrix method
vi. Method of flexibility coefficients.

2.3.1 Moment Distribution Method:

The Moment Distribution Method is a classical structural analysis technique used to solve statically indeterminate beams and frames. It was developed by Hardy Cross and first published in 1930 in the Journal of the American Society of Civil Engineers (ASCE). Before the advent of computer-aided analysis, this method was widely used due to its simplicity and effectiveness in analyzing complex frame structures.

This method primarily considers flexural effects while neglecting axial and shear deformations. It is based on the principle of achieving moment equilibrium at joints by iteratively distributing and balancing the moments generated due to external loads.

In this approach, all joints are initially assumed to be fixed, and fixed-end moments (FEMs) are calculated for each member. Then, each joint is gradually released, allowing it to rotate. The unbalanced moments at each joint are distributed to the adjacent members in proportion to their stiffness using distribution factors. After distributing, a portion of the moment is "carried over" to the far ends of the connected members, a process governed by the carry-over factor (typically 0.5 for prismatic members). This iterative cycle continues until the moments at all joints reach equilibrium.

Mathematically, the moment distribution method represents an iterative solution of a system of simultaneous equations describing the moment equilibrium at each joint. Though largely replaced by matrix methods and software tools today, it remains a fundamental method for understanding the behavior of indeterminate structures and is still taught in structural engineering courses.

2.3.2 Slope Displacement Equations:

The Slope Deflection Method is a structural analysis technique developed by George A. Maney in 1914. It was one of the earliest systematic approaches for analyzing statically indeterminate beams and frames**.** This method was widely adopted for more than a decade until the development of the Moment Distribution Method, which offered a more streamlined approach for manual calculations.

The slope deflection method involves forming equations that relate end moments of members to their rotations (slopes) and displacements at the joints. These equations,

known as slope displacement equations**,** incorporate the stiffness of members and the effects of external loads.

The general process includes:

- Forming slope-deflection equations for each member.
- Applying joint moment equilibrium conditions and shear force continuity.
- Solving the resulting system of equations to obtain unknown joint rotations and displacements.
- Substituting these values back into the slope-deflection equations to determine final member end moments**.**

Applications and Considerations of the Slope Deflection Method

The method is suitable for a variety of structural configurations, including:

1. **General Case** – Application to beams or frames with various boundary conditions.
2. **Stiffness Coefficients** – Use of coefficients relating moment to slope and displacement.
3. **Stiffness Coefficients Derivation** – Based on elastic beam theory and boundary conditions.
4. **Fixed-End Moments (FEM)** – Used as input for member moment equations.
5. **Pin-Supported End Span** – Treated with special conditions due to zero moment resistance.
6. **Typical Problems** – Used for basic indeterminate beams and small frames.
7. **Analysis of Beams** – Continuous beams with intermediate supports and loads.
8. **Analysis of Frames: No Side Sway** – For symmetric loading and geometry.
9. **Analysis of Frames: With Side Sway** – Requires additional equilibrium conditions due to lateral displacement.
10. **Simultaneous Equations** – The solution often involves a large system of linear equations, which makes it tedious for manual computations.
11. **Scalability Limitation** – Not recommended for large frames (more than two bays or two stories) due to computational complexity.

2.3.3 Portal Method:

The Portal Method is an approximate analytical technique used to evaluate the internal forces in statically indeterminate portal frames subjected to lateral loads, such as wind or seismic forces. It is particularly useful for multi-storey buildings, industrial sheds, factories, and bridges where frames must resist significant horizontal forces.

Portal frames are designed to effectively transfer lateral loads from the upper levels to the supports at the base. Due to this function, they are often externally statically indeterminate, meaning that the number of unknown reactions exceeds the available equilibrium equations. To address this, the Portal Method applies a set of simplifying assumptions that make the analysis feasible by hand.

Basic Assumptions of the Portal Method

1. **Inflection Points at Member Centers**
   – A point of zero moment (inflection point) is assumed at the center of each beam and column.
2. **Column Shear Distribution**
   – Interior columns resist twice the shear force compared to exterior columns on the same storey.
3. **Lateral Loads Resisted by Frame Action**
   – All horizontal forces (such as wind or seismic) are resisted by the frame action, neglecting other systems like shear walls or bracing (unless specified).
4. **Inflection Points at Mid-Height of Columns**
   – This assumption allows the column to be treated as two separate cantilever segments, simplifying the moment calculation.
5. **Inflection Points at Mid-Span of Beams**
   – Beams are also treated as simply supported at the midpoints, where no moment is assumed to occur.
6. **Column Shear Based on Tributary Area**
   – Shear forces are distributed based on the area or position of the columns in the frame.

7. **Overturning Resisted by Exterior Columns Only**
   – The overturning moment due to lateral loading is assumed to be counteracted solely by axial forces in the outermost columns.

2.3.4 Cantilever Method:

The Cantilever Method is an analytical technique used to calculate and analyze the shear forces and bending moments developed in individual members, such as beams and columns, of a frame or structure subjected to lateral loads. These lateral loads include forces from sources such as wind load and earthquake load, both of which must be accounted for when designing buildings.

This method is based on certain assumptions that simplify the analysis process:

1. **Point of Contra-flexure** – The point of contra-flexure, where the bending moment is zero, is assumed to be located at the midpoint of the vertical and horizontal members.
2. **Direct Stresses in Columns** – The direct stresses in the columns are assumed to be proportional to their distances from the centroid axis of the frame.
3. **Stepwise Analysis** – The frame is analyzed step-by-step, with the shear forces and bending moments calculated progressively at each stage. This iterative approach helps to accurately reflect the behavior of complex frames under lateral loads.

The Cantilever Method is highly versatile and can be applied to frames of any number of storeys or floors. While it is particularly useful for simplified analysis of lateral load effects, it is important to note that this method is often used for preliminary design and cannot replace more advanced techniques like finite element analysis for detailed evaluation of complex or irregular structures.

2.3.5 Matrix method:

The Matrix Method, also known as the Direct Stiffness Method, is a widely used structural analysis technique, particularly suited for the computer-automated analysis of complex structures, including statically indeterminate types. This method is

grounded in the concept of stiffness relations of structural members and is typically implemented using matrix mathematics to compute the member forces and displacements in a structure.

The Direct Stiffness Method is essentially the most common form of the Finite Element Method (FEM), a numerical technique widely used in engineering. In this method, the entire structure is modeled as a system of simplified, idealized elements connected at nodes. Each element is characterized by its material properties, such as stiffness, which contribute to the overall behavior of the structure.

The process involves the following steps:

1. **Element Stiffness Matrices** – For each element of the structure, a stiffness matrix is derived based on its material properties and geometry.
2. **Assembly** – The individual element stiffness matrices are then assembled into a global stiffness **matrix** that represents the entire structure.
3. **Solving the System** – The global matrix equation is solved to determine the unknown displacements and forces at the nodes of the structure.

This method allows for the efficient analysis of structures with complex geometry, boundary conditions, and loading scenarios. It is particularly effective for statically indeterminate structures and plays a crucial role in modern structural engineering software, forming the basis for many finite element analysis (FEA) tools used in residential, commercial, and infrastructure projects.

2.3.6 Method of flexibility coefficients.

The flexibility coefficient is widely used in the analysis of arch dams, where it plays a crucial role in understanding the macroevolution of shape**,** safety, and economy of the structure. The method of consistent deformations, often referred to as the force or flexibility method, is one of several techniques used to analyze indeterminate structures. This method is particularly useful in analyzing externally indeterminate structures**,** which have single or double degrees of indeterminacy**.**

Procedure of the Consistent Deformations Method

The method is based on the concept of reducing a hyperstatic (statically indeterminate) structure to a determinate structure by removing redundant supports or introducing appropriate cuts or hinges. The steps involved in the procedure are as follows:

1. **Removal of Redundant Supports** – Redundant supports (or restraints) are removed from the structure, transforming it into a determinate form.
2. **Introduction of Cuts or Hinges** – Alternatively, cuts or hinges are introduced in the structure to reduce the degrees of indeterminacy, making the system solvable.

By applying consistency conditions to the displacements and deformations, the unknown reactions, forces, and displacements can be computed.

Limitations of the Flexibility Method

While the flexibility method is a powerful tool for structural analysis, it has limitations:

It is not applicable for structures with a degree of redundancy greater than 3, as the method becomes increasingly complex and less practical for high levels of indeterminacy.

2.4 : Computer-Aided Methods

2.4.1 ETABS 19.1.0:

The innovative and revolutionary new ETABS 2019 (Version 19.1.0) (Extended 3D Analysis of Building System) is the ultimate integrated software package for the structure analysis and design of buildings.

This version introduces several new features and enhancements that make it an essential tool for engineers working on building and infrastructure projects. Key improvements include enhanced modeling capabilities, advanced design options for various materials like concrete and steel, and improved integration with other software such as AutoCAD and Revit. The software also offers seismic analysis and more sophisticated wind load

calculations, ensuring that designs meet modern safety standards. ETABS 2019 is known for its user-friendly interface, making it easier for engineers to set up, analyze, and optimize complex structural models with greater accuracy and efficiency. With these enhancements, ETABS 2019 provides a comprehensive solution for both simple and complex structural designs, delivering faster results and more reliable insights into structural performance.

2.4.2 AutoCAD 2025:

AutoCAD is a CAD (Computer Aided Design or Computer Aided Drafting) software application for 2D and 3D design and drafting, developed and sold by Autodesk. It is a vector graphics drawing program. AutoCAD 2025 is a cutting-edge software solution for drafting, designing, and modeling in both 2D and 3D.

This version introduces several enhancements to improve efficiency, collaboration, and performance. Notable features include better integration with cloud services for real-time collaboration, AI-driven tools that automate tasks like smart block adjustments, and improved 3D modeling and rendering capabilities. AutoCAD 2025 also boasts faster performance, especially for handling large files and complex designs, alongside a refined user interface with customizable features and dark mode options for a more intuitive experience. These upgrades enable engineers, architects, and designers to work more productively, streamline workflows, and create precise, high-quality designs faster than ever before.

CHAPTER 03

METHODOLOGY

3.1 Introduction:

In this chapter, the methodology of the work is discussed. This project is primarily based on the use of software, specifically:

- ETABS 2019 (Version 19.1.0)
- AutoCAD 2025

The necessary data for analysis and model development using ETABS (Version 19.1.0) are explained in detail. The structural analysis has been carried out considering Zone-2 (Dhaka), as per seismic zoning. Design data have been adopted from the Bangladesh National Building Code (BNBC) 2020.

3.2 Different Types of Loads in Structure:

Structural members must be designed to safely support various types of loads. Loads refer to the forces that a structure is expected to withstand throughout its service life. Generally, loads can be classified into the following categories:

1. Dead Loads
2. Imposed Loads or Live Loads
3. Wind Loads
4. Earthquake Loads

3.2.1 Dead Load:

Dead loads consist of the permanent loads arising from the construction materials of the structure, including the roof, floors, walls, foundation systems, finishes, and fixed equipment. These are the static loads that generally remain constant over time. Examples include the weight of concrete columns, concrete floors, bricks, roofing materials, and other permanently attached structural components. In ETABS, dead load assignment is automated by specifying the properties of structural members. The

software includes an option called Self-Weight under the load case settings, which calculates the weight based on the material properties, such as density.

In this study, the dead load on the slabs includes:

- The self-weight of the slab,
- A floor finish load of 25 psf, and
- A random partition wall load of 30 psf,
  in addition to the slab's self-weight.

3.2.2 Live Load:

Live loads are generated by the use and occupancy of a building. These loads include the weight of human occupants, furniture, movable equipment, stored materials, and activities related to construction and maintenance. Live loads are typically expressed as uniform area loads, concentrated loads, or uniform line loads, depending on the nature of the occupancy and structural requirements.

In ETABS, live loads are assigned as uniformly distributed loads (U.D.L.). A specific load case for live load is created, and the relevant slabs are selected to carry this load accordingly.

For this study, considering the residential nature of the building, the following live loads have been adopted:

- 45 psf for typical floor areas,
- 100 psf for the rooftop and staircase areas.

These live loads have been applied as per the guidelines provided in BNBC 2020.

3.2.3 Wind Load:

According to the Bangladesh National Building Code (BNBC), 2020, all buildings and structures—including the Main Wind-Force Resisting System (MWFRS) and their components and cladding—must be designed and constructed to resist wind loads as specified by the code.

Wind Load Determination Procedures

Design wind loads can be calculated using any of the following three methods:

- **Method 1**: Simplified procedure — applicable to structures meeting specific code requirements.
- **Method 2**: Analytical procedure — generally used for most buildings conforming to standard design conditions.
- **Method 3**: Wind tunnel testing — applicable for complex or tall structures requiring advanced evaluation.

The purpose of wind load calculation is to ensure structural stability against shear**,** sliding**,** overturning**,** and uplift. The calculations are based on the sustained wind pressure acting on building surfaces at any height zzz above ground.

Wind Pressure Calculation (for V_b in km/h)

$Q_z = C_c \cdot C_i \cdot C_z \cdot V_b^2$.....(i)

Where:

- Q_z= Sustained wind pressure at height z (kN/m^2)
- C_i = Importance coefficient of the structure
- C_c= Velocity-to-pressure conversion coefficient
- C_z = Combined height and exposure coefficient
- V_b = Basic wind speed (km/h)

Velocity Pressure (for V in m/s)

$q_z = (0.000613 \cdot V^2) \cdot K_z \cdot K_{zt} \cdot K_d \cdot I$.....(ii)

Where:

- q_z = Velocity pressure at height z (kN/m^2)
- K_z, K_{zt}, K_d = Exposure-related coefficients
- I = Importance factor

Design Wind Pressure

If V_b is in km/h:

$P_z = C_G \cdot C_p \cdot Q_z$.....(iii)

If V_b is in mile/h:

$P_z = C_t \cdot CG \cdot C_p \cdot Q_z$.....(iv)

Where:

- P_z= Design wind pressure at height zzz (kN/m^2)
- C_G = Gust factor
- C_p = Pressure coefficient
- C_t = Topography coefficient (assumed = 1 in flat terrains)

Total Wind Force

The total wind force acting on a surface is calculated using the projected area method:

$F_z = P_z \cdot A_z$.....(v)

Where:

- F_z = Total wind force (kN)
- A_z = Projected area perpendicular to wind direction (m^2)

Basic Wind Pressure Formula

$p = q \cdot G \cdot C_p$.....(vi)

Where:

- p = Wind pressure (kN/m^2)
- q = Velocity pressure
- G = Gust effect factor
- Cp= Pressure or shape coefficient

Code Considerations (**BNBC 2020**)

- Positive pressure acts toward the surface, while negative pressure acts away.
- Critical loading occurs by combining external and internal pressures algebraically to obtain the worst-case scenario.
- For component and cladding areas > 65 m², MWFRS-based provisions apply.

Main Wind-Force Resisting Systems **(MWFRS)**

For Rigid Buildings of All Heights

$p = q \cdot G \cdot C_p - q_i \cdot (G.C_{pi})$.....(vii)

Where:

p = Net design wind pressure on the surface (kN/m²)

q = Velocity pressure at height z (external)

G = Gust effect factor (typically 0.85 for rigid buildings)

C_p = External pressure coefficient (depends on building surface and wind direction)

q_i = Internal velocity pressure (usually taken at mean roof height)

C_{pi} = Internal pressure coefficient

$G \cdot C_{pi}$ = Combined internal gust and pressure effect

For **Low-Rise Buildings**

$p = q_h \cdot (GC_{pf} - GC_{pi})$.....(viii)

Where:

- q_h = Velocity pressure at mean roof height
- GC_{pf}, GC_{pi} = External and internal pressure coefficients

For **Flexible Buildings**

$P = q \cdot G_f \cdot C_p - q_i \cdot (GC_{pi})$.....(ix)

Where:

- G_f = Gust factor for flexible structures

Wind Pressure on Parapets

Table 3.1: Basic Wind Speeds, V, For Selected Locations in Bangladesh (BNBC 2020)

Location	Basic Wind Speed (m/s)	Location	Basic Wind Speed (m/s)
Angatpota	47.8	Laimonirhat	63.7
Bagerhat	77.5	Madaripur	68.1
Bandarban	62.5	Magura	65.0
Barguna	80.0	Manikganj	58.2
Barisal	78.7	Meherpur	58.2
Bhola	69.5	Maheshkhali	80.0
Bogra	61.9	Moulvibazar	53.0
Brahmanbaria	56.7	Munshiganj	57.1
Chandpur	50.6	Mymensingh	67.4
ChapaiNawabganj	41.4	Naogaon	55.2
Chittagong	80.0	Narail	68.6
Chuadanga	61.9	Narayanganj	61.1
Comilla	61.4	Narsinghdi	59.7
Cox’s Bazar	80.0	Natore	61.9
Dahagram	47.8	Netrokona	65.6
Dhaka	65.7	Nilphamari	44.7
Dinajpur	41.4	Noakhali	57.1
Faridpur	63.1	Pabna	63.1
Feni	64.1	Panchagarh	41.4
Galbandha	65.6	Patuakhali	80.0
Gazipur	66.5	Pirojpur	80.0
Gopalganj	74.5	Rajbari	59.1
Habiganj	54.2	Rajshahi	49.2
Hatiya	80.0	Rangamati	56.7
Ishurdi	69.5	Rangpur	65.3
Joypurhat	56.7	Satkhira	57.6
Jamalpur	56.7	Shariatpur	61.9
Jessore	64.1	Sherpur	62.5
Jhalakati	80.0	Sirajganj	50.6
Jhenaidah	65.0	Srimangal	50.6
Khagrachhari	56.7	St. Martin’s Island	80.0
Khulna	73.3	Sunamganj	61.1
Kutubdia	80.0	Sylhet	61.1
Kishoreganj	64.7	Sandwip	80.0
Kurigram	65.6	Tangail	50.6
Kushtia	66.9	Teknaf	80.0
Lakshmipur	51.2	Thakurgaon	41.4

$P_p = Q_p \cdot GC_{pn}$.....(x)

Where:

- P_p = Net wind pressure on parapets
- Q_p = Velocity pressure at parapet height
- GC_{pn} = Net pressure coefficient

  = +1.5 for windward

  = –1.0 for leeward par

Wind Load in Dhaka

According to BNBC 2020, the basic wind speed for Dhaka is 65.7 m/s**.**

3.2.4 Earthquake Load (BNBC-2020)

In accordance with the Bangladesh National Building Code (BNBC 2020), earthquake loading has been calculated using the Equivalent Static Analysis method and applied at the center of mass of the building. This method simplifies the dynamic response of a structure during seismic activity by transforming the inertia forces generated at various lumped mass levels (i.e., story levels) into equivalent horizontal static forces.

These lateral forces are proportional to both the mass (and weight) of each story and its corresponding displacement (which correlates with acceleration during ground motion). The total of these forces is referred to as the base shear, which acts at the base of the structure and must be resisted by the foundation system.

This analytical approach is especially suitable for regular, low- to mid-rise buildings where dynamic effects can be reasonably approximated using static procedures. It is based on the assumption that the building's response can be captured by its fundamental mode of vibration, and it forms the basis for many seismic design calculations under BNBC-2020 guidelines.

Design Base Shear:

The total design base shear V in a given direction is determined using the following equation:

$V = S_a \cdot W$.....(xi)

Where:

- S_a = Lateral seismic force coefficient
- W = Total seismic weight of the building

The lateral seismic force coefficient Sa is calculated based on the dynamic properties of the structure and the seismic characteristics of the location as defined in BNBC 2020. The total seismic weight W includes the dead load and applicable portions of live load, as defined by the code.

For buildings with a fundamental natural period less than or equal to 2.0 seconds, the seismic design base shear can alternatively be calculated using the ASCE 7-02 procedure, with seismic design parameters provided in Appendix C of the BNBC 2020.

However, it is important to note that the minimum value of Sa should not be less than $0.044 \cdot SDS \cdot I$, where:

- SDS = Design spectral acceleration at short periods (as provided in Appendix C)
- I = Importance factor of the structure

Structure Period

The fundamental period TTT of the structure can be determined using one of the following methods:

Method A: Empirical Determination of the Fundamental Period

For seismic design, the fundamental period (T) of a structure may be approximated using the following empirical formula:

$$T = C_t \times h_n^x \quad \text{.....(xii)}$$

Where:

- T = Fundamental period of the building (in seconds)
- C_t = Empirical coefficient based on the structural system
- h_n = Height (in meters) from the base to the highest level of the structure
- x = Exponent depending on structural type

The values of Ct for different structural systems as per BNBC 2020 are:

- $C_t = 0.0724$ for steel moment-resisting frames
- $C_t = 0.0731$ for reinforced concrete moment-resisting frames and eccentric braced steel frames
- $C_t = 0.0466$ for reinforced concrete shear wall systems
- $C_t = 0.0488$ for all other structural systems

Alternative Formula for Shear Wall Buildings

For buildings with concrete or masonry shear walls, the coefficient Ct may alternatively be taken as:

$$C_t = \frac{0.031}{\sqrt{Ac}} \quad \text{.....(xiii)}$$

Where:

- A_c = Combined effective area (in square meters) of the shear walls in the first story

The effective area Ac is calculated using the following formula:

$$A_a = \sum A_e \times [0.2 + (D_e / h_n)^2] \quad \text{.....(xiv)}$$

Where:

- Ae = Effective horizontal cross-sectional area (in m^2) of each shear wall in the first story
- De = Length (in meters) of the shear wall element in the direction of applied seismic force
- hn = Total height of the building

Note: The ratio D_e / h_n should not exceed 0.9.

Method B: Analytical Determination of the Fundamental Period

The fundamental period (T) of a structure may be calculated using the structural properties and deformational characteristics of the seismic-force-resisting elements through a properly substantiated analysis.

This requirement can be satisfied using the following general formula:

$$T = \sqrt{[\ \Sigma(w_i \times d_i) / \Sigma(f_i \times d_i)\ ]} \quad \text{.....(xv)}$$

Where:

- T = Fundamental period of the building (in seconds)
- w_i = Seismic weight at level i
- d_i = Lateral displacement at level i due to applied force
- f_i = Lateral force at level i, distributed approximately in accordance with accepted seismic design principles

Note: This method is particularly applicable for buildings with irregular configurations or where more accurate modeling of dynamic response is required.

Table 3.2: Seismic Zone Coefficient, Z

Seismic Zone	Zone coefficient
1	0.12
2	0.20
3	0.28
4	0.36

Table 3.3: Structural Importance Coefficient, I

Structure Importance Category	Structure Importance Coefficient	
	I	I'
I Essential Facilities	1.25	1.50
II Hazardous Facilities	1.25	1.50
III Special Occupancy Strictures	1.00	1.00
IV Standard Occupancy Structures	1.00	1.00
V Low-risk Structures	1.00	1.00

Table 3.4 : Description of Seismic Zones

Seismic Zone	Location	Seismic Intensity	Seismic Zone Coefficient, Z
1	Southwestern part including Barisal, Khulna, Jessore, Rajshahi	Low	0.12
2	Lower Central and Northwestern part including Moderate Noakhali, Dhaka, Pabna, Dinajpur, as well as Southwestern corner including Sundarbans	Moderate	0.20

3	Upper Central and Northwestern part including Severe Brahmanbaria, Sirajganj, Rangpur	Severe	0.28
4	Northeastern part including Sylhet, Mymensingh, Kurigram	Very Severe	0.36

Table 3.5 : Seismic Zone Coefficient Z for Some Important Towns of Bangladesh

Town	Z	Town	Z	Town	Z	Town	Z
Bagerhat	0.12	Gaibandha	0.28	Magura	0.12	Patuakhali	0.12
Bandarban	0.28	Gazipur	0.20	Manikganj	0.20	Pirojpur	0.12
Barguna	0.12	Gopalganj	0.12	Maulvibarar	0.36	Rajbari	0.20
Barisal	0.12	Habiganj	0.36	Meherpur	0.12	Rajshahi	0.12
Bhola	0.12	Jaipurhat	0.20	Mongla	0.12	Rangarnati	0.28
Bogra	0.28	Jamalpur	0.36	Munshiganj	0.20	Rangpur	0.28
Brahmanbaria	0.28	Jessore	0.12	Mymensingh	0.36	Satkhira	0.12
Chandpur	0.20	Jhalokati	0.12	Narail	0.12	Shariatpur	0.20
Chapainababganj	0.12	Menaidah	0.12	Narayanganj	0.20	Sherpur	0.36
Chittagong	0.28	Khagrachari	0.28	Narsingdi	0.28	Sirajganj	0.28
Chuadanga	0.12	Khulna	0.12	Nature	0.20	Srimangal	0.36
Comilla	0.20	Kishoreganj	0.36	Naogaon	0.20	Sunamganj	0.36
Cox’s Bazar	0.28	Kurigram	0.36	Netrakona	0.36	Sylhet	0.36
Dhaka	0.20	Kushtia	0.20	Nilphamari	0.12	Tangail	0.28
Dinajpur	0.20	Lakshmipur	0.20	Noakhali	0.20	Thakurgaon	0.20
Faridpur	0.20	Lalmanirhat	0.28	Pabna	0.20		
Feni	0.20	Madaripur	0.20	Panchagarh	0.20		

Table 3.6: Site Dependent Soil Factor and Other Parameters Defining Elastic Response Spectrum

Soil type	S	$T_B(S)$	$T_C(S)$	$T_D(S)$
SA	1.0	0.15	0.40	2.0
SB	1.2	0.15	0.50	2.0
SC	1.15	0.20	0.60	2.0
SD	1.35	0.20	0.80	2.0
SE	1.4	0.15	0.50	2.0

Building Categories:

Buildings are classified into four occupancy categories in Chapter 1 (Table 6.1.1), based on the following criteria:

- The consequences of collapse for human life
- The importance for public safety and civil protection in the immediate post-earthquake period
- The social and economic impact of potential collapse

Depending on the occupancy category, buildings may be required to resist higher seismic forces through the use of an importance factor (I) greater than one.

Table 6.2.17 defines the various occupancy categories and their corresponding importance factors. The importance factor is a multiplier applied to seismic design forces to ensure adequate performance based on a structure's criticality.

Note: Each country or region may have specific regulations and standards that define importance factors based on local conditions and priorities.

Importance of Adhering to Local Guidelines

It is crucial to adhere to jurisdiction-specific codes and guidelines to ensure:

- The seismic safety of buildings

- Protection of human life and property
- Continued functionality of critical infrastructure (e.g., hospitals, emergency centers)

Role of Importance Factors in Seismic Design

Importance factors are essential in:

- Determining design forces
- Setting appropriate performance objectivesz
- Reflecting the functional significance of structures
- Ensuring resilience during and after seismic events

Table 3.7: Importance Factors for Buildings and Structures for Earthquake design

Occupancy Category	Importance factor, I
I, II	1.00
III	1.25
IV	1.50

Table 3.8: Site Dependent Soil Factor and Other Parameters Defining Elastic Response Spectrum

Soil Type	S	T_B(S)	T_C(S)	T_D(S)
SA	1.0	0.15	0.40	2.0
SB	1.2	0.15	0.50	2.0
SC	1.15	0.20	0.60	2.0
SD	1.35	0.20	0.80	2.0
SE	1.4	0.15	0.50	2.0

Importance Factors for Buildings in Seismic Design: It the design of buildings and structures to resist earthquake forces, importance factors are key considerations in

determining the appropriate seismic design requirements. These factors, which vary based on local building codes and standards, reflect the varying needs for seismic safety depending on the nature and function of the structure.

Role of Importance Factors:

- Purpose: The importance factor serves as a multiplier that adjusts seismic design forces based on the structure's intended function, occupancy, and role in society.
- Variation by Building Type: The importance factor differs for various types of buildings, with more critical structures requiring higher levels of protection to ensure occupant safety and structural integrity during and after an earthquake.

Occupancy Category in Seismic Design: Buildings are classified into different occupancy categories based on their function and potential consequences in the event of an earthquake. These categories include residential, commercial, industrial, educational, healthcare, and essential facilities. Each category has varying levels of occupancy and critical functions, which influence the level of seismic protection required.

- **Higher Importance for Critical Buildings**: Structures that have higher occupancy or perform critical functions (such as healthcare facilities or schools) generally require a higher **importance factor**. This factor ensures that the building can withstand seismic forces adequately, protecting the lives of the occupants and maintaining essential services during and after an earthquake.

Life Safety in Seismic Design: The primary objective of seismic design is to protect human life. Buildings that are assigned higher importance factors prioritize life safety and are subject to more stringent design criteria. These criteria ensure the safety of occupants during an earthquake by accounting for factors such as:

- **Occupancy**: The number and type of occupants within the building.
- **Criticality**: The importance of the building's function, such as hospitals, schools, and emergency services.

- **Economic Impact**: The potential financial consequences of damage to the building.
- **Societal Considerations**: The broader impact on society if the building fails during an earthquake.

Table 3.9: Seismic Design Category of Buildings

Site Class	Occupancy Category I,II and III				Occupancy Category VI			
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 1	Zone 2	Zone 3	Zone 4
SA	B	C	C	D	C	D	D	D
SB	B	C	D	D	C	D	D	D
SC	B	C	D	D	C	D	D	D
SD	C	D	D	D	D	D	D	D
SE, S1, S2	D	D	D	D	D	D	D	D

Table 3.10: Values for Coefficients to Estimate Approximate Period

Structure Type	C_tm
Concrete moment-resisting frames 0.0466 - 0.9 Steel moment-resisting frames 0.0724- 0.8 Eccentrically braced steel frame 0.0731- 0.75 All other structural systems 0.0488- 0.75	Note: Consider moment resisting frames as frames which resist 100% of seismic force and are not enclosed or adjoined by components that air more rigid and will prevent the frames from deflecting under seismic forces.

Location within Seismic Zoning Map

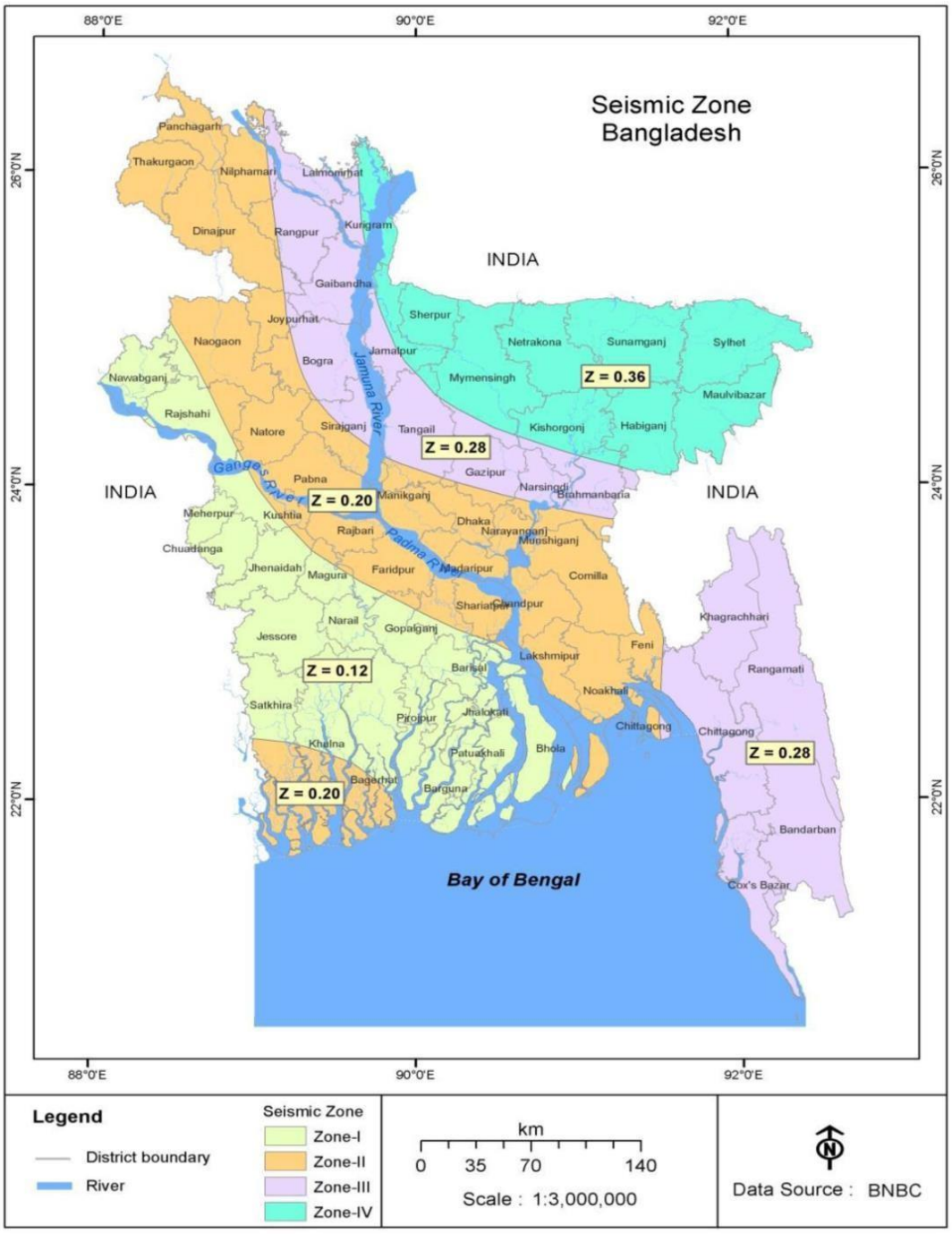


Figure 3.1: Seismic zoning map in Bangladesh

Table 3.11: Response Reduction Factor, Deflection Amplification Factor and Height Limitations for Different Structural Systems

Seismic Force-Resisting System	Response Reduction Factor	System Over Strength Factor	Deflection Amplification Factor	Seismic Design Category	Seismic Design Category	Seismic Design Category

Seismic Force-Resisting System	Response Reduction Factor ,R	System Over Strength Factor, Ω_o	Deflection Amplification Factor, C_d	Seismic Design Category B	Seismic Design Category C	Seismic Design Category D
				Height limit (m)		

BEARING WALL SYSTEMS (No frame)

1. Special reinforced concrete shear walls	5	2.5	5	NL	NL	50
2. Ordinary reinforced concrete shear walls	4	2.5	4	NL	NL	NP
3. Ordinary reinforced masonry shear walls	2	2.5	1.75	NL	50	NP
4. Ordinary plain masonry shear walls	1.5	2.5	1.25	18	NP	NP

Seismic Force-Resisting System	Response Reduction Factor ,R	System Over Strength Factor, Ω_o	Deflection Amplification Factor, C_d	Seismic Design Category B	Seismic Design Category C	Seismic Design Category D
				Height limit (m)		

4. Special reinforced concrete moment frames	8	3	5.5	NL	NL	NL
5. Intermediate reinforced concrete moment frames	5	3	4.5	NL	NL	NP
5. Ordinary reinforced concrete moment frames	3	3	2.5	NL	NL	NP

DUAL SYSTEMS: SPECIAL MOMENT FRAMESCAPABLE OF RESISTING AT LEAST 25% OFPRESCRIBED SEISMICFORCES (with bracing or shear wail)

1. Steel eccentrically braced frames	8	2.5	4	NL	NL	NL
2. Special steel concentrically braced frames	7	2.5	5.5	NL	NL	NL
3. Special reinforced concrete shear walls	7	2.5	5.5	NL	NL	NL
4. Ordinary reinforced concrete shear walls	6	2.5	5	NL	NL	NP

DUAL SYSTEMS: INTERMEDIATE MOMENT FRAMES CAPABLE OF RESISTING AT LEAST 25% OF PRESCRIBED SEISMIC FORCES (with bracing or shear wall)

1. Special steel concentrically braced frames	6	2.5	5	NL	NL	11
2. Special reinforced concrete shear walls	6.5	2.5	5	NL	NL	50
3. Ordinary reinforced masonry shear walls	3	3	3	NL	50	NP

Seismic Force-Resisting System	Response Reduction Factor ,R	System Over Strength Factor, Ω_o	Deflection Amplification Factor, C_d	Seismic Design Category B	Seismic Design Category C	Seismic Design Category D
				Height limit (m)		

A. BUILDING FRAME SYSTEMS (with bracing or shear wall)

1. Steel eccentrically braced frames, moment resisting connections at columns away from links	8	2	4	NL	NL	50
2. Steel eccentrically braced frames, non-moment-resisting, connections at columns away from links	7	2	4	NL	NL	50
3. Special steel concentrically braced frames	6	2	5	NL	NL	50
4. Ordinary steel concentrically braced frames	3.25	2	3.25	NL	NL	11
5. Special reinforced concrete shear walls	6	2.5	5	NL	NL	50
6. Ordinary reinforced concrete shear walls	5	2.5	4.25	NL	NL	NP
7. Ordinary reinforced masonry shear walls	2	2.5	2	NL	50	NP
8. Ordinary plain masonry shear walls	1.5	2.5	1.25	18	NP	NP

B. MOMENT RESISTING FRAME SYSTEMS (no shear wall)

1. Special steel moment frames	8	3	5.5	NL	NL	NL
2. Intermediate steel moment frames	4.5	3	4	NL	NL	35
3. Ordinary steel moment frames	3.5	3	3	NL	NL	NP

Seismic Force-Resisting System	Response Reduction Factor , R	System Over Strength Factor, Ω_o	Deflection Amplification Factor, C_d	Seismic Design Category B	Seismic Design Category C	Seismic Design Category D
				Height limit (m)		

4. Ordinary reinforced concrete shear walls	5.5	2.5	4.5	NL	NL	NP
F. DUAL SHEAR WALL-FRAME SYSTEM: ORDINARY REINFORCED CONCRETE MOMENT FRAMES AND ORDINARY REINFORCED CONCRETE SHEAR WALLS	4.5	2.5	4	NL	NP	NP
G. STEEL SYSTEMS NOT SPECIFICALLY DETAILED FOR SEISMIC RESISTANCE	3	3	3	NL	NL	NP

Notes:

1. Seismic design category, NL = No height restriction, NP = Not permitted. Number represents maximum allowable height 21 (m).

2. Dual Systems include buildings which consist of both moment resisting frame and shear walls (or braced frame) where both systems resist the total design forces in proportion to their lateral stiffness.

3. See Sec. 10.20 of Chapter 10 of this Part for additional values of R and C_d and height limits for some other types of steel structures not covered in this Table.

4. Where data specific to a structure type is not available in this Table, reference may

be made to Table 12.2-1 of ASCE 7-05.

5. Dual Systems include buildings which consist of both moment resisting frame and shear walls (or braced frame) where both systems resist the total design forces in proportion to their lateral stiffness.

3.2.5 Statement of Project Salient Features:

Table 3.12 : Statement of project Salient features

Utility of Building	Residential Purpose
1. Number of Stories	Ten Storied
2. Shape of Building	Rectangle
3. Number of Staircase & Lift	01
4. Types of Construction	R.C.C framed Structure
5. Types of Walls	Bricks wall

Geometric Details:

Table 3.13 : Statement of project Geometric Details

1. Ground Floor	10ft
2. Floor to Floor height	10ft
3. Height of plinth	2ft

BNBC-2020 Table 6.C.1: Parameters S_s And S_1 for Different Seismic Zones

Parameters	Zone-1	Zone-2	Zone-3	Zone-4
S_s	0.3	0.5	0.7	0.9
S_1	0.12	0.2	0.28	0.36

S_1=0.4S_s not independent of S_s,
as in ASCE 7-05 S_1= MCE-level PGA = Z,
Seismic Zone Coefficient

3.3 Load Groups: All possible live loads applied on floors and roof of a building due to various occupancies and uses, shall be divided into three load groups as described below for determining the appropriate live load reduction factors

1. Load Group I: Uniformly distributed live loads arising from occupancies and uses such as assembly areas with live loads of 5.0 kN/m² or less, machinery and equipment with specifically allocated live load allowances, special roof live loads, and facilities including printing plants, vaults, strong rooms, and armories shall be classified under Load Group I.

For structural members or portions thereof subjected to this load group, no reduction in live load shall be permitted. A reduction factor R=1.0 must be applied as per standard design practice.

2. Load Group II: Uniformly distributed live loads resulting from the following occupancies or uses shall be classified under Load Group II:

(i) Assembly areas with a uniform live load greater than 5.0 kN/m²

(ii) Storage, mercantile, industrial, and retail stores

For this load group, a live load reduction factor (R) in the range of 1.0 > R > 0.7 shall be applied. The exact value depends on the tributary area of the floor or roof supported by the structural member, as specified by the applicable building code provisions.

3. Load Group III: Load Group III includes uniformly distributed live loads arising from all other occupancies and uses not covered under Load Group I or Load Group II. For this group, a live load reduction factor (R) ranging from 1.0 > R > 0.5 shall be applied. The specific value depends on the tributary area of the structure being supported, as outlined in relevant building codes.

Tributary Area

The **tributary area** of a structural member represents the portion of a floor or roof that contributes load to that member and is determined as follows:

- **a) For Walls, Columns, Piers, Footings, and Similar Elements**:
  The tributary area includes portions of all floors, roofs or combinations there of that transfer live loads to the specific structural element.
- **b) For Beams, Girders, Flat Plates, and Flat Slabs**:
  The tributary area consists of that portion of the roof or floor at a single level that delivers loads to the beam or slab in question.

Exposure Category

The **exposure category** defines the type of terrain surrounding a building, which influences wind pressure calculations and overall structural design:

- **Exposure A**:
  Includes urban, suburban, industrial, or wooded areas, or hilly terrain where at least 20% of the area is covered by obstructions 6 meters or taller, extending 500 meters or 10 times the structure height (whichever is greater) from the site.
- **Exposure B**:
  Refers to open terrain with scattered obstructions generally less than 10 meters in height. Examples include airfields, parks, outskirts of towns, and grasslands, extending 800 meters or more in any full quadrant from the site.
- **Exposure C**:
  Includes flat and unobstructed open terrain, such as coastal regions and riversides facing large bodies of water (1.5 km or more in width)**.** Exposure C extends 400 meters or 10 times the height of the structure (whichever is greater) inland from the shoreline.

3.4 Load Combinations:

Load combinations are used in structural analysis and design to consider the simultaneous effects of different types of loads on a structure. The following load combinations can be used to analyze wind load and seismic effects on low-rise and high-rise multistory structures according to the Bangladesh National Building Code (BNBC) 2020.

As per BNBC 2020, Chapter 2- Part 6 , following load cases must be considered for analysis:

1. 1.4 D.L

2. 1.4 DL + 1.6 L.L+ 0.5Lr

3. 1.2 D.L + 1.6 Lr + L.L

4. 1.2 D.L+1.6 Lr + 0.8W

5. 1.2 D.L + 1.6 W + L + 0.5 Lr

6. 1.2 D.L + E.L+ L.L

7. 0.9 DL + 1.6 WL

8. 0.9 D.L + E.L

Earthquake load and Wind Load must be considered for +X, -X, +Y and-y directions. Thus, + EL and + WL above implies 24 cases, and in all, 26 cases as per Table 3.6 must be considered. All 31 load combinations are analyzed using software.

It is important to consult the specific provisions of the BNBC 2020 and any local design codes applicable to your region for the most accurate and up-to-date load combinations.

(1) 1.4D	(1)	1.4D
(2) 1.2D+1.6L+0.5Lr	(2)	1.2D+1.6L+0.5Lr
(3) 1.2D+1.6Lr+L	(3)	1.2D+1.6Lr+L
(4) 1.2D+1.6Lr+0.8W	(4)	1.2D+1.6Lr+0.8Wx
	(5)	1.2D+1.6Lr-0.8Wx
	(6)	1.2D+1.6Lr+0.8Wy
	(7)	1.2D+1.6Lr-0.8Wy
(5) 1.2D+1.6W+L+0.5Lr	(8)	1.2D+1.6Wx+L+0.5Lr
	(9)	1.2D-1.6Wx+L+0.5Lr
	(10)	1.2D+1.6Wy+L+0.5Lr
	(11)	1.2D-1.6Wy+L+0.5Lr
(6) 1.2D+E+L	(12)	1.277D + Ex + 0.3Ey + L
	(13)	1.277D + Ex - 0.3Ey + L
	(14)	1.277D - Ex + 0.3Ey + L
	(15)	1.277D - Ex - 0.3Ey + L
	(16)	1.277D + 0.3Ex + Ey + L
	(17)	1.277D + 0.3Ex - Ey + L
	(18)	1.277D - 0.3Ex + Ey + L
	(19)	1.277D - 0.3Ex - Ey + L
(7) 0.9D+1.6W	(20)	0.9D+1.6Wx
	(21)	0.9D-1.6Wx
	(22)	0.9D+1.6Wy
	(23)	0.9D-1.6Wy
(8) 0.9D+E	(24)	0.823D + Ex + 0.3Ey
	(25)	0.823D + Ex - 0.3Ey
	(26)	0.823D - Ex + 0.3Ey
	(27)	0.823D - Ex - 0.3Ey
	(28)	0.823D + 0.3Ex + Ey
	(29)	0.823D + 0.3Ex - Ey
	(30)	0.823D - 0.3Ex + Ey
	(31)	0.823D - 0.3Ex - Ey

Figure 3.2: Load Combinations

3.5 Design data:

Load Consideration: BNBC 2020 for Zone 2.

3.5.1. Dead Load: (for Zone -2)

Floor Finish (FF)	: 15 psf
External Wall	: 376 1b/ft (8.75 ft) (Weight 16 kN/m^3)
External Wall	: 4451b/ft (8.75 ft) (Weight18.9 KN/m^3)
Parapet wall	:129 psf(3ft)
Parapet wall	:153 psf(3ft)
Partition wall (PW)	:376 1b/ft (8.75 ft)
Partition wall (PW)	:445 1b/ft (8.75 ft)

3.5.2. Live Load:

Floor	: 2KN/m^2 or 41.78 psf
Stair	: 4.8KN/m^2 or 100 psf
Roof Over	: 3.9 KN/m^2 or 60.58 psf
Head Water Tank	: 312 psf

3.5.3 Wind Pressure (BNBC 2020)

Location	: Dhaka
Basic Wind speed V	: 147 mph
Structural Important Coefficient	: 1.0
Expose Category	: B
Gust Factor	: 0.85
Windward Coefficient	: 0.80
Leeward Coefficient	: 0.50

3.5.4. Earthquake Category Base Shear (BNBC 2020)

Seismic Zone	: Zone II
Seismic Zone factor (Z)	: 0.20
Response Reduction Factor, R	: 8
System Over strength Ω (omega)	: 3

Deflection Amplification, C_d	: 5.5
Structural Importance Factor (1)	: 1.0
Site Coefficients, S	: 1.2
Time Period, T	: 0.41 sec
Seismic Zone	: Zone II
Seismic Zone factor (Z)	: 0.20
Response Reduction Factor, R	: 8

Material Properties:

Unit weight of concrete	: 1501b/ft

Compressive Strength:

For slab, f_c	: 3500 psi
For beam, f_c '	: 3500 psi
For Column: f_c '	: 3500 psi
Steel: Yield strength of Steel, f_y	: 60 ksi

3.6 Auto CAD Model:

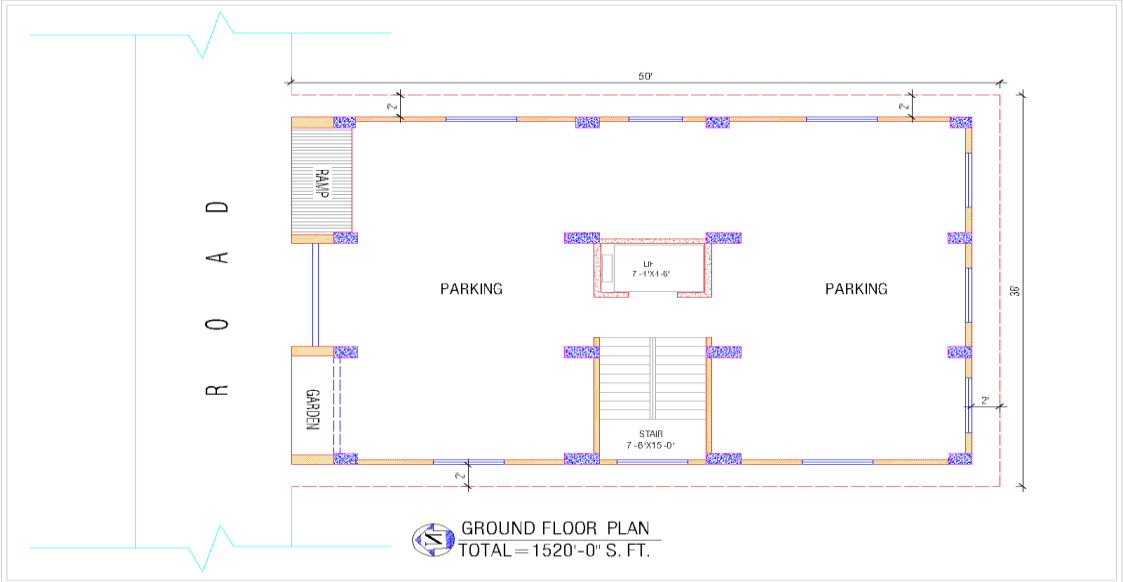


Figure: 3.3 Architectural Plan Ground Floor

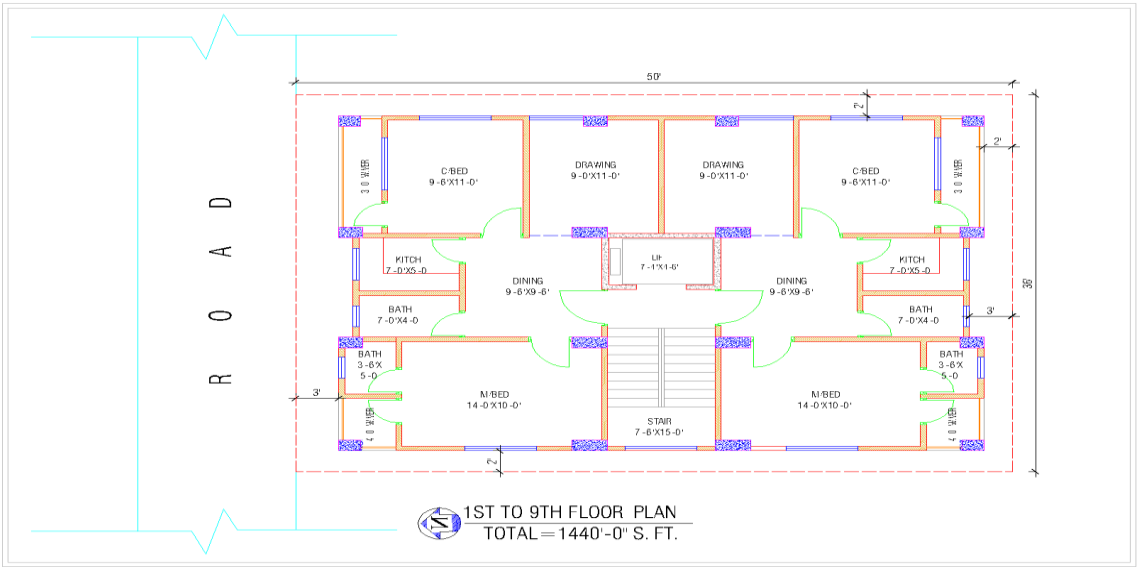


Figure: 3.4 Architectural Plan 1St to 9TH Floor

3.7 Column & Beam Layout:

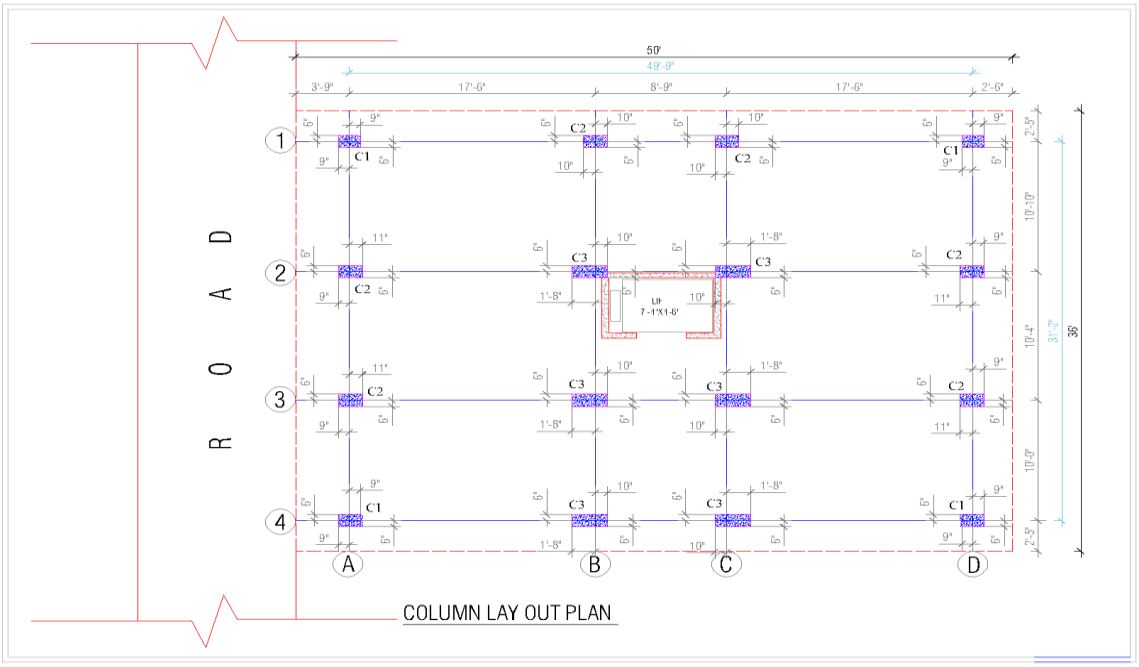


Figure: 3.5 Column layout

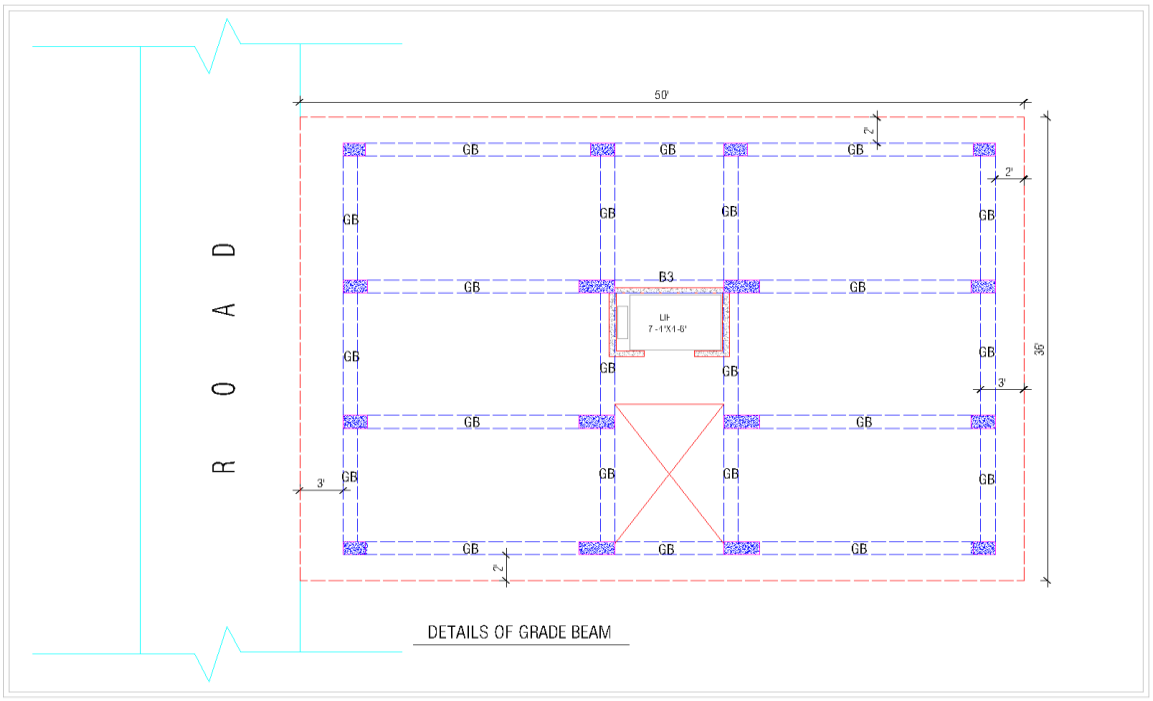


Figure 3.6 Grade Beam layout

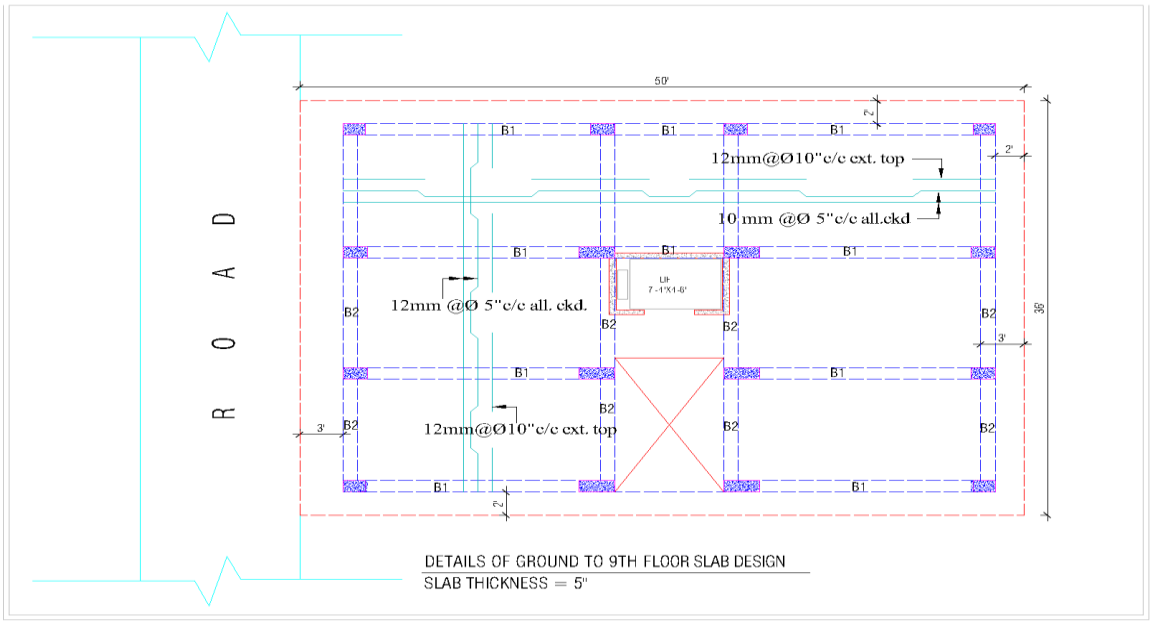


Figure 3.7 Floor Beam Layout

3.8 Beam Section :

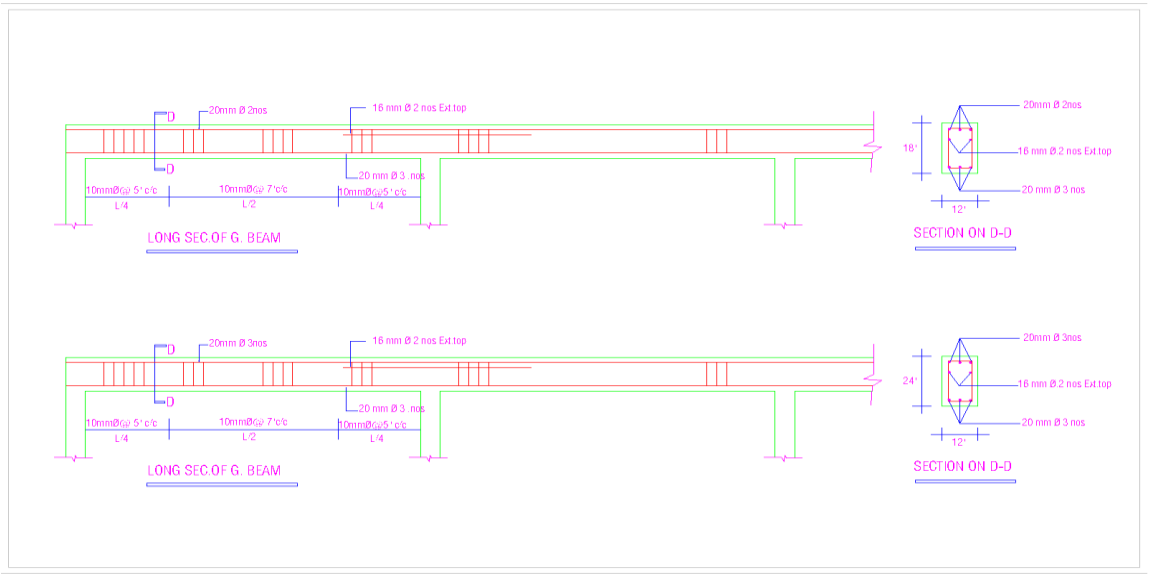


Figure 3.8 Grade Beam Section

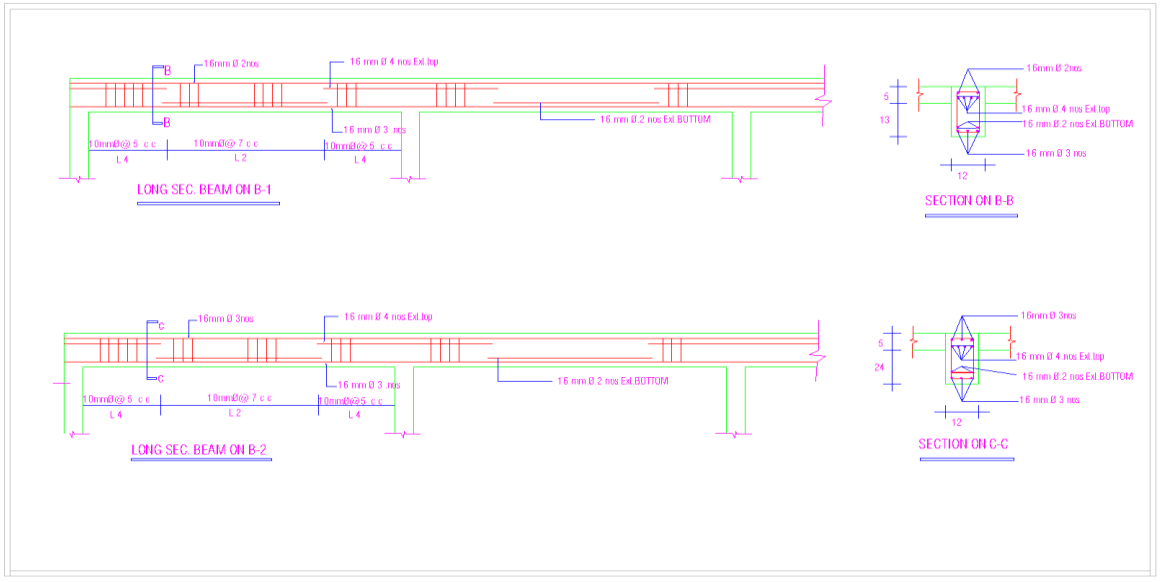


Figure 3.9 Floor Beam Section

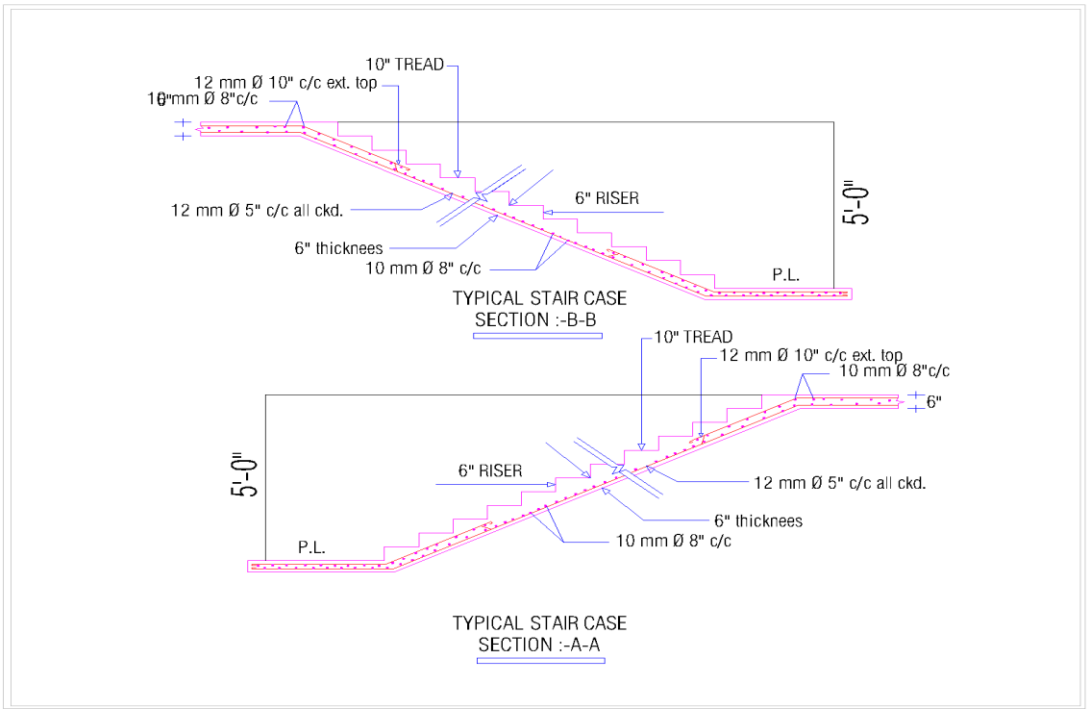


Figure: 3.10 Stair Section

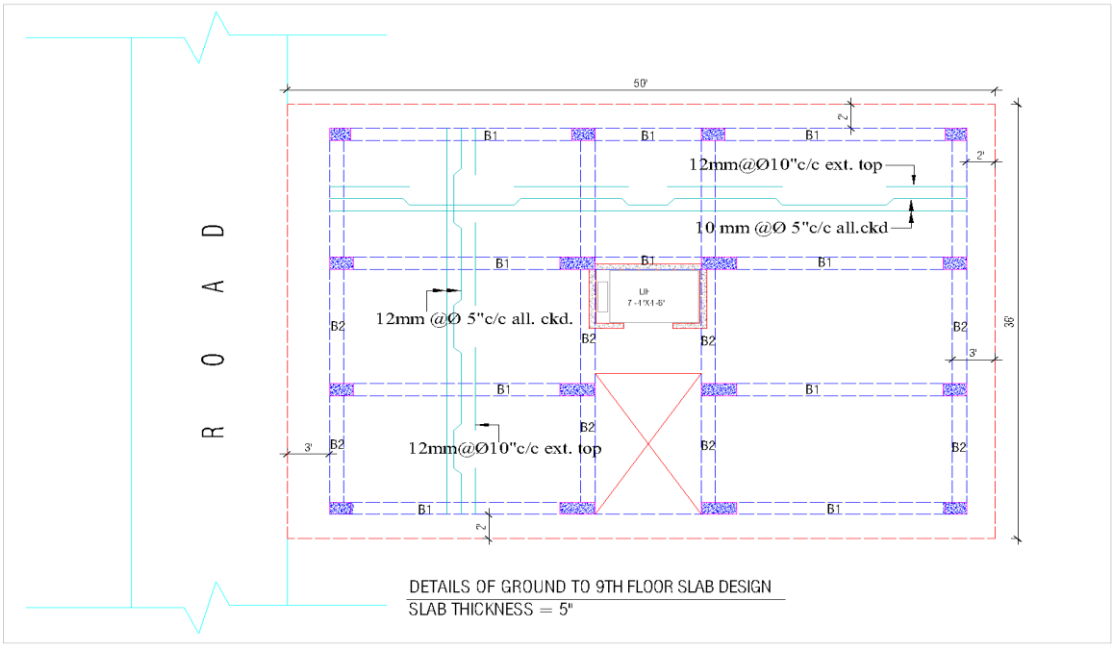


Figure: 3.11 Slab Reinforcement

3.9 Model with EATBS:

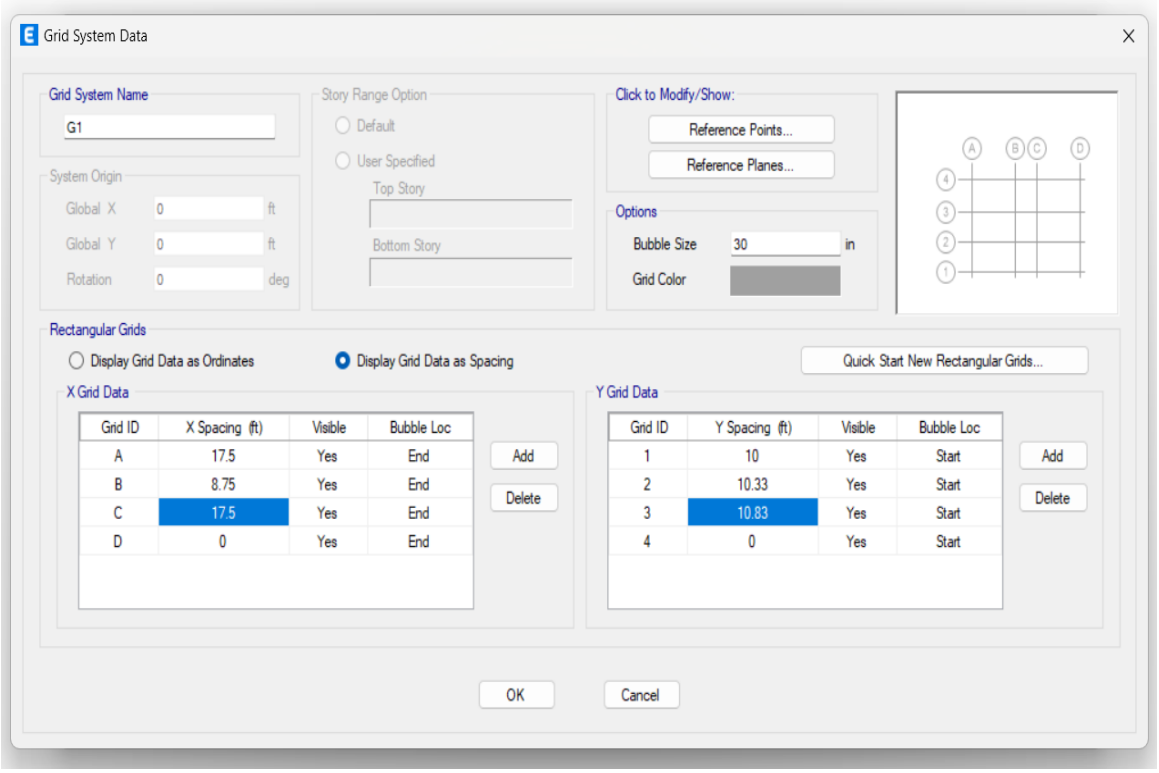


Figure: 3.12 Grid selection of the Model

- File> New model
- If it is uniform grid then file up the "Uniform grid Spacing" Box
- Input number of grid in X,Y direction
- Take number of Stories
- Change unit to kip-ft.
- Input typical of stories
- Input bottom story height
- If the grid is not uniform, then go to the Custom Grid Spacing
- Edit Grid
- Cheek Spacing

- Cheek glue to grid lines
- Input spacing of grid in X,Y direction
- Ok

3.9.2 Define Materials Properties and Frame Section:

Materials Properties: Materials Properties refer to the physical and mechanical characteristics of the materials used in the structural analysis and design process. In ETABS, you define these properties to accurately represent the behavior of different materials such as concrete, steel, wood, etc. Some common material properties include.

Frame Section: In ETABS, a "Frame Section" refers to the cross-sectional properties of the structural members, such as beams and columns, within the analyzed frame elements of a building or structure. These properties define the shape, dimensions, and material properties of the sections, which are essential for accurately analyzing and designing the structural members.

ETABS uses these section properties to calculate the member's stiffness, resistance to bending, shear, and torsion, and other relevant properties required for structural analysis and design.

- **Materials Properties**
    i. Concrete
    ii. Modify if need

- **Frame Section**
    i. Select all existing property
    ii. Delete all
    iii. Add rectangle/Circle
    iv. For beam

v. Select Reinforcement

vi. Then select beam

vii. Define all frame section in this process

By properly defining materials properties and frame sections in ETABS, you can accurately model and analyze the behavior of the structure and obtain reliable results for further design and evaluation purposes.

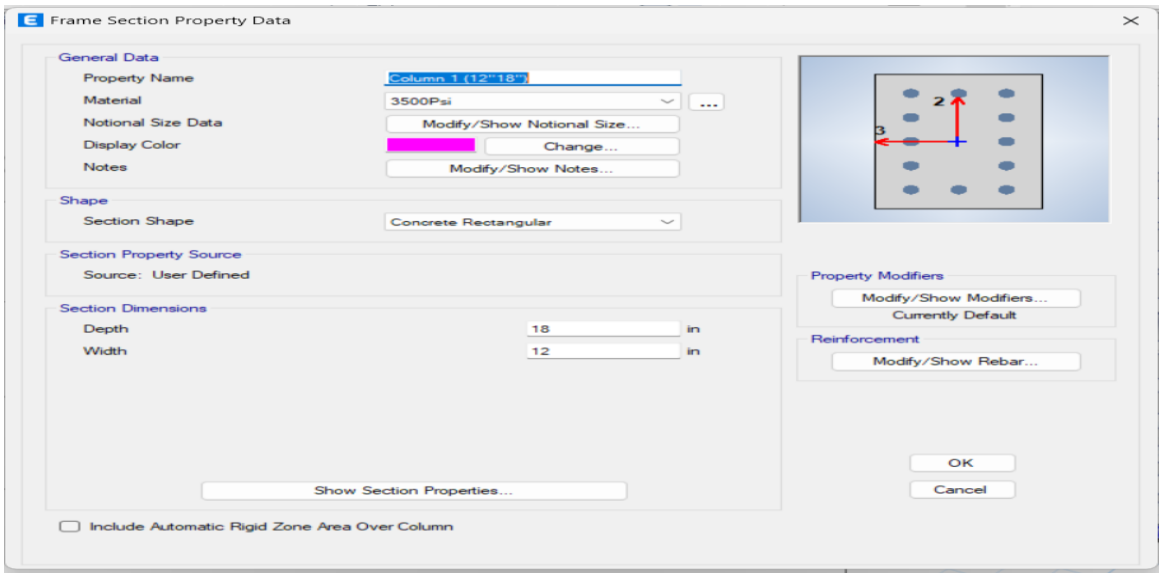


Figure: 3.13 Frame Section property Column

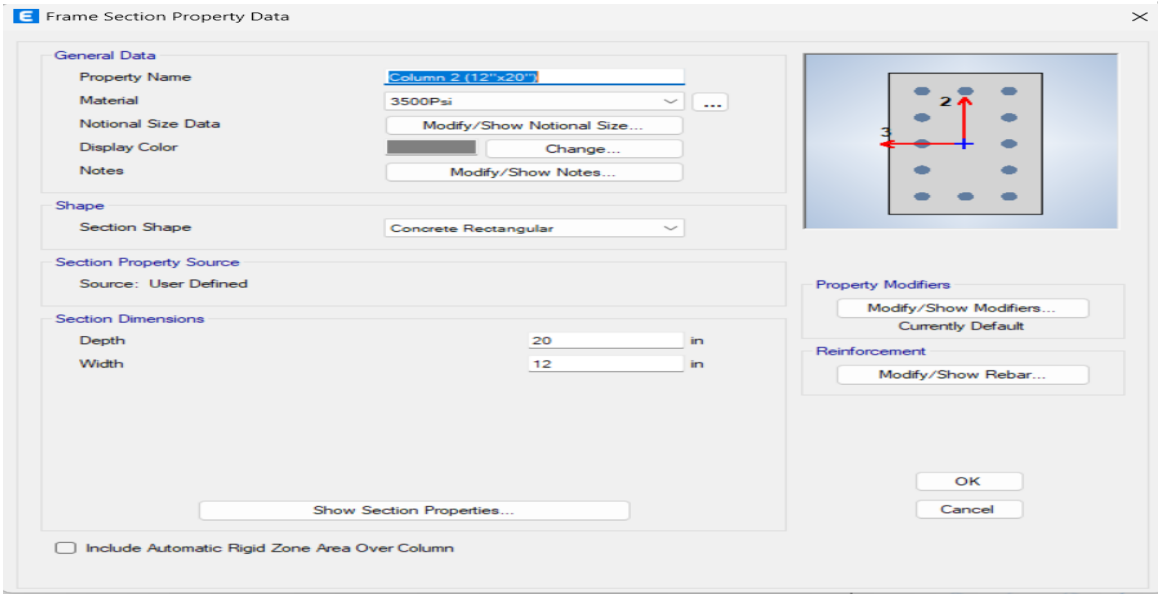


Figure 3.14 Frame Section property Column

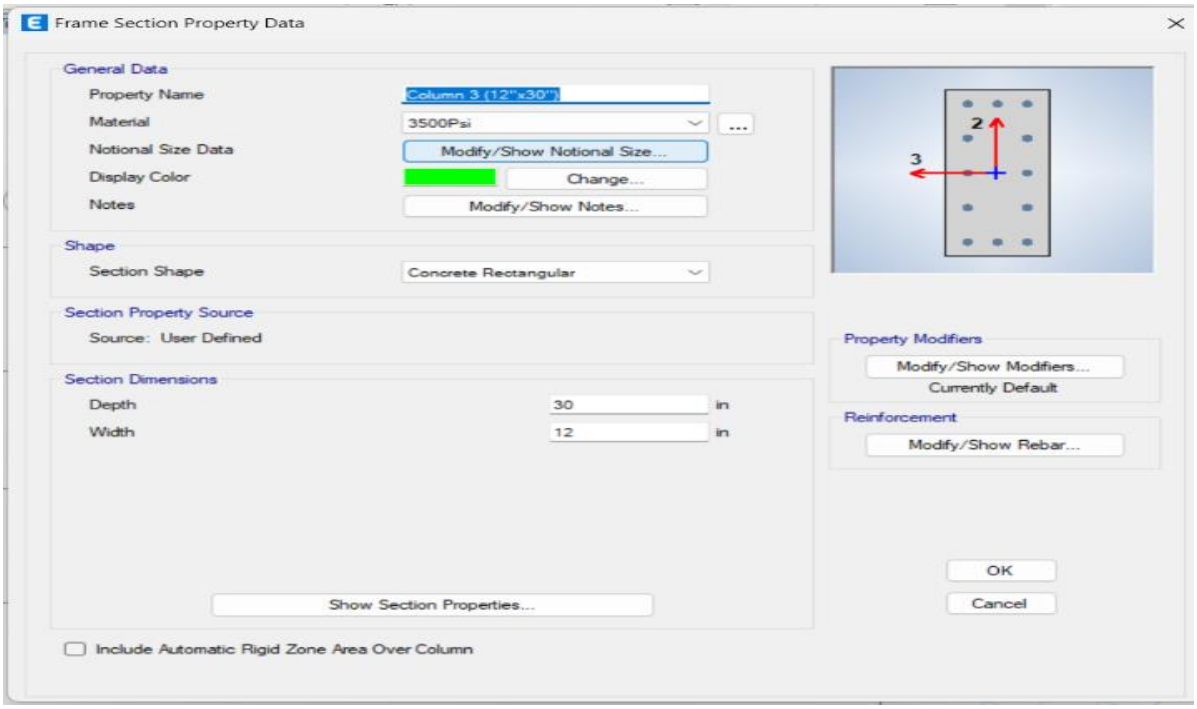


Figure 3.15 Frame Section property Column

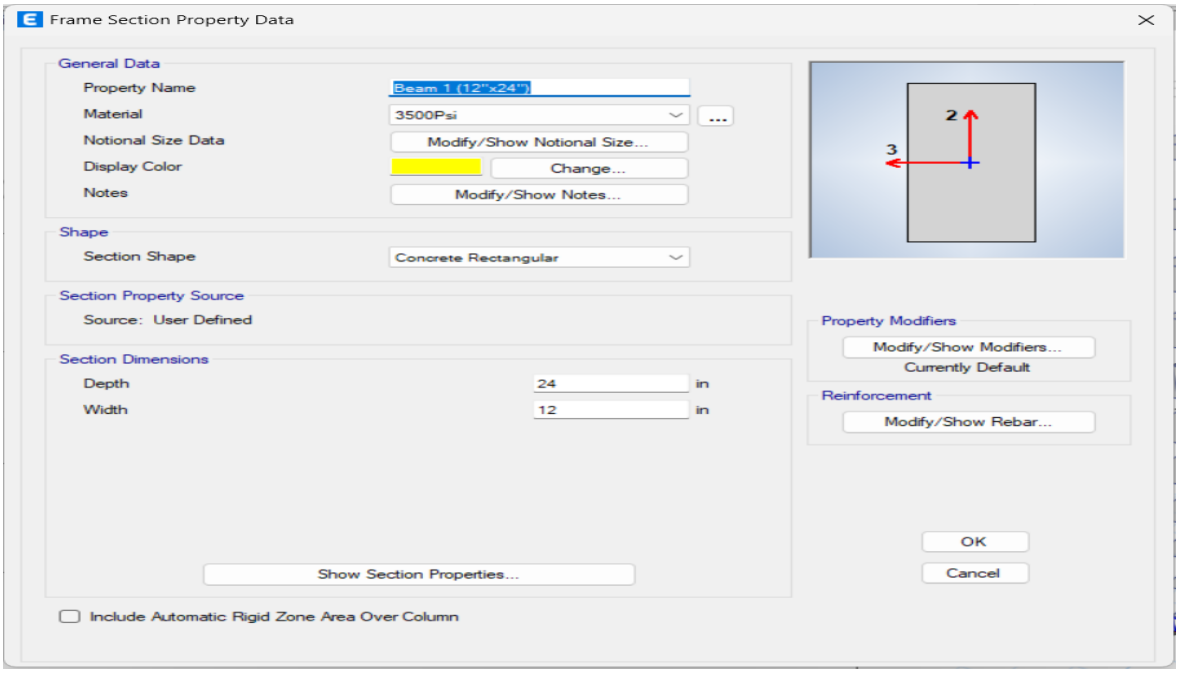


Figure 3.16 Frame Section property Beam

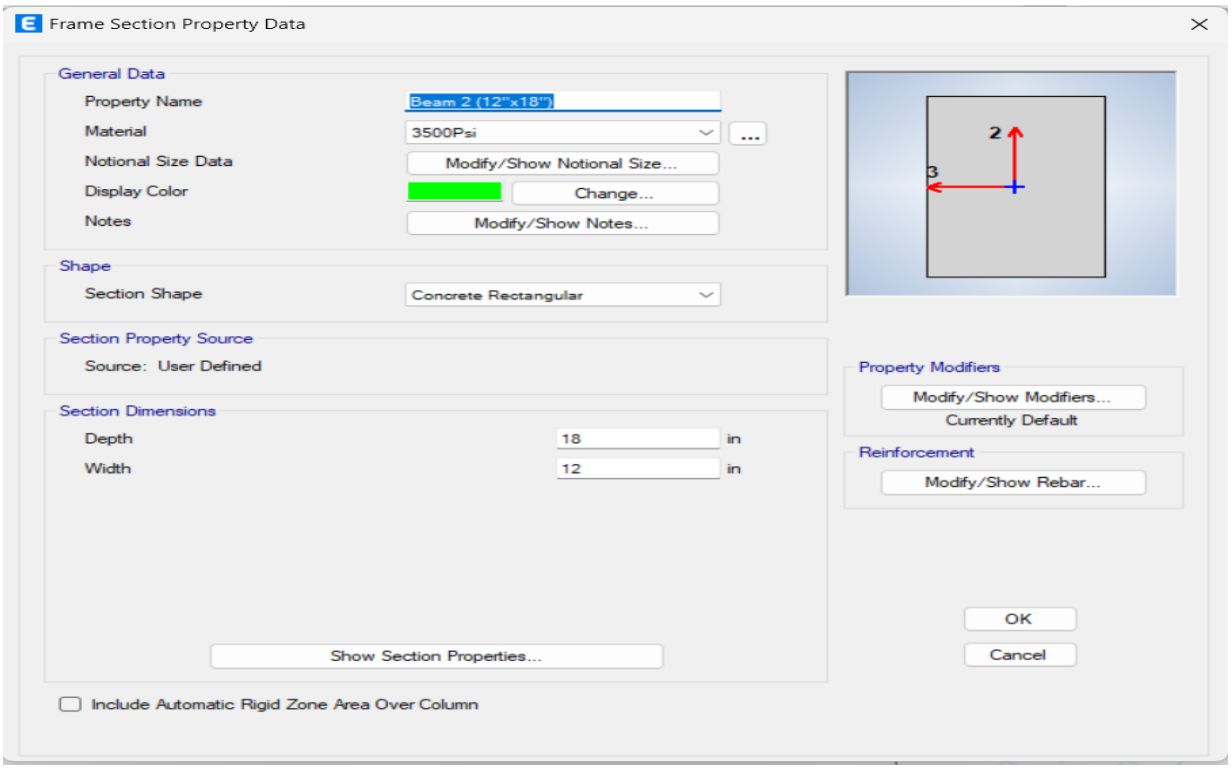


Figure: 3.17 Frame Section property Beam

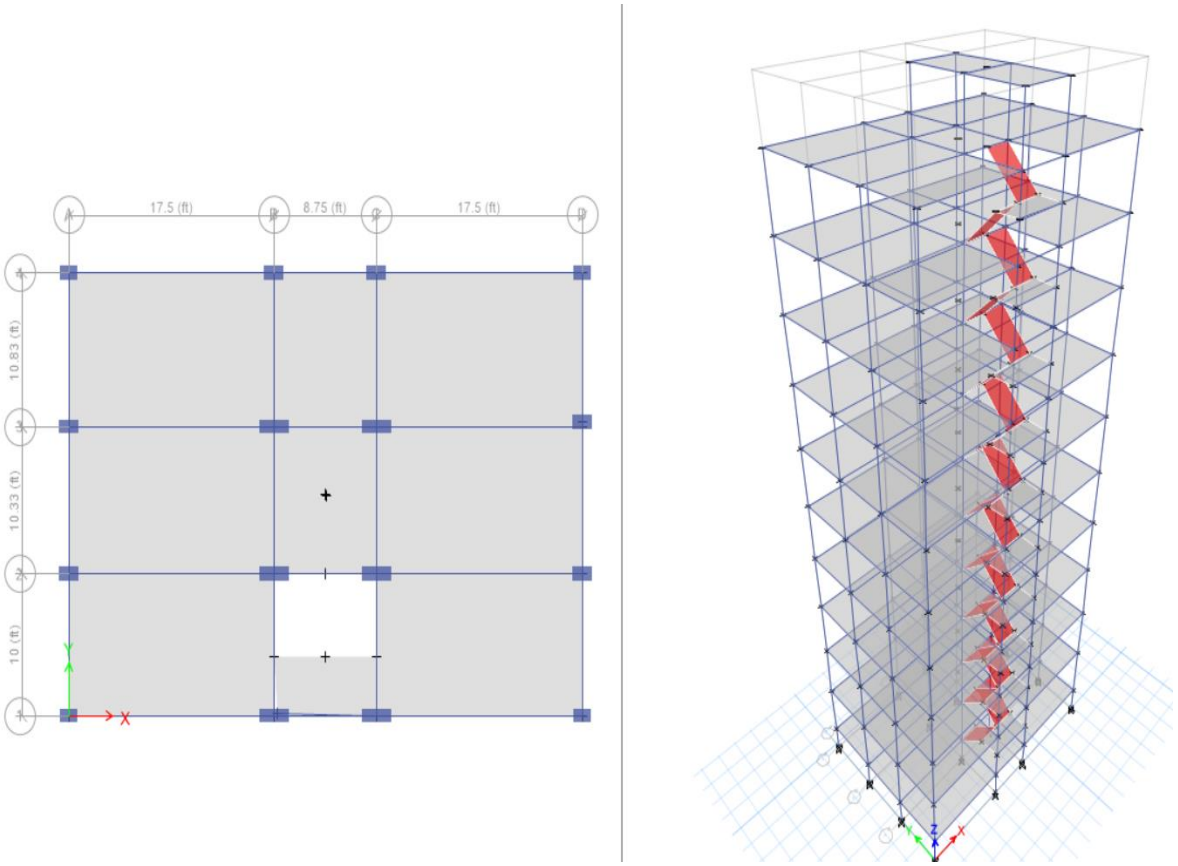


Figure 3.18 Drawn different section

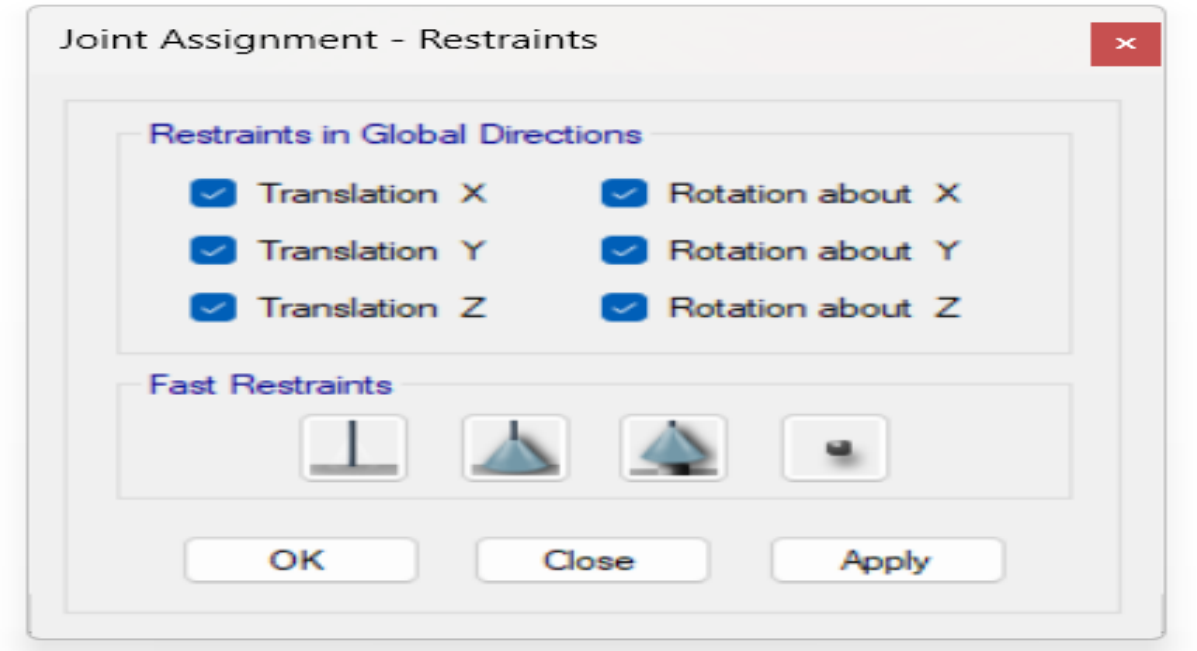


Figure 3.19 Assigning of supports

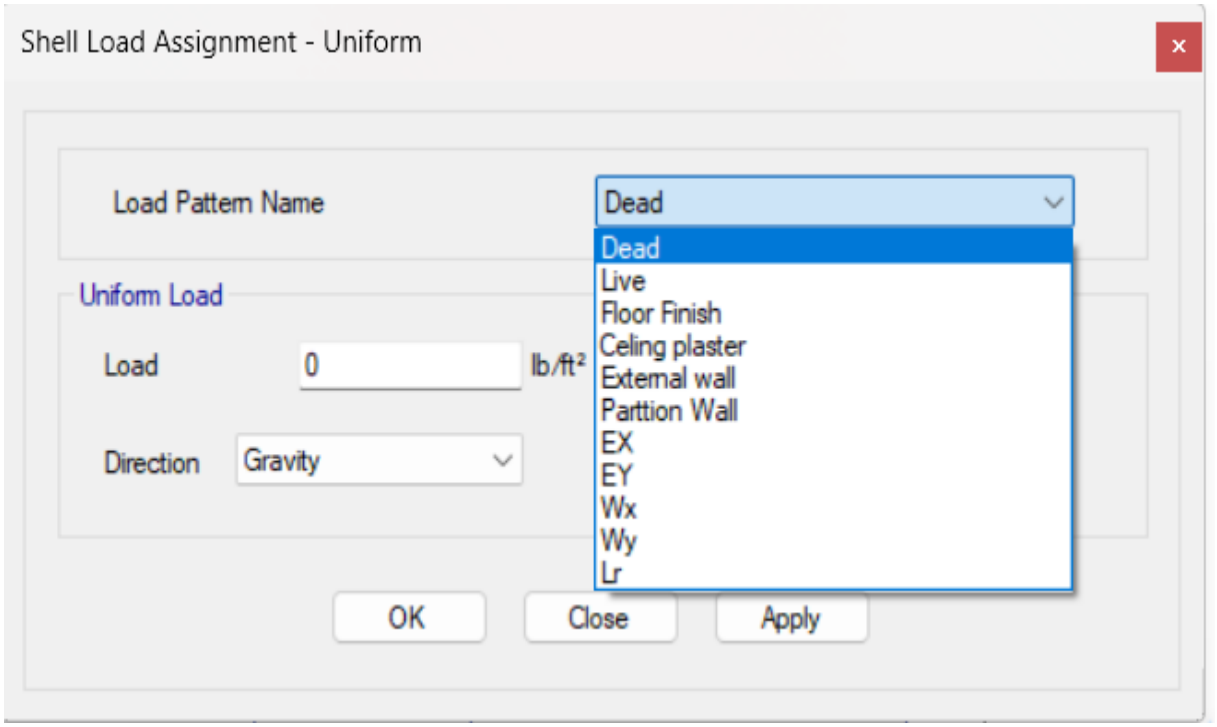


Figure 3.20 Assigning Load

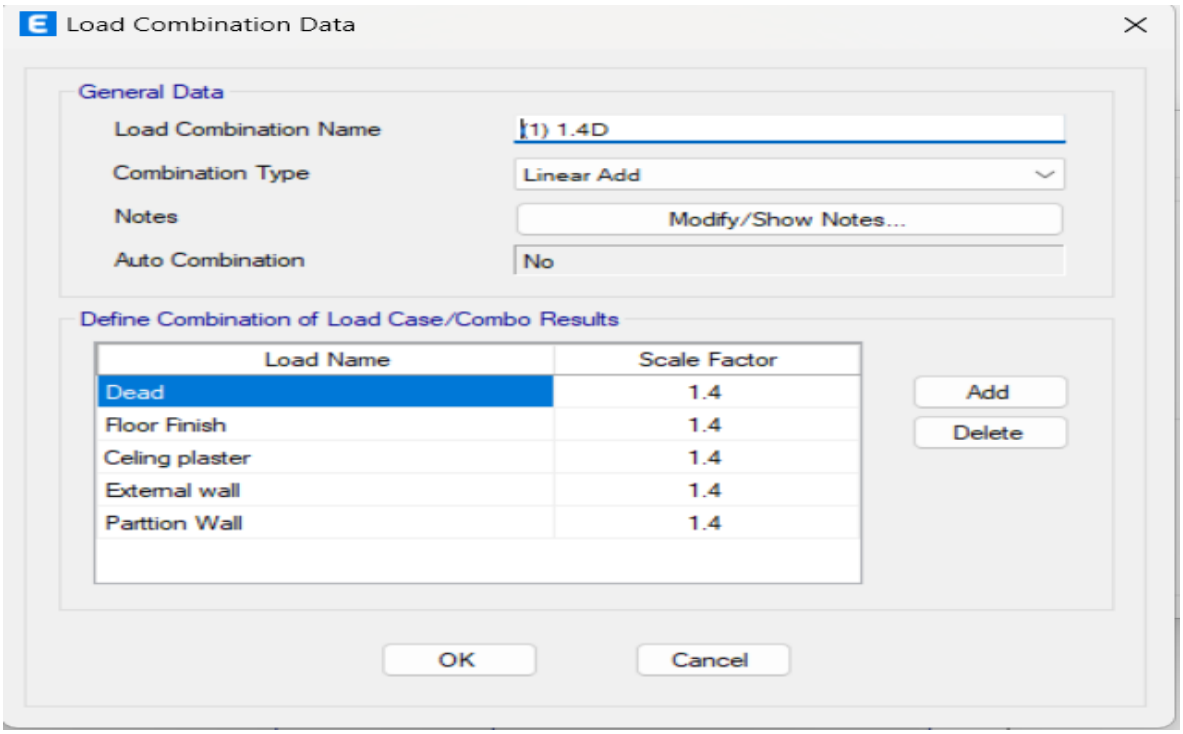


Figure 3.21 Assigning Load Combination

Mass Source: The Mass Source feature in ETABS allows you to define the mass properties of different structural elements such as beams, columns, slabs, walls, and other components. It helps in creating a realistic model by accounting for the mass distribution of the structure.

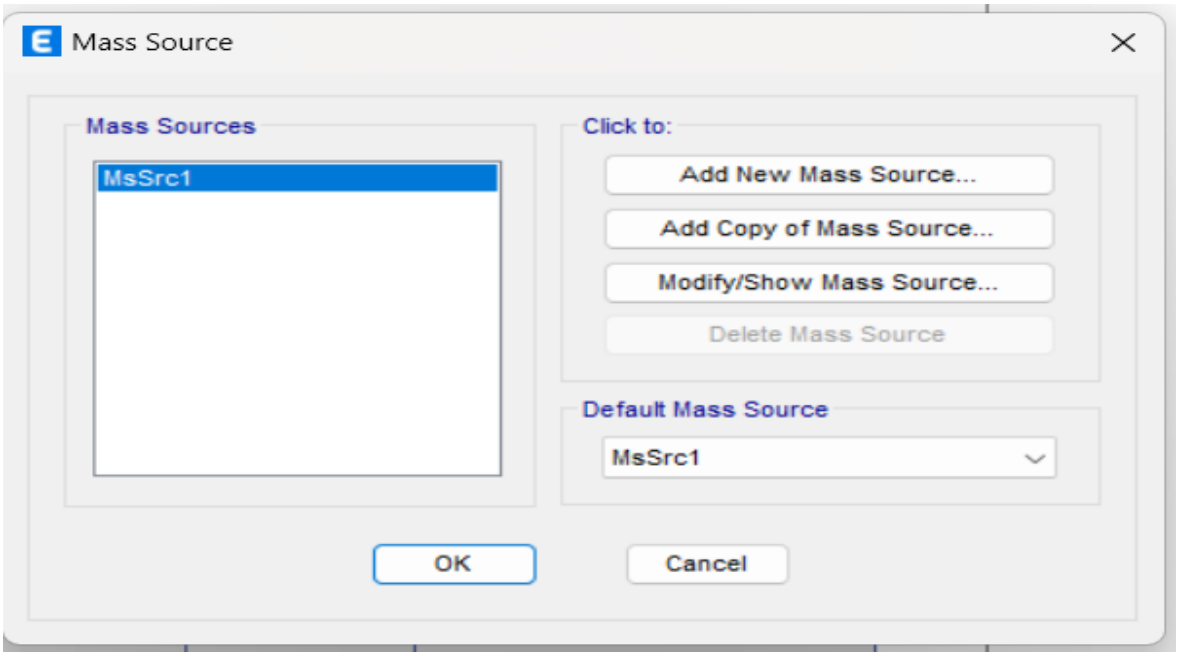


Figure: 3.22 Mass Source Data

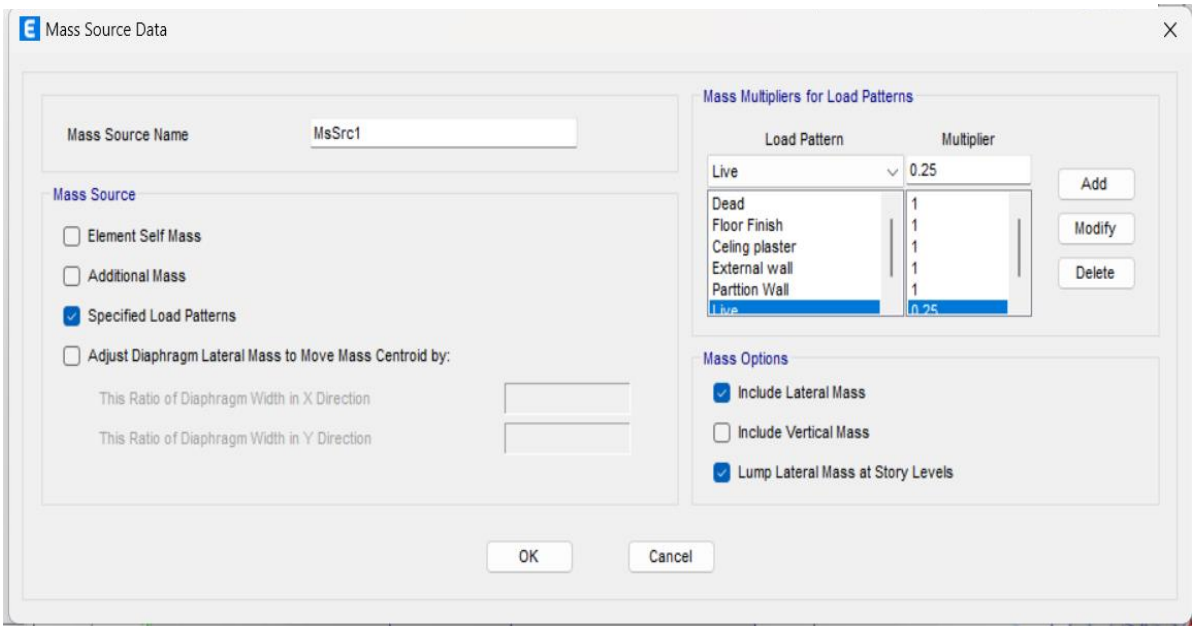


Figure: 3.23 Mass Multipliers

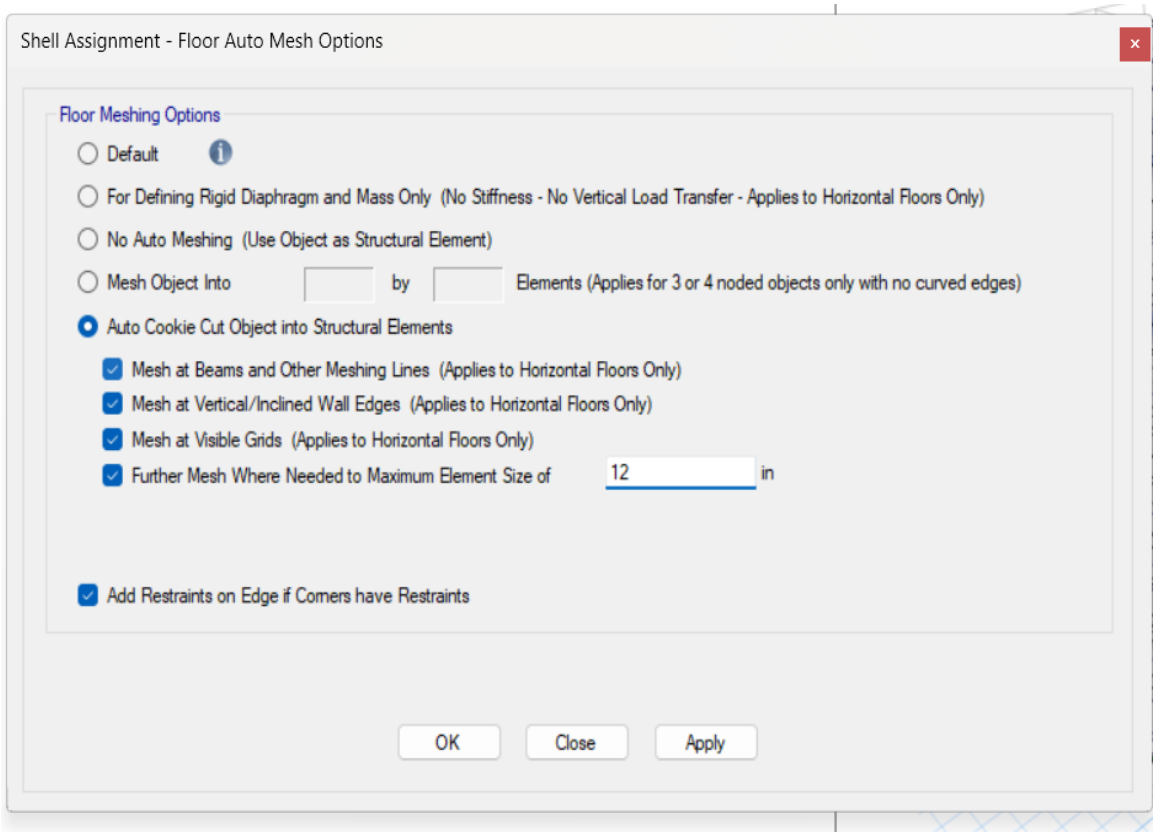


Figure 3.24 Auto Mesh

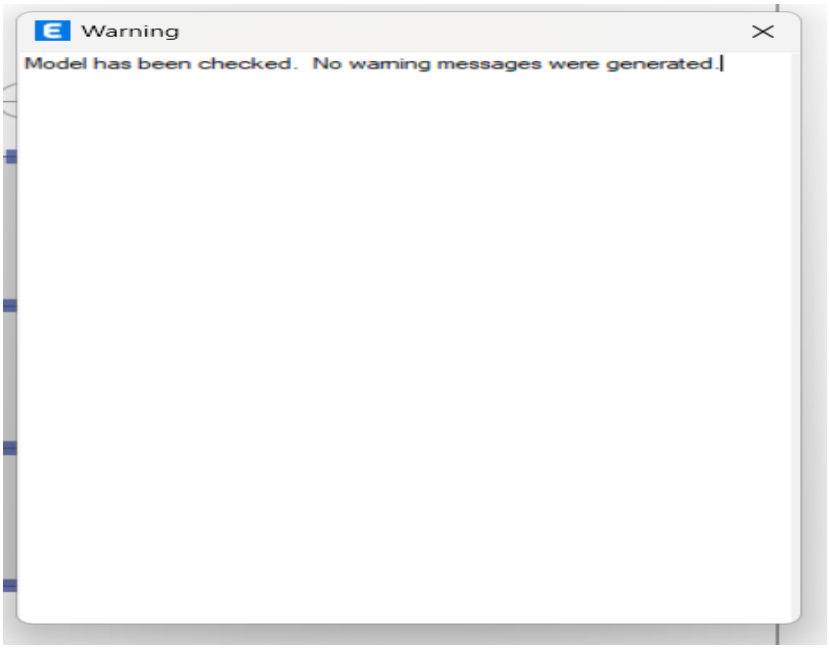


Figure 3.25 Check Model

3.9.6 DEFLECT SHAPE OF THE MODEL:

To check error in data input for lateral load click Display-show table and select the item and cheek the earth quack load in X,Y direction

To show deflect Shape select the 3D view window &click show deformed shape icon from display window.

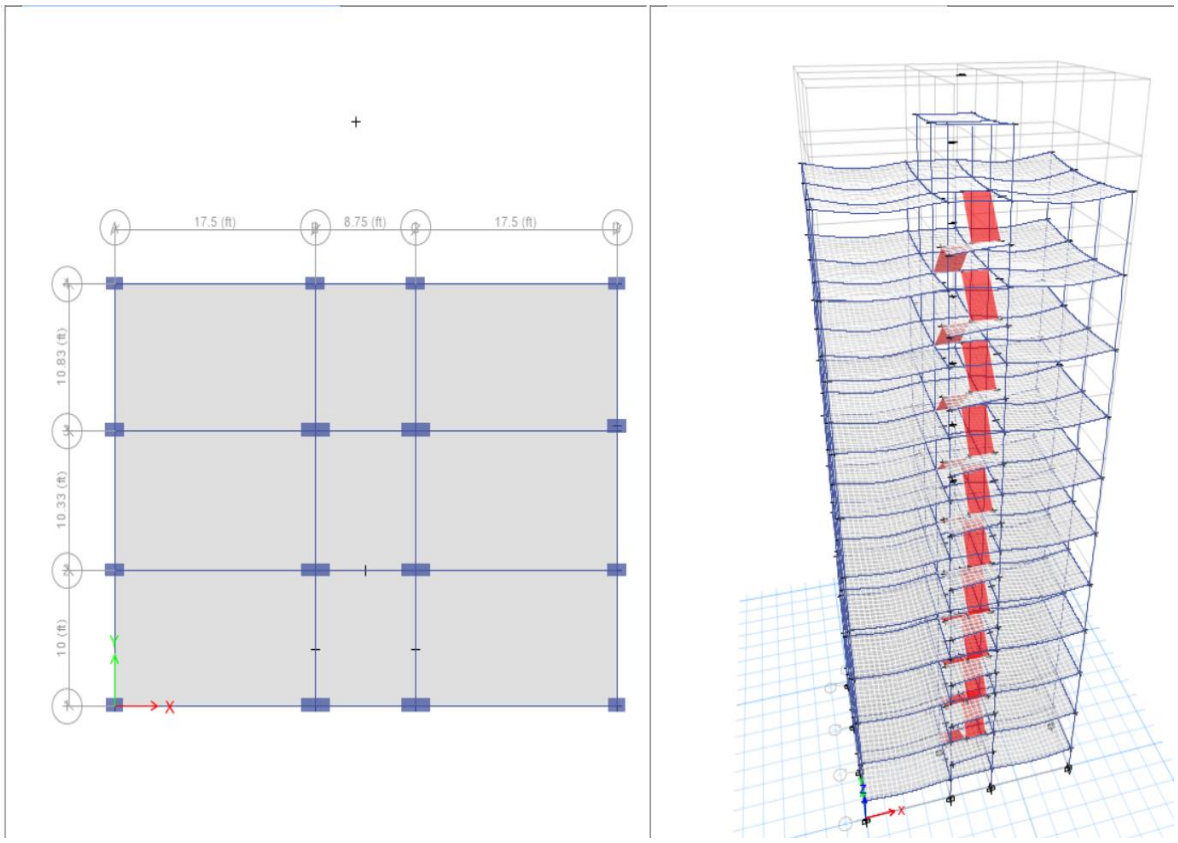


Figure: 3.26 Deflected Shape of the Model

3.9.7 Structure Need to Complete the Following Steps.

1. Open the ETABS window
2. Click new from main bar

3. Chose default from new model initialization window
4. Modify data from Building Plan Grid system and story data definition window
5. Click set plan view icon firm main toolbar and select plan view
6. Define load cases

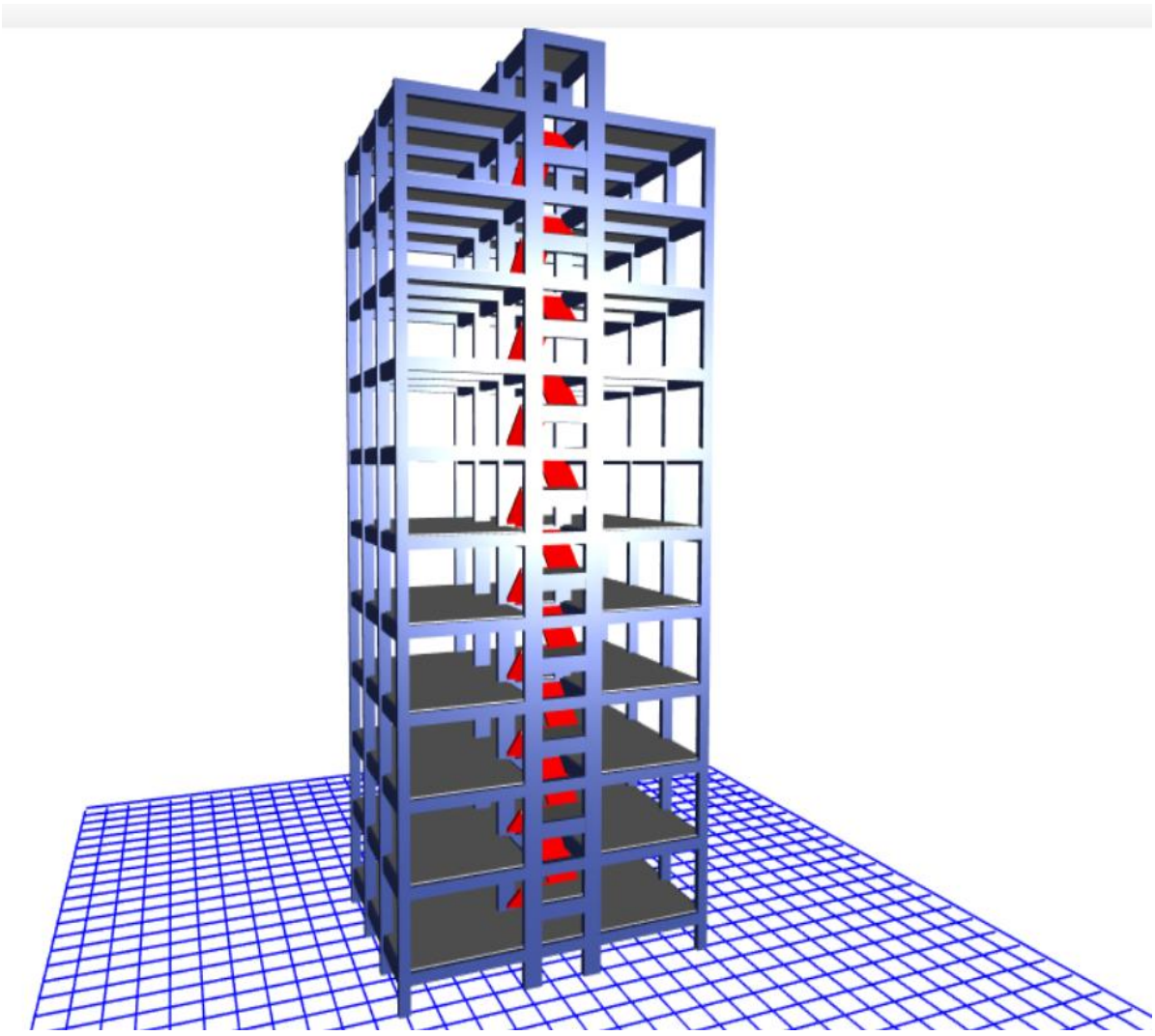


Figure: 3.27 3D Model

CHAPTER 04

RESULT AND DISCUSSION

4.1 Introduction

"In this chapter, the results of the model have been presented and discussed. From the comparison, it is evident that there are significant differences in the design methods and formulas used for conventional building and Light Weight buildings as per BNBC 2020 when analyzed using ETABS."

4.2 Design Results

SFD and BMD of Conventional Building

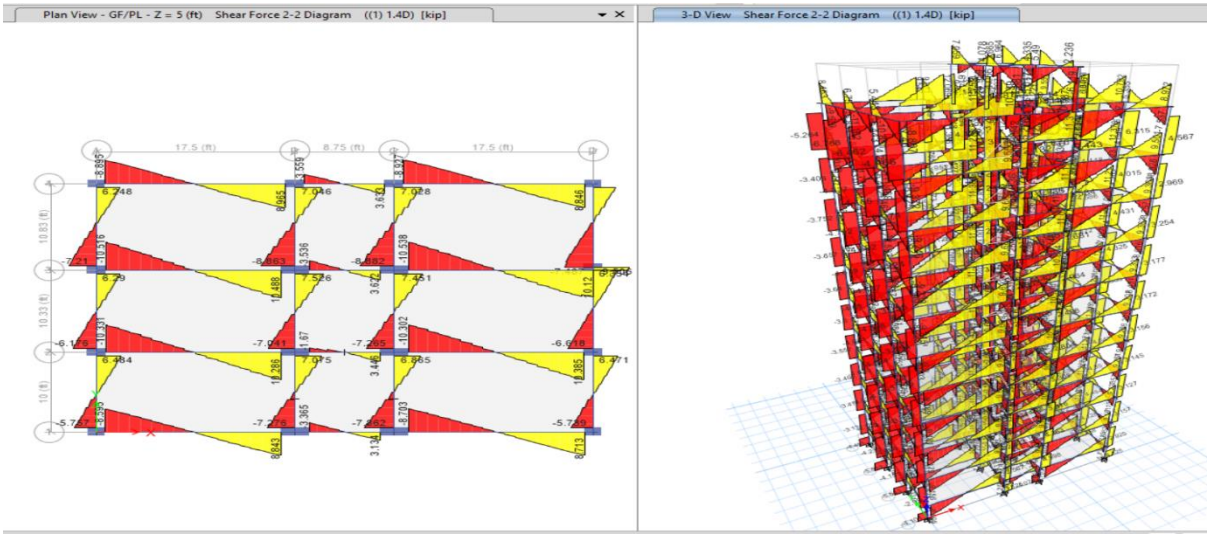


Figure: 4.1 SFD of Conventional Building

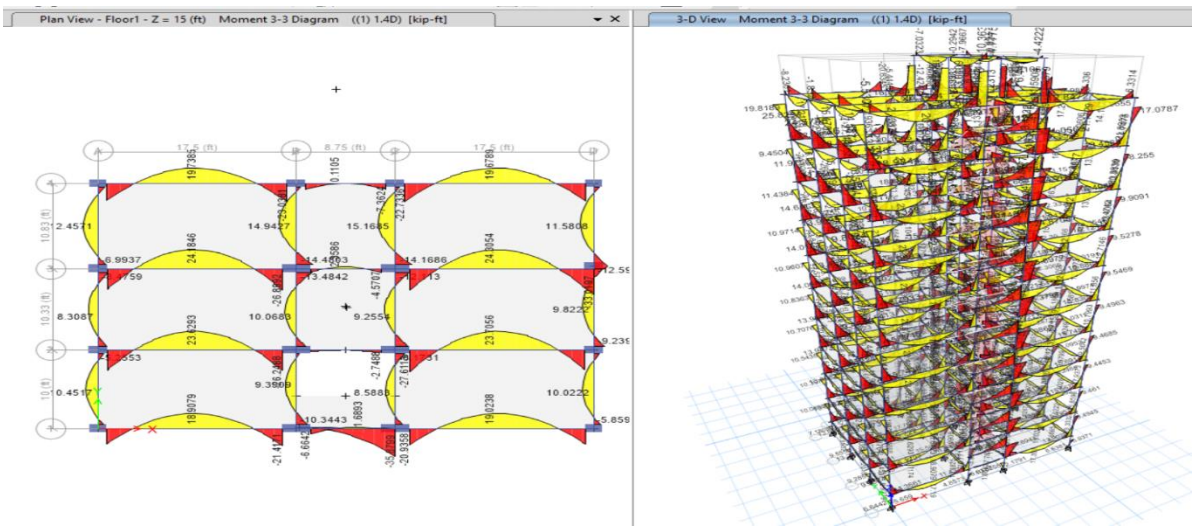


Figure: 4.2 BMD of Conventional Building

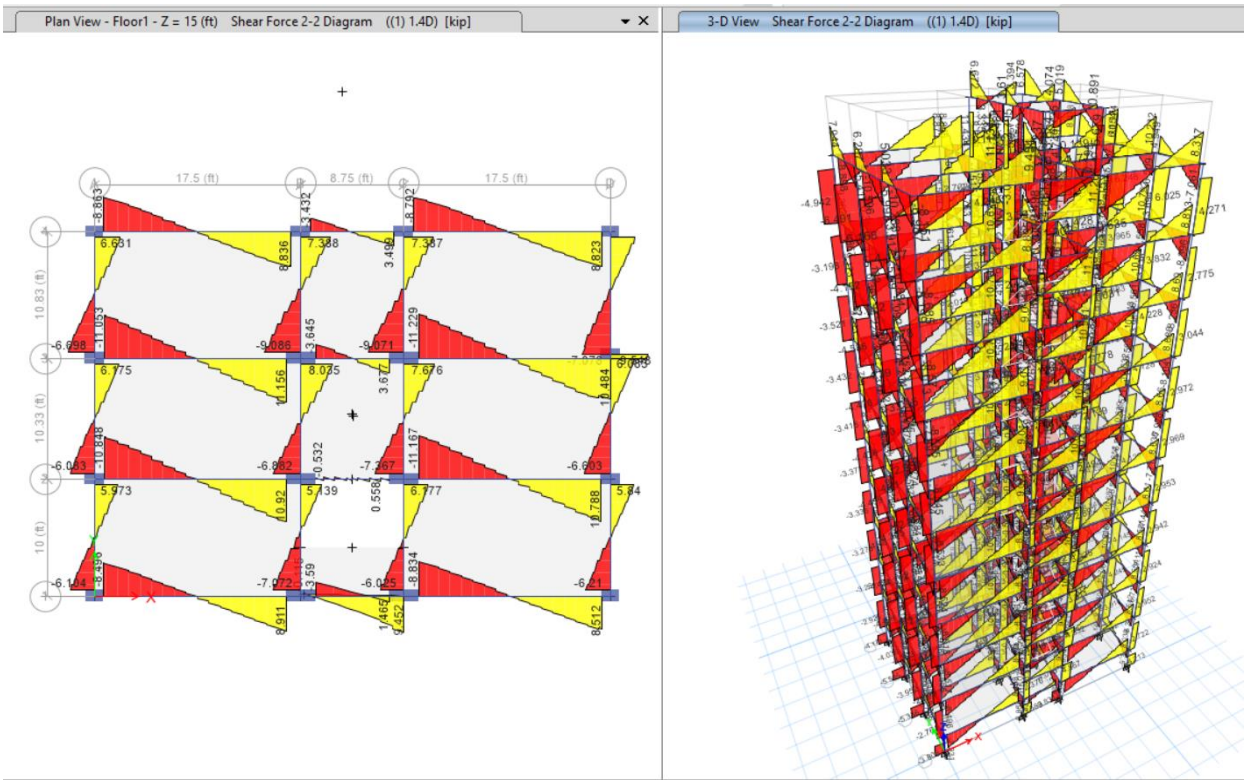


Figure: 4.3 SFD of Light weight Concrete Block Building

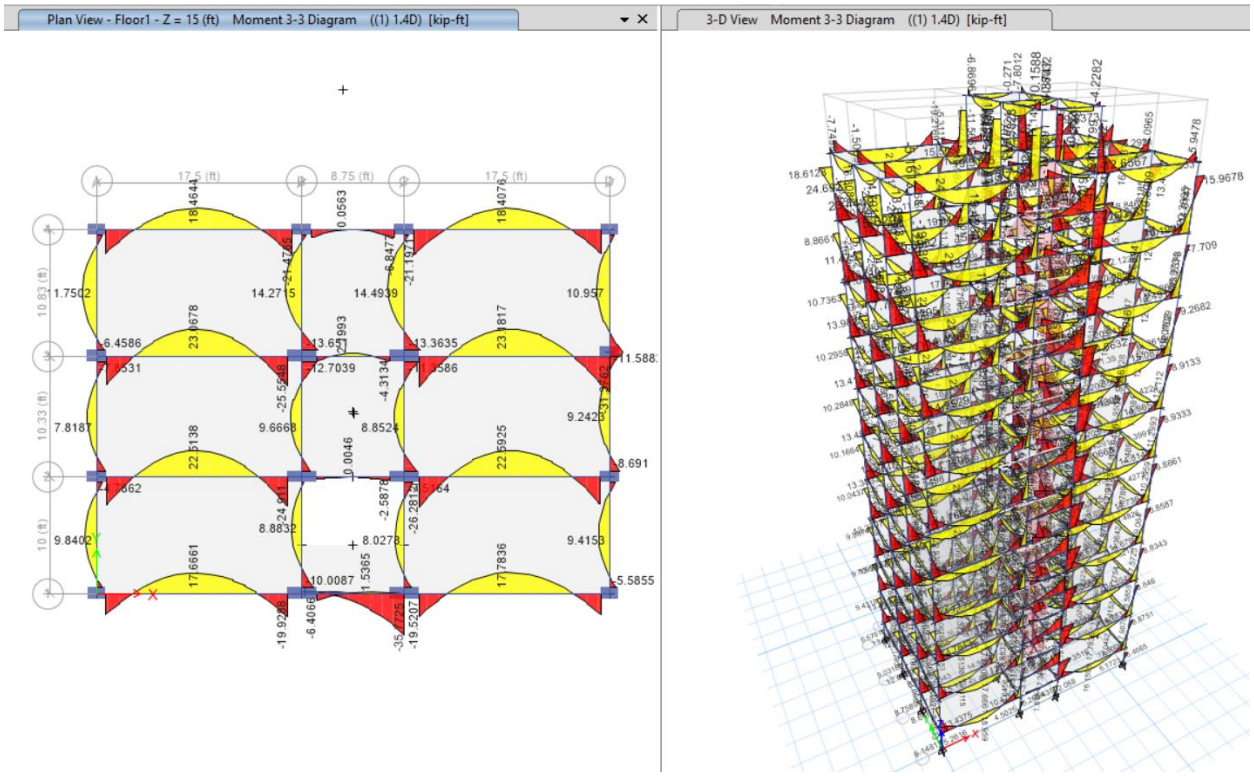


Figure: 4.4 BMD of Light weight Concrete Block Building

Longitudinal Reinforcement for Different Stories of **Conventional Building**

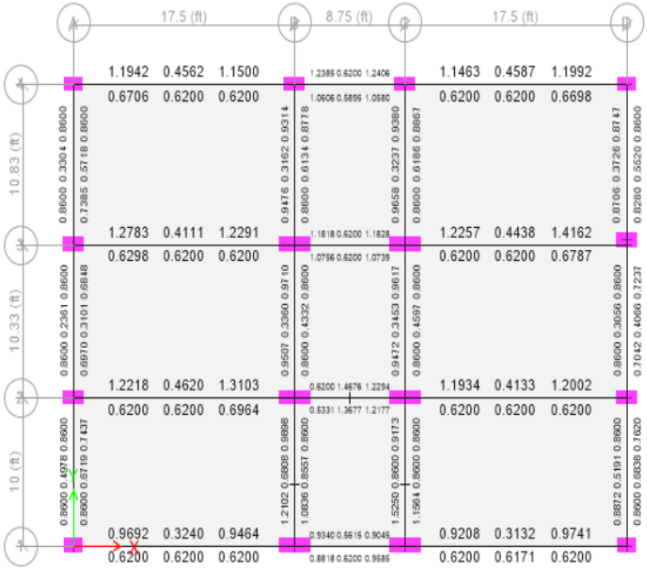


Figure 4.5 Ground Floor

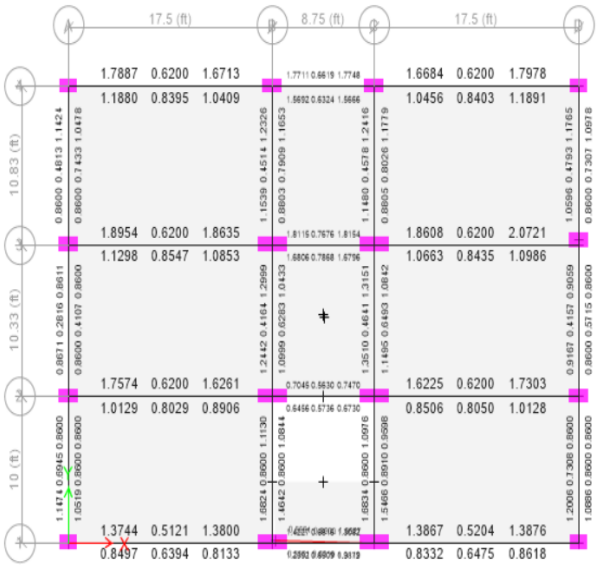


Figure 4.6 1st Floor

Longitudinal Reinforcement for Different Stories of **Light weight Concrete Block Building**

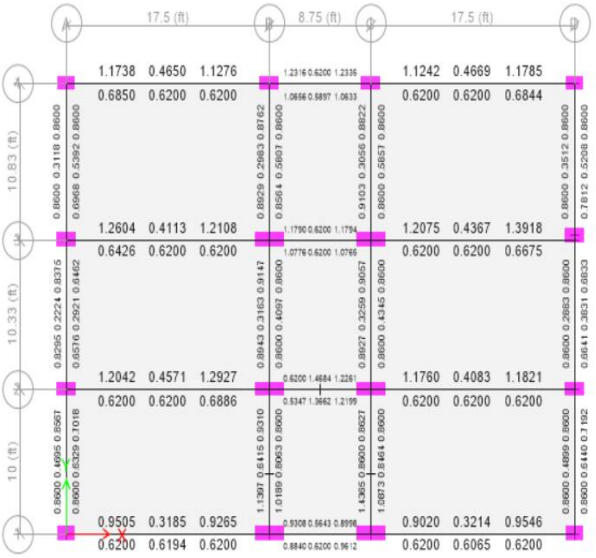


Figure 4.7 Ground Floor

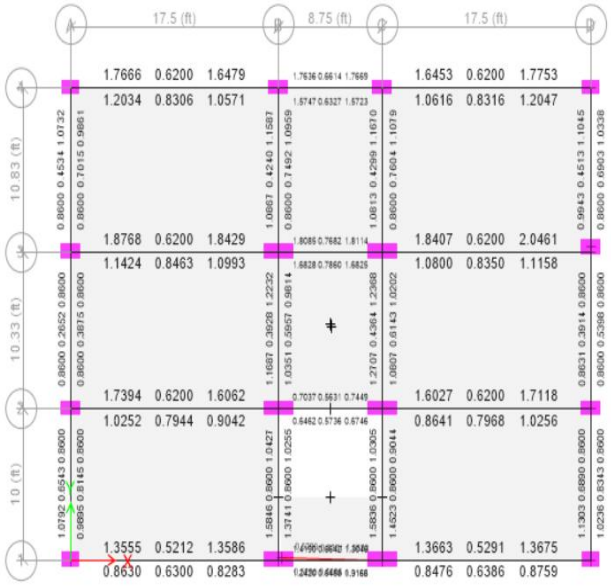


Figure 4.8 1st Floor

Rebar percentage for Different Stories of **Conventional Building**

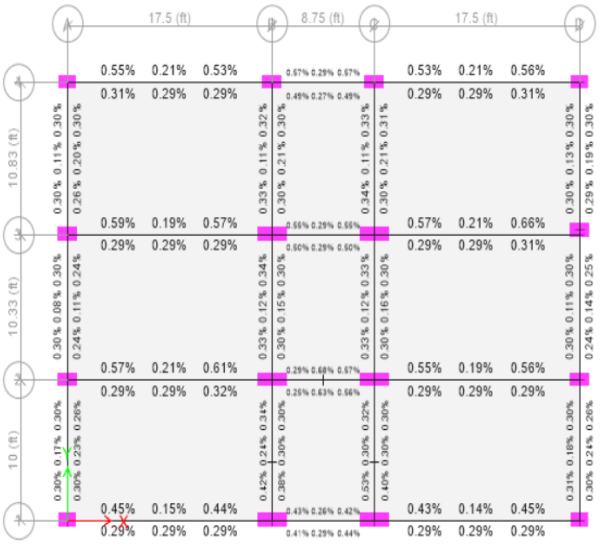


Figure 4.9 Ground Floor

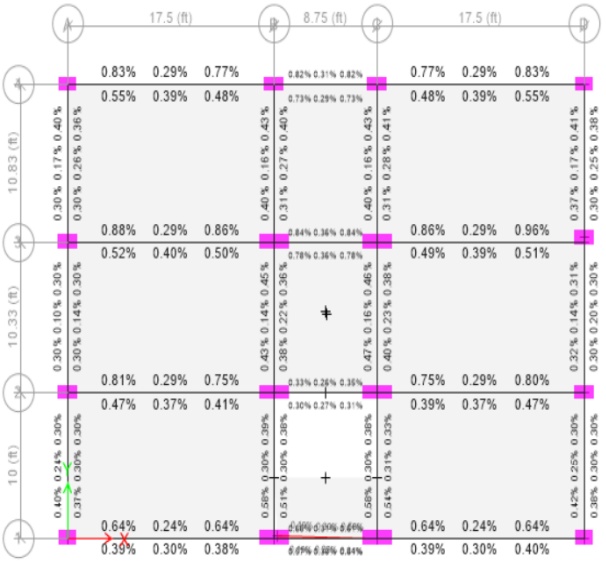


Figure 10. 1st Floor

Rebar percentage for Different Stories of **Light weight Concrete Block Building**

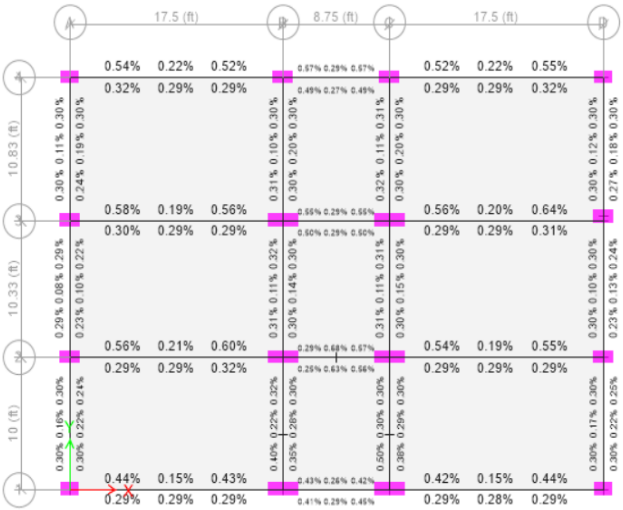


Figure 4.11 Ground Floor

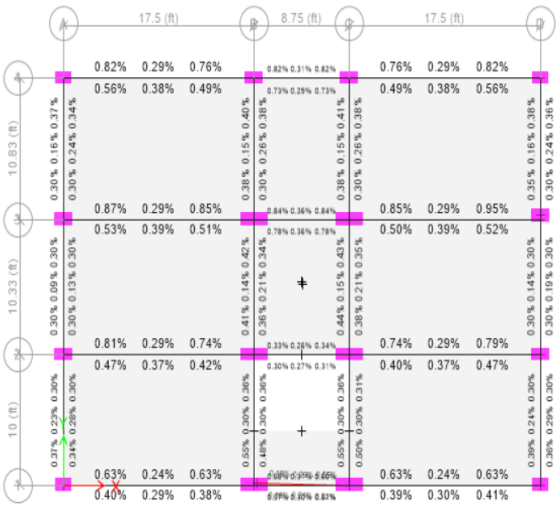


Figure 4.12 1st Floor

Shear Reinforcement for Different Stories of **Conventional Building**



Figure 4.13 Ground Floor



Figure 4.14 1st Floor

Shear Reinforcement for Different Stories of **Light weight Concrete Block Building**

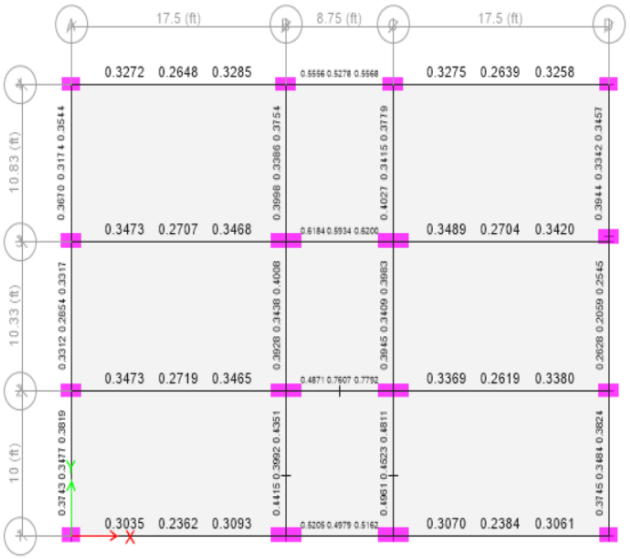


Figure 4.15 Ground Floor

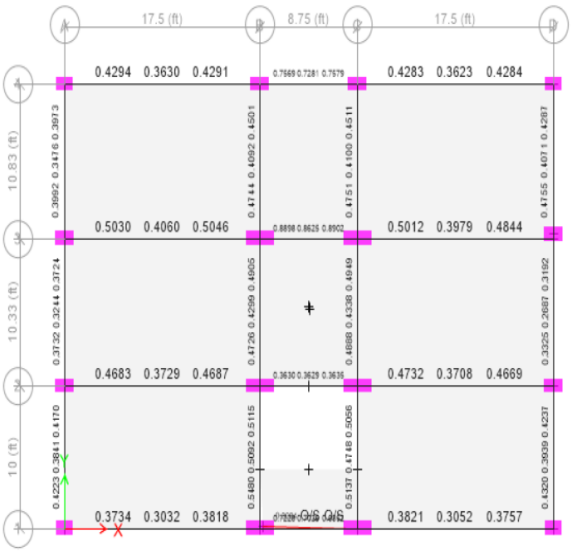


Figure 4.16 1st Floor

Structural Details of a Building with **Conventional and Light weight Concrete Block Building**



Figure 4.17 Maximum SF and BM of Beam B-1 OF Conventional Building



Figure 4.18 Maximum SF and BM of Beam B-2 OF Conventional Building

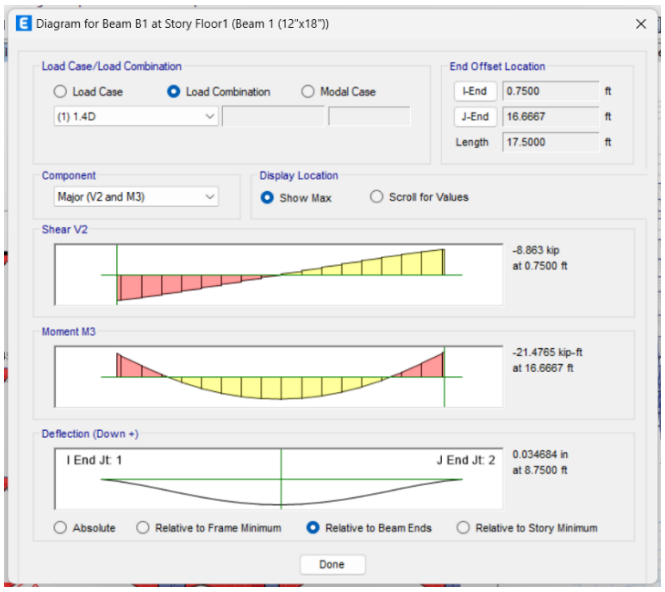


Figure 4.19 Maximum SF and BM of Beam B-1 of Light weight Concrete Block Building

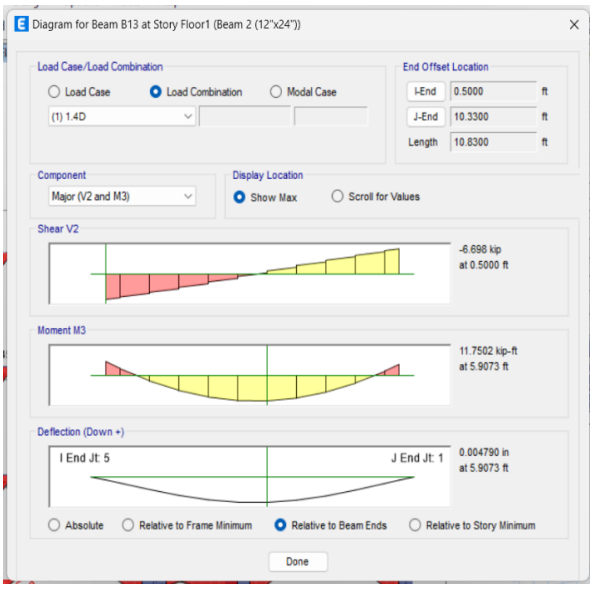


Figure 4.20 Maximum SF and BM of Beam B-2 of Light weight Concrete Block Building

Column:



Figure 4.21 Maximum SF and BM of Beam C-1 OF Conventional Building

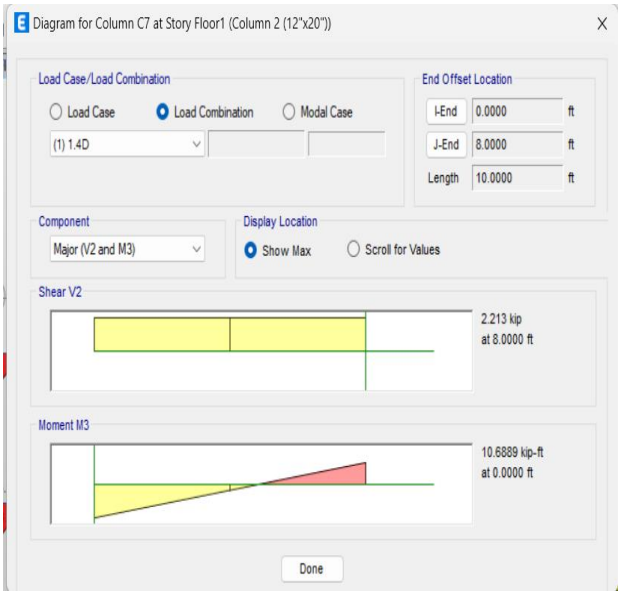


Figure 4.22 Maximum SF and BM of Beam C-7 OF Conventional Building

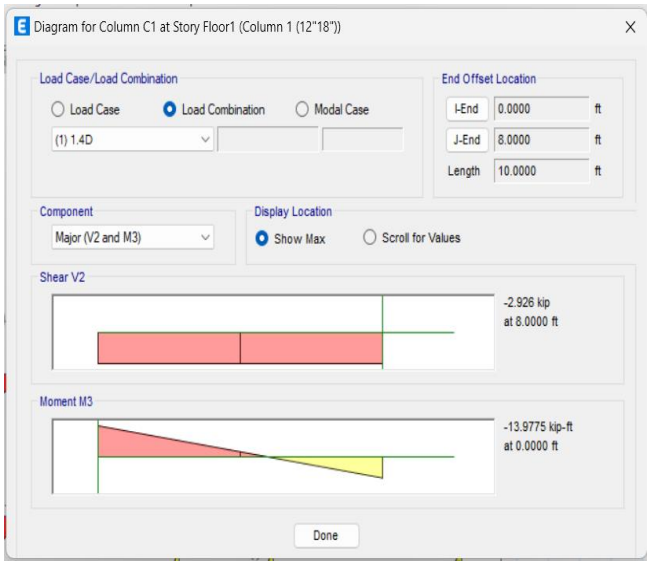


Figure 4.23 Maximum SF and BM of Beam C-1 of Light weight Concrete Block Building

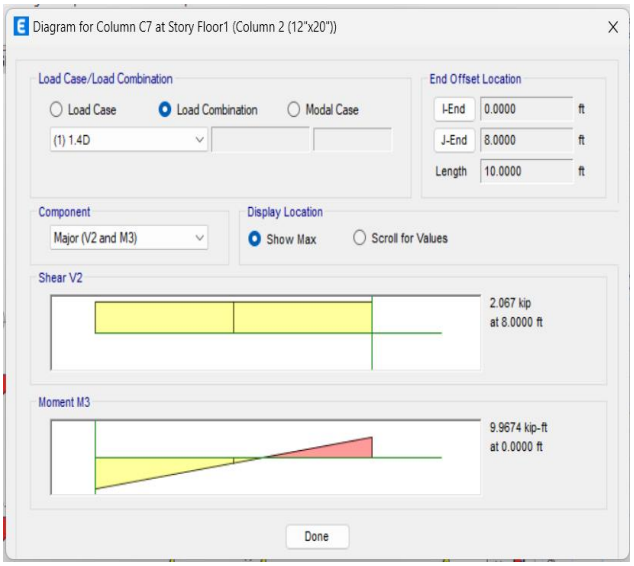


Figure 4.24 Maximum SF and BM of Beam C-7 of Light weight Concrete Block Building

4.3 ANALYSIS RESULTS

Percentage of reduction in BM and SF in Corner Beam1 from figures 4.17 & 4.19:

- From the analysis 6.80% of shear force is reduced in light weight bricks when compared to conventional bricks.
- Where as 7.13% of bending moment is reduced in beam.

Percentage of reduction in BM and SF in Corner Column1 from figures 4.21 & 4.23:

- From the analysis 6.70% of shear force is reduced in light weight bricks when compared to conventional bricks.
- Where as 6.74% of bending moment is reduced in column.

Percentage of reduction in BM and SF in Intermediate Beam2 from figures 4.20 & 4.22:

- From the analysis 6.94% of shear force is reduced in light weight bricks when compared to conventional bricks
- Where as 5.62% of bending moment is reduced in beam

Percentage of reduction in BM and SF in Intermediate Column 7 from figures 4.22 & 4.24:

- From the analysis 6.78% 0f shear force is reduced in light weight bricks when compared to conventional bricks.
- Where as 6.74% of bending moment is reduced in column.

Reduction Dead load about 2,07,000 Ib for 10 storied building.

4.4 Materials Separation

Table 4.3.1 Difference Between Concrete Block and Clay Brick

Category	Lightweight Concrete Block Building (e.g., AAC/CLC)	Conventional Clay Brick Building
Raw Materials	Fly ash, cement, foam or aluminum powder, sand, water	Natural clay, sand, straw, water
Manufacturing Process	Factory-made with precise mold and curing process	Burned in kilns after molding and drying
Unit Size	Larger blocks (e.g., 600x200x200 mm)	Small bricks (e.g., 240x115x75 mm)
Weight per Unit	8–15 kg (lightweight)	~2.5–3.0 kg (heavier for volume)
Structural Load	Low dead load – reduces foundation and structural cost	High dead load – needs stronger structure
Construction Speed	Faster due to fewer, larger blocks	Slower due to many small units
Thermal Insulation	Excellent (reduces energy usage)	Poor to average
Fire Resistance	High (non-combustible material)	Moderate (depends on clay quality)
Sound Insulation	High (ideal for apartments, hospitals, schools)	Moderate
Dimensional Accuracy	Very accurate – less plaster and mortar required	Less accurate – needs more plaster
Water Absorption	Low – reduces risk of dampness and mold	High – prone to dampness and efflorescence
Eco-Friendliness	High – uses industrial waste, low carbon footprint	Low – uses natural topsoil, high energy use
Seismic Performance	Better – less mass reduces earthquake force	Weaker – heavy mass increases seismic risk

Labor Skill Requirement	Skilled labor for cutting and alignment	General labor sufficient
Durability	Very high	Good
Cost Consideration	Lower	higher
Best Use Cases	High-rise buildings, green buildings, fast projects	Low-rise buildings, traditional construction

4.5 : Result Comparison and Discussion

The comparative analysis between **Light weight Concrete Block Buildings** and **Conventional Clay Brick Buildings** reveals significant differences in terms of structural efficiency, environmental impact, construction speed, and overall cost-effectiveness.

◆ **Structural Performance:**

Lightweight concrete blocks, such as AAC and CLC, significantly reduce the **dead load** of a building. This translates into lighter foundations and smaller structural members, offering clear advantages in multi-storey and earthquake-prone areas. In contrast, clay bricks, being heavier, increase the load on the structure and foundation, making them less ideal for high-rise or seismic zones.

◆ **Construction Efficiency:**

Lightweight blocks are larger and easier to install, leading to **faster construction times**. Fewer joints reduce the requirement for mortar and plaster, resulting in lower labor and material usage. On the other hand, clay bricks, due to their smaller size and inconsistent shapes, require more time and labor, especially for large projects.

◆ **Thermal and Acoustic Properties:**

Lightweight blocks offer superior **thermal insulation**, contributing to reduced energy usage for cooling and heating. This makes them ideal for modern energy-efficient

building standards. They also provide better **sound insulation**, making them suitable for urban and institutional buildings. Clay bricks, while durable, have relatively poor insulation characteristics.

◆ **Fire Resistance and Moisture Control:**

AAC blocks, in particular, offer excellent **fire resistance** (up to 4–6 hours), whereas clay bricks provide moderate resistance. Moreover, lightweight blocks absorb less water, minimizing the risks of dampness, mold, and efflorescence. Clay bricks have higher porosity, which can lead to moisture-related problems over time.

◆ **Environmental Impact:**

Lightweight blocks are **eco-friendly**, using industrial by-products (like fly ash) and not requiring topsoil or high-temperature kilns. Clay bricks, in contrast, contribute to **topsoil erosion** and consume significant energy during kiln burning, making them less sustainable.

◆ **Cost and Labor Consideration:**

Although lightweight blocks have a higher **initial cost per unit**, the savings in structural design, mortar, labor, and energy consumption often result in a **lower overall project cost**. Skilled labor is needed for precise installation. Clay bricks are cheaper and easier to use with general labor but result in higher long-term costs.

CHAPTER 5

CONCLUSION AND RECOMMANDATION

5.1 Conclusions

This study has provided a comparative analysis between light weight concrete block buildings (such as those using AAC or CLC blocks) and conventional clay brick buildings. Based on the analysis, it is evident that lightweight blocks offer significant advantages over traditional clay bricks in terms of:

- **Reduced structural dead load**
- **Improved thermal and acoustic insulation**
- **Higher fire resistance**
- **Faster construction time**
- **Eco-friendliness**
- **Lower long-term cost**

While the initial cost of lightweight blocks may be slightly higher, their performance and efficiency make them more suitable for **modern construction**, especially in **multi-storey residential and commercial buildings**, **seismic zones**, and **energy-efficient projects**. On the other hand, clay bricks, though widely available and traditional, present limitations in thermal performance, sustainability, and construction speed.

5.2 Limitations And Recommendation:

5.2.1 Limitations

1. In this study, only the ETABS software is used for the analysis.
2. The building is not designed for any expansion (Horizontally or vertically) in future.
3. If the analysis results compare with the actual hand calculation data, then more reliable results will be found. It should be done in the future work.

5.2.2 Recommendation:

Based on the findings of this study, the following recommendations are proposed:

1. **Adoption in High-Rise and Seismic Zones**: Lightweight concrete blocks should be prioritized in high-rise construction and earthquake-prone areas due to their low dead load and seismic performance.
2. **Promotion of Sustainable Construction**: Government agencies and developers should encourage the use of AAC and CLC blocks in public and private projects to reduce environmental impact.
3. **Training for Skilled Labor**: As lightweight block installation requires precision, training programs should be organized to develop a skilled workforce.
4. **Incentives for Green Materials**: Policy-makers should provide **tax benefits or subsidies** to builders using environmentally friendly materials like AAC blocks.
5. **Further Research**: Future studies should evaluate the **long-term performance** of lightweight blocks in different climates and conditions, including durability, water resistance, and maintenance needs.

5.3 Scope for Future Study

This study offers a foundation for understanding the benefits and limitations of lightweight concrete block construction compared to conventional clay brick systems. However, further research is encouraged in the following areas:

1. **Long-Term Durability and Performance**: Investigating the behavior of lightweight blocks under prolonged exposure to environmental conditions such as moisture, freeze-thaw cycles, and chemical attack.
2. **Life Cycle Cost Analysis (LCCA)**: A comprehensive study of maintenance, energy savings, and total lifecycle costs compared to clay brick buildings over 20–30 years.
3. **Integration with Green Building Systems**: Exploring how lightweight blocks can be incorporated into LEED, EDGE, or other green certification systems.
4. **User Feedback and Post-Occupancy Evaluation**: Collecting data from occupants of buildings constructed with lightweight blocks to evaluate comfort, energy savings, and acoustic performance in real use.
5. **Rural Feasibility Study**: Assessing the potential and economic viability of using lightweight blocks in rural and low-cost housing projects where labor skills and material access may be limited.

REFERENCES

[1] Kumar, S., and Gupta, R., "Study on Lightweight Concrete Blocks for Sustainable Construction," Journal of Building Materials and Structures, vol. 10, no. 2, pp. 56–63, 2017.

[2] Saha, A., and Roy, T., "Structural Analysis and Design of RCC Buildings Using ETABS," International Journal of Civil Engineering and Technology, vol. 9, no. 5, pp. 201–210, 2018.

[3] Ahmed, F., and Kundu, S., "Behavior of RCC Structures with Lightweight Concrete: A Comparative Study," Journal of Structural Engineering, vol. 144, no. 3, pp. 180–189, 2018.

[4] Patel, M. B., and Joshi, P. S., "Application of ETABS for Design of Multi-Storey RCC Buildings," International Journal of Engineering Research & Technology, vol. 5, no. 7, pp. 324–330, 2016.

[5] Sharma, R., and Singh, D., "Seismic Analysis of RCC Structures with Lightweight Concrete Blocks," International Journal of Civil Engineering and Construction Technology, vol. 8, pp. 92–100, 2019.

[6] Bhatt, R. S., and Mehta, P., "Design of RCC Structures with Lightweight Concrete and the Use of ETABS for Analysis," Journal of Advanced Concrete Technology, vol. 11, pp. 210–220, 2015.

[7] IS 3370-2 (2009), Code of Practice for Concrete Structures for the Storage of Liquids – Part 2: Reinforced Concrete Structures, Bureau of Indian Standards, 2009.

[8] ETABS (2016), Integrated Software for Structural Analysis and Design, Computers and Structures, Inc., Berkeley, CA.