IMPACT OF P-DELTA EFFECTS ON THE SEISMIC PERFORMANCE OF HIGH-RISE RC BUILDINGS WITH VERTICAL GEOMETRIC IRREGULARITIES

Dipesh D. Sambare[1], Trupti Narkhede[2], P. J. Salunke[3]

[1]PG Student, Dept. of Civil Engineering, Mahatma Gandhi Mission's College of Engineering and Technology (MGMCET), Kamothe, Navi Mumbai, Maharashtra, India
[2]Assistant Professor, Dept. of Civil Engineering, Mahatma Gandhi Mission's College of Engineering and Technology (MGMCET), Kamothe, Navi Mumbai, Maharashtra, India
[3]Head of Department, Dept. of Civil Engineering, Mahatma Gandhi Mission's College of Engineering and Technology (MGMCET), Kamothe, Navi Mumbai, Maharashtra, India

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Abstract - *The seismic performance of high-rise reinforced concrete (RC) buildings with vertical geometric irregularities is a critical aspect of structural engineering. This study evaluates the impact of P-Delta effects on a G+50 RC building with T-shape, L-shape, and Step-back irregularities under Nonlinear Time History Analysis (NLTHA) using Bhuj earthquake data. A model was analyzed in ETABS, considering variations in structural configuration and the presence or absence of P-Delta effects. The results indicate that displacement, story drift, and shear forces increase significantly when P-Delta effects are included, particularly in upper stories. Among the irregular configurations, L-shape structures exhibited the highest displacement and drift, indicating increased vulnerability. Step-back configurations demonstrated better stability, reducing excessive lateral deformations due to their inherent mass and stiffness distribution.*

Key Words: P-Delta, Time History Analysis, Shear Wall, Seismic Performance, Vertical Geometric Irregularities, high-rise RC Buildings.

1.INTRODUCTION

The seismic performance of high-rise reinforced concrete (RC) buildings is a critical aspect of structural engineering, particularly in regions prone to earthquake activity. Buildings with vertical geometric irregularities such as T-shape, L-shape, and Step-back configurations pose additional challenges in ensuring stability. These irregularities disrupt the uniform distribution of mass and stiffness, influencing the overall seismic response. To accurately assess the behavior of such structures, Time History Analysis is a widely adopted method. This method provides detailed insights into the dynamic response of buildings under real earthquake conditions, making it particularly suitable for evaluating high-rise structures.

2. METHODOLOGY

A G+50 RC building is modeled in ETABS, incorporating three types of vertical geometric irregularities:

- L-shape irregularity
- Inverted T irregularity
- Step-back configuration

Table -1: Model data in ETABS for parent model

Description	Data values
Material property	
Concrete grade	M40
Steel grade	Fe550
Building data	
Story	G+50
Building height	150 m
Story height	3 m
Beam size	300x600 mm
Wall thickness	230 mm
Column size	Base to 20th = 1000x550 mm 21th to 35th = 900x450 mm 36th to 50th = 800x450 mm
Shear walls	Base to 20th = 450 mm 21th to 50th = 400 mm
Slab thickness	150 mm
Soli type	II
Seismic zone	V
Importance factor	1.5
Response reduction factor	5
Loading data	
Dead Load	Self-Weight
Live Load	3 KN/Sq.m
Floor Finish load	1.2 KN/Sq.m
Time History Data	Bhuj

Table 2. Various models considered in the project

Type of Irregularity	Model Name
Model 1 Irregularity on both sides	For 20% Setback [T-20]
	For 40% Setback [T-40]
	For 60% Setback [T-60]
	For 80% Setback [T-80]
Model 2 Multiple setback irregularity	For 20% Setback [S-20]
	For 40% Setback [S-40]
	For 60% Setback [S-60]
	For 80% Setback [S-80]
Model 3 Irregularity on one side	For 20% Setback [L-20]
	For 40% Setback [L-40]
	For 60% Setback [L-60]
	For 80% Setback [L-80]

2.1 Time History Analysis

Time History Analysis (THA) is a dynamic analysis method used to determine the structural response under a specified earthquake ground motion. Unlike static methods, THA captures the real-time variation of forces, displacements, and accelerations throughout the building during seismic events. For this study, the Bhuj earthquake data was scaled appropriately to match the site-specific seismic parameters. Time history analysis allows precise evaluation of displacement, drift, shear forces, and other critical parameters, which are essential in identifying the influence of P-Delta effects on tall buildings.

This study investigates the impact of P-Delta effects on a G+50 RC building with various vertical geometric irregularities. Models were developed to analyze the combined influence of irregularities, structural configurations, and the presence or absence of P-Delta effects.

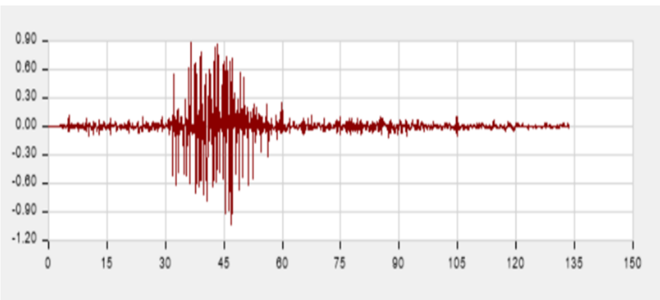

Fig -1: Earthquake data for bhuj

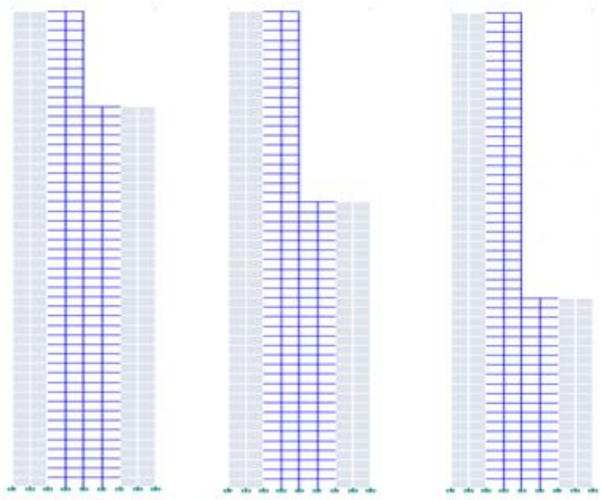

Fig -2: Elevation of building model - L-20 , L-40 , L-60

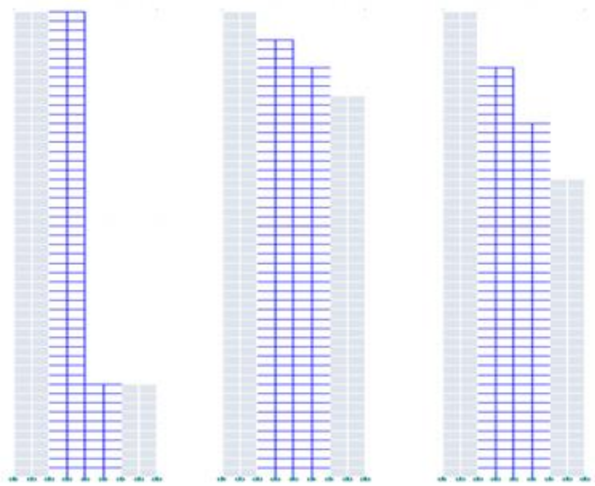

Fig -3: Elevation of building model - L-80 , S-20 , S-40

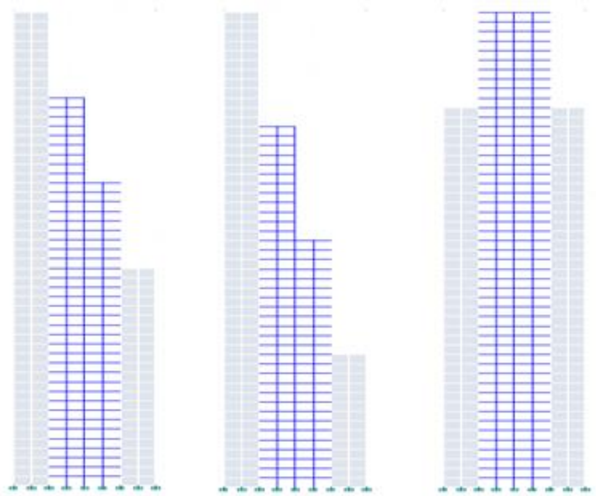

Fig -4: Elevation of building model - S-60 , S-80 , T-20

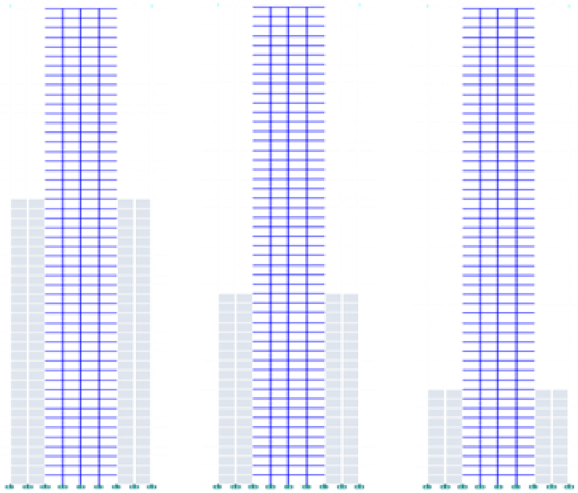

Fig -5: Elevation of building model - T-40 , T-60 , T-80

3. RESULTS & DISCUSSION

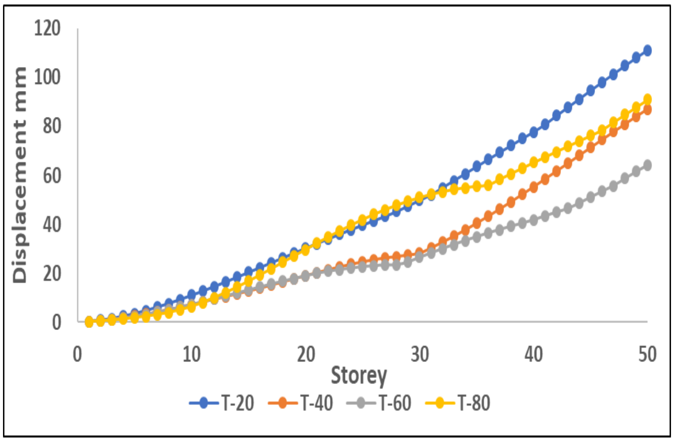

Chart -1: Maximum Storey displacement along X direction with P-Delta for T

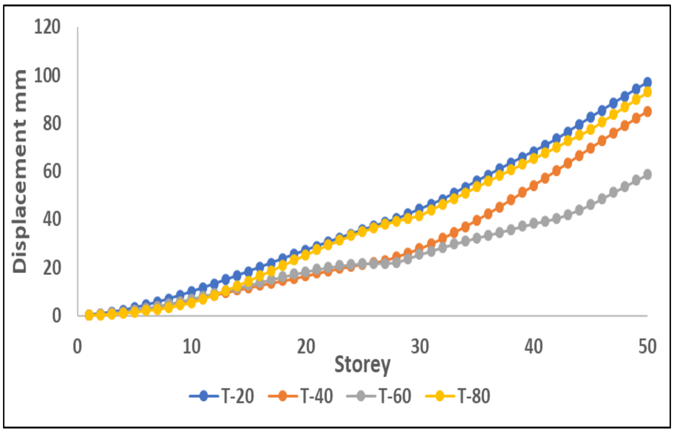

Chart -2: Maximum Storey displacement along X direction without P-Delta for T

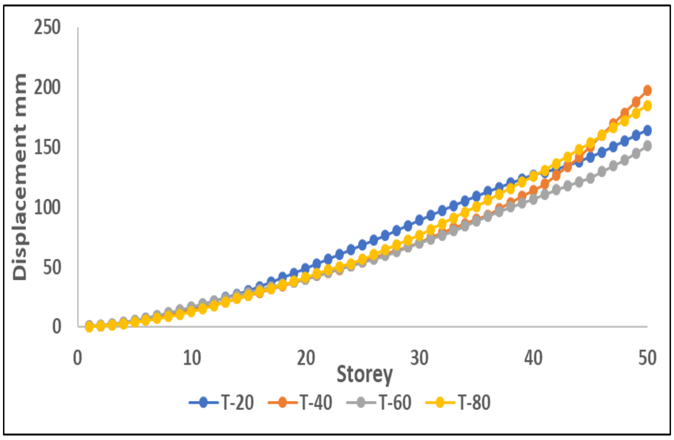

Chart -3: Maximum Storey displacement along Y direction with P-Delta for T

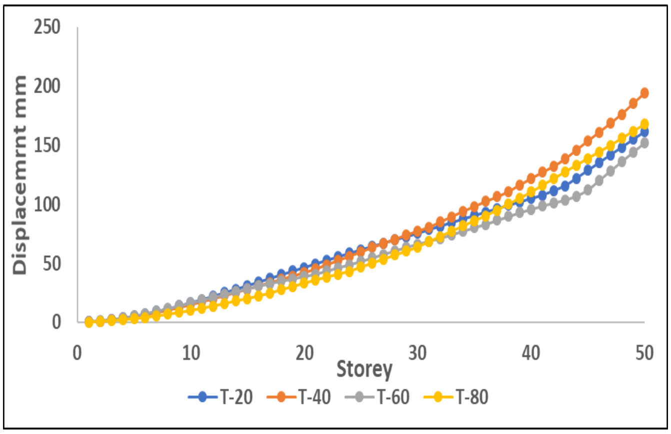

Chart -4: Maximum Storey displacement along Y direction without P-Delta for T

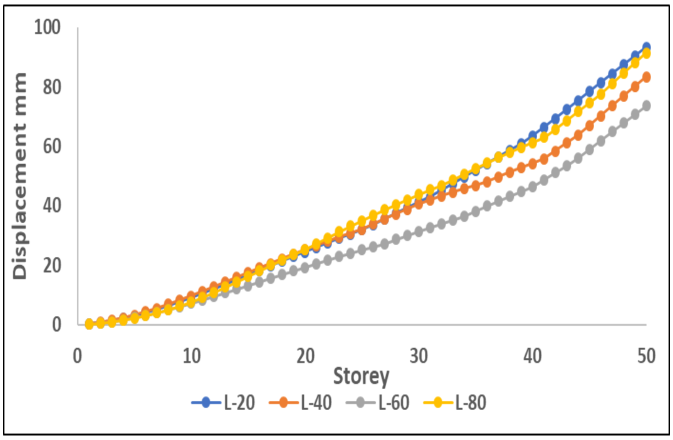

Chart -5: Maximum Storey displacement along X direction with P-Delta for L

Displacement Observations:

Displacement values increased when the P-Delta effect was considered, with greater differences observed in upper stories. Among the analyzed irregularities, L-shape structures exhibited the most significant displacement increase, indicating higher instability due to asymmetry. Step-back models showed better control over displacement due to improved stiffness distribution.

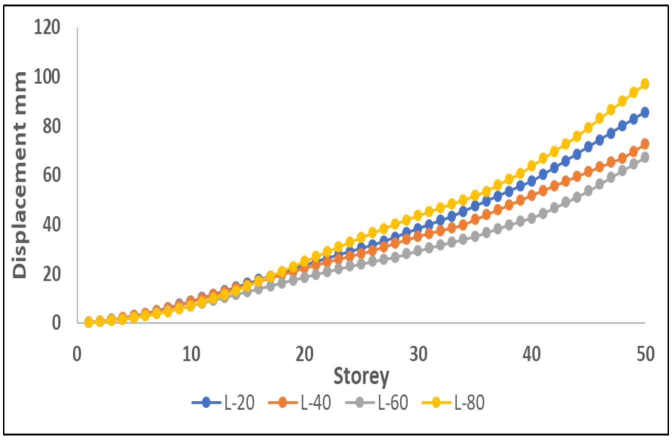

Chart -6: Maximum Storey displacement along X direction without P-Delta for L

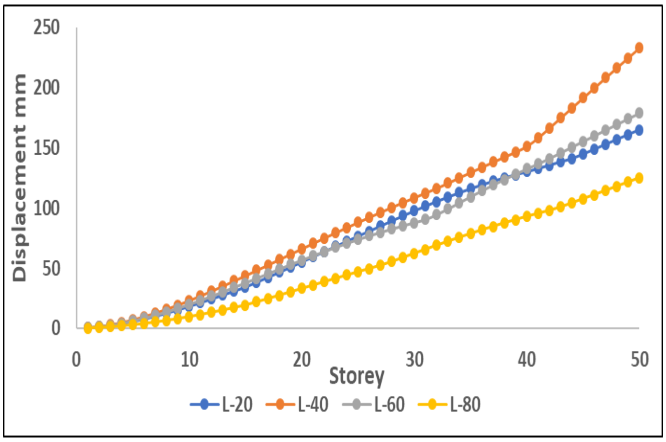

Chart -7: Maximum Storey displacement along Y direction with P-Delta for L

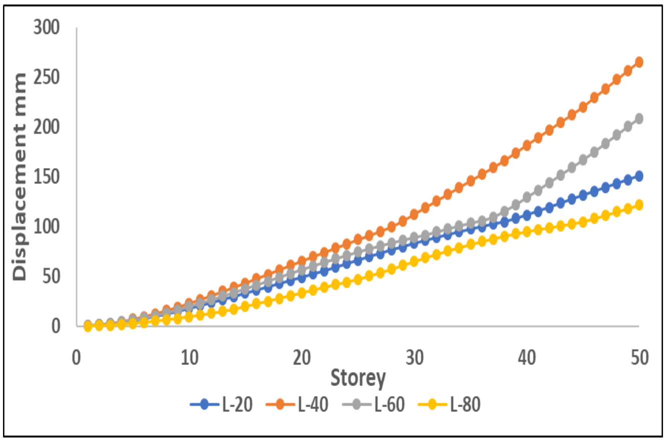

Chart -8: Maximum Storey displacement along Y direction without P-Delta for L

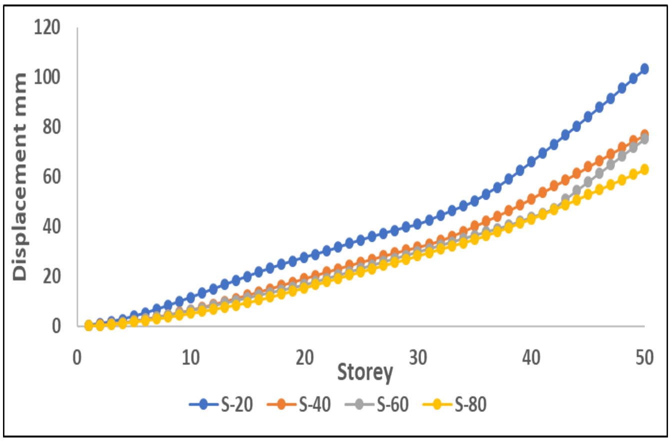

Chart -9: Maximum Storey displacement along X direction with P-Delta for S

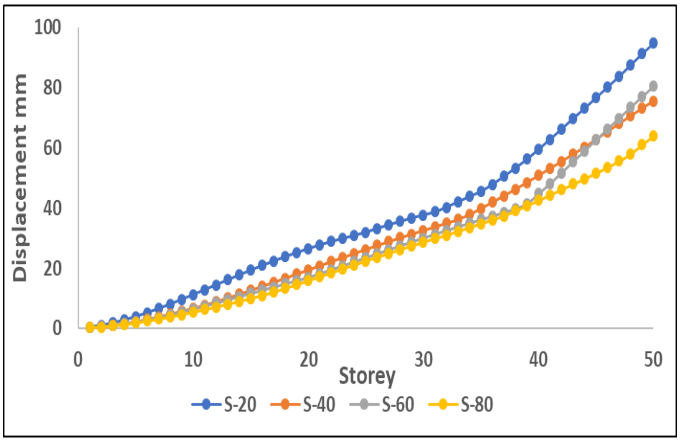

Chart -10: Maximum Storey displacement along X direction without P-Delta for S

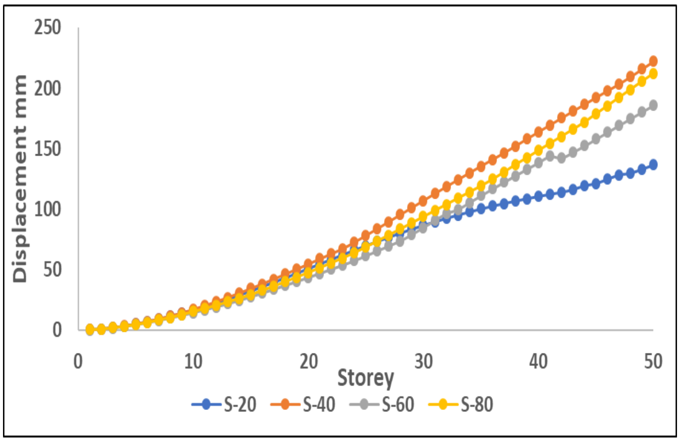

Chart -11: Maximum Storey displacement along Y direction with P-Delta for S

The inclusion of P-Delta effects led to an overall increase in displacement, with the most significant variations observed in the upper stories.

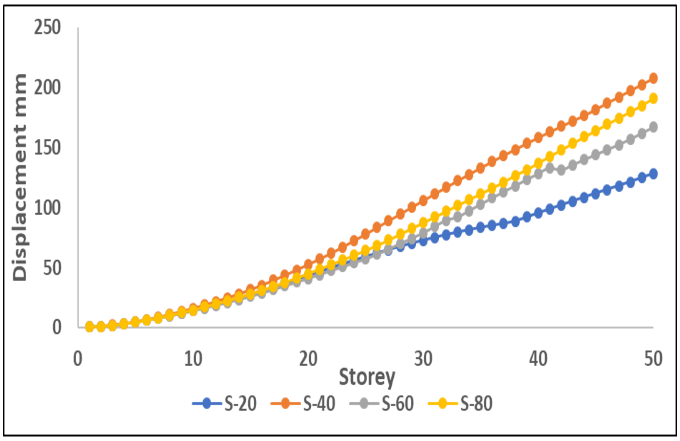

Chart -12: Maximum Storey displacement along Y direction without P-Delta for S

Drifts: Results:

The drift values increased significantly in mid-to-upper storeys when the P-Delta effect was considered. L-shape configurations experienced the highest drift amplification, particularly in the direction of their asymmetric geometry.

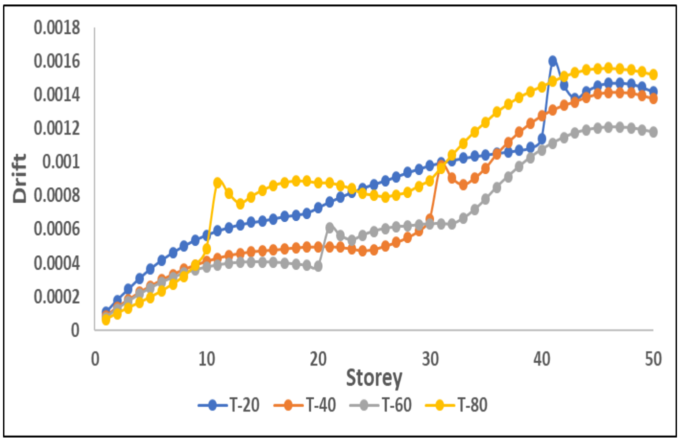

Chart -13: Storey Drift in X direction with P-Delta for T

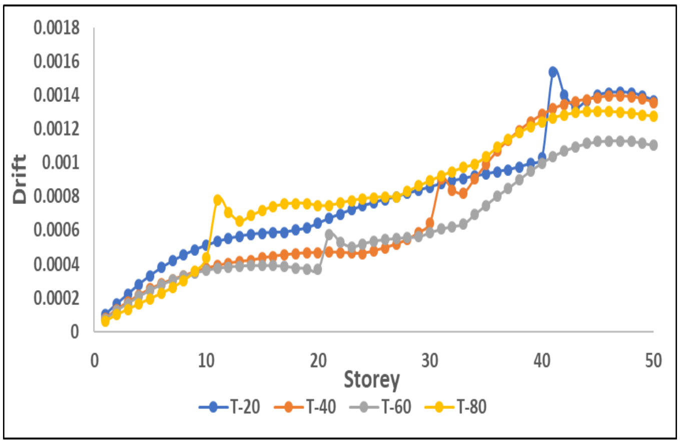

Chart -14: Storey Drift in X direction without P-Delta for T

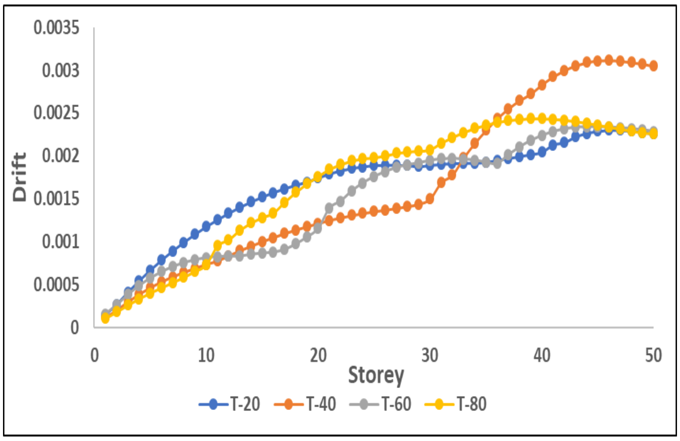

Chart -15: Storey Drift in Y direction with P-Delta for T

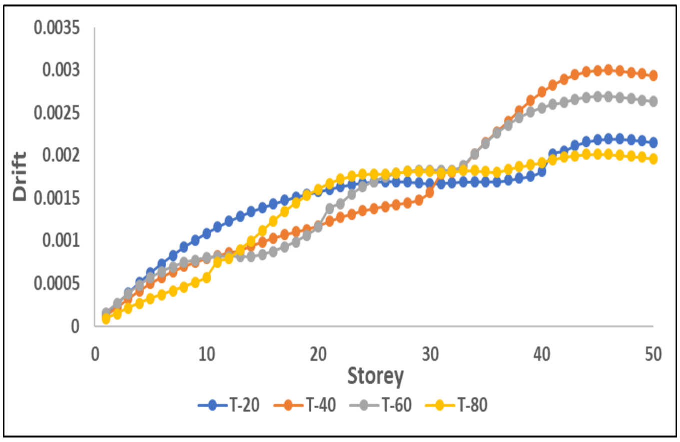

Chart -16: Storey Drift in Y direction without P-Delta for T

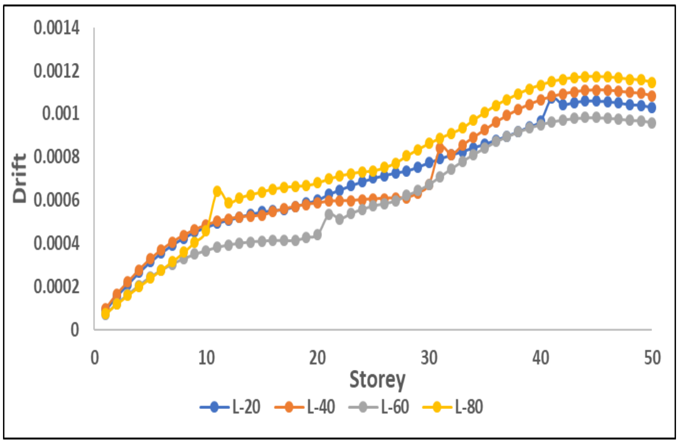

Chart -17: Storey Drift in X direction with P-Delta for L

Drift values increased significantly in mid-to-upper stories when P-Delta effects were considered, leading to higher structural instability. L-shape configurations showed the highest drift due to their asymmetric stiffness distribution, resulting in uneven lateral deformations.

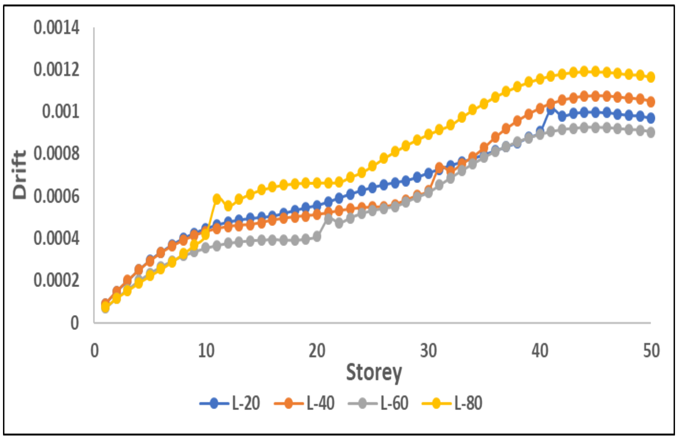

Chart -18: Storey Drift in X direction without P-Delta for L

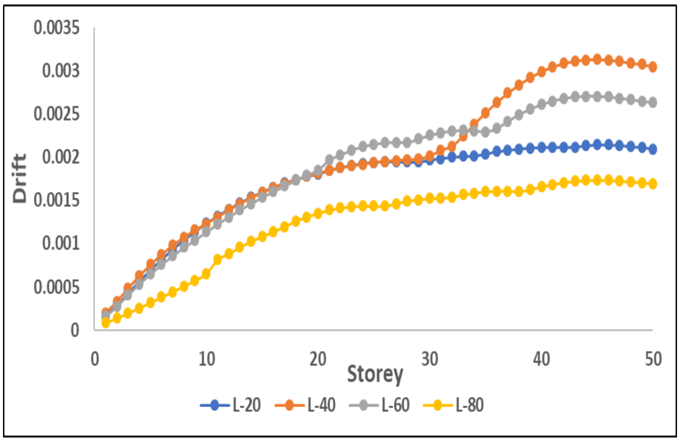

Chart -19: Storey Drift in Y direction with P-Delta for L

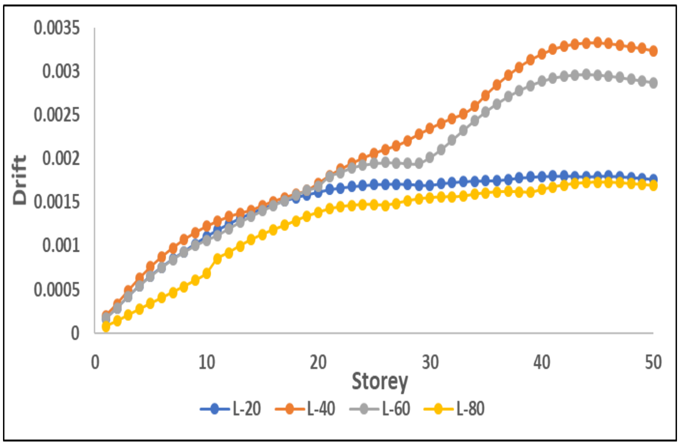

Chart -20: Storey Drift in Y direction without P-Delta for L

Step-back models exhibited better drift control, as the staggered geometry helped in distributing seismic forces more efficiently. Maximum drift was observed around mid-height levels, where P-Delta effects coupled with structural irregularities led to greater lateral movement.

Structural Efficiency: Buildings with optimized shear wall placements and additional bracing showed lower drift increments, demonstrating the effectiveness of lateral stiffness enhancement.

Higher drift values corresponded to increased seismic loading intensity, reinforcing the need for advanced mitigation strategies in high-rise irregular structures.

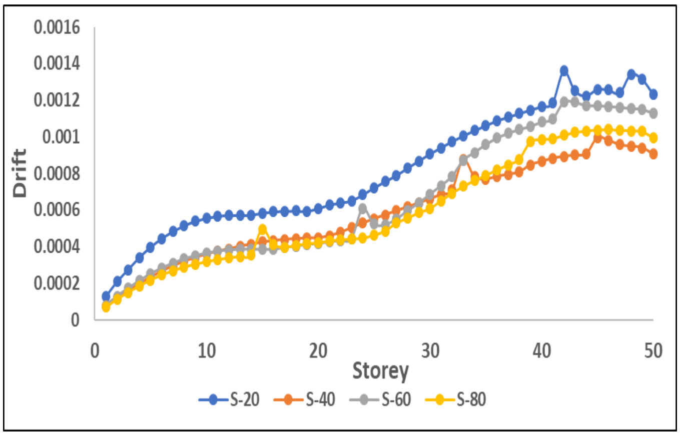

Chart -21: Storey Drift in X direction with P-Delta for S

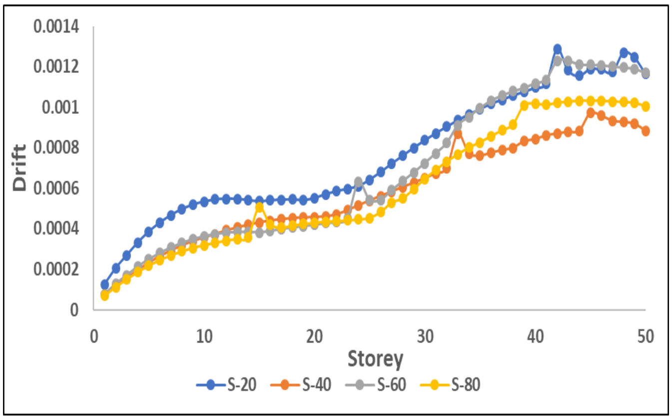

Chart -22: Storey Drift in X direction without P-Delta for S

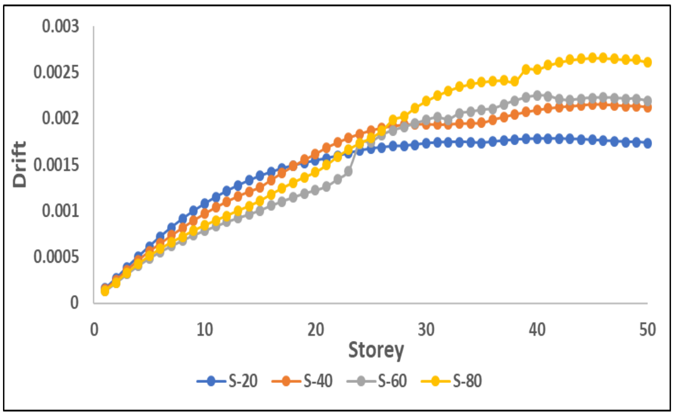

Chart -23: Storey Drift in Y direction with P-Delta for S

4. CONCLUSION

While significant progress has been made in understanding the seismic behaviour of high-rise buildings, there are still several gaps:

- The study reveals that P-Delta effects have a considerable impact on the seismic response of high-rise RC buildings with vertical geometric irregularities.
- L-shape buildings demonstrated the most significant displacement, drift, and shear force increases, indicating higher vulnerability to seismic loads.
- Step-back structures proved to be the most stable configuration, showing improved performance under P-Delta effects due to their staggered mass and stiffness distribution.
- Incorporating advanced stability measures such as outrigger systems, braced frames, and optimized shear wall placements can effectively mitigate these effects and enhance the seismic performance of irregular high-rise buildings.
- The presence of P-Delta effects significantly influenced the seismic behavior of high-rise buildings with vertical geometric irregularities, increasing displacement, drift, and shear forces.

4. FUTURE SCOPE

Further research can expand on the following areas to improve understanding and design strategies:

- Investigating the combined effects of soil-structure interaction with P-Delta effects for buildings on soft soils.
- Exploring the influence of material nonlinearity in combination with geometric irregularities for improved accuracy.
- Examining alternative damping systems such as tuned mass dampers (TMDs) to reduce dynamic responses in high-rise structures.
- Extending the study to include wind load effects in combination with seismic forces for comprehensive design strategies.

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