

Performance-Based Design of A Skyscraper Using ETBS

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Abstract - Urban densification and rapid growth of metropolitan cities have resulted in the construction of tall and slender buildings. Such structures are highly sensitive to lateral loads arising from earthquakes and wind. Traditional force-based design methods, although codal compliant, do not explicitly quantify damage levels or post-earthquake usability of buildings. Performance-Based Design (PBD) addresses this limitation by linking structural demand with expected performance objectives.

This study presents a detailed performance-based evaluation of a G+24 storey reinforced concrete skyscraper with multiple basements, modeled and analyzed using ETABS software. The structural system primarily consists of reinforced concrete moment-resisting frames integrated with a central core shear wall system. The building is analyzed under gravity loads, wind loads, equivalent static seismic loads, and response spectrum-based seismic loads as per relevant Indian Standard codes.

Key response parameters such as fundamental time period, modal mass participation, storey displacement, inter-storey drift, base shear, and lateral stiffness distribution are evaluated. The study demonstrates how proper structural planning, shear wall placement, stiffness distribution, and ductile detailing improve the seismic performance of tall buildings.

Key Words: Performance-Based Design (PBD), ETABS, Reinforced Concrete Building, Seismic Analysis, Response Spectrum Analysis, Shear Wall.

1. INTRODUCTION

1.1 BACKGROUND

Rapid urbanization and continuous population growth have led to a significant increase in the construction of high-rise buildings, particularly in metropolitan cities where land availability is limited. Reinforced concrete (RC) skyscrapers have become a preferred structural solution because of their strength, durability, and efficient utilization of vertical space. However, as the height of a building increases, its response to lateral forces such as earthquakes and wind becomes more critical. These lateral loads can cause excessive storey displacement, inter-storey drift, torsional effects, and structural instability, making seismic and wind-resistant design an essential aspect of modern structural engineering.

Conventional structural design methods primarily focus on providing adequate strength to resist design loads specified in building codes. Although these methods ensure structural safety, they do not directly evaluate the expected performance or damage level of a building during severe earthquake events. Therefore, there is an increasing need for advanced design

approaches that not only satisfy strength requirements but also improve the overall structural performance and serviceability of tall buildings.

1.2 PERFORMANCE-BASED DESIGN OF TALL BUILDINGS

Performance-Based Design (PBD) is an advanced structural design philosophy that evaluates the expected behavior of a building under different levels of loading. Unlike conventional force-based design, PBD considers predefined performance objectives such as immediate occupancy, life safety, and collapse prevention. This approach enables engineers to estimate structural damage, deformation, and post-earthquake functionality, resulting in safer and more economical designs.

The availability of advanced structural analysis software has further improved the implementation of Performance-Based Design. ETABS is one of the most widely used software applications for modelling and analyzing multi-storey buildings. It provides efficient three-dimensional modelling capabilities and supports static as well as dynamic analysis under gravity, wind, and seismic loading conditions. Parameters such as storey displacement, storey drift, base shear, modal mass participation, natural time period, and lateral stiffness can be accurately evaluated using ETABS, making it highly suitable for the performance assessment of tall reinforced concrete buildings.

1.3 RESEARCH GAP AND OBJECTIVES

1.3.1 Research Gap

- Most existing studies primarily focus on conventional force-based design, while limited research has been carried out using Performance-Based Design (PBD) for high-rise reinforced concrete buildings.
- Previous research has generally investigated regular building configurations, whereas the behaviour of tall buildings with slab cut-outs, vertical irregularities, and central shear wall core systems has received comparatively less attention.
- Limited studies have evaluated the combined effects of wind and seismic loading on G+24 reinforced concrete skyscrapers using the latest Indian Standard codes.
- Comprehensive assessment of structural response parameters such as storey displacement, inter-storey drift, base shear, modal mass participation, and lateral stiffness in a single study is relatively limited.

1.3.2 Objectives of the Present Study

- To develop a three-dimensional analytical model of a G+24 reinforced concrete skyscraper using ETABS.
- To analyse the building under gravity, wind, equivalent static seismic, and response spectrum loading conditions.
- To evaluate the seismic performance of the structure using the Performance-Based Design approach.
- To study important structural response parameters including storey displacement, storey drift, base shear, modal characteristics, and lateral stiffness.
- To assess the effectiveness of the shear wall core system in improving the overall stability and seismic performance of the building.
- To verify the structural performance with respect to the relevant Indian Standard code provisions.
- To examine the influence of wind and earthquake forces on the overall behaviour of the building.
- To demonstrate the suitability of ETABS software for the analysis and performance evaluation of modern high-rise reinforced concrete buildings.

1.3.3 Significance of the Study

The rapid growth of urban infrastructure has led to an increasing demand for safe and efficient high-rise buildings capable of resisting earthquake and wind forces. Performance-Based Design (PBD) provides a more realistic approach to structural design by evaluating the expected behaviour of buildings under different loading conditions rather than relying only on strength-based design methods. This study contributes to the understanding of the seismic performance of reinforced concrete skyscrapers by applying Performance-Based Design principles using ETABS software.

The findings of this study are useful for structural engineers, designers, researchers, and students involved in the planning and analysis of tall buildings. The study also highlights the importance of shear wall systems and response spectrum analysis in improving the safety, stability, and serviceability of high-rise reinforced concrete structures designed according to Indian Standard codes.

1.4 SCOPE OF STUDY

The scope of the present study is limited to the performance-based evaluation of a G+24 reinforced concrete skyscraper with multiple basement levels using ETABS software. The study focuses on assessing the structural behaviour of the building under gravity, wind, and seismic loading conditions in accordance with the relevant Indian Standard codes. The major scope of the work includes:

- Development of a three-dimensional analytical model of the proposed high-rise building using ETABS.
- Modelling of reinforced concrete moment-resisting frames integrated with a central shear wall core system.
- Application of gravity loads, wind loads, equivalent static seismic loads, and response spectrum analysis.
- Evaluation of key structural response parameters such as storey displacement, inter-storey drift, base shear, modal mass participation, and lateral stiffness.
- Assessment of the effectiveness of the shear wall system in improving the overall seismic performance and stability of the structure.

- Verification of structural performance with respect to the requirements of relevant Indian Standard codes.
- Interpretation of analytical results to determine the overall safety, serviceability, and structural efficiency of the proposed skyscraper.

1.5 METHODOLOGY (OVERVIEW)

The methodology adopted in the present study consists of the following steps:

- Selection of a G+24 reinforced concrete skyscraper with multiple basement levels for performance-based evaluation.
- Development of a three-dimensional structural model using ETABS software.
- Definition of material properties, structural member sections, and building geometry based on the design requirements.
- Modelling of reinforced concrete moment-resisting frames integrated with a central shear wall core system.
- Application of gravity loads, wind loads, equivalent static seismic loads, and response spectrum loading in accordance with the relevant Indian Standard codes.
- Execution of linear static and dynamic analyses to determine the structural response under different loading conditions.
- Evaluation of key performance parameters, including storey displacement, inter-storey drift, base shear, modal mass participation, natural time period, and lateral stiffness.
- Comparison of the analytical results with the codal limits to assess the overall safety, stability, and seismic performance of the proposed building.

2. OVERVIEW OF THE METHODOLOGY

The present study adopts a systematic Performance-Based Design (PBD) approach to evaluate the structural behaviour of a reinforced concrete skyscraper under gravity, wind, and seismic loading conditions. A three-dimensional analytical model of the building was developed using ETABS software by considering the structural configuration, material properties, and design provisions specified in the relevant Indian Standard codes. The complete methodology adopted in the study is presented in the following sections.

2.1 SELECTION AND DESCRIPTION OF THE BUILDING MODEL

2.1.1 Rationale for Selection of the Skyscraper

The selected building is a G+24 reinforced concrete skyscraper with multiple basement levels. The building was chosen because high-rise structures are more susceptible to lateral forces generated by earthquakes and wind compared to low-rise buildings. The presence of greater height, larger slenderness ratio, and increased flexibility makes skyscrapers more challenging to design and analyse. Therefore, they provide an appropriate case study for evaluating the effectiveness of the Performance-Based Design approach.

The selected structural system incorporates reinforced concrete moment-resisting frames together with a central shear wall core to enhance lateral stiffness and overall structural stability. The building also contains slab cut-outs and structural irregularities,

making it suitable for studying realistic structural behaviour under different loading conditions.

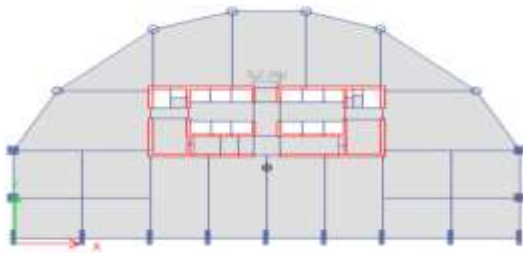


Figure 1: Typical Floor Plan of the G+24 Storey Building

2.1.2 General Building Details

The analytical model represents a G+24 reinforced concrete skyscraper with multiple basement levels designed for structural performance evaluation using ETABS software. The building consists of reinforced concrete beams, columns, slabs, and a centrally located shear wall core that serves as the primary lateral load-resisting system.

The structural model was developed by considering the actual building geometry, member dimensions, floor configuration, and loading conditions. Gravity loads, wind loads, equivalent static seismic loads, and response spectrum loading were applied in accordance with the relevant Indian Standard codes. The selected building configuration enables a comprehensive assessment of displacement, storey drift, base shear, modal characteristics, and overall structural performance under various loading conditions.

Table 1: Project Details

Parameter	Value
Building Type	Commercial
Number of Storeys	3B + G + 24
Total Height	117.4 m
Location	Gurugram
Seismic Zone	IV
Soil Type	Medium
Importance Factor	1.2
Response Reduction Factor	4
Analysis Software	ETABS
Design Approach	Performance-Based Design

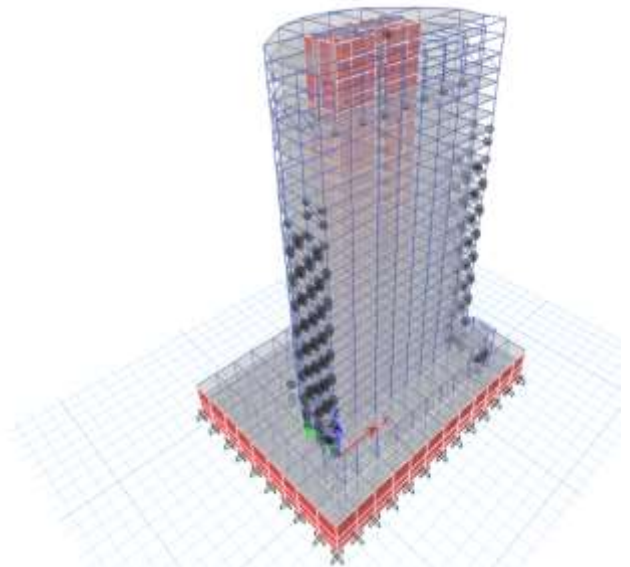


Figure 2: Three-Dimensional ETABS Model of the G+24 Reinforced Concrete Skyscraper

2.2 MATERIAL PROPERTIES AND DESIGN STANDARDS

2.2.1 Material Specifications

The proposed skyscraper was modelled using reinforced concrete and high-strength reinforcing steel to ensure adequate strength, durability, and seismic resistance. Material properties were assigned in ETABS according to the project specifications and relevant Indian Standard codes. The selected materials provide sufficient stiffness, stability, and ductility for high-rise construction.

Table 2: Material Specifications

Material	Specification
Concrete Grade	M45, M60,etc.
Reinforcement Steel	Fe550
Structural System	Reinforced Concrete (RC)
Analysis Software	ETABS

2.2.2 Design Codes Considered

The structural analysis and design were carried out in accordance with the relevant Indian Standard codes. These standards were used for material design, gravity loading, wind loading, seismic analysis, and structural safety. The structural analysis and design of the proposed G+24 reinforced concrete skyscraper were carried out in accordance with the relevant Indian Standard (IS) codes. These standards provide comprehensive guidelines for determining design loads, material properties, structural safety, seismic resistance, and serviceability requirements. Adherence to these codes ensures that the structural system satisfies the prescribed safety criteria and performs efficiently under both gravity and lateral loading conditions. The selected codes also provide a reliable framework for achieving a safe, durable, and code-compliant structural design.

Table 3: Design Code Considered

Code	Description
IS 456:2000	Plain and Reinforced Concrete
IS 875 (Part 1)	Dead Loads
IS 875 (Part 2)	Live Loads
IS 875 (Part 3)	Wind Loads
IS 1893 (Part 1):2016	Earthquake Resistant Design
IS 16700:2023	Tall Concrete Buildings

2.3 STRUCTURAL MODELING PROCEDURE

2.3.1 Modeling Philosophy

The structural model of the skyscraper was developed using a three-dimensional approach to realistically simulate the behaviour of the building under various loading conditions. The modelling was carried out with the objective of capturing the actual structural response, including stiffness distribution, load transfer mechanism, and lateral stability of the system. The Performance-Based Design approach was adopted to evaluate the seismic performance of the structure under different demand levels.

2.3.2 Modeling of Structure in ETABS

The complete structural model was created in ETABS by defining the geometry, storey data, and material properties of the building. Beam, column, slab, and shear wall elements were modelled using appropriate section properties. The structural connectivity and boundary conditions were defined to ensure realistic behaviour of the model.

The model was analysed under gravity, wind, and seismic loads as per relevant Indian Standard codes. Both linear static and response spectrum analysis methods were used to evaluate the structural response parameters such as displacement, drift, and base shear.

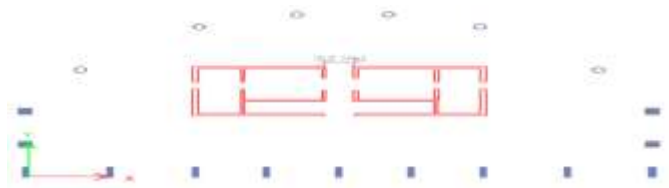


Figure 3: Shear Wall Layout

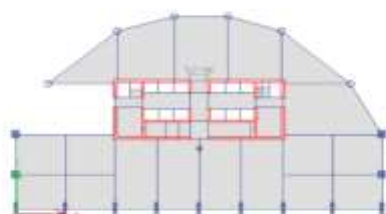


Figure 4: Plan View of the Building

2.4 LOAD ESTIMATION AND APPLICATION

2.4.1 Dead Load

Dead loads were assigned based on the self-weight of structural members and other permanent building components. ETABS automatically calculated the self-weight, while additional dead

loads were applied according to the relevant Indian Standard provisions. The dead load consists of the self-weight of all permanent structural and non-structural components of the building, including beams, columns, slabs, walls, floor finishes, and other fixed elements. These loads remain constant throughout the service life of the structure and form the primary vertical loading considered during analysis. The dead load calculations were carried out in accordance with the provisions of **IS 875 (Part 1)** to ensure realistic representation of the permanent loads acting on the building.

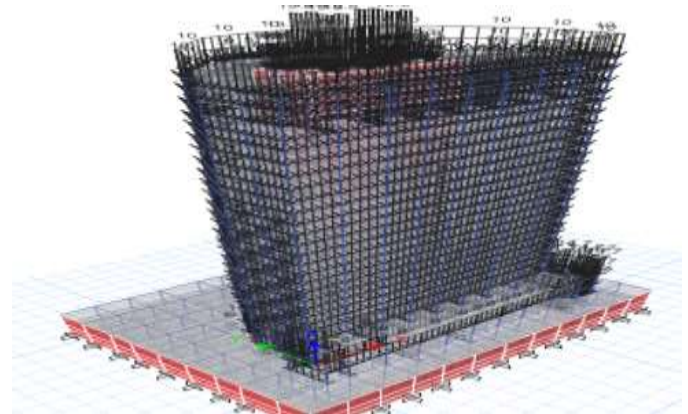


Figure 5: Load Display in ETABS

2.4.2 Live Load

Live loads were assigned considering the intended occupancy of the commercial building. Appropriate live load values were applied on all floors as specified in IS 875 (Part 2). The live load represents the variable loads acting on the building during its service life, including the weight of occupants, furniture, equipment, and movable objects. These loads were assigned in accordance with the provisions of **IS 875 (Part 2)** based on the intended occupancy of the commercial building. Appropriate live load values were considered to ensure realistic loading conditions during structural analysis. The inclusion of live loads enables an accurate assessment of the building's strength, stability, and serviceability under normal operating conditions.

2.4.2 Wind Load

Wind loads were evaluated in accordance with IS 875 (Part 3):2015. The required parameters, including building height, location, and terrain conditions, were considered to determine the design wind forces acting on the structure. The wind load acting on the building was determined in accordance with the provisions of **IS 875 (Part 3)**. The wind forces were calculated by considering factors such as the geographical location of the building, design wind speed, terrain category, building height, and topographic conditions. These parameters ensure a realistic estimation of wind pressure acting on the structure. The calculated wind loads were applied in both principal directions to evaluate the lateral response and overall stability of the skyscraper.

2.4.3 Seismic Load

Seismic loads were determined as per IS 1893 (Part 1):2016 by considering the building location in Seismic Zone IV, medium soil conditions, importance factor, and response reduction factor. Both equivalent static and response spectrum analyses were performed to evaluate the seismic behaviour of the structure. The seismic load was evaluated in accordance with the provisions of **IS 1893 (Part 1):2016** by considering the seismic zone, importance factor, response reduction factor, soil type, and fundamental time period of the building. Since the

proposed structure is located in **Seismic Zone IV**, special attention was given to earthquake-resistant design to ensure structural safety under seismic excitation. The calculated seismic forces were applied in both the X and Y directions to evaluate the lateral response and dynamic behaviour of the building.

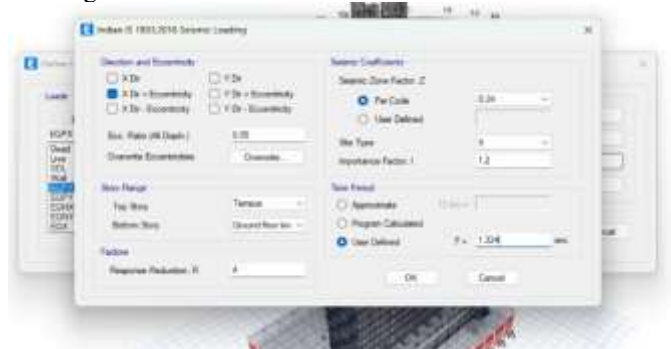


Figure 6: Seismic Parameters



Figure 7: Assigned Response Spectrum Function in ETABS

2.4.4 Load Combinations

Load combinations involving dead load, live load, wind load, and seismic load were generated according to the relevant Indian Standard codes. These combinations were used to identify the critical loading conditions for structural analysis and design. The structural model was analysed using appropriate load combinations to evaluate the behaviour of the building under various loading conditions. These combinations were prepared in accordance with the relevant Indian Standard codes by considering the simultaneous effects of dead load, live load, wind load, and seismic load. The use of multiple load combinations ensures that the structure is assessed under the most critical loading scenarios likely to occur during its service life.

2.5 ANALYSIS METHODOLOGY

The structural analysis of the proposed skyscraper was carried out using ETABS software. The analytical model was subjected to gravity loads, wind loads, equivalent static seismic loads, and response spectrum analysis in accordance with the relevant Indian Standard codes. The structural response was evaluated by analysing parameters such as storey displacement, inter-storey drift, base shear, modal characteristics, and lateral stiffness. The obtained results were compared with the codal requirements to assess the overall structural performance and safety of the building. The analysis included gravity load analysis, wind load analysis, equivalent static seismic analysis, and response spectrum analysis. The structural response was assessed using parameters such as storey displacement, inter-storey drift, base shear, modal characteristics, and lateral stiffness. The results obtained from ETABS were carefully interpreted to verify the safety, stability, and overall performance of the proposed skyscraper under the prescribed design loads.

2.6 PERFORMANCE EVALUATION METHODOLOGY

The performance of the building was assessed by examining its behaviour under different loading conditions. Important response parameters, including storey displacement, storey drift, base shear, modal mass participation, and stiffness distribution, were considered to evaluate the structural efficiency. The results obtained from ETABS were used to determine whether the building satisfies the performance objectives and seismic safety requirements. The performance of the proposed G+24 reinforced concrete skyscraper was evaluated by analysing its structural response under gravity, wind, and seismic loading conditions using ETABS software. The assessment was carried out by considering key performance parameters such as storey displacement, inter-storey drift, base shear, modal characteristics, and overall structural stability. These parameters provide a comprehensive understanding of the behaviour of the building under different loading scenarios.

2.7 INTERPRETATION AND DISCUSSION

The analytical results obtained from ETABS were carefully interpreted to understand the structural behaviour of the skyscraper. The response of the building under gravity, wind, and seismic loads was analysed by comparing different performance parameters with the permissible limits specified in the relevant design codes. The observations provide useful information regarding the stability, stiffness, and overall structural performance of the proposed building. The analytical results demonstrate that the adopted structural system performs efficiently under the applied loading conditions. The reinforced concrete moment-resisting frame, combined with the centrally located shear wall core, provides adequate lateral stiffness and strength to resist wind and seismic forces. The evaluated response parameters indicate a stable structural behaviour, with all major performance criteria remaining within the permissible limits specified by the relevant Indian Standard codes. Overall, the analysis confirms that the proposed structural configuration is capable of ensuring safety, serviceability, and satisfactory performance throughout its design life.

2.8 ANALYSIS REPORT

The structural response of the proposed G+24 reinforced concrete skyscraper was evaluated using ETABS under gravity, wind, and seismic loading conditions. The performance of the building was assessed by examining important response parameters such as storey displacement, storey drift, drift performance, structural stability, and wind response. The obtained results were compared with the relevant Indian Standard provisions to verify the structural safety and performance of the building.

2.8.1 Storey Displacement

Storey displacement was evaluated in both the X and Y directions to determine the lateral movement of the building under seismic loading. The displacement gradually increased with building height, while the maximum displacement was observed at the top storey. The obtained values remained within

the permissible limits, indicating satisfactory structural performance.

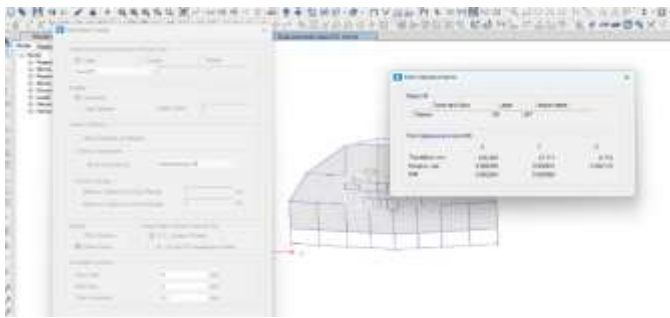


Figure 8: Storey Displacement in X Direction

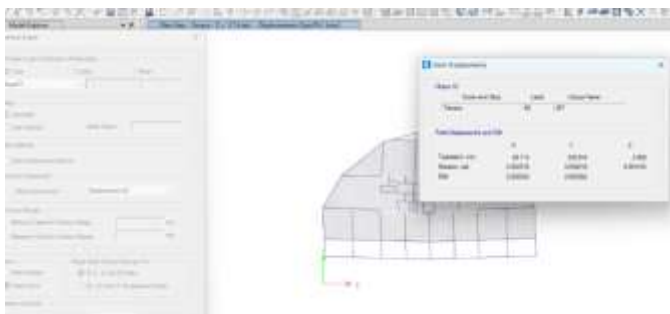


Figure 9: Storey Displacement in Y Direction

2.8.2 Storey Drift

Storey drift was analysed to evaluate the relative displacement between two consecutive storeys during seismic excitation. The drift values were found to be within the codal limits specified in IS 1893 (Part 1):2016, demonstrating adequate lateral stiffness and seismic resistance of the building. The inter-storey drift values increase gradually from the lower floors towards the upper levels and remain within the allowable limits specified by IS 1893 (Part 1):2016. The results indicate that the structural system possesses adequate lateral stiffness and effectively controls excessive deformation during seismic loading. The incorporation of the central shear wall core significantly contributes to improving the seismic performance and overall stability of the building.

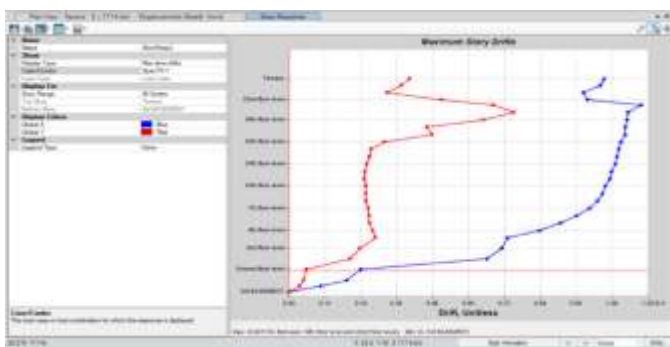


Figure 10: Storey Drift in X Direction

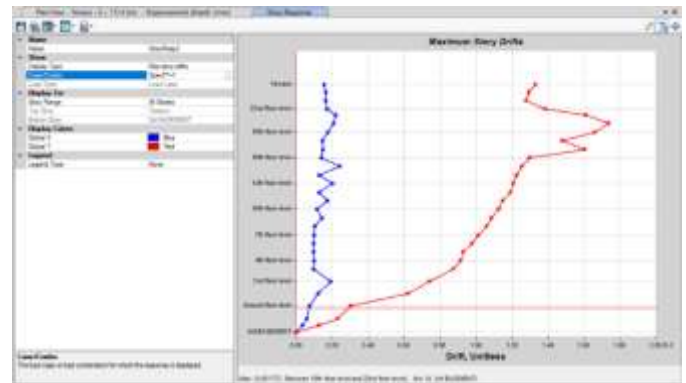


Figure 11: Storey Drift in Y Direction

2.8.3 Drift Performance

The overall drift performance of the structure was assessed based on the maximum inter-storey drift values obtained from the analysis. The results indicate that the building satisfies the prescribed drift limits and exhibits stable behaviour under the considered loading conditions. The drift results indicate that the building performs efficiently under seismic loading. A gradual increase in drift is observed with increasing height, which is expected in high-rise buildings. The presence of the shear wall system effectively controls excessive lateral movement and improves the overall stability of the structure. Therefore, the building satisfies the drift requirements specified in the relevant Indian Standard codes.

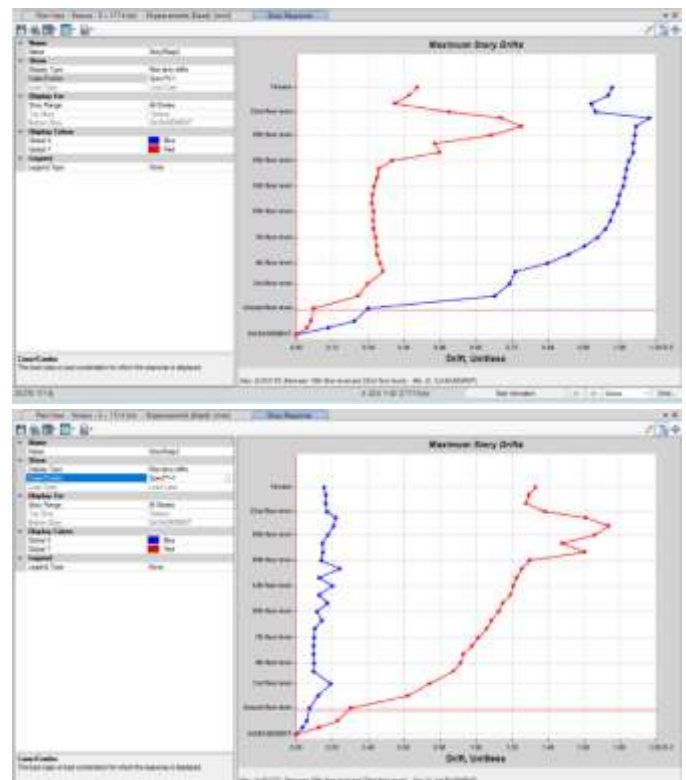


Figure 12: Drift Performance

2.8.4 Structural Stability

The structural stability of the building was evaluated by analysing its overall response under combined loading conditions. The analytical results demonstrate that the adopted

structural system provides sufficient stiffness, strength, and stability to resist lateral forces effectively.

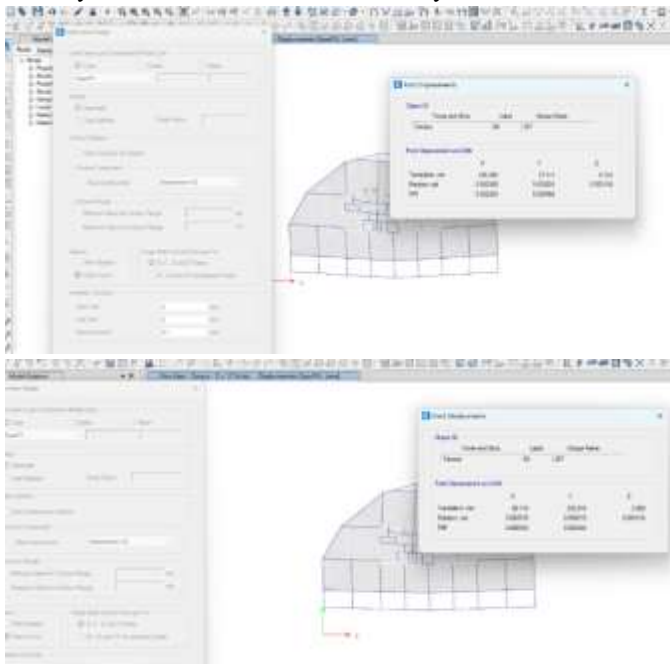


Figure 13: Structural Stability

2.8.5 Wind Analysis

The effect of wind loading on the building was examined by evaluating the maximum storey displacement. The wind analysis indicates that the lateral displacement remains within acceptable limits, confirming the satisfactory performance of the structure under wind loading. The wind analysis results indicate that the building exhibits a stable and controlled response under the applied wind loading conditions.

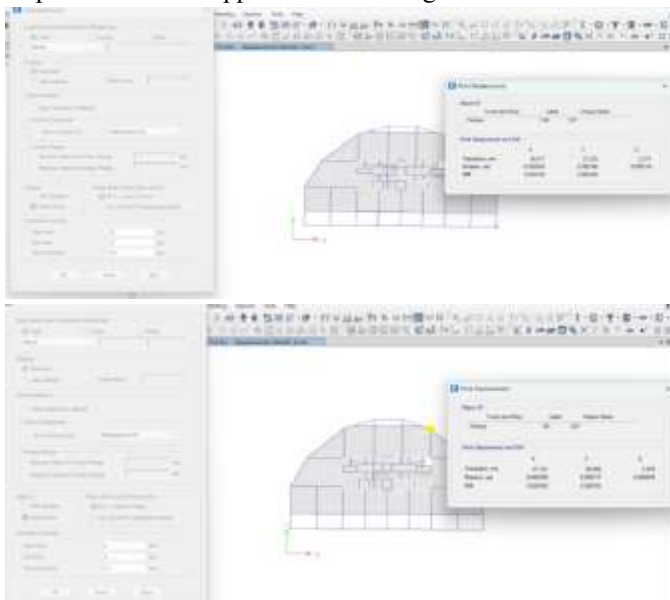


Figure 14: Maximum Storey Displacement under Wind Analysis

3. DISCUSSION OF RESULTS

The analytical results obtained from ETABS indicate that the proposed G+24 reinforced concrete skyscraper exhibits satisfactory structural behaviour under gravity, wind, and seismic loading conditions. The storey displacement increases

progressively with height, which is a typical response of tall buildings subjected to lateral loads. However, the maximum displacement remains within the permissible limits prescribed by the relevant Indian Standard codes, indicating adequate lateral stiffness and stability.

The inter-storey drift values obtained from the seismic analysis are also within the codal limits specified in IS 1893 (Part 1):2016. This demonstrates that the adopted structural configuration is capable of controlling excessive deformation during earthquake excitation. The provision of a centrally located shear wall core significantly contributes to reducing lateral displacement and improving the overall seismic performance of the building.

The wind analysis further confirms that the structure performs satisfactorily under wind loading, with acceptable storey displacement throughout the height of the building. The combined action of reinforced concrete moment-resisting frames and shear walls provides sufficient strength, stiffness, and stability to resist both wind and earthquake forces effectively.

Overall, the results demonstrate that the Performance-Based Design approach provides a realistic assessment of structural behaviour and helps in evaluating serviceability, safety, and stability requirements for modern high-rise reinforced concrete buildings. The overall analytical findings indicate that the proposed G+24 reinforced concrete skyscraper possesses adequate strength, stiffness, and stability to withstand the combined effects of gravity, wind, and earthquake loads. The integration of Performance-Based Design principles with ETABS analysis provides a realistic evaluation of the structural response under different loading conditions. The observed behaviour confirms that the adopted structural system efficiently controls lateral deformation while maintaining acceptable serviceability and safety limits. These results demonstrate the effectiveness of the selected design approach for modern high-rise buildings constructed in seismic-prone regions.

4. CONCLUSIONS

The present study evaluated the seismic and structural performance of a G+24 reinforced concrete skyscraper using the Performance-Based Design approach in ETABS. The building was analysed under gravity, wind, and earthquake loading conditions in accordance with the relevant Indian Standard codes. The analytical results indicated satisfactory structural behaviour, with storey displacement and storey drift remaining within the permissible limits. The incorporation of reinforced concrete moment-resisting frames and a central shear wall system significantly enhanced the lateral stiffness and stability of the structure. Overall, the study demonstrates that the adopted structural configuration is capable of providing safe and efficient performance under the considered loading conditions and is suitable for modern high-rise construction. The study also demonstrates that the use of ETABS software provides an efficient and reliable platform for the modelling, analysis, and performance evaluation of high-rise reinforced concrete buildings. The adoption of Performance-Based Design enables engineers to assess the

expected structural response under different loading conditions and to make informed design decisions at an early stage. The findings of this research may serve as a useful reference for future studies on tall building design and contribute to the development of safer and more sustainable urban infrastructure. The results obtained from the present study demonstrate that the adopted structural configuration provides satisfactory performance under gravity, wind, and seismic loading conditions. The integration of reinforced concrete moment-resisting frames with a centrally located shear wall system effectively improves the lateral stiffness and overall stability of the building. The evaluated response parameters indicate that the proposed design satisfies the requirements of the relevant Indian Standard codes and is suitable for high-rise construction. The implementation of the Performance-Based Design approach enables a more comprehensive assessment of structural behaviour compared to conventional design methods. By evaluating key performance parameters such as storey displacement, inter-storey drift, and structural stability, the study confirms that ETABS is an efficient tool for the analysis and design of modern skyscrapers. The outcomes of this research may serve as a valuable reference for structural engineers and researchers involved in the design and evaluation of tall reinforced concrete buildings.

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His research interests include structural design using modern software / technology for fast and correct design. His research work focuses on the "Performance-Based Design of a Skyscraper Using ETABS".

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