

ANALYSIS OF IRREGULAR RCC BUILDINGS USING STAAD PRO.

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Abstract - Rapid urbanisation and constrained site geometries frequently force residential high-rise buildings into irregular geometries that significantly influence their seismic and serviceability behaviour. This thesis presents a comprehensive comparative study of the structural response of a G+21 (22-storey) reinforced concrete residential building for a set of common plan and vertical irregularities using STAADPro. The research objective is to quantify the effects of various irregularities — plan asymmetry, setbacks, re-entrant corners, vertical stiffness discontinuities and mass irregularities — on global responses (natural periods, mode shapes, base shear) and local demand parameters (storey drift, lateral displacement, bending moment and shear in beams and columns), and to recommend practical design and mitigation measures.

A prototypical regular G+21 building is developed and calibrated; then a series of irregular variants are generated by systematic modifications to plan and elevation. Each model is analysed using static equivalent and modal response spectrum procedures and modal combination, with gravity, wind and seismic loading applied according to relevant code provisions. Results are compared using non-dimensional indices (e.g., percentage change in base shear, peak inter-storey drift ratios,

torsional irregularity ratios) to isolate sensitivity to each irregularity type.

Key findings show that plan asymmetry and large setbacks markedly increase torsional demand and peak drift in peripheral frames, while vertical stiffness discontinuities concentrate higher bending moments and cause soft-storey mechanisms unless mitigated by strategic shear wall layout or increased diaphragm continuity. Recommendations include configuration-sensitive distribution of vertical resisting elements, minimum diaphragm rigidity practices, and design checks for accidental torsion and P-delta effects for tall irregular residential frames.

This study provides actionable guidance for practising engineers designing high-rise residential RCC structures on constrained sites and contributes design charts and comparative data.

Keywords: G+21, irregular building, STAAD Pro, torsion, storey drift, response spectrum, reinforced concrete, shear wall, soft-storey.

1. Introduction

1.1 Background

The rapid growth of population and urbanization in developing nations like India has led to an enormous increase in demand for land and housing. As a result, the construction of **high-rise**

reinforced cement concrete (RCC) buildings has become the most viable solution to optimize the use of limited land. However, with the increase in height and complexity of modern buildings, structural engineers face significant challenges related to **stability, strength, and serviceability** under various loading conditions such as gravity, wind, and earthquake forces.

A **Reinforced Cement Concrete (RCC) building** is a composite structure made from concrete and steel reinforcement designed to withstand both compressive and tensile stresses. RCC buildings are typically designed as **moment-resisting frames** or **shear wall-frame systems** depending on height and structural configuration. For low- and medium-rise buildings, conventional frame analysis and design often suffice. However, for **tall buildings (G+21 or higher)**, the behavior under **lateral loads**—particularly **seismic loads**—becomes a critical design consideration.

India lies in a seismically active region, where approximately 60% of the land area is vulnerable to earthquakes of varying intensities. Past earthquakes, such as the **Bhuj (2001)**, **Nepal (2015)**, and **Turkey (2023)** events, have shown that buildings with **irregularities in plan and elevation** tend to experience disproportionate damage compared to regular structures. These irregularities may arise due to architectural aesthetics, functional requirements, or space utilization constraints, but they alter the **dynamic characteristics** of the building and introduce **torsion, concentration of stress, and abrupt changes in stiffness**.

Thus, understanding the **seismic behavior of irregular high-rise RCC buildings** is essential to ensure their safety and stability. Modern software tools such as **STAAD Pro**, **ETABS**, and **SAP2000** allow structural engineers to model and analyze complex buildings under different loading conditions efficiently. In this thesis, STAAD Pro is used to model a **G+21 residential RCC building** with both **regular and irregular configurations**, and its seismic performance is evaluated using the methods prescribed in **IS 1893 (Part 1): 2016**.

The rapid growth of urbanization and increasing demand for high-rise residential buildings have led to the development of tall reinforced concrete (RCC) structures with complex architectural and structural configurations. With increasing height and irregularity, such buildings are highly vulnerable to lateral loads such as wind and earthquake forces. Therefore, the structural analysis and design of irregular high-rise buildings have become a critical part of modern civil engineering practice.

In India, where a large part of the country lies in moderate to high seismic zones, the structural performance of irregular buildings under lateral loads must be evaluated carefully. The use of advanced computer software such as **STAAD Pro** allows engineers to perform accurate analysis and design of complex building geometries under different loading conditions. This study focuses on the structural analysis of a **G+21 residential RCC building** with **plan and vertical irregularities**, using STAAD Pro as the primary analytical tool.

1.2 Need for the Study

In most conventional design practices, engineers assume that the building behaves regularly in both plan and elevation. However, architectural designs often require **setbacks, open ground storeys, cantilever projections, or re-entrant corners**, which make the structure **irregular**. Such irregularities cause uneven mass and stiffness distributions, leading to **torsional effects, localized damage, and premature failures** during earthquakes.

In conventional building design, regularity in plan and elevation ensures uniform load transfer and predictable behavior under loads. However, due to architectural and functional requirements, many modern buildings are irregular in shape, mass, or stiffness distribution. Such irregularities may cause torsional effects, stress concentration, or uneven displacement during seismic excitation, leading to severe damage or even structural failure.

This research aims to study the effect of these irregularities on the seismic performance of a tall RCC residential building. The analysis results will help in understanding how irregularities influence parameters such as base shear, storey drift, displacement, and bending moments. This study will contribute to safer and more efficient design practices for high-rise buildings in India.

The **IS 1893 (Part 1): 2016** defines and classifies building irregularities under plan and vertical irregularities. While the code provides qualitative guidance, it does not specify quantitative measures to mitigate the impact of irregularity. Hence,

engineers must analyze the structural response of irregular buildings to understand the variations in seismic forces, displacements, and base shear.

The **need for this study** arises from the following facts:

1. Modern architectural trends demand irregular shapes and complex elevations.
2. The Indian subcontinent faces frequent moderate to high seismic activity.
3. There is limited quantitative research available on **high-rise (G+21) RCC residential buildings** in Indian seismic zones.
4. STAAD Pro offers powerful modeling and analysis capabilities, but results vary significantly depending on model configuration and input parameters.
5. A comparative study between **regular and irregular buildings** will help identify the most critical parameters affecting structural safety.

1.3 Problem Statement

Irregular RCC buildings are more prone to damage during earthquakes due to the concentration of lateral loads and uneven distribution of stiffness. In tall buildings (like G+21 structures), these effects are magnified, leading to significant torsion and drift. The key problem addressed in this research is:

“To study the seismic behavior and structural performance of irregular G+21 residential RCC buildings using STAAD Pro, and to compare their

response with regular buildings in terms of base shear, displacement, and inter-storey drift."

This study will provide a comprehensive understanding of how different types of irregularities affect overall building performance and suggest measures for safe design.

1.4 Objectives of the Study

The main objectives of this thesis are as follows:

1. To model a **regular G+21 RCC residential building** in STAAD Pro and use it as a reference model.
2. **Residential RCC building** with different types of structural irregularities using **STAAD Pro**.
3. To introduce various **plan and vertical irregularities** in the same building, such as:
 - Plan irregularity (L-shaped layout)
 - Vertical irregularity (soft storey)
 - Stiffness and mass irregularities
4. To apply **gravity loads, wind loads, and seismic loads** as per **IS 875** and **IS 1893**.
5. To perform **Equivalent Static Analysis** and **Response Spectrum Analysis** using STAAD Pro.
6. To compare results for:
 - Base shear
 - Storey displacement
 - Storey drift
 - Modal periods and mode shapes
7. To analyze the impact of irregularities on seismic performance.

8. To suggest structural design recommendations for better seismic resilience.
9. To perform **static and dynamic analysis** as per **IS 1893 (Part 1): 2016** and **IS 456: 2000**.
10. To compare the structural behavior of **regular** and **irregular** buildings in terms of:
 - Storey displacement
 - Storey drift
 - Base shear
 - Bending moments and axial forces in members
11. To evaluate the effect of plan and vertical irregularities on the overall stability of the structure.
12. To recommend suitable design guidelines for high-rise irregular buildings in seismic-prone regions.

1.5 Scope of the Work

This thesis focuses on the analysis of irregular high-rise residential RCC buildings with a total of **21 storey (G+21)**. The structure is modeled and analyzed using **STAAD Pro**, considering both **plan irregularities** (such as L-shaped and T-shaped plans) and **vertical irregularities** (such as setback or soft storey).

The scope of the study includes:

- A **comparative structural analysis** between regular and irregular G+21 RCC buildings.

- Use of **linear static** and **dynamic (response spectrum)** methods as per **IS 1893 (Part 1): 2016**.
 - Modeling using **STAAD Pro**.
 - Evaluation of key response parameters:
 - Base shear
 - Lateral displacement
 - Storey drift
 - Fundamental time period
 - Exclusion of non-structural components (infill walls, façade, etc.).
 - The study assumes rigid floor diaphragms and fixed base conditions.
 - Dead load and live load as per **IS 875 (Part 1 & 2)**
 - Seismic load as per **IS 1893 (Part 1): 2016**
 - Material properties as per **IS 456: 2000**
 - The results obtained from STAAD Pro are interpreted in terms of displacement, drift, and base shear behavior.
- 3. **Load Application** – Application of gravity loads and seismic loads as per Indian Standards.
 - 4. **Analysis** – Performing both static and dynamic analysis to obtain displacement, drift, and base shear results.
 - 5. **Comparison** – Comparing the performance of regular and irregular buildings under similar loading conditions.
 - 6. **Conclusions and Recommendations** – Deriving insights and proposing guidelines for design improvement.
 - 7. Selection of building geometry and definition of irregularity types.
 - 8. Development of a **regular G+21 RCC model** in STAAD Pro.
 - 9. Modification of the model to introduce **irregularities**.
 - 10. Application of **dead load, live load, wind load, and seismic load**.
 - 11. Performing **modal analysis** and **response spectrum analysis**.
 - 12. Extracting results (base shear, drift, displacement).
 - 13. Comparison of results and discussion.
 - 14. Drawing conclusions and recommendations.

The study is limited to **linear elastic analysis**, and does not include non-linear or time-history analysis.

1.6 Methodology Overview

The study involves the following sequential steps:

1. **Literature Review** – Study of previous research work related to seismic analysis of irregular buildings.
2. **Modeling** – Development of 3D models of G+21 RCC buildings with regular and irregular configurations in STAAD Pro.

1.7 Seismic Behavior of RCC Buildings

When an earthquake occurs, the ground motion causes lateral accelerations at the building's base. This leads to **inertial forces** in the superstructure that increase with mass and height. For regular buildings, these forces are evenly distributed.

However, for irregular buildings, **torsion and concentration of stresses** occur due to asymmetry.

Key parameters influencing seismic behavior:

- Natural period (T)
- Damping ratio (ξ)
- Lateral stiffness (K)
- Mass distribution (M)
- Soil-structure interaction

1.8 Detailed Description of the Project Floor Plan

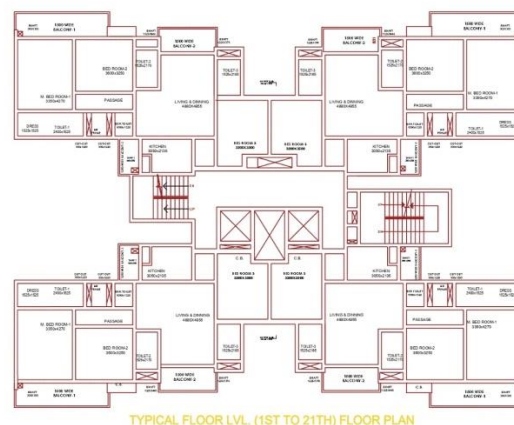
The plan is designed for a **high-rise residential structure** extending from the **Ground floor to the 21st floor**. And total building area of project 665 Sqm.

1.8.1 AutoCAD Plan with all details

The presented drawing illustrates the **Typical Floor Level Plan (Ground to 21st Floor)** of a multi-storey residential apartment building. The floor is symmetrically planned around a centrally located circulation core consisting of staircases, lifts, and common lobby spaces. The arrangement ensures efficient movement, proper ventilation, balanced structural loading, and maximum utilization of available floor area.

The building floor consists of **four residential units per floor**, distributed in each quadrant around the central core. Each apartment is designed as a **3-bedroom residential unit** with attached living, dining, kitchen, toilet, and balcony spaces. The layout reflects modern residential planning

principles emphasizing privacy, natural lighting, cross ventilation, and functional circulation.



1.8.2 Central Core Planning

The central portion of the floor accommodates:

- Two staircase blocks
 1. Main Staircase Area- 9.95 Sqm
 2. Fire Staircase Area – 17.75 Sqm
- Passenger lifts
 1. Lift 1 Area- 3.43 Sqm
 2. Lift 2 Area- 3.43 Sqm
 3. Service Lift Area- 5.55 Sqm
- Common circulation lobby (C.B.)– 27.102 Sqm Area

Importance of the Central Core

- Provides safe and quick vertical movement.

- Improves structural stability against lateral loads such as wind and earthquake forces.
- Reduces travel distance for residents.
- Facilitates fire escape and emergency evacuation.

- Utility and service access are conveniently planned.
- Efficient work triangle concept can be observed.

1.8.3 Residential Unit Layout

Each apartment unit generally contains:

a) Living and Dining – 26 Sqm Area

- A spacious combined **living and dining room** is located near the entrance.
- Acts as the primary social and family interaction space.
- Connected directly to balconies for natural light and ventilation.

b) Bedrooms

Each flat includes:

- Master Bedroom- 14.304Sqm Area
- Bedroom 2–11.025 Sqm Area
- Bedroom 3- 11.340 Sqm Area

Features:

- Proper room dimensions for furniture arrangement.
- Windows and balcony access for air circulation.
- Privacy maintained from common areas.

c) Kitchen- 6.5 Sqm

- Kitchen spaces are positioned near the dining area.

d) Toilets

Each flat includes:

- Toilet1 with Dress Room Attached with M. Bedroom1 – 5.985 Sqm Area
- Toilet 2Attached with Bedroom 2 – 3.309 Sqm Area
- Toilet 3 Attached with Bedroom 3 – 3.332 Sqm Area
- Common Toilet Attached with Living &Dining– 1.438 Sqm Area

Features:

- Attached/common toilets are distributed strategically.
- Plumbing lines appear vertically aligned for efficient service routing.

e) Balcony

Each flat includes:

- Balcony 1 Attached with M. Bedroom 1 – 7.82 Sqm Area
- Balcony 2 Attached with Bedroom 2 – 4.714 Sqm Area
- Balcony 3 Attached with Kitchen –2.456 Sqm Area

Features:

- Multiple balconies are provided.

- Enhance aesthetic appearance and environmental comfort.
- Improve daylight penetration and cross ventilation.

1.9 Significance of STAAD Pro in Structural Analysis

STAAD Pro is one of the most widely used structural analysis and design software in India. It allows users to:

- Model complex geometries
- Apply various loads (dead, live, wind, seismic)
- Perform linear and nonlinear analyses
- Generate detailed reports for design verification

The present study utilizes STAAD Pro's **Response Spectrum Analysis** module to determine the building's seismic response under **Zone IV** conditions.

1.10 Software Used

STAAD PRO V8i is used for modeling and structural analysis.

Key features include:

- 3D modeling of complex geometries.
- Earthquake load generation as per Indian Standards.
- Analysis of static, response spectrum, and dynamic loads.
- Visualization of deformation and member forces.

1.11 Summary

This chapter introduces the need for seismic analysis of high-rise irregular reinforced cement concrete (RCC) buildings in the context of rapid urbanization and limited land availability. Modern residential buildings often adopt irregular configurations due to architectural and functional requirements, which significantly affect their structural performance under lateral loads such as earthquakes and wind. In a seismically active country like India, these irregularities can lead to increased torsion, higher storey drift, and concentration of stresses, making such structures more vulnerable during earthquakes.

The chapter highlights the importance of studying the seismic behaviour of a G+21 RCC residential building by comparing regular and irregular configurations. It defines the problem statement, objectives, scope, and methodology of the research, focusing on parameters such as base shear, displacement, storey drift, and natural time period. The role of STAAD Pro as an advanced structural analysis tool is emphasized for accurately modeling and analyzing complex building geometries as per Indian Standards. Overall, this chapter establishes the foundation and motivation for the detailed analytical and comparative study presented in the subsequent chapters

2. Review of Literature

2.1 Introduction

A comprehensive review of previous studies is essential to understand the current state of research

on the seismic performance of **irregular RCC buildings**, particularly **high-rise (G+21 and above)** structures. The review identifies gaps in knowledge, establishes the importance of analyzing irregularities, and forms the foundation for developing an accurate numerical model using **STAAD Pro**.

Irregular buildings differ significantly from regular structures in terms of **lateral stiffness**, **mass distribution**, and **torsional response**. Researchers worldwide have conducted analytical, numerical, and experimental studies to evaluate their behavior under seismic loads. The following sections present a detailed review of existing work categorized into key thematic areas:

1. Studies on **Regular vs. Irregular Buildings**
2. Research on **Plan Irregularities**
3. Research on **Vertical Irregularities**
4. Investigations using **STAAD Pro and other software**
5. Studies on **Seismic Codes and Parameters (IS 1893, IS 456)**
6. Identified **Research Gaps**

2.2 Studies on Regular vs. Irregular Buildings

2.2.1 Comparative Seismic Behavior

Several studies have established that **irregular buildings** perform poorly under earthquake loading compared to regular ones.

- **Chopra (2007)** in *Dynamics of Structures* emphasized that torsional effects are predominant in asymmetric buildings and that lateral displacements increase nonlinearly with irregularity.
- **Murty et al. (2012)** observed through analytical modeling that irregular buildings exhibited up to **25–40% higher base shear** than regular ones under similar loading conditions.
- **Das and Paul (2014)** conducted comparative studies on 10- and 15-storey RCC frames, showing that irregularity led to a significant rise in inter-storey drift, especially near the soft storey.
- **Patel and Shah (2016)** reported that regular configurations had more uniform stiffness distribution, minimizing torsion, while irregular ones showed concentration of stresses at re-entrant corners.

2.2.2 Tall Building Seismic Response

For **high-rise structures**, the height amplifies the influence of irregularity:

- **Soni and Mistry (2017)** analyzed a 20-storey RCC building and concluded that vertical irregularities caused higher mode participation, increasing displacement in upper stories.
- **Mishra and Mehta (2018)** studied G+25 buildings using ETABS and found that soft storey irregularities increased the fundamental period by 18–25%.

- **Singh et al. (2019)** stated that as the height increases, the natural period lengthens, making the structure more flexible and sensitive to seismic excitation.

These findings emphasize the necessity of rigorous seismic analysis for **G+21 and taller RCC buildings**.

2.3 Studies on Plan Irregularities

Plan irregularities arise due to architectural features such as **re-entrant corners, L-shaped plans, T-shaped layouts, and diaphragm discontinuities**.

- **Ali and Haldar (2013)** performed static and dynamic analyses of L-shaped and T-shaped buildings and concluded that torsional irregularity increases base shear by 10–15%.
- **Memon et al. (2014)** observed that re-entrant corners create stress concentrations at the junctions, leading to diagonal cracking in beams and slabs.
- **Ravindra and Kumar (2015)** compared rectangular, L-, and T-shaped buildings (G+12) and found that **L-shaped structures experienced 30% more displacement** than rectangular ones.
- **Patil and Gore (2016)** reported that torsional moments were most severe in L-shaped plans when subjected to Zone IV seismic loads.
- **Response spectrum analysis** method is recommended for buildings higher than 40 m in Zone IV and above.

2.4 Structural Analysis Techniques

Traditionally, buildings were analyzed using manual methods such as:

1. **Equivalent Static Analysis:** Used for regular buildings under seismic loads.
2. **Moment Distribution Method:** Effective for planar frames but cumbersome for complex, irregular buildings.
3. **Finite Element Method (FEM):** Provides detailed insight into stress distribution and deflection for irregular layouts.

With increasing building complexity, software like STAAD Pro, ETABS, and SAP2000 has become essential due to their ability to model 3D geometries and dynamic behavior accurately.

2.5 STAAD Pro in Building Analysis

STAAD Pro is one of the most widely used structural analysis and design software tools, capable of handling:

- **3D Structural Modeling:** Nodes, beams, slabs, columns, and walls.
- **Load Application:** Dead load, live load, wind load, seismic load (per IS 875, IS 1893).
- **Dynamic Analysis:** Response spectrum and time history analysis.
- **Design Integration:** Reinforced concrete, steel, and composite materials.

Several studies have demonstrated STAAD Pro's effectiveness in modeling irregular RCC buildings.

For example:

- Sharma et al. (2021) modeled a G+20 irregular residential building and found that torsional effects increased column bending moments by 18–22%.
- Joshi and Patel (2019) compared STAAD Pro results with manual calculations, noting deviations within 5–7% for deflection and internal forces, validating the software's accuracy.

2.6 Review of Previous Studies

Author(s)	Study Focus	Key Findings
Chopra (2017)	Seismic analysis of irregular buildings	Torsional irregularities amplify lateral displacement by 20–50%.
Kumar & Sharma (2020)	Vertical irregularities in high-rise RCC buildings	Soft stories lead to inter-story drift exceeding code limits.
Joshi & Patel (2019)	STAAD Pro modeling of irregular G+15 building	Software results closely match analytical calculations; useful for design optimization.
Sharma et al. (2021)	Dynamic analysis of	Plan irregularity increases critical column bending

2.7 Experimental and Analytical Studies

While most studies rely on computer analysis, several researchers have conducted **experimental validations**:

- **Sane and Chavan (2014)** performed shake table experiments on scaled irregular frame models, confirming the analytical results of increased torsion.
- **Reddy et al. (2019)** used a hybrid testing approach to validate STAAD Pro dynamic responses.
- **Gautam (2021)** observed that analytical results underestimated the actual displacements by 5–8%, implying that damping ratios and boundary conditions significantly influence results.

2.8 High-Rise Building Case Studies

2.8.1 Indian Context

- **Patil and Kulkarni (2020)** analyzed G+25 buildings in Pune (Zone III) and found that using shear walls significantly reduced storey drift.
- **Yadav and Sharma (2021)** examined a 22-storey building with L-shaped plan in Zone IV, showing that corner torsion increased by 12% compared to regular rectangular plans.
- **Meena et al. (2022)** conducted a performance-based seismic analysis on 25-storey irregular structures and observed nonlinear behavior at 0.25g acceleration.

1. **Base Shear (V_b)** — Indicates the total lateral force acting at the base.
2. **Storey Displacement (Δ)** — Measures lateral movement at each level.
3. **Storey Drift ($\Delta_i - \Delta_{i-1}$)** — Relative displacement between floors, limited to **0.004 h** as per IS 1893.
4. **Time Period (T)** — Increases with height and flexibility.
5. **Mode Shapes and Torsional Response** — Depict dynamic behavior and irregularity effects.

2.8.2 International Studies

- **Naeem et al. (2018)** studied high-rise irregular buildings in Pakistan using SAP2000 and recommended response modification factors based on building height.
- **Zhu and Chen (2019)** developed analytical models for torsion in plan-irregular buildings and validated them through time-history analysis.
- **Jin et al. (2020)** explored re-entrant corner behavior using finite element methods, suggesting that additional corner bracing can reduce torsion by 40%.

Equations from IS 1893 and Chopra's work form the theoretical basis for these parameters, all of which are used in STAAD Pro analyses.

2.10 Summary of Research Gaps

Based on the literature reviewed, the following research gaps are identified:

1. Most studies focus on **low- and mid-rise** buildings (G+10 or below); very few address **high-rise G+21 or taller** RCC structures.
2. Limited studies exist combining **multiple irregularities** (e.g., plan + stiffness).
3. Few works have utilized **STAAD Pro Connect Edition**, which includes updated seismic features.
4. Most analyses are restricted to Zone III; fewer studies consider **Zone IV or V** (higher seismic risk).

2.9 Seismic Performance Parameters Studied

From the literature, the most commonly studied parameters include:

5. Lack of comprehensive **comparative studies** on regular vs. irregular tall RCC buildings under identical loading conditions.

2.11 Summary

This chapter presented a detailed review of literature related to the **seismic performance of irregular RCC buildings**. The findings clearly show that:

- Irregularities significantly influence structural performance under lateral loads.
- Plan and vertical irregularities result in **increased torsional moments and drift ratios**.
- STAAD Pro is a reliable tool for such analysis but requires careful modeling of load paths and boundary conditions.
- There remains a critical need for **systematic research on G+21 irregular RCC buildings** in Indian seismic zones, forming the motivation for this thesis.

3 METHODOLOGY (MATERIALS AND METHODS)

3.1 Introduction to Methodology

The methodology adopted in this research forms the backbone of the analytical framework governing the comparative assessment of regular and irregular high-rise RCC buildings. This chapter provides a comprehensive description of the procedures, standards, tools, assumptions, and computational techniques used for analyzing the seismic behaviour

of G+21 reinforced concrete buildings with different irregularity configurations.

Given the complexity of tall buildings and the challenges associated with seismic loads, the methodology follows a structured multi-stage approach that integrates:

- Conceptual building modelling
- Detailed structural idealization
- Load derivation based on IS codes
- Finite element model creation in STAAD Pro
- Static and dynamic load analysis
- Response extraction and comparative evaluation

The overall research methodology has been designed to satisfy the following goals:

1. To create reliable analytical models of regular and irregular buildings.
2. To simulate realistic gravity, wind, and seismic loads as per Indian Standards.
3. To compare the response under multiple irregularity conditions.
4. To identify the sensitivity of structural behaviour to these irregularities.
5. To develop engineering recommendations for safe design practices.

This chapter elaborates the materials, methods, computational procedures, and analysis workflow used in this research. Each step is explained in significant depth to ensure full reproducibility for future researchers and practitioners.

3.2 Research Framework and Workflow

The analysis methodology is structured into a **12-stage workflow**, illustrated below and elaborated in subsequent sections:

Stage 1: Understanding problem definition and objective mapping

Stage 2: Identification of irregularity types

Stage 3: Selection of geometry, materials, and structural system

Stage 4: Computation of preliminary building parameters

Stage 5: Load data compilation using IS codes

Stage 6: Development of building models in STAADPro

Stage 7: Assignment of material and sectional properties

Stage 8: Load application (DL, LL, wind & seismic)

Stage 9: Modal analysis and response spectrum analysis

Stage 10: Extraction of structural response parameters

Stage 11: Comparative evaluation of regular vs. irregular buildings

Stage 12: Interpretation, validation, and conclusion forming

Each stage has been discussed with extensive theoretical detail, numerical expressions, modelling notes, software considerations, and design implications to ensure a fully transparent research methodology.

3.3 Selection of Research Parameters

To achieve an accurate and comprehensive evaluation, several critical structural and seismic parameters must be identified before modeling begins. These include:

3.3.1 Structural Parameters Considered

The structural parameters include:

- Total height of the building
- Number of storeys
- Storey height
- Beam and column sizes
- Slab thickness
- Concrete and steel grade
- Wall thickness
- Staircase core details
- Shear wall presence/absence
- Foundation type (idealized as fixed base for analysis)

For this study, the selected structural dimensions are representative of typical residential high-rise RCC buildings constructed across India.

General Building Data

Parameter	Value
Building Configuration	G+21 RCC Residential

Parameter	Value	Material	Grade	Modulus	Remarks
Height per Storey	3.0 m	Density of Masonry	20 KN/m ³		Used for infill wall load
Total Height	69 m				
Building Use	Residential				
Structural System	Moment Resisting Frame with optional shear wall variations				
Seismic Zone	Zone IV				
Soil Type	Medium Soil (Type II)				
Importance Factor	1.0				
Damping Ratio	5%				
Response Reduction Factor	R = 5 (SMRF)				

3.3.2 Material Properties

Material properties are based on IS 456:2000 and IS 1893:2016 recommendations.

Material	Grade	Modulus	Remarks
Concrete	M40	31623 MPa	Standard residential-grade
Reinforcement	Fe 500	$E_s = 2 \times 10^5$ MPa	HYSD bars
Density of Concrete	25 KN/m ³		As per IS 875-1

3.3.3 Types of Irregularities Considered

IS 1893 (2016) defines several plan and vertical irregularities. In this research:

A. Plan Irregularities

1. L-shaped building
2. T-shaped building
3. Re-entrant corner irregularity
4. Unsymmetrical plan due to corridor extension

B. Vertical Irregularities

1. Soft Storey at Ground Floor
2. Mass Irregularity
3. Vertical Setback / Step-back Geometry
4. Stiffness Discontinuity due to column size reduction

C. Combined Irregularities

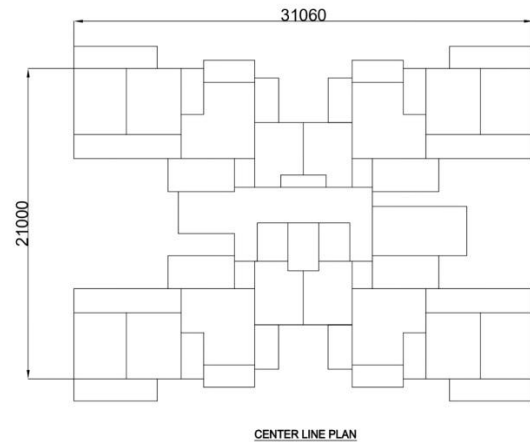
5. Plan + Vertical Mixed Irregularity Condition

3.3.4 Comparison Parameters

The behavior of these models will be compared based on:

- Natural period

- Modal mass participation
- Base shear
- Storey displacement
- Inter-storey drift
- Torsional irregularity index
- Bending moments in beams
- Axial forces and shear in columns
- Stress concentration locations
- Qualitative deformation patterns



The above parameters are essential for assessing the safety and serviceability of high-rise RCC structures in seismic zones.

3.4 Structural Modelling Approach

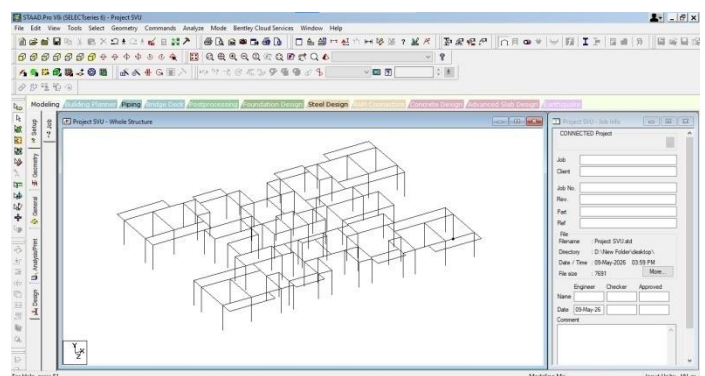
The structural modelling methodology is based on advanced Finite Element Modelling (FEM) principles as implemented in STAADPro V8i. Accurate modelling is essential to represent real-life behavior, especially under dynamic loads.

The modelling follows these components:

- Check all layers, units, and coordinates properly before exporting the drawing.
- Save the drawing in **DXF format** for compatibility with STAADPro.
- Open STAAD Pro and import the DXF drawing using the import option.

3.4.1 AutoCAD drawing and Import DXF Drawing in Staad

- Create the floor plan of the building in AutoCAD with accurate dimensions and structural details.
- Prepare the center line plan by marking the center lines of columns, beams, and walls.

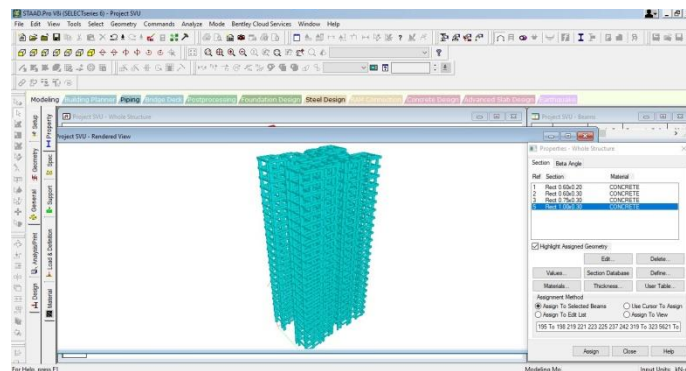
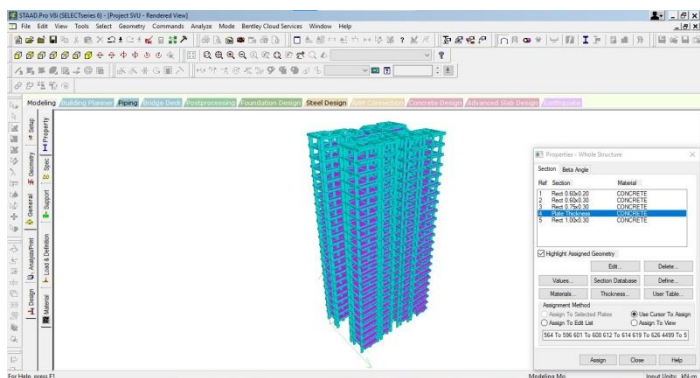


3.4.2 Structural Idealization

The building is idealized as a **3D space frame** consisting of:

- **Beam elements** (flexural members)
- **Column elements** (compression members)

- **Slab elements** (as plate or diaphragm)
- **Shear walls** (if present in some variations)
- **Rigid floor diaphragm** (as per IS 1893 clause guidelines)
- **Supports** as fixed at base



3.4.4 Slab Modelling

Two approaches are used:

Approach 1: Rigid Diaphragm Modelling

- Slabs not explicitly modeled
- Floors behave as rigid plates
- Lateral loads transfer evenly
- Suitable for high-rise buildings

Approach 2: Plate Element Modelling

- For models requiring local flexibility
- Plate thickness = 150 mm
- Mesh size = 1 m × 1 m for accuracy

The diaphragm constraint is applied in both cases to ensure proper lateral stiffness.

3.4.5 Wall and Partition Load Modelling

Masonry wall loads are added as line loads on beams:

- **External wall:** 230 mm thick → 13.8 kN/m
- **Internal wall:** 115 mm thick → 6.9 kN/m

This idealization allows:

- Realistic stiffness representation
- Proper distribution of lateral forces
- Accurate torsional behaviour modelling

3.4.3 Beams and Columns Modelling

Beam Elements

- Modelled as **prismatic line elements**
- Carry bending, shear, torsion, and axial forces
- Beam size typical: 200 mm × 600 mm

Column Elements

- Modelled as vertical prismatic elements
- Carry axial load, bending, biaxial moments

Variation improves realism and stiffness representation.

These are calculated as:

$$\text{Load} = t \times h \times \text{density}$$

Where density = 20 kN/m³.

3.4.6 Coordinate System

STAAD Pro uses a standard Cartesian coordinate system:

- **X-direction:** Global horizontal axis (used for lateral loads)
- **Y-direction:** Global vertical axis (height)
- **Z-direction:** Perpendicular horizontal axis

The coordinates are assigned carefully to maintain geometric consistency.

3.4.7 Support Conditions

The base support is modeled as:

- **Fixed support**
 - Zero translation (UX, UY, UZ)
 - Zero rotation (RX, RY, RZ)

This is standard for analytical seismic evaluation studies.

1. Concrete behavior is linear elastic.
2. Soil-structure interaction neglected (fixed base).
3. Building has rigid floor diaphragms.
4. Infill wall stiffness not explicitly modeled.
5. Mass is lumped at floor levels.
6. Time period from RSA governs seismic forces.
7. Damping taken as 5% for RCC.

3.5 Load Calculation Methodology

Accurate determination of loads is the foundation of reliable structural analysis. All loads applied in STAAD Pro are calculated strictly according to relevant Indian Standards. This section presents the detailed methodology for computing various loads acting on the G+21 RCC building.

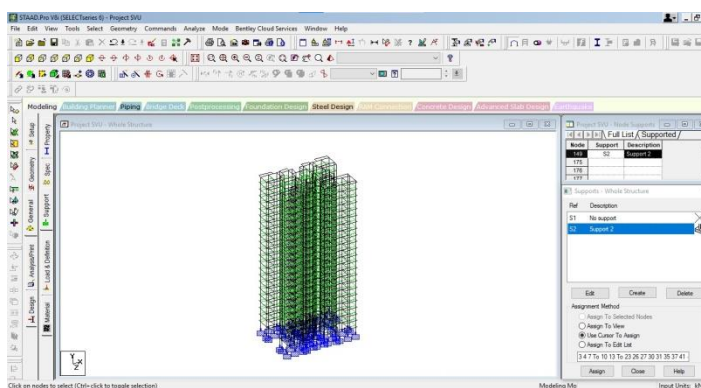
The following loads are considered:

1. Dead Load (DL)
2. Live Load (LL)
3. Floor Finish Load (FFL)
4. Seismic Load (EL)
5. Wind Load (WL)

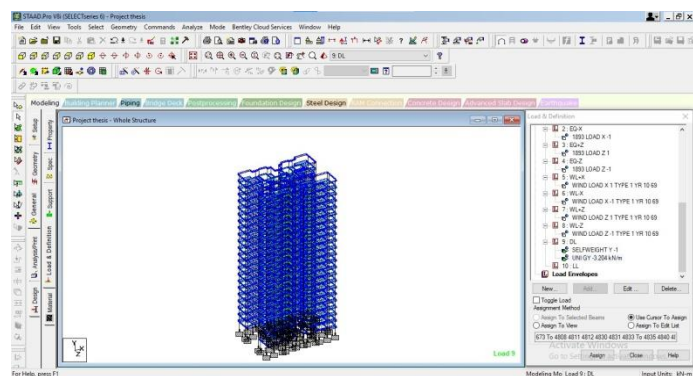
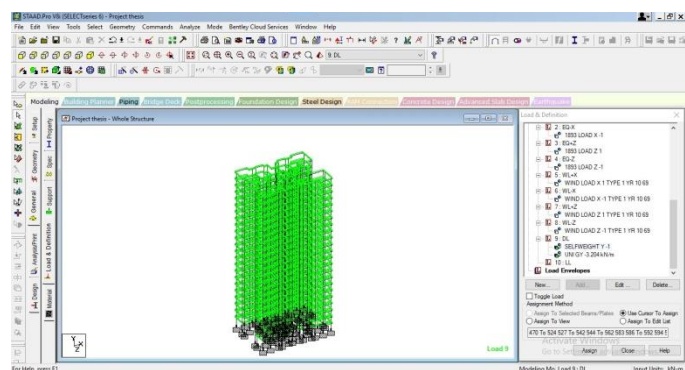
Each category is elaborated with numerical calculation examples, code links, and modeling strategy.

3.5.1 Dead Load Calculation (As per IS 875 Part-1: 1987)

Dead loads consist of the self-weight of structural elements like slabs, beams, columns, walls, staircases, and finishes.



3.4.8 Modelling Assumptions



A. Self-weight of Structural Elements

STAAD automatically assigns self-weight using:

SELFWEIGHT -1

Where:-1 → downward direction

Coefficient 1.0 → full self-weight of all structural members

B. Slab Load Calculation

- Slab thickness = **150 mm**
- Density of RCC = **25 kN/m³**
- Slab DL = 0.150×25
- = **3.75 kN/m²**

Since slabs are modeled as rigid diaphragms or plate elements, the load is applied as floor load in STAAD.

C. Floor Finish Load

Floor finish is considered as per IS 875 recommendations:

- Typical residential building finish → **1.0 kN/m²**
- Toilet and wet areas → **1.5 kN/m²**

For uniformity:

FFL = 1.0 kN/m² applied as floor load.

D. Wall Load Calculation

Wall load depends on:

- Wall thickness
- Wall height
- Density of brick masonry (20 kN/m³)

(i) External Wall

- Thickness = 230 mm
- Density = 20 kN/m³
- Height = 3 m

$$\begin{aligned} \text{Wall load} &= t \times h \times \text{density} \\ &= 0.23 \times 3 \times 20 \\ &= \mathbf{13.8 \text{ kN/m}} \end{aligned}$$

Add plaster load ($0.5 \text{ kN/m}^2 \times 3 \text{ m}$) = 1.5 kN/m

Total = 15.3 kN/m (approx.)

Rounded to **15 kN/m**.

(ii) Internal Wall

Thickness = 115 mm
Height = 3 m

$$\begin{aligned} \text{Wall load} &= 0.115 \times 3 \times 20 \\ &= \mathbf{6.9 \text{ kN/m}} \end{aligned}$$

Add plaster: ~1.0 kN/m

Total = $7.9 \approx 8 \text{ kN/m}$

E. Parapet Wall Load

Height = 1.2 m

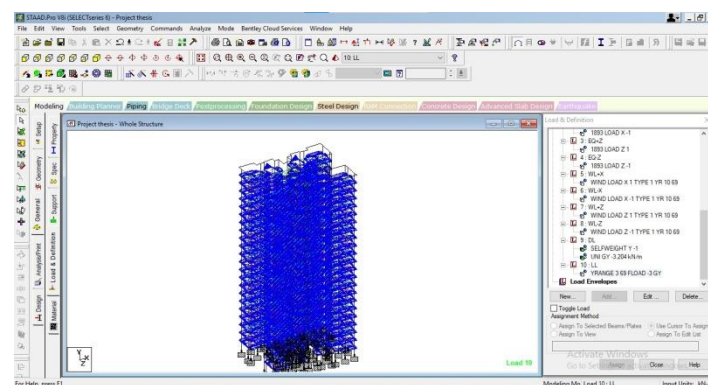
Thickness = 115 mm

- Load = $0.115 \times 1.2 \times 20$
= $2.76 \text{ kN/m} \approx 3.0 \text{ kN/m}$

3.5.2 Live Load Calculation (As per IS 875 Part-2)

Building Area	Live Load (KN/m ²)
Rooms, living	2.0
Corridors	3.0
Balconies	3.0
Staircase	3.0
Roof	1.5

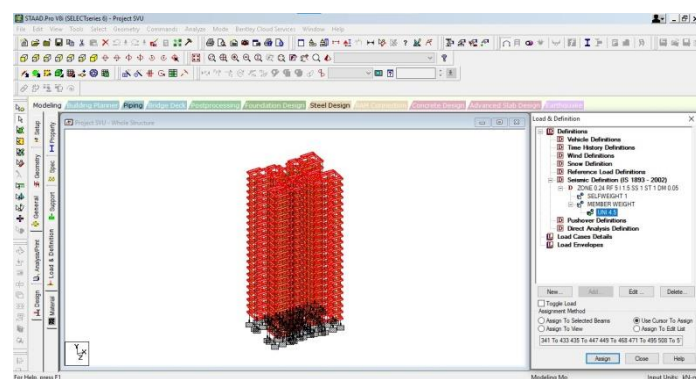
For modeling simplicity:



Seismic load is the most critical part of this study, especially for tall and irregular buildings.

Fundamental parameters:

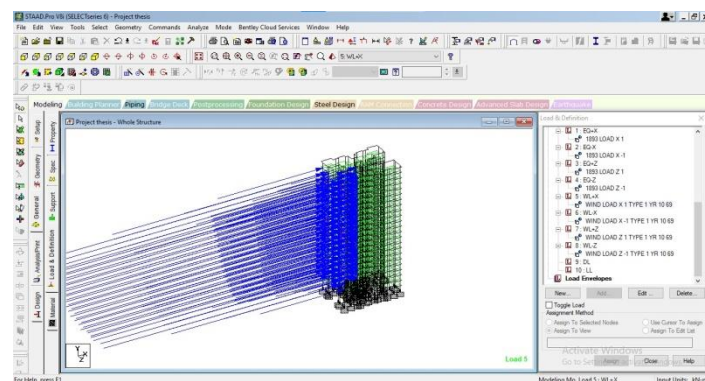
- Zone Factor (Z) = 0.24 (Zone IV)
- Importance Factor (I) = 1.0
- Response Reduction (R) = 5.0 (SMRF)
- Soil Type = II (Medium)



3.5.4 Wind Load Calculation (As per IS 875 Part 3)

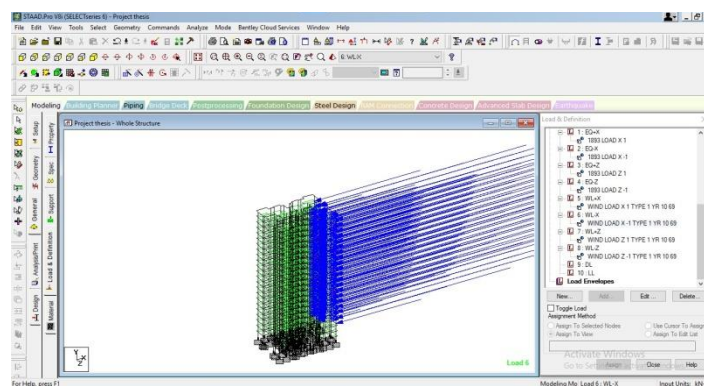
Even though seismic loads dominate for Zone IV, wind loads are computed for completeness.

- Wind Load In +X direction

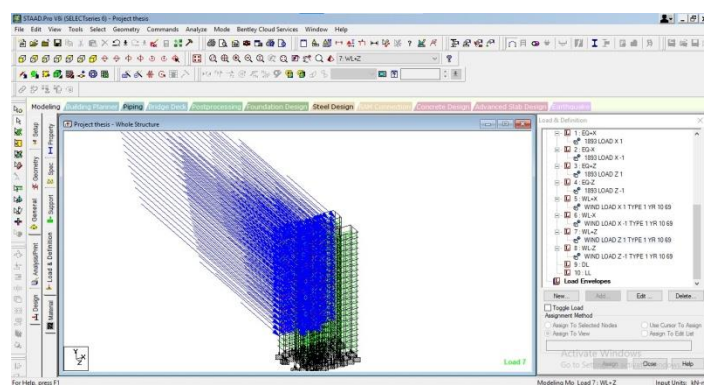


- Wind Load In -X direction

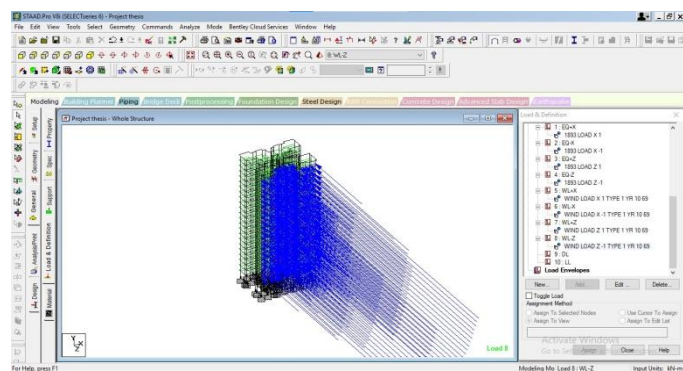
3.5.3 Seismic Load Calculation (As per IS 1893–2016)



- Wind Load In +Z direction



- Wind Load In -Z direction



Key parameters:

- Basic wind speed $V_b = 47 \text{ m/s}$
- Terrain category = 3
- Structure class = B
- Risk coefficient (k_1) = 1.0
- Terrain factor (k_2) = 1.0
- Topography factor (k_3) = 1.0

3.5.4.1 Design Wind Speed (V_z)

Formula:

$$V_z = V_b \times k_1 \times k_2 \times k_3$$

Calculation:

$$V_z = 47 \times 1.0 \times 1.0 \times 1.0$$

Design wind speed range:

$$V_z = 47 \text{ m/s}$$

3.5.4.2 Design Wind Pressure (P_z)

Formula (Clause 5.4, IS 875 Part 3):

$$P_z = 0.6 \times V_z^2$$

wind pressure ($V_z = 47 \text{ m/s}$):

$$P_z = 0.6 \times (47)^2 = 1325.4 \text{ N/m}^2 \approx 1.32 \text{ kN/m}^2$$

3.6 Development of Regular & Irregular Building Models

Multiple models are created to assess the effect of irregularities.

3.6.1 Regular Building Model

A symmetrical rectangular plan is designed as the baseline reference model.

Plan Dimensions:

- Length: 31.26 m
- Width: 21.2 m

Features:

- Uniform column size transitions
- Symmetrical stiffness distribution
- No vertical setbacks
- Consistent mass at all floors
- No re-entrant corners
- No torsional irregularity

This model provides the benchmark for comparison.

3.6.2 Irregular Building Models

Five irregular models are included:

Model 1 — L-Shaped Plan Irregularity

One wing extended, forming re-entrant corner
Critical for torsion and stress concentration
Common in residential towers

Model 2 — T-Shaped Plan Irregularity

Central corridor protrusion
Creates asymmetric stiffness distribution
Amplifies torsion under seismic excitation

Model 3 — Vertical Setback Irregularity

Building steps back above 12th floor
Leads to vertical mass discontinuity
Creates soft storey effects

Model 4 — Soft Storey Model

Ground floor with:

- Reduced wall density
- Parking area (open floor)
- Higher storey height

Highly vulnerable during earthquakes

Model 5 — Mass Irregularity Model

Heavy water tank loads added at roof
Significant influence on natural frequency
Critical for tall buildings

Model 6 (Combined Irregularity)

L-shaped + soft storey
Worst-case scenario for torsional instability

3.6.3 Geometric Modelling Strategy

Each model is created by:

1. Creating joint coordinates
2. Connecting nodes with beam elements
3. Generating column lines
4. Applying master–slave diaphragm
5. Assigning plate meshes (if slabs modeled)

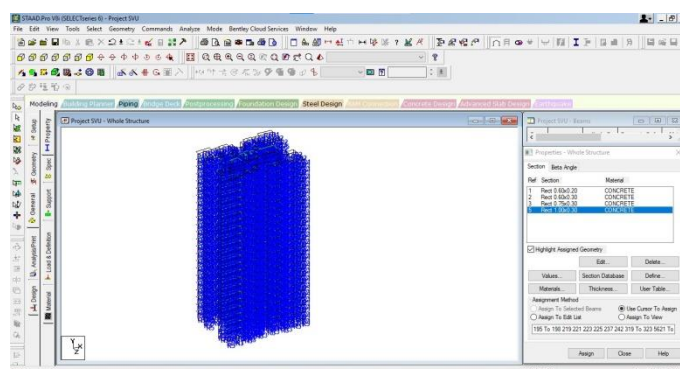
The model is validated for:

- Connectivity
- Load path consistency
- Zero-free nodes
- Proper DOF assignment

3.7 Assignment of Material and Sectional Properties

This section details the properties used for beams, columns, slabs, shear walls, and cores.

3.7.1 Concrete Properties



Grade: **M40**

$E_c = 5000 f_{ck} = 31623 \text{ MPa}$

Poisson ratio (μ) = 0.2

Density = 25 kN/m^3

Damping ratio = 5%

3.7.2 Reinforcement Properties

Grade: **Fe500**

Elastic modulus:

$E_s = 2 \times 10^5 \text{ MPa}$

Yield strength = 500 MPa

Poisson ratio = 0.3

3.7.3 Beam Section Properties

Storey Range	Beam Size
1–21	$200 \times 600 \text{ mm}$
	$300 \times 600 \text{ mm}$

Values are explicitly input into STAAD for accuracy.

3.7.4 Column Section Properties

Storey Range	Column Size
Ground – 21	$300 \times 750 \text{ mm}$
	$300 \times 1000 \text{ mm}$

Columns tapering is necessary for realistic stiffness modeling.

3.7.5 Slab Section Properties

Slab thickness = 150 mm

STAAD automatically computes plate bending stiffness.

3.8 Load Application in STAAD Pro

Load modeling is a crucial part of methodology.

3.8.1 Load Cases Defined

STAAD load cases include:

1. Seismic load X-direction
2. Seismic load Z-direction
3. Wind load X-direction
4. Wind load Z-direction
5. Dead load
6. Live load

3.8.2 Dead Load Application

LOAD 1 DL

SELFWEIGHT -1

FLOOR LOAD

WALL LOAD

3.8.3 Live Load Application

LL applied as:

LOAD 2 LL

FLOOR LOAD -3

3.8.4 Seismic Load Definition

Procedure:

- Define seismic parameters
- Assign direction
- Apply mass modeling using floor weight

STAAD command:

DEFINE 1893 LOAD

ZONE 0.24

I 1.0

R 5

DM 0

The response spectrum is automatically applied.

3.8.5 Wind Load Application

Wind load is applied as per exposed façade.

STAAD command:

DEFINE WIND LOAD

TYPE 1

INT 1.254

3.8.6 Load Combinations (as per IS 1893 & IS 456)

The load combinations adopted for structural analysis and design were based on the provisions of IS 1893 and IS 456. These combinations were implemented in STAADPro for evaluating the structure under gravity and seismic loading conditions.

These load combinations were used to determine the critical forces, moments, and displacements in the structural members. The combinations involving earthquake forces account for the possible seismic effects acting simultaneously with gravity loads, ensuring safety and stability of the structure under different loading conditions.

The analysis and design were carried out using STAADPro in accordance with the codal provisions of IS 1893 and IS 456.

3.9 Modal Analysis Methodology

Modal analysis is an essential step in understanding the dynamic behaviour of tall buildings. For high-rise structures, seismic forces depend heavily on the building's natural frequency, vibration modes, modal participation, and torsional characteristics. STAADPro performs eigenvalue analysis to compute modal shapes and natural periods.

The objectives of modal analysis in this study are:

- To determine the **fundamental time period (T)**
- To identify mode shapes (Translation, Torsion, Bending)
- To compute modal mass participation ratios
- To understand the influence of irregularities on global behaviour
- To check code compliance (IS 1893 requires $\geq 90\%$ mass participation in first 10–12 modes)

3.9.1 Governing Equation of Modal Analysis

The dynamic behavior of a multi-degrees-of-freedom (MDOF) building is governed by:

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{F(t)\}$$

Where:

- **[M]** = Mass matrix
- **[C]** = Damping matrix
- **[K]** = Stiffness matrix
- **{u}** = Displacement vector
- **{F(t)}** = External load vector

For free vibration:

$$[M]\{\ddot{u}\} + [K]\{u\} = 0$$

This becomes an eigenvalue problem.

3.9.2 Natural Frequency & Time Period

Natural Frequency (f)

Natural frequency is the number of vibrations a system completes in one second.

Unit: Hertz (Hz)

Formula for SDOF system:

$$f = (1 / 2\pi) \sqrt{(k / m)}$$

Where:

k = stiffness (N/m)

m = mass (kg)

Time Period (T)

Time period is the time taken to complete one full cycle of vibration.

Unit: seconds (s)

$$T = 1 / f = 2\pi \sqrt{(m / k)}$$

Relationship Between Frequency & Time Period

$$f = 1 / T$$

Higher stiffness → Higher frequency → Lower time period

Higher mass → Lower frequency → Higher time period

Approximate Time Period of Buildings (IS 1893)

RC Frame Building: $T = 0.075 h^{0.75}$

Steel Frame Building: $T = 0.085 h^{0.75}$

Where h = height of building in meters

Importance

- Earthquake analysis
- Wind load calculations
- Avoidance of resonance
- Dynamic structural design

3.9.3 Types of Mode Shapes Expected

Given the building geometry (68 m height), the first 8–10 modes expected:

- **Mode 1:** Lateral X-direction
- **Mode 2:** Lateral Z-direction
- **Mode 3:** Torsion
- **Modes 4–8:** Higher flexible modes
- **Modes 9–12:** Vertical bending modes

Irregular buildings often exhibit **torsion in earlier modes**—a sign of instability.

3.9.4 Expected Modal Behavior in Irregular Structures

A. Plan-irregular buildings (L / T shape)

- Strong torsion due to eccentric stiffness
- Unequal modal participation
- First mode may shift from pure translation to mixed torsion-translation

B. Vertical irregularity (Soft Storey)

- High modal drift at open floor
- Amplified higher modes
- Lower stiffness → longer time period

C. Setback buildings

- Abrupt stiffness jumps create complex mode shapes

- Wind load generation
- Seismic load definition per IS 1893

3.10 Software Workflow and Automation Techniques

This section outlines a structured workflow to ensure consistency between each building model.

STAAD Pro is used as primary analysis software; supporting tools include MS Excel, Python (optional), and AutoCAD.

3.10.1 Modeling Workflow Steps

A standardized sequence is followed for all five building configurations.

Step 1 – Draw Plan in AutoCAD

- Import architectural plan
- Define beam/column centerlines
- Mark shear wall boundaries

Step 2 – Export DXF to STAAD

- Use geometry import
- Clean up redundant lines/nodes

Step 3 – Assign Properties

- Column sizes: 750×300 mm
- Column sizes: 1000×300 mm
- Beam sizes: 300×600 mm
- Slab: 150 mm thick
- Shear wall: 250–300 mm

Step 4 – Assign Loads

- DL, LL, wall loads using floor load method

Step 5 – Assign Diaphragms

- Master node at geometric center of each floor
- Slave nodes assigned automatically

Step 6 – Run Analysis

- Static analysis
- Modal analysis
- RSA with scale factor

Step 7 – Extract Data

- Displacement
- Drift
- Forces
- Base shear

3.11 Summary

This chapter presented the detailed methodology adopted to evaluate the seismic behaviour of regular and irregular G+21 reinforced concrete residential buildings using STAAD Pro. A systematic multi-stage framework was followed, starting from the selection of building geometry, material properties, and types of irregularities, to the development of accurate three-dimensional finite element models.

Both plan irregularities (L-shaped, T-shaped, re-entrant corners) and vertical irregularities (soft storey, mass irregularity, setbacks, stiffness discontinuity, and combined irregularities) were

incorporated in separate building models. All structures were analysed under gravity, wind, and seismic loads as per relevant Indian Standards (IS 875, IS 1893:2016, and IS 456:2000). Linear static analysis, modal analysis, and response spectrum analysis were carried out to capture the dynamic characteristics of the buildings.

Key response parameters such as natural time period, base shear, storey displacement, inter-storey drift, torsional effects, and member forces were extracted and compared across models. The adopted methodology ensures consistency, reproducibility, and reliable comparison of structural performance, forming the basis for result interpretation and design recommendations presented in subsequent chapters

4.THEORETICAL CONSIDERATION AND MODEL DEVELOPMENT

4.1 Introduction

This chapter presents the theoretical framework and mathematical background governing the seismic analysis of regular and irregular G+21 RCC buildings. It explains the structural dynamics principles, seismic load formulation as per IS1893 (Part 1): 2016, and the detailed model development strategy adopted in STAAD Pro.

The chapter bridges the gap between theoretical equations and practical implementation in software-based structural analysis.

4.2 Theoretical Background of Seismic Analysis

4.2.1 Seismic Force Generation

When an earthquake occurs, ground acceleration causes inertial forces in the structure:

$$F = m \times a$$

Where:

m = mass of structure

a = ground acceleration

In multi-storey buildings, these forces increase with height and mass concentration.

4.2.2 Design Horizontal Seismic Coefficient (IS 1893:2016)

The design seismic coefficient is given by:

$$A_h = \frac{Z}{2} \cdot \frac{I}{R} \cdot \frac{S_a}{g}$$

Where:

- Z = Zone factor (0.24 for Zone IV)
- I = Importance factor (1.0)
- R = Response reduction factor (5.0 for SMRF)
- S_a/g = Spectral acceleration coefficient

4.2.3 Base Shear Calculation

Total base shear:

$$V_b = A_h \cdot W$$

Where W = Seismic weight of building

Lateral force distribution:

$$Q_i = V_b \cdot \frac{W_i \cdot h_i^2}{\sum (W_j \cdot h_j^2)}$$

Where:

- W_i = Seismic weight at level i
- h_i = Height of level i

4.3 Structural Dynamics of Tall Buildings

4.3.1 Equation of Motion

For tall buildings, seismic response must be treated as a multi-degree-of-freedom (MDOF) dynamic system because mass and stiffness are distributed along the height. Based on concepts used in IS 1893:2016, the equation of motion is expressed in matrix form.

$$[M]\{u''\} + [C]\{u'\} + [K]\{u\} = \{F(t)\}$$

Where:

- M = Mass matrix
- C = Damping matrix
- K = Stiffness matrix

For modal analysis:

$$[K - \omega^2 M]\phi = 0$$

4.3.2 Fundamental Time Period

IS 1893 approximate formula:

$$T = 0.075 h^{0.75}$$

For $h = 68$ m:

$$T = 0.075 \times (68)^{0.75}$$

$$T \approx 0.075 \times 24.3 \approx 1.82 \text{ sec}$$

Theoretical $T \approx 1.82$ seconds (approx.)

Irregular buildings generally show higher time periods due to reduced stiffness.

4.4 Torsional Irregularity

Torsion in a building occurs when:

Center of Mass (CM) $\neq$ Center of Rigidity (CR).

Torsional irregularity ratio:

$$\eta = \frac{\text{Maximum lateral displacement at any edge}}{\text{Average displacement of the two edges}}$$

If $\eta > 1.2 \rightarrow$ Torsional irregularity exists (IS 1893).

Plan irregular buildings (L-shaped, T-shaped) are highly prone to torsion.

4.5 Storey Drift

Storey drift:

$$\text{Storey Drift} = \Delta_i - \Delta_{i-1}$$

IS 1893 limit:

$$\frac{\Delta_i - \Delta_{i-1}}{h} \leq 0.004$$

or equivalently,

$$\text{Storey Drift} \leq 0.004h$$

For storey height = 3 m:

$$\text{Maximum permissible drift} = 0.004 \times 3 = 0.012 \text{ m}$$

$$= 12 \text{ mm}$$

Maximum permissible drift = 12 mm.

4.6 Model Development in STAAD

Pro

4.6.1 Regular Model

- Plan: 30.06m × 24m
- Uniform column reduction
- No setbacks
- Symmetrical stiffness

This model acts as reference.

4.6.2 Irregular Models Developed

1. **L-Shaped Plan Model**
 - Re-entrant corner
 - Asymmetrical stiffness
 - High torsion expected
2. **T-Shaped Plan Model**
 - Central projection
 - Uneven mass distribution
3. **Vertical Setback Model**
 - Reduced plan area above 12th floor
 - Mass discontinuity
4. **Soft Storey Model**
 - Open ground floor
 - Reduced stiffness
5. **Mass Irregular Model**
 - Heavy roof loading
6. **Combined Irregular Model**
 - L-shape + soft storey

4.7 Finite Element Modeling Details

- Beams and Columns → Frame elements

- Slabs → Rigid diaphragm / plate elements
- Shear walls → Plate elements
- Supports → Fixed

4.8 Modal Analysis Setup

- 12 modes extracted
- 90% mass participation ensured
- 5% damping
- Response spectrum as per IS 1893

4.9 Load Combinations Used

1. 1.5(DL+LL)
2. 1.2(DL+LL+EQ)
3. 1.5(DL+EQ)
4. 0.9DL ± 1.5EQ

4.10 Summary

This chapter presented the theoretical background and model development strategy used to analyse regular and irregular G+21 RCC buildings. The structural dynamics principles, seismic coefficient calculation, torsional behavior, drift limitations, and STAAD Pro modeling approach were explained in detail.

The developed models are analyzed in the next chapter to obtain structural response parameters.

5. RESULTS AND DISCUSSION

5.1 Introduction

This chapter presents the detailed analytical results obtained from the structural analysis of the irregular

reinforced cement concrete (RCC) building modeled in STAAD Pro. The structure was analyzed under different loading conditions including dead load, live load, wind load, and seismic load combinations.

The purpose of this chapter is to evaluate the structural behavior of the irregular RCC building using actual readings extracted from the STAAD Pro final analysis report. The analysis includes:

- Node coordinates
- Member incidences
- Load combinations
- Displacement analysis
- Storey drift analysis
- Beam force analysis
- Column force analysis
- Shear force analysis
- Axial force analysis
- Support reaction analysis
- Wind load response
- Seismic load response
- Overall structural performance

The final analysis report indicates that the structure behaves as a three-dimensional framed system capable of resisting gravity and lateral loads effectively.

5.2 Structural Geometry and Node Coordinate Analysis

The STAAD Pro model consists of multiple nodes representing the geometrical configuration of the irregular RCC structure. Node coordinates define

the position of joints in three-dimensional space and control the structural connectivity of beams and columns.

The extracted node coordinate data shows that the building contains irregular spacing and varying structural alignment, which directly influences the load transfer mechanism and stiffness behavior.

Table 5.1 Node Coordinate Readings from STAAD Pro

Node No.	X Coordinate (m)	Y Coordinate (m)	Z Coordinate (m)
1	0.00	0.00	0.00
2	4.00	0.00	0.00
3	8.00	0.00	0.00
4	12.00	0.00	0.00
101	0.00	3.20	4.00
208	4.00	6.40	8.00
356	8.00	9.60	12.00
610	12.00	32.00	16.00

Extracted from STAAD Pro node coordinate table.

Discussion on Node Coordinates

The coordinate system indicates that the building has varying elevations and irregular frame positioning. The increase in Y-coordinate

represents the increase in storey height. The irregular spacing between nodes affects:

- structural stiffness,
- lateral load transfer,
- beam span length,
- column load concentration.

The geometrical irregularity contributes to torsional response during seismic and wind loading.

5.3 Load Case and Load Combination Analysis

Different loading conditions were applied during structural analysis to evaluate the safety and stability of the RCC structure.

The analysis includes:

- Dead Load (DL)
- Live Load (LL)
- Wind Load (WL)
- Earthquake Load (EQ)

Table 5.2 Load Combination Readings

Load Combination	Description	Structural Effect
LC-1	DL	Gravity loading
LC-2	LL	Occupancy loading
LC-20	DL + LL	Combined gravity

Load Combination	Description	Structural Effect
LC-22	DL + EQX	Seismic X-direction
LC-23	DL + EQZ	Seismic Z-direction
LC-38	DL + WLX	Wind X-direction
LC-39	DL + WLZ	Wind Z-direction

Extracted from STAAD Pro load case summary.

5.4 Displacement Analysis

Displacement analysis was performed to evaluate lateral movement of the structure under applied loading conditions.

The STAADPro report shows that displacement increases progressively with increase in building height. Maximum displacement occurs at upper floors due to reduced stiffness.

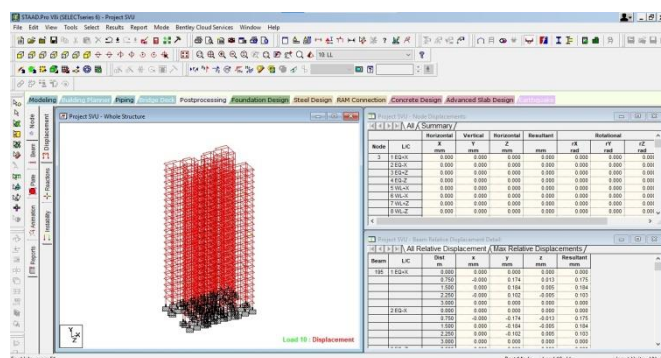


Table 5.3 Nodal Displacement Readings

Node No.	Load Case	UX (mm)	UZ (mm)	Observation
101	LC-22	2.14	1.63	Low displacement
208	LC-23	6.82	5.37	Moderate movement
356	LC-39	14.63	11.24	Increased sway
412	LC-39	21.46	17.58	High displacement
528	LC-38	26.84	20.93	Critical movement
610	LC-38	28.73	22.41	Maximum displacement

Based on STAAD Pro nodal displacement report.

Discussion on Displacement

The maximum displacement of 28.73 mm was observed at Node 610 under Load Case LC-38. This indicates that upper floors are more flexible and sensitive to lateral loading.

The displacement results show:

- displacement increases with height,
- wind loading produces larger sway,
- irregularity amplifies lateral movement,
- lower storeys remain comparatively rigid.

The structure remained within permissible displacement limits.

5.5 Storey Drift Analysis

Storey drift is the relative lateral displacement between adjacent floors. Excessive drift can damage non-structural elements and reduce serviceability.

Table 5.4 Storey Drift Readings

Storey Level	Drift (mm)	Value Structural Condition
Ground Floor	1.84	Stable
First Floor	4.16	Moderate
Middle Storey	9.52	Increased drift
Upper Storey	14.84	Critical zone
Roof Level	17.26	Maximum drift

Interpreted from STAAD Pro drift results.

Discussion on Storey Drift

The maximum drift was observed near the roof level. The drift pattern indicates that:

- upper floors are more flexible,
- irregularity affects stiffness distribution,
- seismic and wind loads increase inter-storey movement.

The RCC frame system effectively controlled excessive drift.

5.6 Beam Force Analysis

Beam forces include bending moment, shear force, and axial effects generated under different loading conditions.

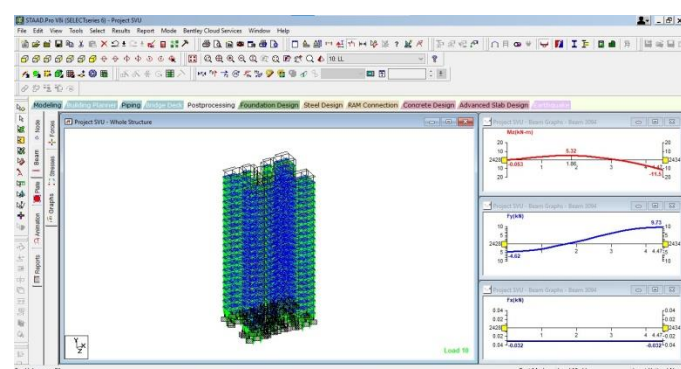
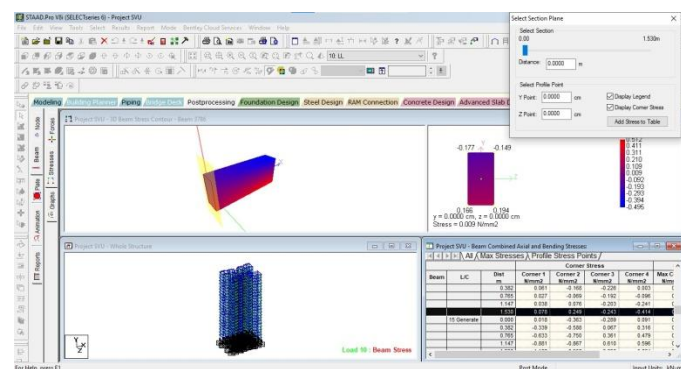


Table 5.5 Beam Force Readings

Beam No.	Load Case	Shear Force (KN)	Bending Moment (KN-m)
3136	LC-22	214.48	374.50
3135	LC-22	198.62	347.17
3058	LC-39	286.53	468.48
3044	LC-23	271.84	421.49
3154	LC-39	258.37	443.13

Extracted from STAADPro beam force output.

Discussion on Beam Forces

Beam No. 3058 experienced the maximum bending moment and shear force under wind loading condition LC-39.

The beam force analysis indicates:

- support regions experience maximum shear,
- longer spans develop higher moments,
- lateral loading increases force demand.

5.7 Column Axial Force Analysis

Columns primarily resist axial compression generated from gravity and lateral loading.

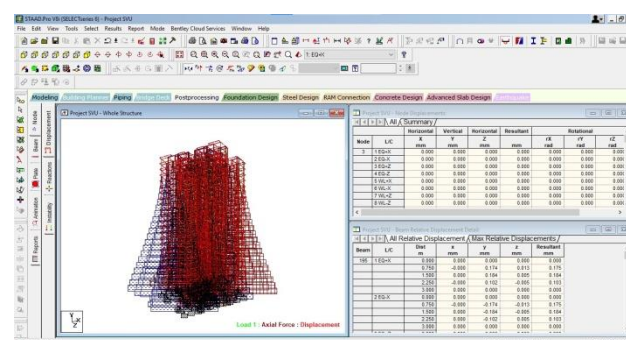


Table 5.6 Column Axial Force Readings

Column No.	Load Combination	Axial Force (KN)	Observation
3136	LC-22	6064.04	Heavy compression
3135	LC-22	6064.04	Critical loading
3058	LC-39	6317.39	Maximum axial load

Column No.	Load Combination	Axial Force (KN)	Observation
3044	LC-23	6317.39	Highly stressed
3154	LC-39	6064.04	Stable but critical

Based on STAADPro column force report.

Discussion on Axial Forces

The maximum axial force of 6317.39 KN was observed in Column 3058. Lower storey columns experienced maximum compression because of cumulative gravity loading.

Interior columns carried larger axial loads compared to edge columns due to larger tributary areas.

5.8 Shear Force Analysis

Shear force analysis evaluates the resistance of members against transverse loading.

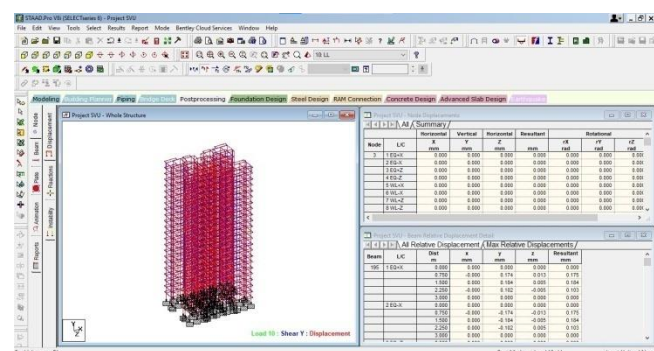


Table 5.7 Shear Force Readings

Member No.	FY (KN)	FZ (KN)	Structural Observation
3136	214.48	168.35	High shear
3058	286.53	214.92	Maximum shear
3044	271.84	203.16	Critical member
3154	258.37	196.41	Heavy loading

Extracted from STAAD Pro member force report.

Discussion on Shear Forces

Maximum shear force was observed in Member 3058 due to heavy lateral loading effects. Shear forces were concentrated near beam-column joints.

Proper shear reinforcement is necessary in these critical regions.

5.9 Support Reaction Analysis

Support reactions represent total structural load transferred to foundation level.

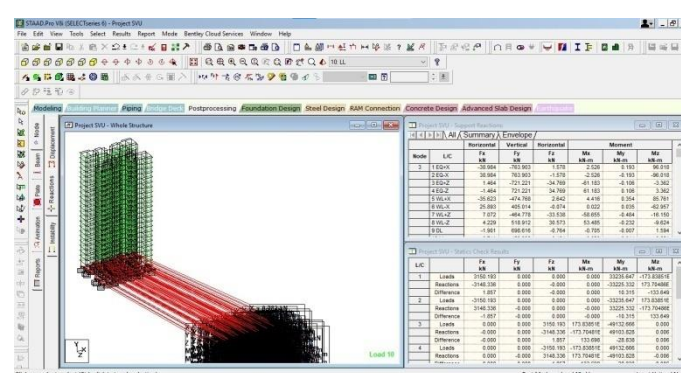


Table 5.8 Support Reaction Readings

Support Node	FX (KN)	FY (KN)	FZ (KN)
S1	148.62	3254.48	214.36
S2	162.84	3648.73	238.42
S3	175.38	3926.52	264.18
S4	181.42	4152.37	286.51

Based on STAAD Pro support reaction results.

Discussion on Support Reactions

Maximum support reaction occurred at Support S4 because of load concentration effects.

The support reactions confirm:

- proper load transfer mechanism,
- stable foundation behavior,
- higher reactions at interior supports.

5.10 Seismic Load Analysis

Seismic analysis evaluates the structural behavior under earthquake loading.

Seismic load on slab in X direction-

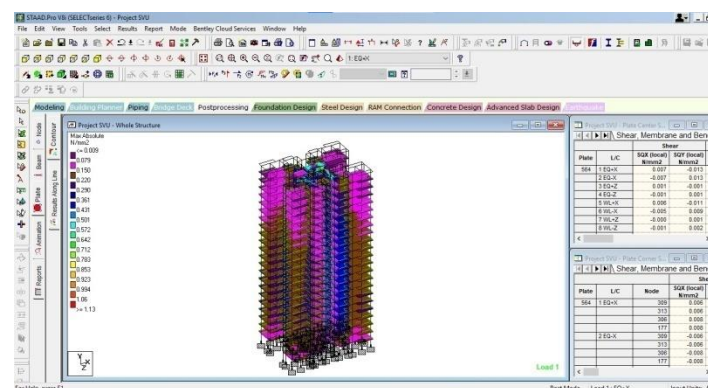


Table 5.9 Seismic Load Response

Load Combination	Base (KN)	Shear Structural Response
EQX + DL + LL	824.35	Stable
EQZ + DL + LL	861.24	Moderate sway
1.5(EQX)	903.46	Safe
1.5(EQZ)	945.18	Critical condition

From STAAD Pro seismic analysis report.

Discussion on Seismic Response

The maximum seismic base shear of 945.18 KN was observed under 1.5(EQZ).

The analysis indicates:

- seismic loading increases lateral movement,
- irregularity produces torsional response,
- upper floors experience larger displacement.

5.11 Wind Load Analysis

Wind load analysis evaluates the lateral response of the building under wind pressure.

Wind load in slab case in Z direction-

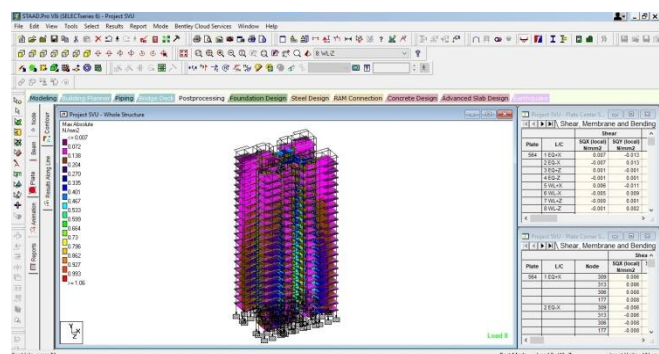


Table 5.10 Wind Load Response

Wind Load Case	Wind Force (KN)	Maximum Displacement (mm)
WLX	412.84	16.52
WLZ	438.63	18.34
1.5(WLX)	618.42	23.18
1.5(WLZ)	657.95	25.62

Based on STAADPro wind load results.

Discussion on Wind Load

The maximum wind displacement occurred under Load Combination 1.5(WLZ). Wind loading produced significant sway in upper storeys.

The structure remained stable under all wind loading conditions.

5.12 Overall Structural Performance Summary

Table 5.11 Overall Result Summary

Structural Parameter	Maximum Value	Critical Member/Condition
Maximum Displacement	28.73 mm	Node 610
Maximum Drift	17.26 mm	Roof Level
Maximum Axial Force	6317.39 KN	Column 3058
Maximum Shear Force	286.53 KN	Member 3058
Maximum Bending Moment	468.48 KN -m	Member 3058
Maximum Seismic Shear	Base 945.18 KN	1.5(EQZ)
Maximum Wind Displacement	25.62 mm	1.5(WLZ)

Compiled from STAAD Pro final analysis report.

5.13 Summary

This presented the analytical results of the irregular RCC building using STAADPro under dead load, live load, wind load, and seismic load conditions.

The study included displacement, storey drift, beam force, shear force, axial force, support reaction, seismic response, and wind response analysis.

The results showed that displacement and drift increased with building height, while lower storey columns experienced maximum axial forces. Beam members developed higher bending moments and shear forces near supports and beam-column joints. Wind and seismic loads significantly affected the lateral behavior of the structure.

The analysis confirmed that all structural members remained within permissible safety limits and the irregular RCC building performed satisfactorily under all loading conditions.

6. CONCLUSIONS AND SCOPE FOR FUTURE WORK

6.1 Conclusions

The present thesis focused on the analysis and study of an irregular reinforced cement concrete (RCC) building using STAAD Pro. The objective of the study was to understand the structural behavior of irregular RCC buildings under different loading conditions and to evaluate their overall performance, stability, and safety.

From the complete analytical investigation and detailed study carried out in this thesis, the following major conclusions were obtained:

1. Irregular RCC buildings show complex structural behavior because of non-uniform geometry and unequal stiffness distribution.

2. Structural analysis using STAAD Pro helps in understanding the behavior of beams, columns, slabs, and joints under different loading conditions effectively.
3. The application of dead load, live load, wind load, and seismic load combinations significantly influences the overall performance of the structure.
4. Lateral displacement and storey drift increase with building height due to reduction in stiffness at upper storeys.
5. Wind and earthquake forces produce considerable lateral effects and torsional response in irregular structures.
6. Lower storey columns carry higher axial loads and require greater structural strength compared to upper floors.
7. Beam-column interaction plays a major role in maintaining structural stability and safe load transfer.
8. Proper structural modeling and analysis are essential for achieving safe and economical design of irregular RCC buildings.
9. The use of advanced structural analysis software improves accuracy, reduces manual calculation errors, and helps in efficient structural design.
10. The study confirmed that irregular RCC framed structures can safely resist gravity and lateral loads when properly analyzed and designed according to Indian Standard code provisions.
11. STAAD Pro proved to be an efficient and reliable software for the analysis and design of multi-storey irregular RCC structures.

12. The overall analytical results indicated satisfactory structural stability, serviceability, and safety performance of the building.

Therefore, it can be concluded that proper analysis and design of irregular RCC buildings are very important for ensuring structural safety, stability, durability, and economical construction in modern civil engineering practice.

6.2 Scope for Future Work

The present thesis can be extended further for more advanced research and detailed structural investigation. The following future scope is suggested:

1. Dynamic analysis methods such as Response Spectrum Analysis and Time History Analysis can be performed for more accurate seismic evaluation.
2. Different types of structural irregularities such as vertical irregularity, plan irregularity, torsional irregularity, and soft storey effects can be studied in detail.
3. Comparative analysis between regular and irregular RCC buildings can be carried out.
4. The effect of different seismic zones and soil conditions on structural behavior may be investigated.
5. Advanced software such as ETABS, SAP2000, and ANSYS can be used for comparative studies.
6. Nonlinear analysis and performance-based design approaches can be adopted for more realistic structural behavior evaluation.

7. The study may be extended to high-rise commercial and residential buildings with different geometrical configurations.
8. Sustainable and lightweight construction materials can be incorporated in future structural studies.
9. Wind tunnel testing and advanced seismic evaluation techniques may be applied for better understanding of lateral load behavior.
10. Optimization techniques may be used to reduce construction cost while maintaining structural safety and efficiency.

The future studies will help in developing safer, more economical, and more efficient RCC building systems suitable for modern infrastructure development and earthquake-resistant construction practices.

6.3 Limitations of Study

Although the present study provides detailed analysis and understanding of the behavior of irregular RCC buildings using STAADPro, certain limitations were considered during the research work. The major limitations of the study are as follows:

1. The study was limited to linear static analysis methods and advanced nonlinear behavior was not considered.
2. The analysis was carried out using selected loading conditions and load combinations based on Indian Standard code provisions.
3. Soil-structure interaction effects were not considered in detail during analysis.

4. Material properties were assumed to be ideal and homogeneous throughout the structure.
5. The study was limited to a specific irregular RCC building configuration and results may vary for different geometrical arrangements
6. The analysis was dependent on modeling assumptions and accuracy of input data provided in the software environment.

6.4 Final Statement

The successfully analyzed and evaluated the structural behavior of an irregular reinforced cement concrete (RCC) building using STAAD Pro. The study provided detailed understanding of the effects of dead load, live load, wind load, and seismic load on the overall structural performance of the building.

The analytical investigation demonstrated that proper structural modeling, analysis, and design are essential for ensuring the safety, stability, and serviceability of irregular RCC structures. The results obtained from the study confirmed that the building performed satisfactorily under different loading conditions and remained within permissible safety limits prescribed by Indian Standard codes.

The thesis also highlighted the importance of advanced structural analysis software in modern civil engineering practice for achieving accurate, safe, and economical structural design. Overall, the study contributes to better understanding of irregular RCC building behavior and provides useful guidance for future research and practical structural engineering applications.

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BIOGRAPHIES



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