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PERFORMANCE BASED SEISMIC ASSESSMENT OF MULTI –STOREY SMRF BUILDINGS USING ETABS

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ABSTRACT

This project focuses on the seismic performance evaluation of RC structures of different heights—G+4, G+9, and G+14—under Zone-V conditions using performance-based seismic assessment (PBSA) procedures. Nonlinear time-history analysis is employed to assess key parameters such as story displacement, drift, shear, and base shear. Results show that as building height increases, both story displacements and drifts intensify, with the G+14 building showing the highest values, indicating greater lateral movement. Maximum story shears rise with building height, emphasizing the need for advanced seismic design in taller structures. The G+14 building experiences the highest base shear in the X direction, while the Y direction shows lower forces. Performance assessments using El Centro earthquake data confirm that the Demand Capacity Ratio (DCR) for critical columns meets acceptable limits. Hinge responses remain within permissible ranges, ensuring seismic resilience. This analysis highlights the importance of tailored seismic design strategies for buildings of varying heights to ensure safety and stability under severe earthquake conditions.

Keywords: Performance Based Design Of Structures, Performance Objective, Non-Linear Time History Analysis, RC Buildings.

I. INTRODUCTION

High-rise buildings, designed to resist vertical and lateral forces from wind and earthquakes, face significant challenges, particularly from seismic events that can induce inelastic deformations and lead to potential collapse. The demand for such structures has increased, accelerating their evolution since the eighteenth century. Modern building regulations emphasize flexible seismic design, with Performance-Based Seismic Design (PBSD) methodologies at the core of seismic evaluations. PBSD involves defining performance objectives for specific seismic hazards, estimating seismic demands through nonlinear structural analysis, and assessing performance at both the system and component levels. PBSD guidelines typically use Nonlinear Time History Analysis (NLTHA) to evaluate seismic performance. Acceptance criteria, including inter-story drift ratios and plastic rotations, gauge a structure's deformation capacity under seismic forces. Building performance is categorized into Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP) levels, reflecting varying degrees of acceptable damage and safety. This study assesses the seismic performance of moment-resisting frames (MRFs), commonly used in Indian construction, under different lateral load patterns. It examines key parameters like the building's fundamental period, roof displacement, inter-story drift, and base shear. The study also determines response and modification factors for individual components to evaluate how well MRFs meet performance limits. By analyzing these factors, the study enhances understanding of MRF performance under seismic loading, contributing to safer, more resilient high-rise buildings.

PERFORMANCE-BASED DESIGN (PBD)

Performance-based seismic assessment is an advanced approach to evaluate and design reinforced concrete (RC) structures to ensure they can withstand seismic events in contrast to traditional methods that primarily emphasize prescriptive measures and force-based criteria, performance-based assessment focuses on achieving specific performance objectives for a range of seismic hazards. This method provides a more comprehensive understanding of how a structure will behave during an earthquake, allowing for optimized design and retrofitting strategies.

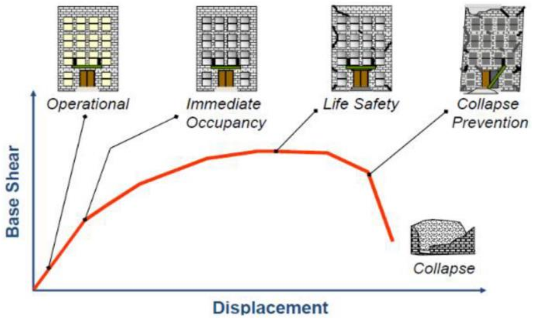


Figure 1: Performance objectives

Performance Objectives: These are predefined goals that a structure must meet under specific seismic conditions. They range from ensuring immediate occupancy and operational functionality after minor earthquakes to preventing collapse during major seismic events. Typical performance levels include:

Operational: Minimal damage, with the structure remaining fully functional.

Immediate Occupancy: Limited damage, ensuring safety and usability with minor repairs.

Life Safety: Significant damage is acceptable, but the structure should not pose a significant risk to occupants.

Collapse Prevention: Extensive damage is allowed, but the structure must not collapse.

Demand and Capacity: This involves estimating the seismic demand (expected earthquake forces and deformations) and the structure's capacity to withstand these demands. Nonlinear analysis methods, such as pushover analysis and time-history analysis, are commonly used to capture the realistic response of RC structures under Ʂeismic loading.

Nonlinear Behaviour: RC structures exhibit nonlinear behaviour during strong earthquakes, including cracking, yielding of reinforcement, and concrete crushing. Performance-based assessment considers these nonlinearities to predict the actual performance more accurately.

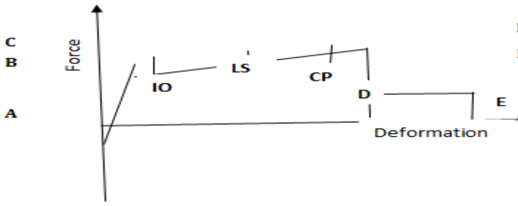


Figure 2: Deformation Control

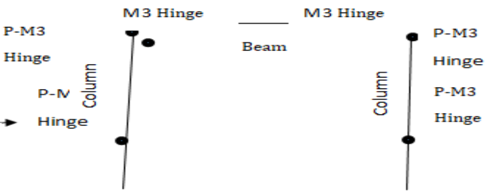


Figure 3: Location of Hinges

Performance-based seismic assessment of RC structures represents a significant advancement in earthquake engineering. By focusing on specific performance objectives and utilizing detailed nonlinear analysis, it provides a more accurate and reliable means of ensuring the safety and functionality of structures during seismic events. Despite its difficulties, this method offers numerous benefits, including tailored solutions, enhanced safety, informed decision-making, and improved risk management.

II. METHODOLOGY

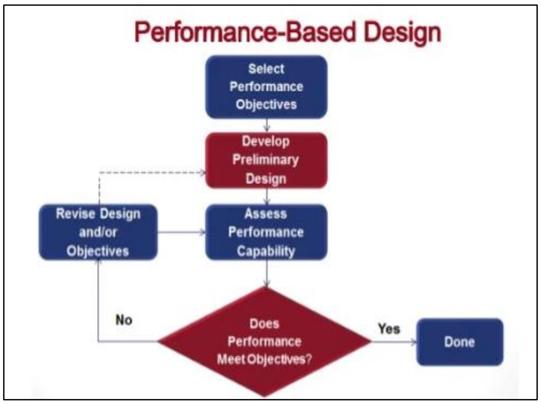


Figure 4: Flow diagram of PBD

Steps in Performance-Based Şeismic Assessment

Hazard Assessment: Determine the Şeismic hazard at the site, typically expressed In terms of Şeismic activity parameters (e.g., peak ground acceleration, spectral accelerations) for various return periods.

Structural Modelling: Develop a detailed analytical model of the RC structure, incorporating material properties, geometry, and boundary conditions. Nonlinear modelling techniques are essential to capture the actual behavior of the structure under seismic loads.

Seismic Demand Analysis: Perform seismic demand analysis using methods like response spectrum analysis, pushover analysis, and nonlinear time-history analysis. This step involves applying seismic loads to the structural model and evaluating the resulting demands (e.g., forces, displacements, deformations).

Capacity Evaluation: Assess the structure's capacity to resist the seismic demands. This involves determining the strength and deformation limits of the structural components (e.g., beams, columns, joints). Capacity is often evaluated through performance criteria like drift limits, plastic hinge rotations, and material strain limits.

Performance Evaluation: Compare the seismic demands with the structural capacities to assess whether the performance objectives are met. If the demands exceed the capacities, the structure may require retrofitting or redesign to improve its seismic performance.

Retrofit and Redesign: If the initial assessment indicates that the structure does not meet the desired performance objectives, retrofit measures or design modifications are implemented. Common retrofitting techniques for RC structures include adding shear walls, steel braces, base isolators, or dampers to strengthen against seismic forces.

Overview of Approach:

Pperformance based Şeismic assessment is a process of designing new buildings or seismic up-gradation of existing buildings, which includes a specific intent to achieve defined performance objectives in future earthquakes. Performance objectives relate to expectations regarding the extent of damage at the impact of earthquake vibrations on a building and the consequences of that damage. Performance objectives are operational (O), immediate occupancy (IO), life safety (LS), collapse prevention (CP), in which Life safety is the major focus to reduce the threats to the life safety of the structure. PBD approach in which Performance levels are defined by in terms of displacement as damage is better correlated to displacements rather than forces. The fundamental goal of PBSD is to obtain structure which will reach a target displacement profile when subjected to earthquakes consistent with a given reference response spectrum. The performance levels of the structure are governed through the choice of appropriate values of the max. Displacement and maximum inter storey drift, story shear, base function and hinge results.

III. MODELING AND ANALYSIS

Modelling and analysing the configuration is executed in ETABS, here low rise, midrise and high rise structures have modelled and analysed. The configuration is designed and appraised for gravity & Seismic loads. NLTHA were performed and outcome are tabulated. Analysis is done by assuming that building is positioned in zone-V. Elcentro earthquake is considered for analysis.

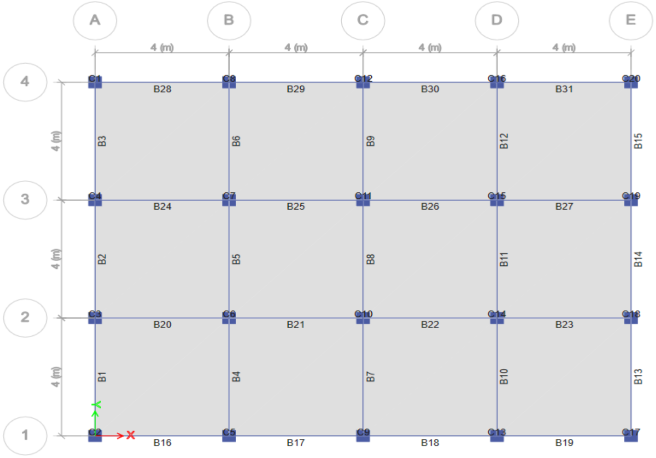


Figure 5: Plan of Building

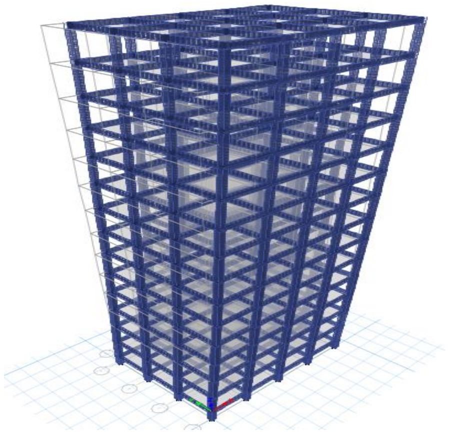


Figure 6: 3D view of building.

Table 1: Structural details

Number of Stories	**5 (G+4)**	**10 (G+9)**	**15 (G+14)**
Building type	Low Rise	Medium Rise	High Rise
Base Story Height	3.0 m	3.0 m	3.0 m
Typical Story Height	3.0 m	3.0 m	3.0 m
Height of the building	12.0 m	27.0 m	42.0 m
X direction Bay Width	4.00 m c/c	4.00 m c/c	4.00 m c/c
Y direction Bay Width	4.00 m c/c	4.00 m c/c	4.00 m c/c
No of Bays in X Dir.	4	4	4
No of Bays in Y Dir.	3	3	3

Table 2: Material Properties and Section data

Grade of concrete	M-30
Grade of steel	Fe-500

IV. RESULTS AND DISCUSSION

A numerical investigation is conducted on low-rise, mid-rise, and high-rise SMRFs using performance-based assessment, considering design parameters like Immediate Occupancy, Life Safety, and Collapse Prevention. Nonlinear time history analysis is performed on both base and superstructure, estimating seismic response parameters such as story displacement, drift, shear, and hinge response. The results highlight the significant role of structural interaction in the seismic behavior of the superstructure, with the deformed shape under transverse load shown in the figure.

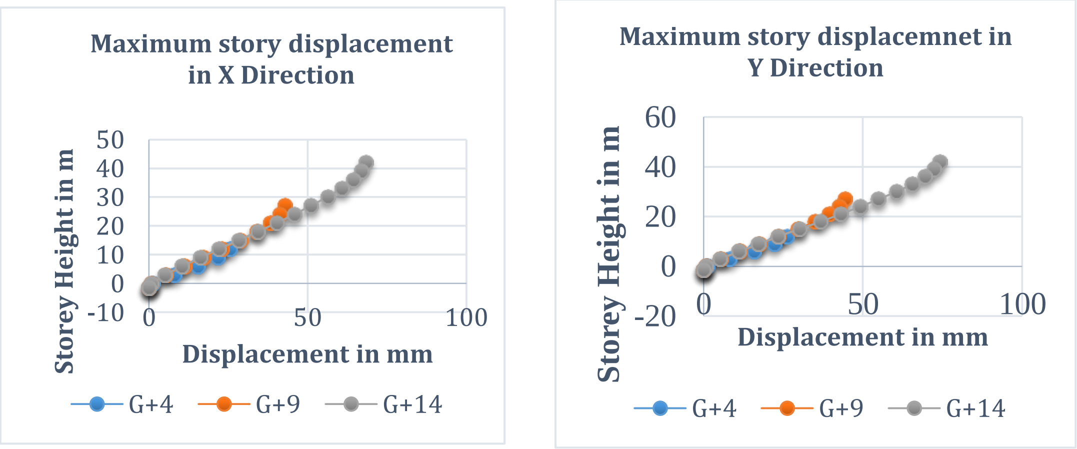


Figure 7: Maximum Story Displacement for X and Y Direction

Story displacement in Zone-V shows increasing values along both axes with building height. For the X-axis, values range from 25.461 mm to 68.301 mm, while for the Y-axis, they range from 26.161 mm to 74.083 mm. Mid-rise buildings display intermediate values in both directions.

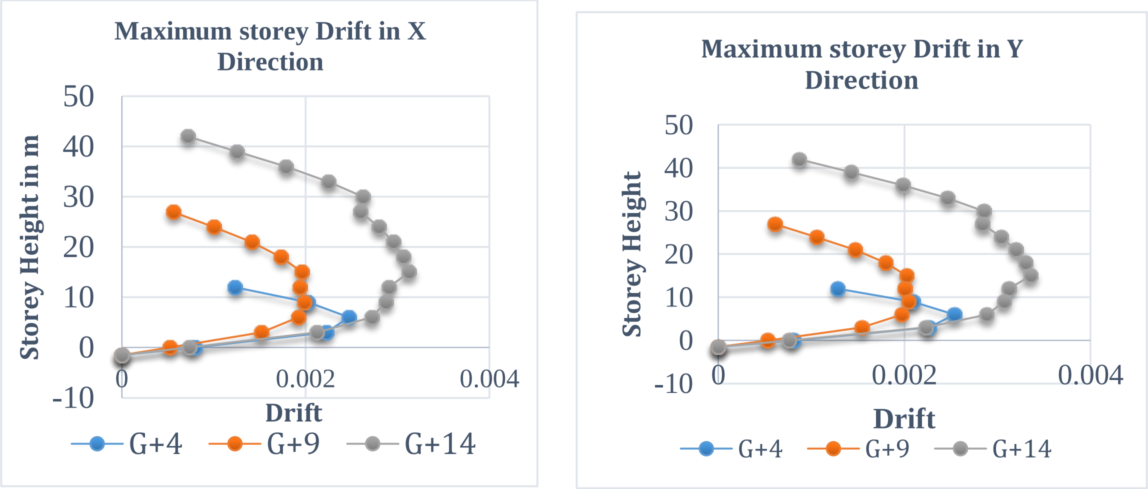
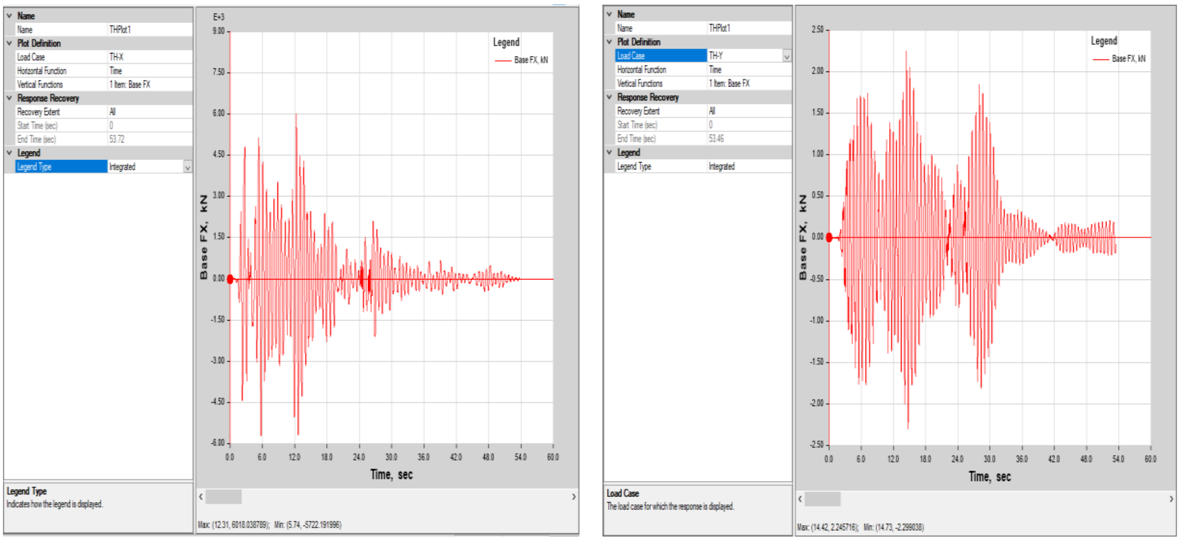


Figure 8: Maximum Story Drift in X and Y direction

The analysis shows maximum story drift along both axes in Zone-V, increasing with building height. For the X-axis, drifts peak at 0.002473 on the second floor of the low-rise, 0.001985 on the third floor of the mid-rise, and 0.003125 on the fifth floor of the high-rise. Similarly, on the Y-axis, peak drifts are 0.00254, 0.002049, and 0.003357 on the same respective floors.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Load Case: TH-X
Horizontal Function: Time
Vertical Functions: 1 Item: Base FX
Response Recovery
Recovery Extent: All
Start Time (sec): 0
End Time (sec): 53.72
Legend
Legend Type: Integrated

Legend Type
Indicates how the legend is displayed.

Max: (12.31, 6018.038789); Min: (5.74, -5722.191996)

Name
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Plot Definition
Load Case: TH-Y
Horizontal Function: Time
Vertical Functions: 1 Item: Base FX
Response Recovery
Recovery Extent: All
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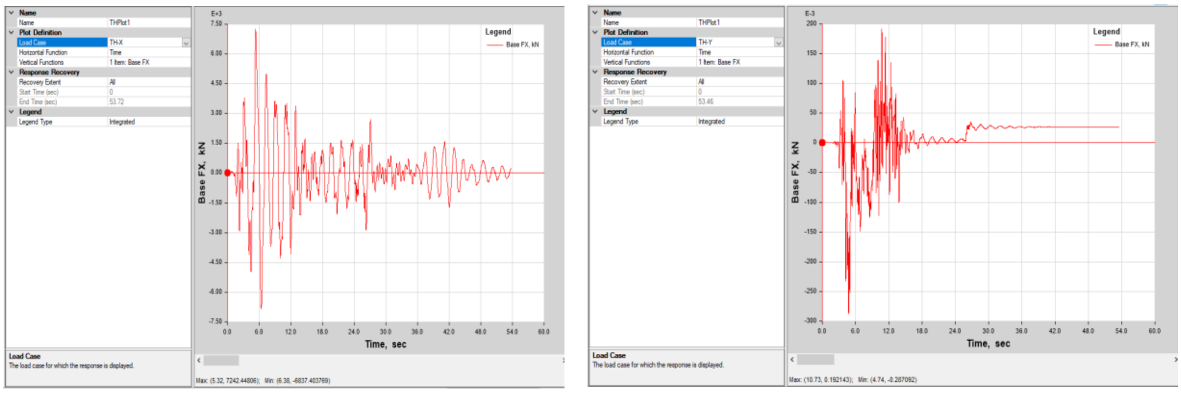
End Time (sec): 53.46
Legend
Legend Type: Integrated

Load Case
The load case for which the response is displayed.

Max: (14.42, 2.245716); Min: (14.73, -2.299038)

Figure 9: Base Shear for G+4 Building in X and Y direction

For the low-rise building in Zone V, the maximum base shear is 6,018.038 kN in the X direction at 12.31 seconds, with a minimum of -5,722.19 kN at 5.74 seconds. Along the Y-axis, the maximum base shear is 2.24 kN at 14.42 seconds, and the minimum is -2.29 kN at 14.73 seconds. These results illustrate the range of seismic forces experienced by the building in both directions.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Legend Type: Integrated

Load Case
The load case for which the response is displayed.

Max: (5.32, 7242.44806); Min: (6.38, -6837.403769)

Name
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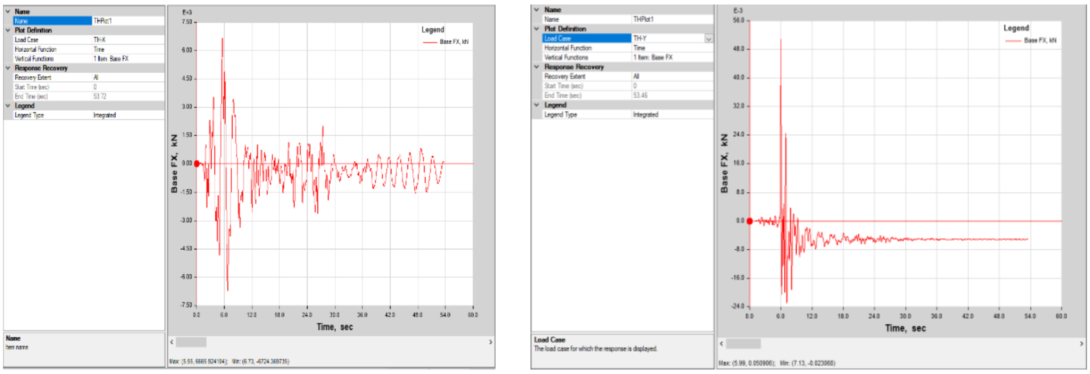
Plot Definition
Load Case: TH-Y
Horizontal Function: Time
Vertical Functions: 1 Item: Base FX
Response Recovery
Recovery Extent: All
Start Time (sec): 0
End Time (sec): 53.46
Legend
Legend Type: Integrated

Load Case
The load case for which the response is displayed.

Max: (10.73, 0.192143); Min: (4.74, -0.287092)

Figure 10: Base shear for G+9 Building in X and Y direction

For the low-rise building in Zone-V, the base shear along the X-axis reaches a maximum of 7,242.44 kN and a minimum of -6,837.40 kN. For the mid-rise building, the base shear along the Y-axis peaks at 0.1921 kN and dips to -0.2870 kN. These results reflect the extremes of base shear observed during the seismic analysis.



Name	
Name	THPlot1
Plot Definition	
Load Case	TH-X
Horizontal Function	Time
Vertical Functions	1 Item: Base FX
Response Recovery	
Recovery Extent	All
Start Time (sec)	0
End Time (sec)	53.72
Legend	
Legend Type	Integrated

Name
Item name

Max: (5.55, 6665.924104); Min: (6.73, -6724.369735)

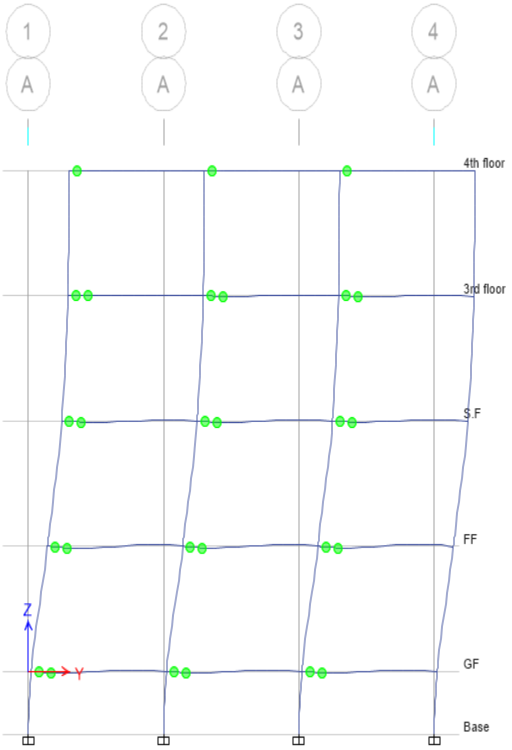
Name	
Name	THPlot1
Plot Definition	
Load Case	TH-Y
Horizontal Function	Time
Vertical Functions	1 Item: Base FX
Response Recovery	
Recovery Extent	All
Start Time (sec)	0
End Time (sec)	53.46
Legend	
Legend Type	Integrated

Load Case
The load case for which the response is displayed.

Max: (5.99, 0.050906); Min: (7.13, -0.023068)

Figure 11: Base Shear for G+14 Building in X and Y direction

For the high-rise building in Zone-V, the base shear along the X-axis ranges from 6,665.92 KN to -6,724.37 kN. For the mid-rise building, the Y-axis base shear varies from 0.050 kN to -0.023 kN. These results highlight the peak and trough of base shear forces observed during the seismic analysis.



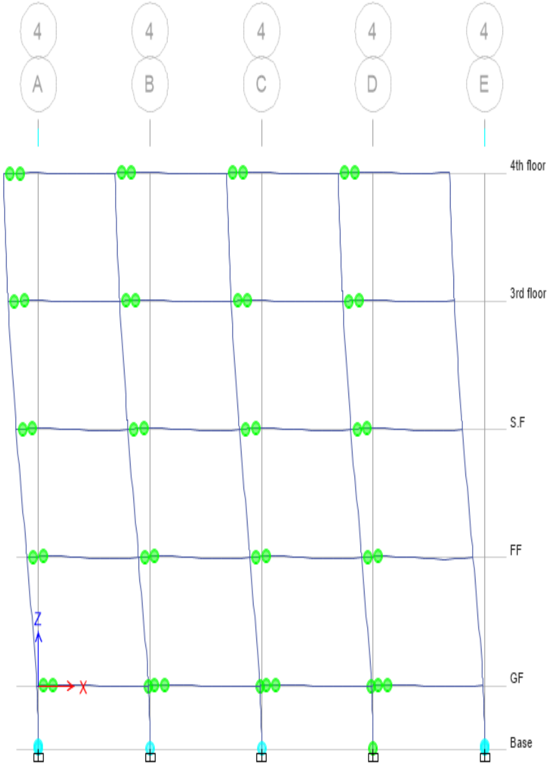


Figure 12: TH-X load case G+4 Building

Figure13: TH-Y load case G+4 Building

Figures 12 and 13 present hinge responses for the low-rise building based on Demand-Capacity Ratios, with color coding indicating performance limits. Most hinges lie between Immediate Occupancy (IO) and Life Safety (LS) levels, with stress-strain points A, B, C, D, and E highlighted. The X and Y time-history load cases show minimal variation in base shear capacity.

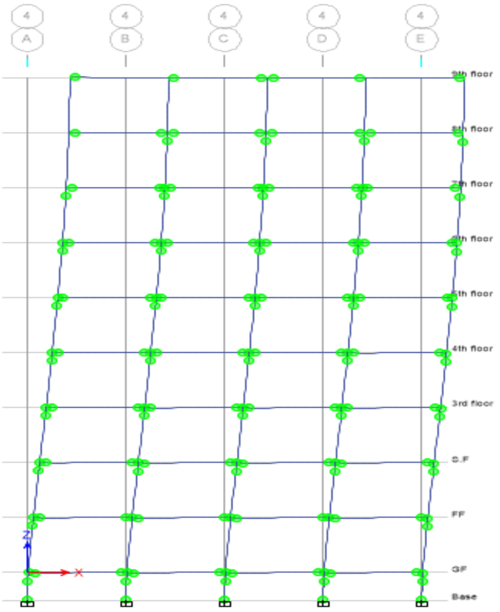


Figure 14: TH-X load case G+9 Building

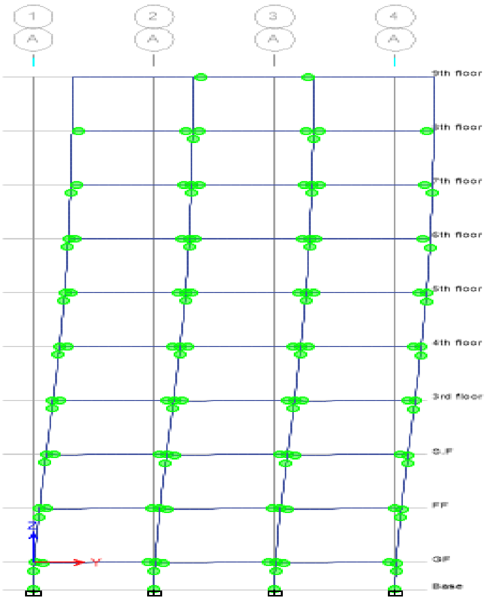


Figure 15: TH- Y load case G+9 Building

Figures 14 and 15 show hinge responses for the mid-rise building based on Demand-Capacity Ratios, with colour coding indicating performance limits. Most hinges fall between Immediate Occupancy (IO) and Life Safety (LS) levels, with stress-strain points A, B, C, D, and E highlighted. The X and Y time-history load cases exhibit minimal variation in base shear capacity.

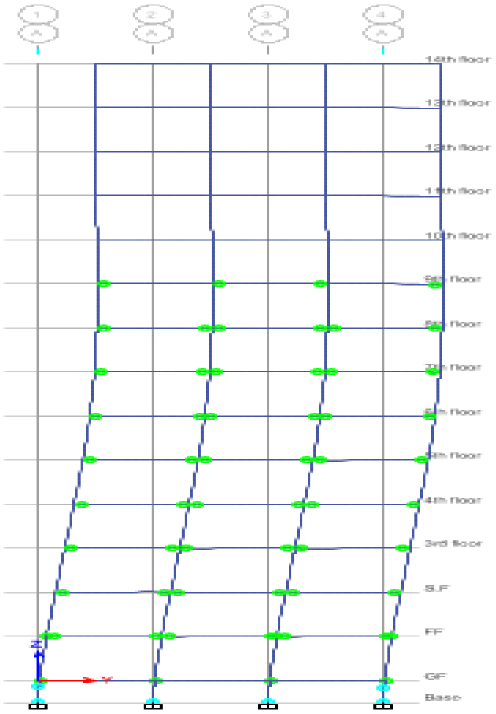


Figure 16: TH- X load case G+14 Building

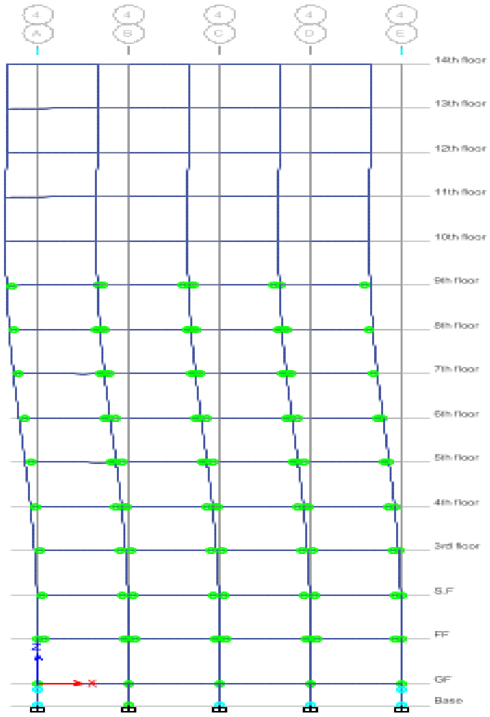


Figure 17: TH-Y load case G+14 Building

Figures 16 and 17 present hinge responses based on Demand-Capacity Ratios and performance-based limits, with colour coding for clarity. For the high-rise building analysed, most hinges fall between Immediate Occupancy (IO) and Life Safety (LS) levels, while the base to ground floor shows some reaching Collapse Prevention (CP). Stress-strain points A, B, C, D, and E are highlighted, and the time-history load cases in the X and Y directions show minimal variation in base shear capacity.

V. CONCLUSION

The seismic performance evaluation of Special Moment Resisting Frames (SMRFs) under various lateral load patterns reveals the critical influence of building height on structural behavior. Nonlinear time-history analysis using El Centro earthquake data highlights that as building height increases, lateral deformations, story drifts, and shear forces rise significantly, particularly in the X direction. High-rise structures like the G+14 building demonstrate the highest demands, requiring more advanced design strategies to manage these effects. Performance-based evaluations confirm that high-rise buildings maintain structural integrity despite increased seismic demands. Interior columns meet Life Safety criteria, while exterior columns satisfy Immediate Occupancy requirements. Additionally, hinge responses at critical locations remain within acceptable limits, ensuring the overall stability and resilience of the structure. These findings emphasize the importance of adopting performance-based seismic engineering to address the challenges posed by taller buildings. The results underscore the need for rigorous design measures, including enhanced lateral load resistance and deformation management, to safeguard against severe seismic events. By integrating advanced design strategies and robust evaluations, performance-based seismic design ensures the safety, stability, and long-term reliability of high-rise structures.

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