

P-DELTA ANALYSIS OF MULTI-STOREY BUILDING USING E-TABS SOFTWARE

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Abstract - The stability of tall and slender reinforced concrete buildings is strongly influenced by second-order effects, particularly the P-Delta phenomenon arising from the interaction of gravity loads and lateral displacements. Neglecting these geometric nonlinearities can lead to underestimated structural responses and unsafe design decisions, especially under seismic and wind loading. This study investigates the influence of P-Delta effects on a multi-storey RC building and evaluates the effectiveness of shear walls in mitigating associated instabilities. A G+24 building model was developed in ETABS and analyzed under identical loading conditions using linear static analysis and nonlinear P-Delta analysis, both with and without shear walls. Key response parameters story displacement, drift, base shear, and overturning moments were examined to quantify the amplification induced by second-order behavior. The results indicate a significant increase in lateral deflection and drift when P-Delta effects are considered, emphasizing their relevance for high-rise structures. Incorporating shear walls markedly improved stiffness and reduced adverse P-Delta impacts, demonstrating their effectiveness as a lateral load-resisting system. The findings highlight the necessity of incorporating geometric nonlinearity in the analysis of tall buildings and optimizing shear wall placement to enhance seismic performance and structural safety.

Key Words: P-Delta effect, geometric nonlinearity, shear wall, ETABS, storey drift, seismic response, second-order analysis.

1. INTRODUCTION

The rapid increase in urbanization has led to a growing demand for high-rise reinforced concrete (RC) buildings, where structural stability under dynamic and lateral loads is a critical design consideration. As building height increases, the influence of geometric nonlinearity becomes more pronounced, particularly the P-Delta effect, which results from the interaction between axial gravity loads (P) and lateral displacements (Δ). This interaction generates secondary moments that magnify structural deformation and may compromise stability during seismic or wind actions. While linear static analysis is widely used in conventional design practice due to its simplicity, it neglects

these second-order effects, potentially leading to inaccurate prediction of drift, stiffness degradation, and internal forces in tall structures.

Advanced numerical tools such as ETABS allow engineers to simulate both first-order and second-order behaviors, enabling a more realistic evaluation of tall structures under lateral loads. Additionally, the use of lateral load-resisting systems—particularly reinforced concrete shear walls—has proven highly effective in reducing deformation and improving the overall stiffness and stability of RC structures. Integrating shear walls within structural frames can help counteract the detrimental effects of P-Delta actions, especially in slender buildings subjected to seismic forces.

Given the limitations of linear analysis and the increasing emphasis on performance-based design, a systematic investigation of the P-Delta effect becomes essential, particularly for buildings with and without shear walls. This research aims to evaluate the significance of P-Delta effects in multi-storey buildings and assess the contribution of shear walls in mitigating instability under seismic conditions.

1.1 Problem Statement

Tall and slender RC buildings are highly susceptible to second-order geometric nonlinearities. However, in routine practice, the P-Delta effect is often ignored or inadequately accounted for, leading to underestimation of displacement, drift, bending moments, and shear forces. This simplification can compromise structural safety during strong ground motion or lateral loading. Moreover, the effectiveness of shear walls in reducing P-Delta-induced amplification remains inadequately quantified for buildings of intermediate to high rise.

Therefore, the problem addressed in this study is:

“To determine how P-Delta effects influence the seismic response of a multi-storey RC building and to evaluate the extent to which shear walls can mitigate these second-order effects when analyzed using ETABS.”

1.2 Research Gap

A review of existing literature reveals the following gaps:

[1] Insufficient comparative studies for buildings with different structural configurations

Many studies have examined P-Delta effects, but only a limited number have compared with vs. without shear wall configurations under identical loading and geometric conditions.

[2] Lack of systematic quantification of response parameters

Most available research highlights the significance of P-Delta effects but does not comprehensively quantify the variation in storey displacement, drift ratio, base shear, and overturning moment using a consistent analysis framework.

[3] Limited studies focused on mid-rise and high-rise buildings using modern IS 1893:2016 provisions

Earlier research often used outdated seismic codes or focused primarily on low-rise buildings, leaving a gap in understanding how P-Delta behavior evolves under updated code requirements.

[4] Insufficient analytical evaluation using advanced E-TABS nonlinear capabilities

While ETABS is widely used, few studies employ its iterative nonlinear P-Delta procedure in a detailed parametric approach, especially for practical structural layouts. Despite numerous studies acknowledging the importance of P-Delta effects, there is no comprehensive, code-based, non-linear comparative evaluation of multi-storey RC buildings with and without shear walls using modern seismic analysis procedures. This gap justifies the need for the present investigation.

1.3 Equivalent Static Method

The Equivalent Static Method is a simplified seismic analysis procedure in which the actual dynamic earthquake forces acting on a structure are represented by an equivalent horizontal static force. This approach does not require detailed determination of higher mode shapes or dynamic characteristics, making it suitable for regular and moderately tall buildings. Base shear is computed using the structure's seismic weight and acceleration coefficients as per code provisions. The calculated base shear is then distributed across the height of the structure to estimate storey-level forces. Modern software tools automate the computation of the fundamental time period, lateral load distribution, overturning moments, torsional effects, shear

forces, and displacements, allowing faster and more accurate implementation of this method.

1.4 Second-Order Analysis

Second-order analysis considers the additional displacements, forces, and moments that arise when loads act on the deformed configuration of the structure. These effects, commonly known as second-order or geometric nonlinear effects, cause increases in deformation and internal forces beyond those predicted by first-order analysis. The influence is most significant in members subjected to both axial compression and bending—often referred to as beam-column elements. While first-order analysis can provide a preliminary estimate, accurate assessment of these additional effects requires a true second-order analysis, particularly for slender or heavily loaded structures.

1.5 P-Delta Effect

The P-Delta effect is a form of geometric nonlinearity that arises when vertical loads (P) act on a structure that has undergone lateral displacement (Δ). This interaction produces additional bending moments and shear forces that are not accounted for in simple linear analysis. As the structure drifts laterally under seismic or wind loads, the gravity loads contribute to secondary overturning moments, amplifying the total lateral forces acting on the system. These P-Delta moments are often overlooked in basic static or dynamic analyses, but they can significantly influence stability, especially in tall, slender, or flexible buildings. The magnitude of the effect is directly related to the applied axial loads (P) and the lateral displacement (Delta), making it an important consideration in the design of multi-storey buildings.

1.6 P-Delta Effect

The P-Delta effect represents a form of geometric nonlinearity in which vertical gravity loads (P) interact with the lateral displacement (Δ) of a structure. This interaction generates additional shear forces and bending moments that are not captured in conventional linear analyses. P-Delta is one of several second-order phenomena that arise when loads act on the deformed configuration of a structure rather than its original geometry. When a building undergoes lateral sway due to wind or seismic forces, its mass shifts to a displaced position, causing secondary overturning moments. These additional moments, which result from the product of the axial load (P) and the lateral displacement (Δ), are often underestimated or ignored in basic static and dynamic analyses. Because these effects significantly influence the stability and drift of tall or slender structures, they must be considered to ensure a reliable and safe design.

1.7 Types of P-Delta Effects (P)

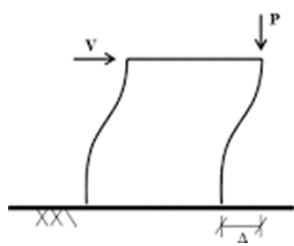


Fig-1: P-Δ Effect

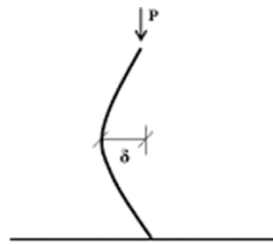


Fig-2: P-δ Effect

1.8 P-Δ Effect (P-Big Delta)

The P-Δ effect refers to the global second-order behavior of the entire structure. When a building is subjected to lateral forces such as wind or earthquake loads, it undergoes large-scale horizontal displacement. At the same time, vertical gravity loads (P) continue to act on the structure. The multiplication of the total vertical load (P) by the overall lateral displacement (Δ) produces additional secondary moments, which further increase the lateral drift and overturning tendency of the structure. This effect becomes particularly significant in high-rise buildings with greater flexibility.

1.8 P-δ Effect (P-Small Delta)

The P-δ effect describes local second-order behavior within individual structural members. It occurs when an axial load acts on a member—such as a column—that exhibits curvature or local deflection between its ends. The axial load (P) acting on the localized deformation (δ) induces additional internal bending moments in that member. For example, a column that experiences curvature due to beam-column interaction or unequal end rotations is affected by this phenomenon. The P-δ effect is critical for evaluating the stability and buckling behavior of individual compression members.

1.9 Objectives Of The Study

The primary objective of this research is to evaluate the influence of geometric nonlinearity, specifically the P-Delta effect, on the seismic performance of a multi-storey reinforced concrete building and to assess the role of shear walls in mitigating these effects. The specific objectives are:

- To perform linear static (first order) and P-Delta (second order) analysis on multi-storey RC buildings.
- To study displacement, drift, base shear and overturning moment for different building shapes.
- To evaluate the influence of shear walls on reducing P-Delta effects.

- To identify the most stable configuration among sharp edge, cut shape, and recessed shape buildings.

2. METHODOLOGY

The methodology adopted in this research is designed to systematically evaluate the influence of P-Delta effects on a G+24 multi-storey reinforced concrete building, with and without shear walls. The entire process involves model creation, load assignment, analytical procedures, and comparison of structural response parameters. The steps followed in this study are described below. A 24-storey RC building (G+24) with a uniform storey height of 3 m was modelled and analyzed using ETABS software. Four different analytical cases were developed:

1. Linear Static Analysis (LSA) without shear wall
2. P-Delta Analysis without shear wall
3. Linear Static Analysis with shear wall
4. P-Delta Analysis with shear wall

2.1 Building Information

Table 1: Geometry of Model

Sr. No.	Parameter	Value
1	Number of storeys	G+24
2	Height of each storey	3 m
3	Location of structure	Guwahati
4	Length in X-direction	30 m
5	Length in Y-direction	30 m
6	Slab depth	150 mm
7	Beam size	300 × 600 mm
8	Column size	750 × 750 mm
9	Shear wall thickness	250 mm
10	Brick wall thickness	230 mm

Table 2: Load Proportions

A. Dead Load (IS 875 Part-1)

Sr. No.	Load Type	Value
1	Self-weight	As per software
2	Floor finish	1.5 kN/m ²
3	Roof finish	1.5 kN/m ²
4	Wall load	11.04 kN/m
5	Parapet wall load	6.9 kN/m

B. Imposed Load / Live Load (IS 875 Part-2)

Sr. No.	Load Type	Value
1	Live load on floor slab	4 kN/m ²
2	Live load on roof slab	1.5 kN/m ²

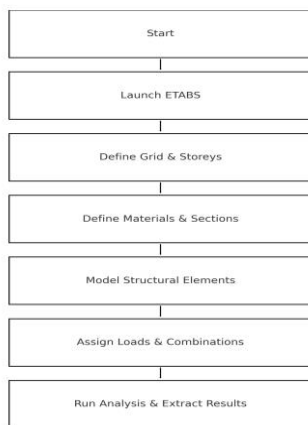
C. Earthquake Load (IS 1893:2016 Part-1)

Sr. No.	Factor	Value
1	Response reduction factor (R)	5
2	Zone factor (Z)	0.36
3	Importance factor (I)	1.5
4	Damping	5%
5	Soil type	Medium
6	Seismic zone	Zone V (Guwahati)

Table 3: Load Combinations (IS 1893:2016 Clause 6.12.3.2)

Sr. No.	Load Combination
1	1.5 (DL + LL)
2	1.2 (DL + LL + EQX)
3	1.2 (DL + LL - EQX)
4	1.2 (DL + LL + EQY)
5	1.2 (DL + LL - EQY)
6	1.5 (DL + EQX)
7	1.5 (DL - EQX)
8	1.5 (DL + EQY)
9	1.5 (DL - EQY)

2.2 Modelling Steps in E-TABS



2.3 Different Models considered for Analysis

2.3.1 Sharp edges at the Corners of building

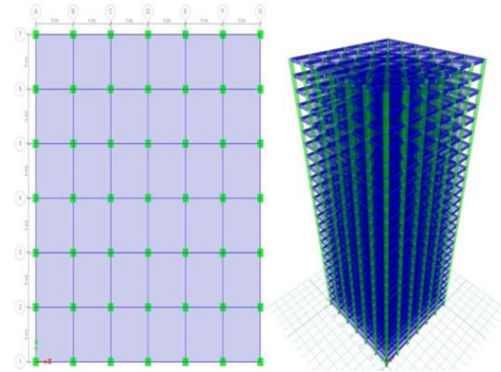


Fig 2.1- 2-D and 3-D View of Sharp edge at the corners of the building

2.3.2 Cut Shape at the Corners of building

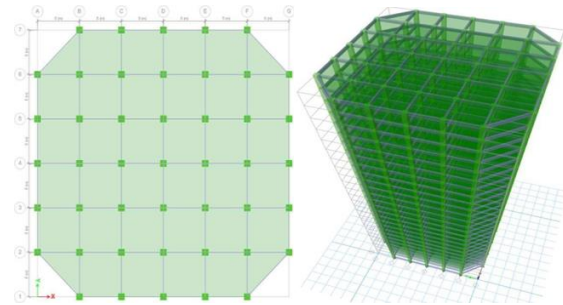


Fig 2.2: 2-D and 3-D Rendered view of Cut Shape at the corners of the building

2.3.3 Recessed shape at the Corners of building

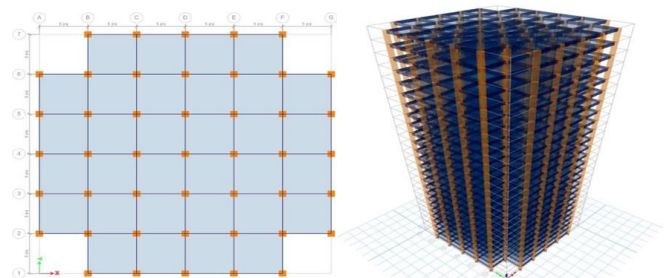


Fig 2.3: 2-D and 3-D Rendered view of Recessed Shape at the corners of the building

3. RESULT

This chapter presents the analytical results obtained from the E-TABS models for all four cases With Different Models:

1. Linear Static Analysis (LSA) – Without Shear Wall
2. P-Delta Analysis – Without Shear Wall
3. Linear Static Analysis – With Shear Wall
4. P-Delta Analysis – With Shear Wall

The building response was evaluated using the following key parameters:

- Storey Displacement
- Storey Drift
- Base Shear
- Overturning Moment

The results derived from both linear and second-order analyses are compared to understand the influence of geometric nonlinearity and the effectiveness of shear walls.

3.1 Comparison of Overturning Moment

Overturning moments were calculated for all four models.

Key Observations:

- P-Delta analysis results in slightly higher overturning moments compared to linear analysis.
- Shear walls contribute to reduced overturning moments, as they increase stiffness and limit overall sway.
- The reduction is more evident for the upper storeys where lateral displacement is highest

Table-3.1 Comparison of Overturning Moment

Shape	Linear	P-Delta	Linear wsw	P-Delta wsw
Recessed Shape	6776022	6876640	6485441	6586976
Sharp Edge	7450903	7541517	7124290	7228521
Cut Shape	7120793	7218634	6883849	6991222

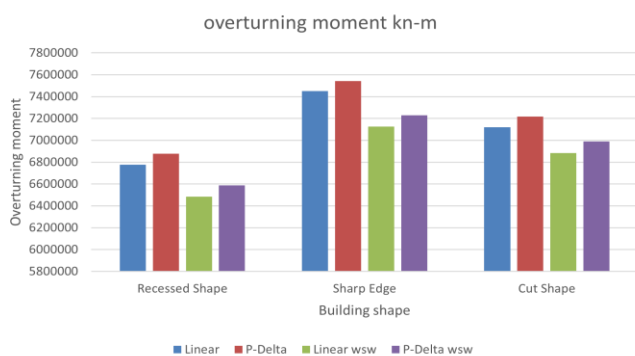


Figure-3.1 Comparison of Overturning Moment

3.2 Comparison of Base Shear

Base shear values for linear and P-Delta cases were extracted in both X and Y directions.

Key Observations:

- Only a small variation in base shear is observed between linear and P-Delta analyses.

- The presence of shear walls increases the lateral load-resisting capacity, but base shear values remain close across all cases.
- The difference in base shear is not as large as displacement or drift changes, indicating that P-Delta effects mainly influence deformation rather than base reaction.

Shape Type	Linear	P-Delta	Linear (With Shear Wall)	P-Delta (With Shear Wall)
Recessed	8111.32	8301.56	7255.39	7607.96
Sharp Edge	9829.15	9999.87	9004.76	9414.76
Cut Shape	8611.85	8943.41	7731.18	8118.88

Table 3.2 Base Shear (kN) Comparison

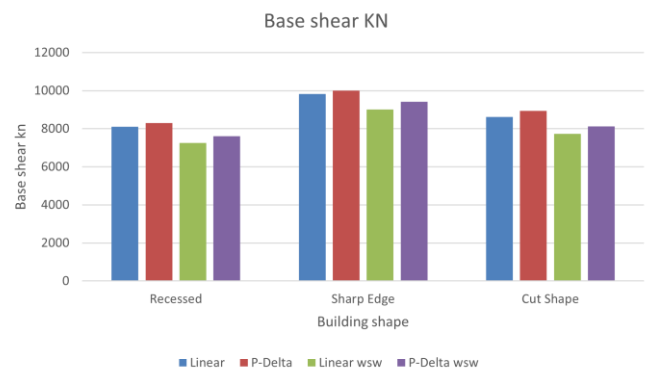


Figure 3.2 Base Shear (kN) Comparison

3.3 Comparison of Storey Displacement

The storey displacement graph shows a gradual increase in displacement with height for all building shapes. Sharp-edge buildings exhibit the maximum lateral displacement, while recessed shape buildings display the least. The application of shear walls results in a substantial reduction in displacement values, indicating their critical role in enhancing overall stiffness and minimizing horizontal deflection due to seismic or wind loading.

Table.3.3.1 Recessed Shape Displacement

Storey No	Recessed EQX Linear WSW (mm)	Recessed EQX P-Delta WSW (mm)	Recessed EQX Linear (mm)	Recessed EQX P-Delta (mm)
G+24	94	104.1	127.5	139.9
G+23	93.4	103.5	126	138.4
G+22	92.9	102.9	124.1	136.4

G+21	92.3	102.3	121.7	133.9
G+20	91.5	101.4	118.7	130.8
G+19	90.2	100	115.2	127.2
G+18	88.3	98.1	111.2	123
G+17	85.9	95.6	106.8	118.5
G+16	83	92.5	102	113.5
G+15	79.7	89.2	96.9	108.1
G+14	75.9	84.9	91.5	102.3
G+13	71.7	80.4	85.9	96.3
G+12	67.3	75.6	80	90
G+11	62.5	70.5	74	83.4
G+10	57.6	65.1	67.8	76.6
G+9	52.4	59.4	61.5	69.7
G+8	47.1	53.6	55	62.6
G+7	41.7	47.5	48.6	55.3
G+6	36.2	41.3	42	48
G+5	30.7	35	35.5	40.6
G+4	25.1	28.7	29	33.3
G+3	19.5	22.3	25.7	29.5
G+2	14	16	18.4	20.4
G+1	8.8	9.9	11.4	11.4
GF	4.4	5.2	4.6	5.1
Plinth	0.6	0.6	0.7	0.7
Base	0	0	0	0

Table.3.3.2 Cut Shape Displacement

Storey No	Cut EQX Linear WSW (mm)	Cut EQX P-Delta WSW (mm)	Cut EQX Linear (mm)	Cut EQX P-Delta (mm)
G+24	103.02	110.4	127.4	139.5
G+23	100.51	107.8	126	138.4
G+22	97.79	104.96	124.1	136.1
G+21	94.85	101.8	121.7	133.6
G+20	91.65	98.48	118.7	130.5
G+19	88.18	94.84	115.2	126.2
G+18	84.44	90.9	111.3	122.8
G+17	80.43	86.68	106.9	118.2
G+16	76.17	82.18	102.2	113.2
G+15	71.68	77.43	97.1	107.9

G+14	66.98	72.43	91.7	102.2
G+13	62.1	67.23	86.1	96.1
G+12	57.07	61.84	80.2	89.8
G+11	51.93	56.31	74.2	83.3
G+10	46.7	50.67	67.8	76.5
G+9	41.44	44.97	61.7	69.6
G+8	36.18	39.26	55.2	62.5
G+7	30.97	33.59	48.7	55.5
G+6	25.87	28.03	42.2	48
G+5	20.94	22.65	35.7	40.6
G+4	16.26	17.84	29	33.3
G+3	11.9	12.8	22.6	25.8
G+2	7.98	8.54	16.2	18.4
G+1	4.63	4.92	10.1	11.4
GF	2.1	2.4	4.6	5.1
Plinth	0.4	0.42	0.7	0.7
Base	0	0	0	0

Table.3.3.3 Sharp Edge Shape Displacement

Storey No	Sharp EQX Linear WSW (mm)	Sharp EQX P-Delta WSW (mm)	Sharp EQX Linear (mm)	Sharp EQX P-Delta (mm)
G+24	118.3	129.6	129.9	141.1
G+23	115.6	126.7	128.4	139.6
G+22	112.7	123.5	126.4	137.5
G+21	109.5	120	123.9	134.9
G+20	105.9	116.2	121.8	131.8
G+19	102	112	116.2	128
G+18	97.8	107.5	112.2	123.8
G+17	93.3	102.6	108.7	119.2
G+16	88.4	97.4	102.8	114.1
G+15	83.3	91.9	97.6	108.6
G+14	78	86.1	92.1	102.8
G+13	72.4	80	87.4	96.7
G+12	66.6	73.7	81.4	90.4
G+11	60.7	67.2	75.2	83.7
G+10	54.7	60.5	68.9	76.9
G+9	48.6	53.8	61.5	69.9

G+8	42.5	47.1	56	62.8
G+7	36.4	40.4	49.4	55.5
G+6	30.5	33.7	41.8	48.2
G+5	24.7	27.3	35.1	40.7
G+4	19.2	21.2	29.5	33.3
G+3	14.1	15.5	22.9	25.9
G+2	9.5	10.4	16.5	18.5
G+1	5.6	6.1	10.3	11.5
GF	2.4	2.6	4.7	5.2
Plinth	0.4	0.4	0.7	0.7
Base	0	0	0	0

G+19	0.001322	0.001376	0.001512	0.001594
G+18	0.001458	0.001529	0.001653	0.001776
G+17	0.001588	0.001669	0.001828	0.001941
G+16	0.0017	0.001796	0.001957	0.002091
G+15	0.001798	0.001911	0.002071	0.002228
G+14	0.001883	0.002015	0.002169	0.002351
G+13	0.001955	0.002107	0.002324	0.002462
G+12	0.002017	0.002188	0.002234	0.00256
G+11	0.002067	0.002258	0.002383	0.002646
G+10	0.002108	0.002319	0.00243	0.002721
G+9	0.002138	0.00237	0.00245	0.002785
G+8	0.00216	0.002412	0.002491	0.002838
G+7	0.002173	0.002445	0.002506	0.002881
G+6	0.002179	0.002468	0.002512	0.002913
G+5	0.002177	0.002477	0.002507	0.002936
G+4	0.002159	0.002447	0.002488	0.002926
G+3	0.002121	0.002442	0.002441	0.002882
G+2	0.002034	0.002341	0.002335	0.002755
G+1	0.001784	0.002143	0.00203	0.002375
GF	0.000667	0.000848	0.000916	0.001692
Plinth	0.000437	0.000479	0.000492	0.000549
Base	0	0	0	0

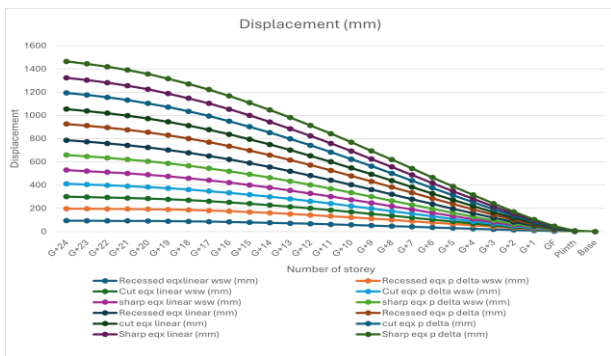


Fig re.3.3.1 Comparison of Storey Displacement

3.4 Comparison of Storey Drift

- The storey drift comparison highlights that sharp-edge buildings experience the highest drift ratios, especially around mid-storey levels.
- The inclusion of P-Delta effects further increases drift, while shear walls effectively control this deformation.
- Recessed shape buildings show the lowest drift, demonstrating superior lateral stiffness and better control of inter-storey movement.

Table.3.4.1 Recessed Shape Storey Drift

Storey No	Recessed EQX Linear WSW (mm)	Recessed EQX P-Delta WSW (mm)	Recessed EQX Linear (mm)	Recessed EQX P-Delta (mm)
G+24	0.000489	0.000506	0.000566	0.000591
G+23	0.000648	0.000661	0.000739	0.000769
G+22	0.000832	0.000857	0.00094	0.000981
G+21	0.000999	0.001032	0.001149	0.001196
G+20	0.001168	0.00121	0.001343	0.001403

Table.3.4.2 Cut Shape Storey Drift

Storey No	Cut EQX Linear WSW (mm)	Cut EQX P-Delta WSW (mm)	Cut EQX Linear (mm)	Cut EQX P-Delta (mm)
G+24	0.000508	0.000526	0.000871	0.000913
G+23	0.000660	0.000681	0.000975	0.001020
G+22	0.000792	0.000815	0.001082	0.001132
G+21	0.001023	0.001055	0.001200	0.001250
G+20	0.001194	0.001234	0.001317	0.001374
G+19	0.001351	0.001400	0.001434	0.001501
G+18	0.001493	0.001533	0.001559	0.001620
G+17	0.001620	0.001693	0.001660	0.001747
G+16	0.001732	0.001820	0.001760	0.001860
G+15	0.001831	0.001934	0.001851	0.001963
G+14	0.001917	0.002026	0.001932	0.002057
G+13	0.001991	0.002126	0.002000	0.002136

G+12	0.002053	0.002203	0.002056	0.002205
G+11	0.002097	0.002255	0.002101	0.002274
G+10	0.002133	0.002291	0.002144	0.002333
G+9	0.002155	0.002318	0.002174	0.002381
G+8	0.002127	0.002306	0.002196	0.002421
G+7	0.002179	0.002279	0.002209	0.002450
G+6	0.002045	0.002223	0.002213	0.002473
G+5	0.002400	0.002318	0.002240	0.002492
G+4	0.001840	0.002000	0.002193	0.002479
G+3	0.001672	0.001815	0.002155	0.002445
G+2	0.001564	0.002044	0.002069	0.002348
G+1	0.001481	0.001808	0.001892	0.002140
GF	0.000777	0.000846	0.001310	0.001400
Plinth	0.000288	0.000310	0.000451	0.000488
Base	0	0	0	0

G+5	0.00156	0.00161	0.00218	0.00250
G+4	0.00134	0.00138	0.00217	0.00247
G+3	0.00114	0.0012	0.00217	0.00244
G+2	0.001	0.00104	0.00204	0.00234
G+1	0.00083	0.000864	0.00184	0.00209
GF	0.00055	0.000593	0.00131	0.00140
Plinth	0.00022	0.00021	0.00044	0.00048
Base	0	0	0	0

Table.3.4.3 Sharp Shape Storey Drift

Storey No	Sharp EQX Linear WSW (mm)	Sharp EQX P-Delta WSW (mm)	Sharp EQX Linear (mm)	Sharp EQX P-Delta (mm)
G+24	0.00048	0.00049	0.00109	0.00111
G+23	0.00063	0.000654	0.00116	0.00118
G+22	0.000834	0.000854	0.001227	0.001248
G+21	0.000909	0.00102	0.001302	0.00132
G+20	0.001016	0.001037	0.00136	0.00139
G+19	0.00132	0.00137	0.00143	0.00146
G+18	0.00156	0.0016	0.0015	0.00158
G+17	0.00156	0.0016	0.00158	0.00166
G+16	0.00162	0.00166	0.00167	0.00179
G+15	0.00167	0.00171	0.00178	0.00191
G+14	0.00171	0.00175	0.00188	0.00201
G+13	0.00173	0.00179	0.00195	0.0021
G+12	0.00175	0.00181	0.00202	0.00218
G+11	0.00176	0.00182	0.00207	0.00225
G+10	0.00175	0.0018	0.00211	0.00231
G+9	0.00175	0.00182	0.00214	0.00234
G+8	0.00169	0.00174	0.00217	0.00241
G+7	0.0016	0.00167	0.00218	0.00246
G+6	0.00156	0.00161	0.00218	0.00246

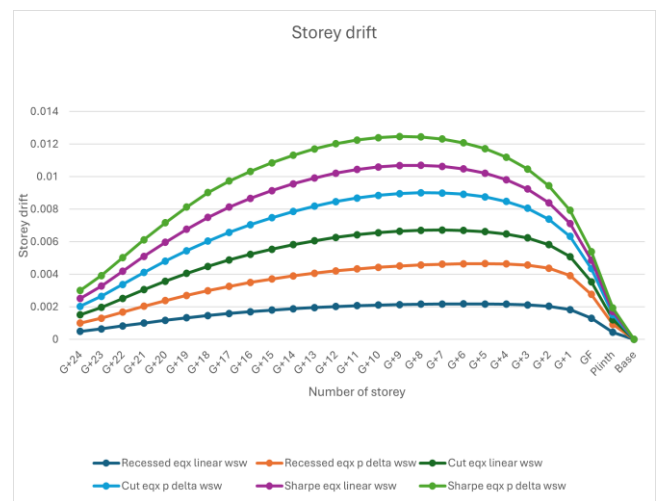


Figure.3.4.1 Comparison of Storey Drift

4. CONCLUSION

- P-Delta effects are significant for tall structures.
- Displacements, drift, base shear and overturning moment increased with P-Delta consideration.
- Shear walls reduced displacements, drift, base shear and overturning moment.
- Recessed shape configuration performed best in seismic resistance.
- Sharp edge buildings experienced highest Displacements, drift, base shear and overturning moment
- P-Delta analysis should be included in design of high-rise buildings.

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