SEISMIC ANALYSIS OF RC FRAME STRUCTURE WITH ASYMMETRIC LIFT-CORE

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Abstract - *Earthquakes stand as one of the most devastating and unpredictable natural phenomena, inflicting severe destruction on both human life and built infrastructure. The forces unleashed during seismic events can critically damage structural components, often leading to their complete failure. Concurrently, rapid urbanization has made available land for construction increasingly scarce and expensive, thereby driving the growing popularity of tall buildings. A beam-column is a structural element designed to resist both axial forces and bending moments. In practice, all members within a frame experience these combined effects, though for simplicity, a member is typically classified as a beam when the axial force is negligible relative to the bending moment, and as a column when the bending moment is insignificant compared to the axial load. In beam-columns, bending moments and deflections arise from two sources: primary effects, caused by applied loads and transverse forces, and secondary effects, known as the P-Delta effect, which result from axial loads acting through lateral displacements.*

This study analyzed two reinforced concrete (RC) models using SAP2000 software, introducing asymmetry in both, while incorporating a lift core in one model to assess its influence on structural behaviour. Vertical and seismic loads were applied to evaluate parameters such as displacements and base shear. Primary moments were examined using the response spectrum method, while secondary moments were assessed through second-order P-Delta analysis, quantifying the percentage increase in secondary moments relative to first-order moments across all columns. Regression analysis was subsequently used to establish relationships between this percentage increase and the number of stories. The results revealed that the asymmetric lift core induces localized stress concentrations, affecting the distribution of internal forces and deformations. For a G+9 building with a lift core, the maximum storey displacement reached 25.5 mm in the X-direction and 20.3 mm in the Y-direction, with P-Delta effects contributing an approximate 10% increase. In contrast, the model without a lift core exhibited higher displacements of 41.3 mm (X) and 41.7 mm (Y), with a 5% increase from P-Delta effects. Maximum storey drift for the model with a lift core was 3.3 mm (X) and 2.6 mm (Y), compared to 5.9 mm in both directions for the model without it. A strong correlation was observed between the maximum displacements of the two models under lateral loads, with correlation coefficients of approximately 0.9934 in the X-direction and 0.98836 in the Y-direction.

Key Words: Storey drift, Storey displacement, P-Delta, Correlation, Base Shear etc.

1.INTRODUCTION

The seismic stability of a structural system when subjected to probable earthquake ground motions can be assessed through a seismic evaluation of the building. Seismic performance refers to a structure's ability to preserve its essential functions—namely safety and usability—both during and after a specified level of seismic exposure. A building is typically considered safe if it does not endanger the lives and well-being of its occupants or nearby individuals through partial or total collapse.

Due to their distinctive characteristics in terms of seismic response, asymmetric structural configurations have garnered significant attention within the field of earthquake engineering. Asymmetries in structural systems refer to the uneven distribution of mass, stiffness, and strength throughout a building. These can arise from variations in floor heights, irregular floor plans, differing column dimensions, and other factors. Such asymmetries lead to an uneven distribution of seismic forces among structural elements, potentially causing localized or global irregularities in response. In the present study, a lift core was incorporated into an asymmetric reinforced concrete (RC) mid-rise frame. The inclusion of a lift core introduces complexity to the building design and can influence its seismic performance. The interaction between inherent asymmetries and the presence of a lift core can substantially affect the dynamic behaviour and seismic response of these structures.

The addition of a lift core, which typically houses a building's vertical transportation system, further accentuates the structural asymmetry. As a concentrated element of both mass and stiffness, the lift core can significantly influence the distribution of seismic forces throughout the building. Depending on its configuration and the existing asymmetries within the structural system, this interaction may either amplify or mitigate the overall seismic response. Structural engineers and designers must understand the seismic implications associated with integrating a lift core into RC mid-rise frames. Such understanding enables informed decision-making during design, leading to safer and more resilient structures. By analyzing the dynamic behaviour of these systems, engineers can identify potential vulnerabilities and develop effective design strategies to enhance seismic performance. This study aims to investigate the seismic effects and response characteristics of RC mid-rise frames incorporating a lift core. Through a detailed examination of various structural properties and configurations, the influence of both inherent asymmetries and those introduced by the lift core on seismic behaviour will be explored. The findings will contribute to the existing body of knowledge in earthquake engineering and support the development of guidelines and recommendations for designing more robust and resilient mid-rise buildings.

Overall, this research seeks to clarify the complex interplay between asymmetries and the integration of a lift core in RC frames. By comprehensively evaluating their seismic implications, this study aims to deepen understanding of these structural systems and offer valuable insights for the design of safer, more efficient buildings in seismically active regions.

These effects can be briefly summarized as follows: a. Buildings characterized by an asymmetric distribution of stiffness and strength in plan experience coupled lateral and torsional motions during earthquakes. Torsional effects are minimized by reducing the distance between the centre of mass and the centre of stiffness. The dynamic response of a building structure is governed by its stiffness characteristics. b. The stiffness characteristics dictate the dynamic behaviour of the building structure. Selecting appropriate stiffness properties is a crucial step during the conceptual design phase. A well-distributed lateral load-resisting system ensures favourable structural performance.

1.1 Objectives

1. To analyze and compare response-spectrum and P-Delta effects using SAP2000 models.
2. To evaluate displacement, storey drift, and base shear in RC buildings with and without a lift core, considering P-Delta effects.
3. To establish regression relationships between the two model types.

1.2 Literature Review

1.2.1 Seismic Behaviour of Irregular Structures

1. Pintucchi et. al. (2008) — Reviewed seismic behavior of plan and vertically irregular buildings. Pushover procedures emerged as effective alternatives. Base isolation and dampers reduce torsional response. Discontinuities in mass, stiffness, or strength do not always cause poor seismic performance.

2. Soni et. al. (2018) — Analyzed regular and irregular flat-slab buildings with mass irregularities. Edge and corner locations exhibited reduced bending moments without mass irregularity. Base shear decreased toward the top when no mass irregularity existed at corners. Vertical irregularity at corners influenced dynamic performance.

3. Kumar et. al. (2020) — Studied lateral load behavior of irregular residential buildings across five offset configurations. Linear analysis produced 70% higher displacement than nonlinear analysis. Base shear increased 30% from Zone 2 to Zone 5. Static analysis yielded 40% higher storey shear than pushover analysis.

1.2.2 Comparative Analysis of Regular and Irregular Buildings

1. Yahyaei et al. (2012) — Compared static and dynamic analysis of 20-story irregular buildings in Zone V. Static analysis produced greater displacement than dynamic analysis, with differences becoming significant at upper stories. Center of mass displacement was lower than at maximum displacement points. Dynamic analysis yielded higher displacement values, making static results uneconomical.

2. Singh et. al (2021) — Analyzed symmetric and asymmetric buildings with and without shear walls across six models. Storey shear increased by 64–75% in models with shear walls. Displacement reduced by 35–40% and storey drift reduced by 43–50% in shear wall models. Model 2 (regular with shear wall) was the most stable.

3. Subash (2017) — Studied P-Delta effects on vertically irregular 30-story RC buildings. Displacement increased with irregularity level. Regular frames exhibited minimal displacement. Seismic parameters were lower without P-Delta effects than with. Irregularities are damaging but unavoidable; designs should mitigate seismic effects.

4. Yerekar Sir et al. (2016) — Examined lift core location effects on G+5 and G+10 buildings in Zone V. Corner lift cores increased storey drift due to torsional mode. Hard soil strata provided optimal safety. Lift cores enable cost-effective design with adequate safety.

5. Azizan et. al. (2017) — Assessed lift core placement sensitivity in T-shaped RC buildings. Lift core position significantly influenced torsional moment across all building heights. Central areas showed pronounced differences. Placing two lift cores at the far end of the top wing effectively reduced torsion.

1.2.3 Review of P-Delta Effect

1. R. Vijayalakshmi et al (2017) — Investigated P-Delta effects in 10 to 40-story high-rise buildings. Analysis showed P-Delta effects were more pronounced in upper stories based on load-deflection curve comparisons.

2. D. Yousuf et al (2013) — Studied global slenderness effects on P-Delta analysis using STAAD Pro v8i across four slenderness ratios. P-Delta analysis is required for structures exceeding seven stories due to significant displacement variation with increasing slenderness.

2. Methodology

2.1 Modelling

1. Two building models—symmetric and asymmetric (the latter featuring an added lift core)—with identical dimensions (G+9, 24m x 20m plan, 5m bay spacing, 3m storey height) were analyzed using SAP-2000 finite element software.

2. A linear dynamic response spectrum analysis was conducted on both models to compare base shear, storey drift, lateral displacement, and irregular locations.

3. The P-Delta effect, which causes second-order moments and deflections that increase member instability, depends on applied loads, material properties, and geometric factors such as height, stiffness, and asymmetry.

4. This study focuses on the elastic range ignoring material yielding, and numerical methods (unlike closed-form solutions) can effectively capture P-Delta effects in both elastic and inelastic ranges.

5. The finite element method, widely accepted in engineering, derives the stiffness matrix by minimizing total potential energy based on the principle of stationary potential energy, where equilibrium occurs when potential energy variation vanishes.

2.2 Research methodology

1. Two building models—symmetric and asymmetric (the latter incorporating a lift core)—with identical dimensions (G+9, 24m x 20m plan, 4m bay spacing, 3m storey height) were modelled using SAP-2000 finite element software.

2. A linear dynamic analysis was conducted on both models to evaluate their seismic behaviour.

3. A comparative assessment was performed focusing on base shear, storey drift, lateral displacement, and identification of irregular locations within each model.

2.2.1 Response Spectrum Method

Response spectrum analysis (RSA) simplifies modal analysis by providing quick peak response estimates without solving differential equations over time, making it far more efficient than time history analysis while conveniently describing seismic hazard through response spectra. Modal analysis transforms a coupled N-degree-of-freedom problem into N uncoupled single-degree-of-freedom problems, whose individual solutions are superimposed to obtain the final result. Structural engineers widely use RSA to evaluate dynamic reactions under earthquakes, relying on response spectra—graphical representations of maximum structural responses (displacement, acceleration, or velocity) across various natural periods. The general process involves defining the design earthquake, modeling structural characteristics to identify periods and mode shapes, deriving the response spectrum from ground motion data applied to single-degree-of-freedom systems, and comparing results against design criteria or codal requirements. This systematic approach is especially valuable in earthquake engineering, enabling informed design decisions that ensure structural safety and reliability.

2.2.2 P-Delta Analysis

The P-Delta effect is a second-order nonlinear phenomenon occurring in structures under axial loads and bending moments, becoming more significant in tall buildings where gravity load (P) acting through first-order displacement (Δ_1) produces additional overturning moments and deflections. Its magnitude depends on axial load, stiffness, and slenderness of both individual members and the overall structure, making it especially critical for high-rise buildings. Two distinct types exist: member P-δ effect, caused by axial force acting on a deflected individual member between endpoints, and structural P-Δ effect, caused by vertical loads acting on the laterally displaced structure as a whole. Both types induce additional stresses and destabilizing effects, therefore seismic design of multi-storey structures must account for P-Delta considerations. In SAP2000, P-Delta analysis performs a first-order linear analysis to derive joint forces, then recalculates forces and displacements in a second-order analysis when specified, and dynamic analysis is carried out if a response spectrum is defined within a load case.

3. Structural Detailing and Analysis of Buildings

The building has a total plan area of 24 m x 20 m, with all structural members (slab, columns, and beams) constructed using M30 grade concrete. The slab thickness is 125 mm, beams in both X and Y directions measure 450 mm x 250 mm, and column sizes vary by storey: 700 mm x 700 mm for storeys 1 to 4, and 500 mm x 500 mm for storeys 5 to 6.

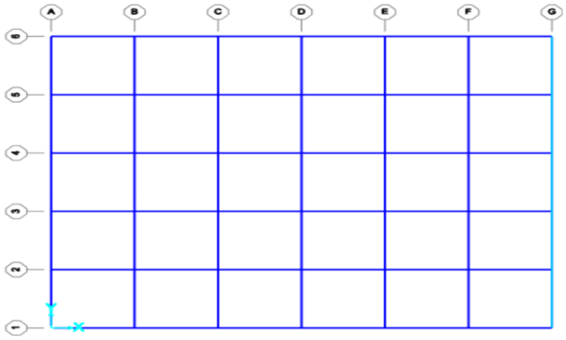


Fig-1: Plan of Model

Table-1: Seismic Zone factor

Seismic Zone Factor	II	III	IV	V
Z	0.1	0.16	0.24	0.36

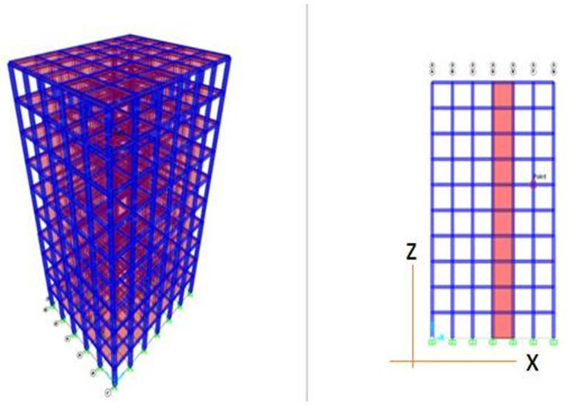


Fig-2: 3D rendered model with lift core in X-Z plane.

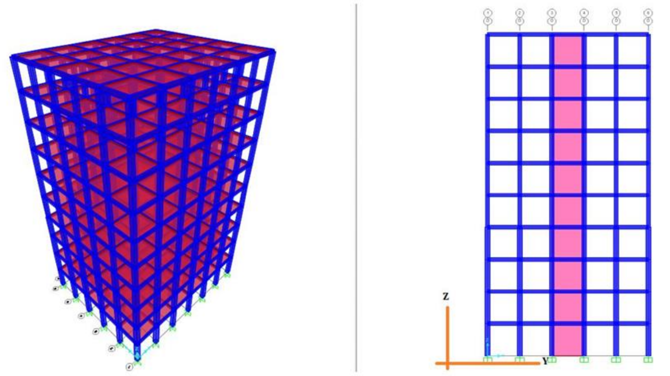


Fig-3: 3D rendered model with lift core in Y-Z plane.

Figure 2 and figure 3 in different planes represents 3D rendered model of G+9 building. as prepare in sap2000.

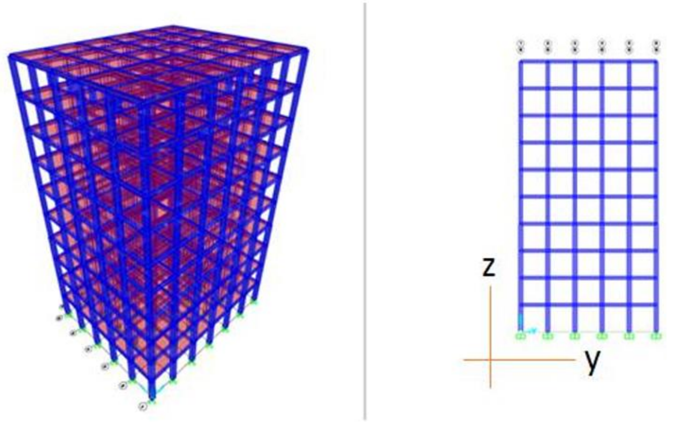


Fig 4: 3D rendered model of G+9 without lift core

3.1 LOADS DETERMINATION

Load values have been taken from IS:875 (Part I)-1987, and IS:875 (Part II)-1987

Dead, live, and seismic loads were assigned per IS codes. Dead load (IS 875:1987) included beam (2.81 kN/m), column (12.25 kN/m for 0.7m, 9 kN/m for 0.6m), slab (3.125 kN/m^2), and floor finish (1.5 kN/m^2, roof 0.9 kN/m^2). Live load (IS 875 Part 2:1987) was 3 kN/m^2. Seismic loads (IS 1893 Part 1:2016) used Zone IV (zone factor 0.24), soft soil (Type III), importance factor 1.2 (residential), and reduction factor 3 (OMRF).

4. Result and Discussion.

4.1 Storey Displacement

4.1.2 Displacement Observed with Response Spectrum Method

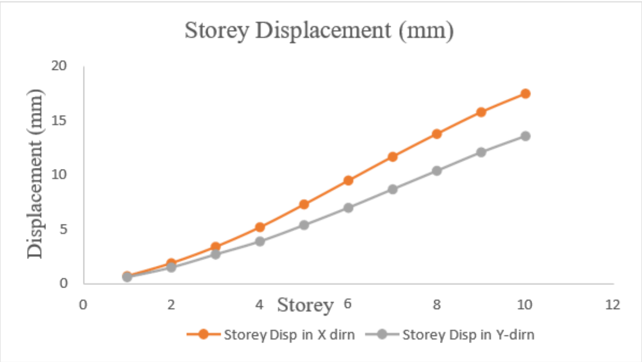


Fig-5: Storey Displacement for G+9 Model with lift core

According to the storey displacement for G+9 Model with lift core graph, the value of storey displacement has increased from the bottom storey to the top storey and is greatest on the top-most level. additionally, storey displacement is greater in the X- direction and much less so in the Y-direction as shown in figure 5. Presence of lift core will cause different storey displacement in both directions.

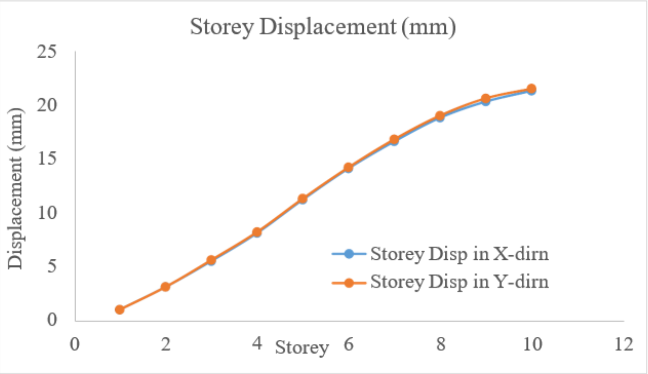


Fig-6: Storey Displacement for G+9 Model without lift core

It is determined that the maximum storey displacement is 21.3 mm in the X-direction and 21.5 mm in the Y-direction. and the topmost story in both directions experiences the most storey displacement as we can observed in figure 6. The storey displacement observed same because no resisting element used in the model.

4.1.2 Displacement observed with P-Delta effect

After P-Delta analysis, the maximum storey displacement was 25.82 mm in the X-direction and 20.3 mm in the Y-direction, both occurring at the top storey. The lift core acted as a shear wall, significantly reducing lateral displacement compared to the model without a lift core, which lacked such a resisting element.

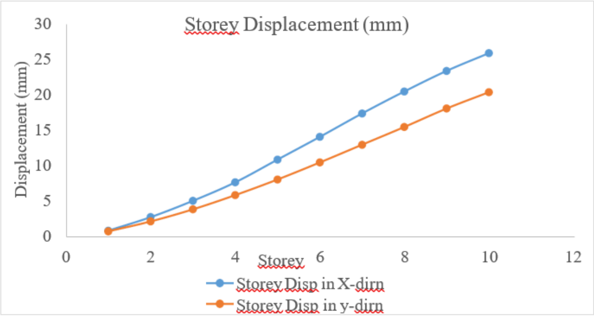


Fig-7: Storey Displacement for G+9 Model with lift core

According to the figure displayed in 8, the maximum storey displacement is 41.3 mm in the X-direction and 41.7 mm in the Y-direction. Also, we can see from the graph that the maximum storey displacement is at top in both directions.

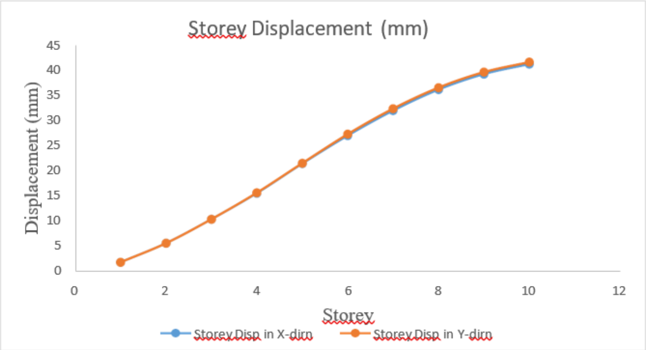


Fig-8: Storey Displacement for G+9 Model without lift core.

4.2 Storey Drift

4.2.1 Storey Drift with Response Spectrum Method

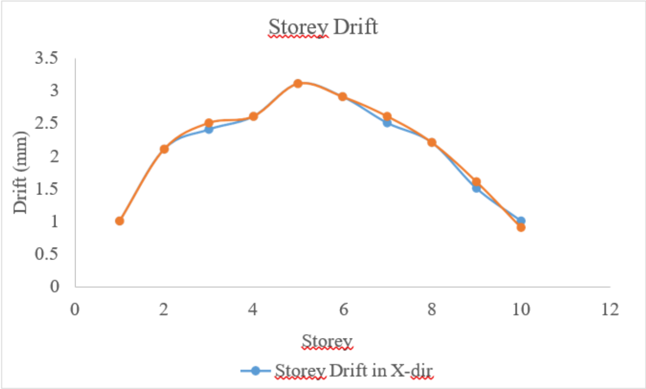


Fig-9: Storey Drift for G+9 Model without lift core

Maximum storey drift is measured to be 3.1 mm in the X and 3.1 mm in the Y directions. the sixth storey is where the maximum storey drift occurs in both X and Y directions as shown in figure 5-5. The storey drift observed same because no resisting element used in the model.

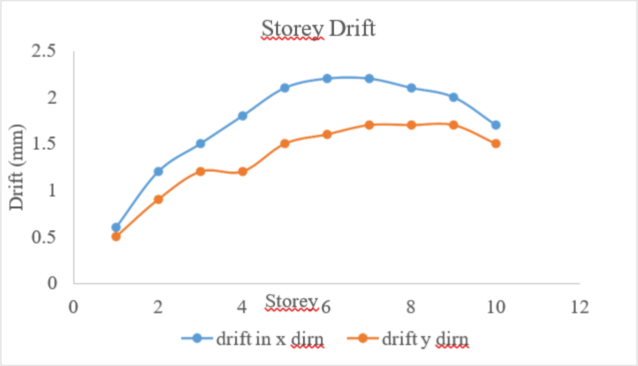


Fig-10: Storey Drift for G+9 Model with lift core

For the G+9 model under X-direction loading, storey drift rises from ground to the sixth storey and then decreases toward the eighth storey. Under Y-direction loading, the highest drift occurs at the eighth, ninth, and tenth storeys, with a minimum value of 0.5 mm. The presence of the lift core reduces storey drift in both directions. As shown in figure 10.

4.2.1 Storey Drift with P-Delta effect

As shown in figure 11, the maximum storey drift magnitude is 5.9 mm in the X- direction and 5.9 mm in the Y-direction. The maximum story drift is on the sixth storey in both the X and Y directions, as seen in figure 11.

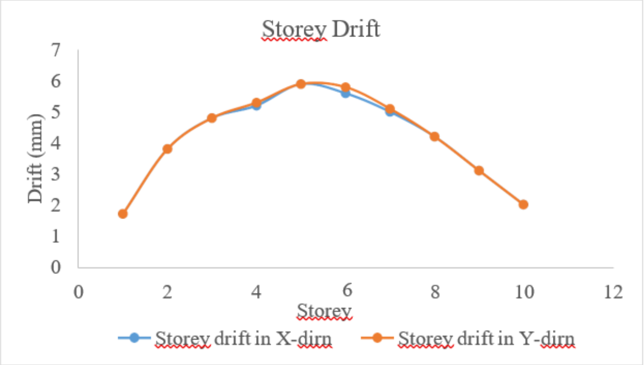


Fig-12: Storey Drift for G+9 Model without lift core

Maximum storey drift is determined to have an amplitude of 3.3 mm in the X-direction and 2.6 mm in the Y-direction. The figure 12 shows that the maximum storey drift occurs at the eighth level when the load is considered to be in the X-direction and at the tenth storey when the force is considered to be in the Y-direction.

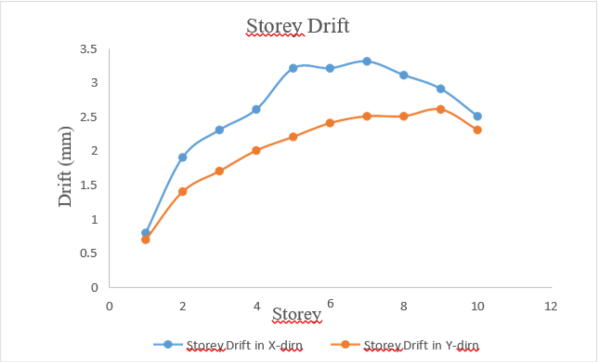


Fig-12: Storey Drift for G+9 Model with lift core

4.3 Time Period and Frequency as Per P-Delta Analysis

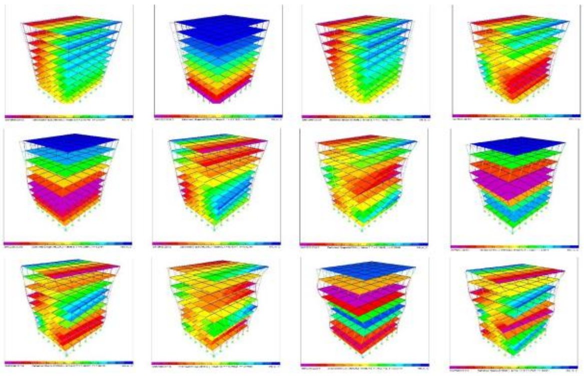
The time period (or natural period) of a structure is the duration to complete one full vibration cycle, primarily influenced by the building's height, stiffness, and mass distribution. Buildings with shorter time periods oscillate quickly under seismic motion, while those with longer periods oscillate slowly. To avoid resonance—which amplifies structural response—buildings should be designed with time periods that do not match typical earthquake ground motion frequencies.

Table-2: Results obtained of Time Period and Frequency for 12 Modes

		Model with liftcore		**Model with liftcore**	
P-Delta Analysis	1	1.159	0.863	1.249	0.800
	2	0.891	1.122	1.236	0.809
	3	0.850	1.176	1.148	0.871
	4	0.389	2.572	0.422	2.370
	5	0.261	3.833	0.418	2.392
	6	0.257	3.898	0.391	2.555
	7	0.217	4.604	0.238	4.201
	8	0.142	7.042	0.236	4.231
	9	0.137	7.295	0.222	4.506
	10	0.127	7.875	0.156	6.408
	11	0.103	9.696	0.155	6.445
	12	0.097	10.258	0.145	6.879

Frequency, measured in Hertz (Hz), is the reciprocal of the time period and represents oscillations per unit time, with different structural elements possessing distinct natural frequencies. Low-frequency ground motions (longer periods) tend to damage taller, flexible structures more, while high-frequency motions (shorter periods) more severely affect shorter, stiffer buildings. Damping refers to the energy loss within a structure during oscillation, and engineers must consider the frequency content of seismic loads to ensure structural components can withstand forces across various frequencies.

Fig-13: Mode shapes for model without lift core.



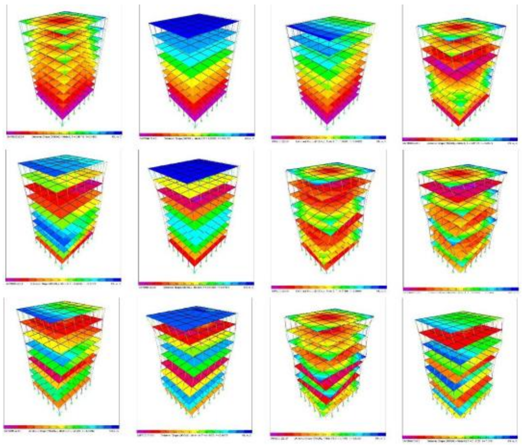


Fig-13: Mode shapes for model with lift core.

4.4 Modal Load Participation Ratios

The Model Load Participation Ratio (MLPR) is a helpful metric for determining how the various vibrational modes affect the structure's overall response. The level of each vibration mode's contribution to conveying the supplied loads or excitations is indicated by the MLPR.

Table-3: Model Participation factor for buildings with and without lift core

		Without lift core		**Without lift core**	
Item Type	Item	Static Percent	Dynamic Percent	Static Percent	Dynamic Percent
Acceleration	UX	99.9621	93.618	99.942	92.5452
Acceleration	UY	99.9625	93.5945	99.953	93.5243

4.5 Correlation Factor

The correlation factor is a dimensionless value between 0 and 1 that quantifies the relationship between lateral displacements and member axial forces or moments in P-Delta analysis. A value of 1 indicates perfect correlation where lateral displacements fully influence axial forces or moments, while 0 indicates no influence. This factor is particularly significant for tall, flexible structures and systems vulnerable to lateral loads or stability issues. By introducing the correlation factor, engineers can accurately model the P-Delta phenomenon during structural analysis. Consequently, it produces more reliable and trustworthy results for structural design and evaluation.

4.5.1 G+9 Modal with and Without Lift Core

- The correlation between the maximum displacement for G+9 with and without lift core is y = 0.9934x when considering displacement in X-direction as the trend chart shown in figure 14.

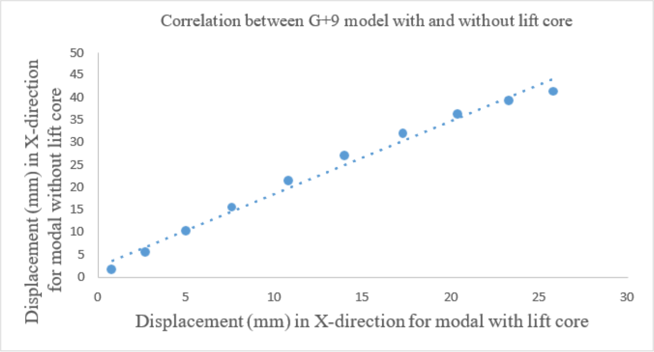


Fig-14: Correlation between G+9 model with and without lift core for displacement in X-direction.

- The correlation between the maximum displacement for G+9 with and without lift core is y = 0.98836x when considering displacement in Y-direction as the trend chart shown in figure 15.

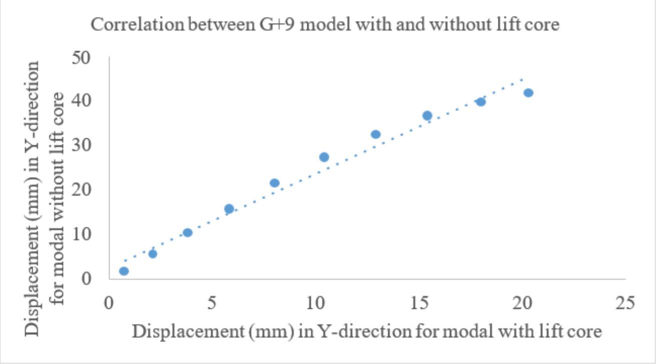


Fig-15: Correlation between G+9 model with and without lift core for displacement in Y-direction.

5 Conclusion

In this study, three distinct models of existing structures are studied in the high seismic zone and are analyzed using SAP2000 software while taking the p–delta analysis into account the following information is recorded:

1) Maximum Displacement:

a) Maximum storey displacement measured for G+9 model with lift core is 25.5 mm in X direction and 20.3 mm in Y direction. The P-delta analysis resulted in a 9.68% or approximately 10% increase in the maximum storey displacement.

b) Maximum storey displacement measured for G+9 model without a lift core is 41.3 mm in X direction and 41.7 mm in Y direction. The P-delta analysis resulted in a 4.84% or approximately 5% increase in the maximum storey displacement

2) Maximum Storey Drift:

a) Maximum storey drift measured for G+9 model with lift core is 3.3 mm in X direction and 2.6 mm in Y direction.

b) Maximum storey drift measured for G+9 model with lift core is 5.9 mm in both the X and Y direction.

3) Correlation Factor:

a) The correlation between the maximum displacement for G+9 with and without lift core is y = 0.9934x while considering lateral load in X-direction.

b) The correlation between the maximum displacement for G+9 with and without lift core is y = 0.98836x while considering lateral load in Y-direction.

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