A Study on P-Delta Effect on Reinforced Concrete Frame Structure Under Eccentricity Changes

[1]Yogeesh Subray Nayak, [2]Naveen Kumar M.
[1] PG Student, [2]Assistant Professor
[1] Department of Civil Engineering,
[1] Dr Ambedkar Institute of Technology, Bengaluru, Karnataka, India

Abstract - P-Delta effect in structure mainly rises from the direct action of lateral forces and the structure in a state of equilibrium where the deformed structure shape is a more responsible factor. This kind of effect is made in the analysis of second order, where the geometry of the elements is come from their changed condition. In this paper seismic analysis has been performed for G+10, G+20, G+30 storey Reinforced Concrete (RC) frame building models with and without steel bracing by response spectrum method for seismic zones-V founded on soil type II as per the IS 1893:2016 specifications and varying different eccentricities levels from 5, 20 & 30 percent. The analysis has been performed using ETABS software. The results have shown that, the eccentricity ratio increases maximum torsional moment also increases and the models analyzed with considering P-Delta effect have significantly more values of displacements, drifts, bending moments and shear force when compared with the models without considering the P-Delta effect, but introducing steel bracing is reduce the P-Delta effect on certain height of the building. Therefore, the P-Delta effect is significant and must be considered in the analysis of multi storey bare buildings.

Keywords: P-Delta effect, Eccentricity, Steel bracing, Response spectrum method, ETABS.

I. Introduction

The behavior of reinforced concrete frame structures under varying eccentricities is a critical aspect of structural engineering that directly influences the safety and performance of buildings. The P- Delta effect,which accounts for the interaction between axial forces and lateral displacements, plays a significant role in the structural response under such conditions. This study aims to comprehensively investigate the implications of the P-Delta effect on reinforced concrete frame structures when subjected to changes in eccentricity.

Reinforced concrete frames are widely utilized in the construction industry due to their versatility and load-bearing capabilities. The eccentricity of loads applied to these frames can arise from a variety of factors, including uneven loading, architectural constraints, or accidental conditions. Understanding the P-Delta effect is crucial because neglecting it can result in inaccurate predictions of structural response, potentiallycompromising the safety and stability of a building. This study employs advanced computational techniques and analytical tools to simulate and analyze the behavior of reinforced concrete frame structuresunder different eccentricity scenarios.

Ultimately, the findings of this study have the potential to influence the design codes and guidelines for reinforced concrete frame structures, enhancing their resilience and safety when subjected to varying eccentricities. In a broader context, this research contributes to advancing the field of structural engineering, enabling the creation of more robust and reliable structures in the face of real-world loading conditions.

P-Delta analysis, also known as second-order analysis, is a vital engineering technique used to evaluate thestructural stability and behavior of buildings under the influence of gravity and lateral loads. In traditionalfirst-order analysis, the effects of displacements on the structure are neglected, assuming that the load distribution remains unchanged. However, P-Delta analysis considers the second-order effects, which account for the deformation-induced changes in the structural behavior. P-delta is a term coined from P that is load and delta is the lateral deformation. These lateral deformationsare more lethal in case of earthquakes and not so much in case of wind.

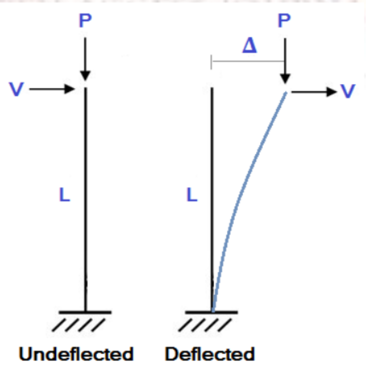


Figure 1: P-Delta effect

II. LITERATURE SURVEY

D J Zavala et al, consider nine models that represent a 20-story building and which, in the X and Y directions of the analysis, take into account a dual-type structural system in a configuration that is resistant to lateral loads. To calculate the percentage variation of the results, a comparison of the responses from the linear and nonlinear analysis is conducted. There have been variations in drifts, shear force, and moments per floor of up to 16.50%, 11.00%, and 14.00%, respectively, when analyzing the structures that take into account stiffness irregularity and the p-delta effect. There is a variation in stiffness of up to 59.85% when the p-delta effect is taken into account in structures with the presence of stiffness irregularity. According to this finding, the p-delta effect results in a greater degradation of the overall stiffness of the structure.

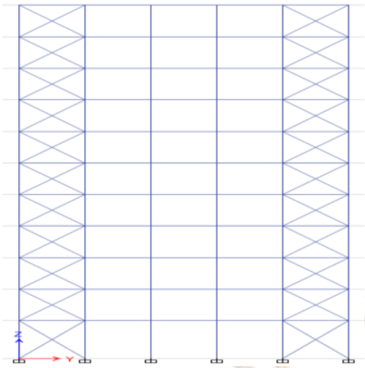
Sruthi K et al, carried out building structure P-delta analysis. The effectiveness and precision of the P-Delta analysis method were examined and contrasted. Even though the analysis took less than one-third as long as the iterative method, the results were the same. P-Delta analysis was discovered to be more appropriate for high rise structures. They came to the conclusion that since there is a nonlinear relationship between deflection and gravity loads, P-Delta analysis must include loads that correspond to the failure state being considered.

III. METHODOLOGY

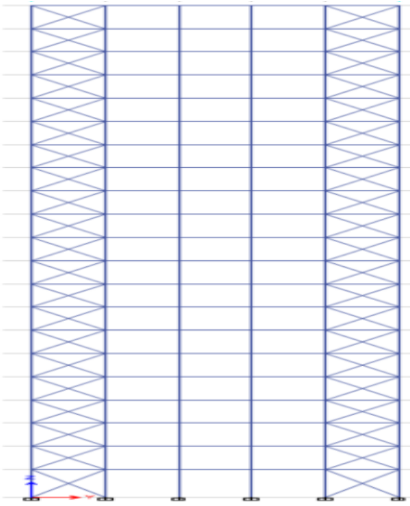
The study focuses on investigating the P-Delta (second-order) effect on a reinforced concrete frame structure subjected to changes in eccentricity. The primary aim is to comprehend how these effects influence the seismic behavior of the structure, in accordance with IS 1893:2016 standards. Response Spectrum Analysis, a widely accepted seismic analysis method, is employed using the ETABS software. The research involves systematically varying the eccentricity of applied loads on the frame members. The study evaluates the structural response in terms of lateral displacements, storey drifts. The Results are crucial for understanding the importance of considering P-Delta effects in seismic design and ensuring the safety and stability of RC frame structures under varying eccentricities.
For this study, three building models, each having G+10, G+20 and G+30 storey is considered. Each type of building has consisted steel bracing at corner. Response spectrum analysis is performed for these models with and without steel bracing. The structure was modelled in ETABS Software by considering the parameter shown in Table 1.

Table 1: Parameters considered in present study

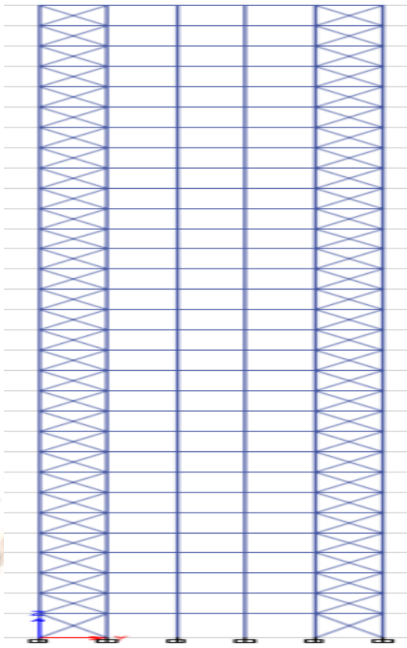
No. of storey	G+10, G+20, G+30
Typical storey height	3.5m
Type of building	Commercial building
Plan Dimension	18 X 21.6 m
Seismic Zone	V
Soil type	II
Building Height	39.7m (G+10) 74.2m (G+20) 109.2m (G+30)
Slab thickness	150mm
Beam size	500 X 500mm (G+10) 500 X 600mm (G+20) 450 X 750mm (G+30)
Column size	450 X 450mm (G+10) 750 X 750mm (G+20) 1000 X 1000mm and 750 X 750mm (G+30)
Bracing Section	ISMB 300 (G+10) ISMB 300 (G+20) ISMB 300 and ISMB 500 (G+30)
Live load	3 kN/m^2
Floor finish	1.5 kN/m^2
Roof live load	1.5 kN/m^2



Model 1: G+10



Model 2: G+20



Model 3: G+30

Figure 2: Elevation of models

IV. Results and Discussions

1. Maximum Displacement

Maximum storey displacement refers to the largest lateral movement experienced by a specific storey or level of a building under the influence of lateral loads such as wind or seismic forces. In structural engineering, buildings are subjected to horizontal forces due to various factors, and these lateral loads can induce lateral displacements in the structure.

According to Indian code Guidelines the variation in storey displacement varies more than 10 percent P-Delta effect should be considered.

1.1 G+10 Storey building:

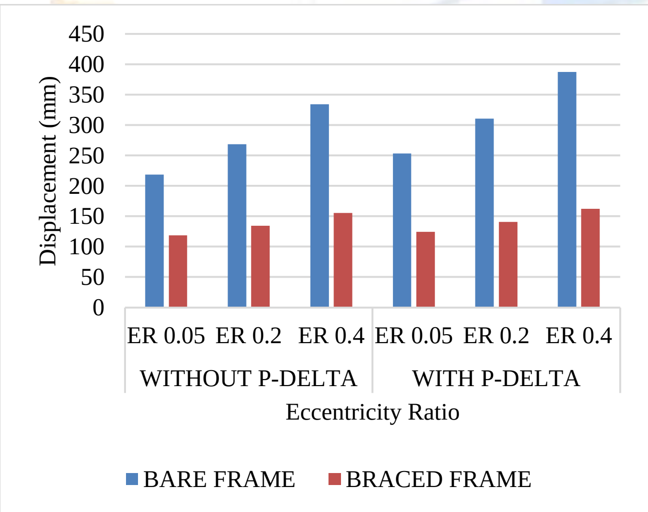


Figure 3: Max. Displacement along X-Direction

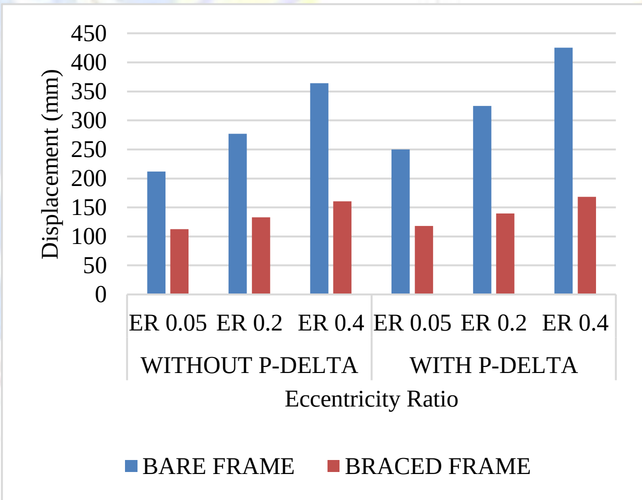


Figure 4: Max. Displacement along Y-Direction

The maximum displacement occurs at 10 storey level. Since in all the level of storey as the eccentricity increases the level of displacement also increases.

When the effects of P-delta are taken into account, the results of storey displacement from the G+10 storey bare and braced model are respectively 13.65% and 4.64% higher than the standard building model (without P-delta).

1.2 G+20 Storey building:

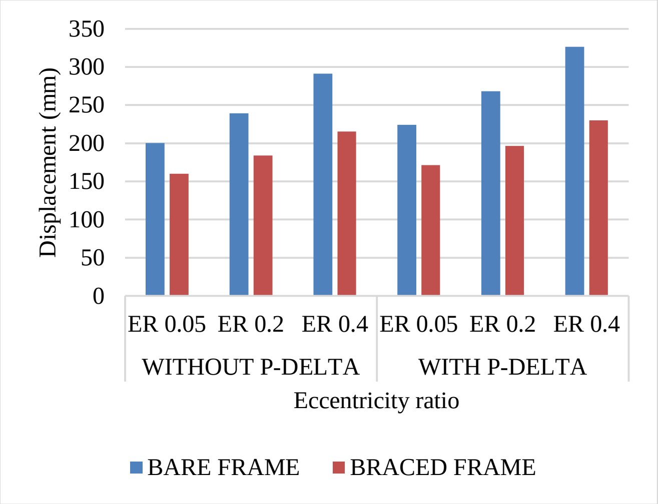


Figure 5: Max. Displacement along X-Direction

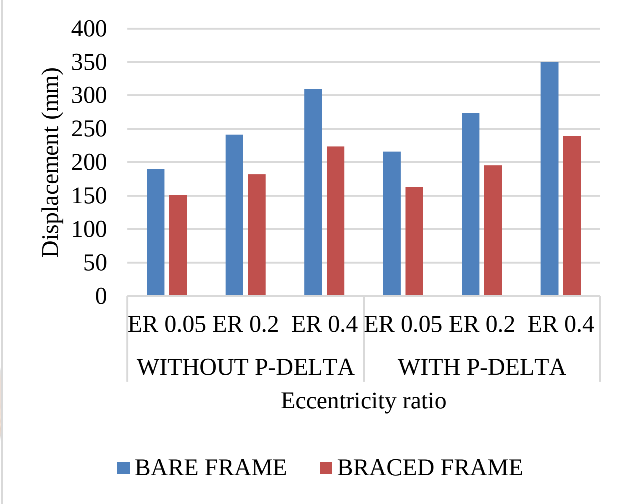


Figure 6: Max. Displacement along Y-Direction

The maximum displacement occurs at 10 storey level. Since in all the level of storey as the eccentricity increases the level of displacement also increases.

When the effects of P-delta are taken into account, the results of storey displacement from the G+20 storey bare and braced model are 10.73% and 6.53% higher than the standard building model (without P-delta).

1.3 G+30 Storey building:

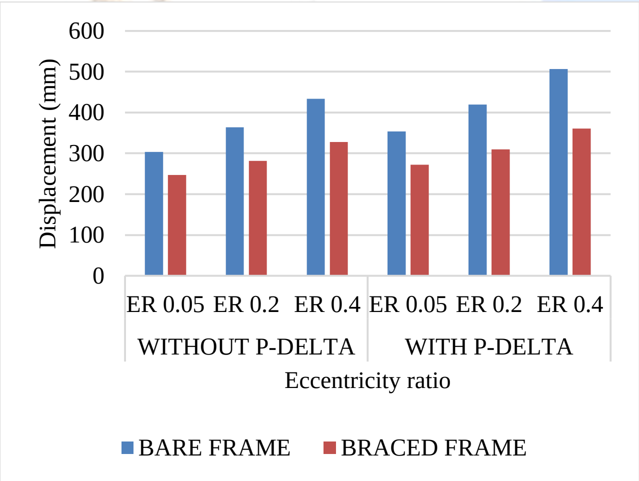


Figure 7: Max. Displacement along X-Direction

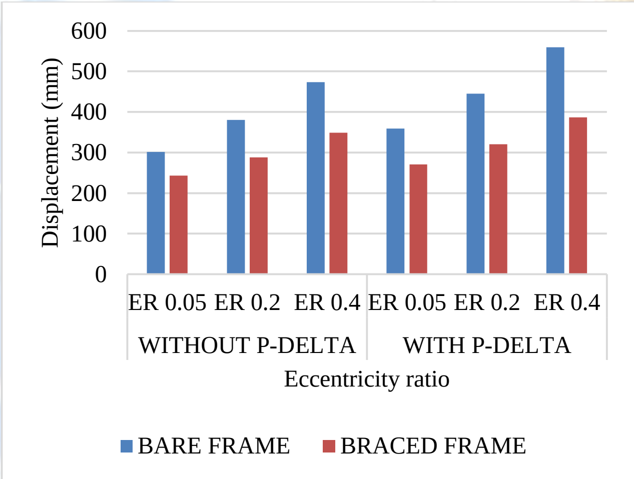


Figure 8: Max. Displacement along Y-Direction

The maximum displacement occurs at 10 storey level. Since in all the level of storey as the eccentricity increases the level of displacement also increases.

When the P-delta effect is considered, the results of the storey displacement obtained from the G+30 storey bare and braced model are respectively 14.39% and 12.96% higher than those obtained from standard building model (without P-delta).

2 Maximum Storey Drift:

Maximum storey drift refers to the largest lateral displacement or deformation that occurs between adjacent floors or levels of a building during an earthquake or other lateral loading events. It is a critical parameter in structural engineering as it helps assess the building's performance under lateral forces and ensures its stability and safety.

According to Indian code Guidelines the variation in storey drift varies more than 10 percent P-Delta effect should be considered.

2.1 G+10 Storey building:

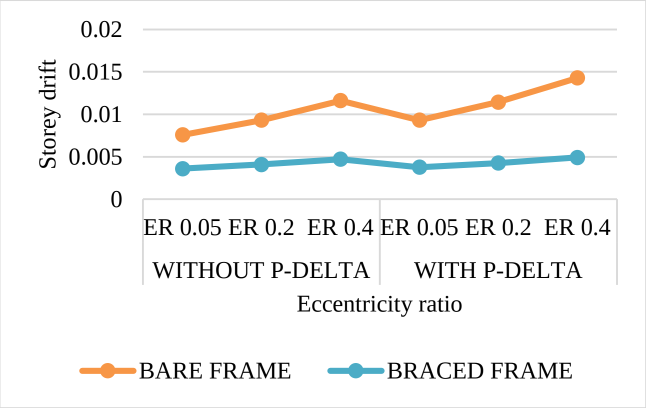


Figure 9: Max. storey drift along X-Direction

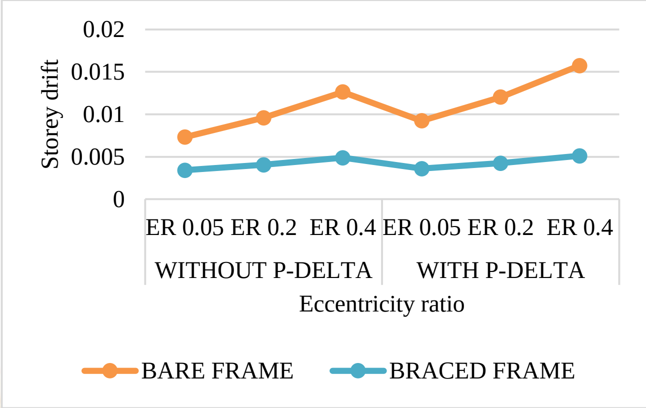


Figure 10: Max. storey drift along Y-Direction

When the effects of P-delta are considered into account, the results of storey drift from the G+10 storey bare and braced model are, respectively, 18.65% and 4.34% higher than the standard building model (without P-delta).

2.2 G+20 Storey building:

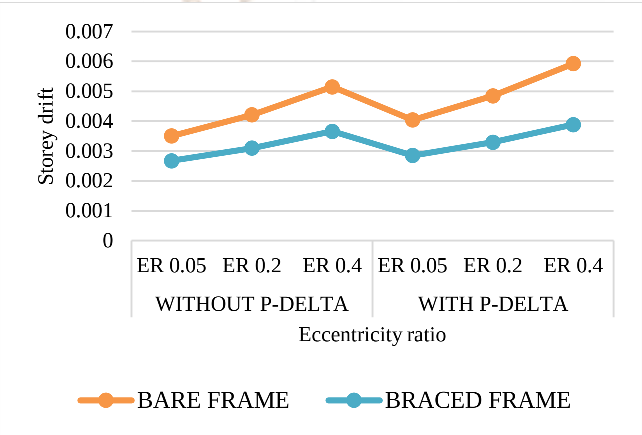


Figure 11: Max. storey drift along X-Direction

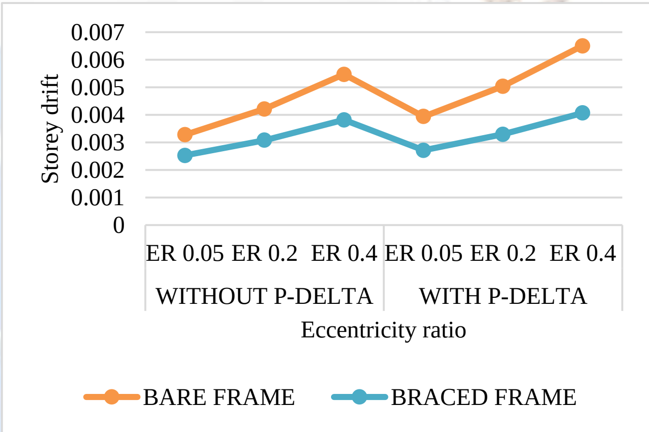


Figure 12: Max. storey drift along Y-Direction

When the effects of P-delta are considered into account, the results of storey drift from the G+20 storey bare and braced frame model are, respectively, 13.21% and 6.15% higher than the standard building model (without P-delta).

2.3 G+30 Storey building:

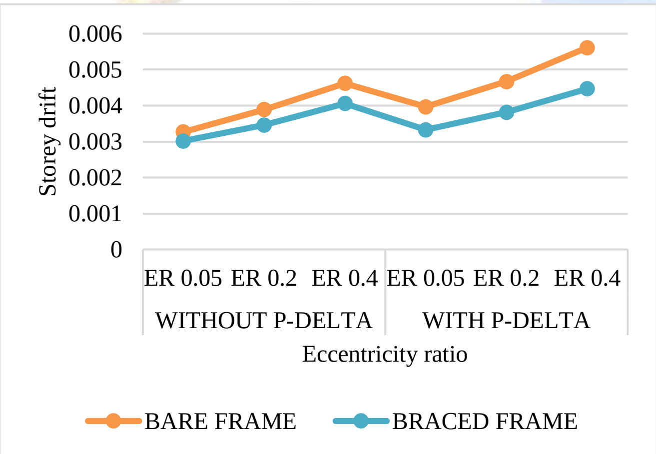


Figure 13: Max. storey drift along X-Direction

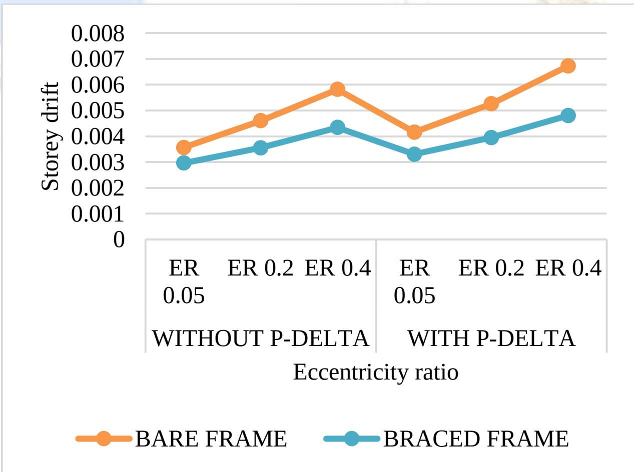


Figure 14: Max. storey drift along Y-Direction

When the P-delta effect is considered, the results of storey drift from the G+30 storey bare and braced frame model are, respectively, 14.31% and 10.43% higher than the standard building model (without P-delta).

3 Torsional Moment:

The twisting or rotational force that results from the application of lateral loads (such as wind or seismic forces) that are not evenly distributed along the height of the building is referred to as a torsional moment in a building. This torsional motion can be caused by the uneven distribution of lateral displacements across the height of the building caused by this twisting force.

Table 2: Variation of Maximum torsional moment at column with change in eccentricity ratio

MODELS	ECCENTRICITY RATIO	MAXIMUM TORSIONAL MOMENT in kN-m
G+10	0.05	1.776
	0.2	7.106
	0.4	14.213
G+20	0.05	15.263
	0.2	39.49
	0.4	71.792
G+30	0.05	21.55
	0.2	86.21
	0.4	172.42

Table 2 shows the variation of maximum torsional moment at column 1 at 6th floor, column 1 at 11th floor and column 1 at 15th floor with different eccentricity ratio in G+10, G+20, G+30 building model respectively. It can see that as eccentricity ratio increases maximum torsional moment also increase.

4 Shear Force

Shear Force is a force which acts tangentially on the body. It is caused by tangential component of a force acting on the body. Due to effect of shear force, the cross-section of the body is deformed, and shear strain will be induced.

According to Indian code Guidelines the variation in shear force varies more than 10 percent P-Delta effect should be considered.

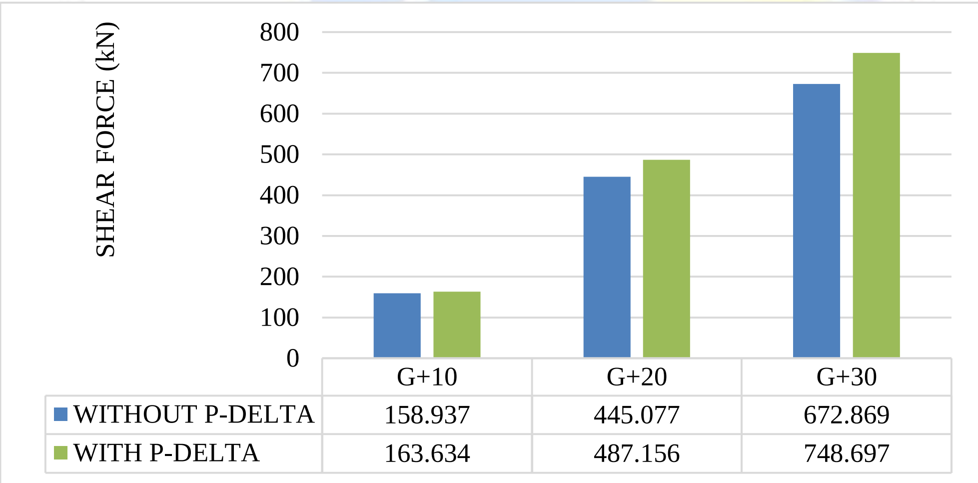


Figure 15: Max. Shear Force in X-Direction

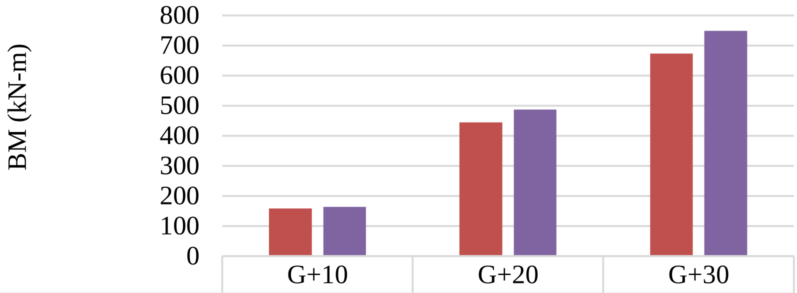
The maximum shear force at column 13 at 5th floor, column 13 at 11th floor and column 13 at 15th floor in G+10, G+20, G+30 building model respectively.

When the P-delta effect is considered, the shear force obtained from the 10,20 and 30 storey braced model are, respectively, 3.6%, 9.23% and 11.58% higher than the standard building model (without P-delta).

5 Bending Moment

Bending moment is the reaction induced in a structural element when an external force or moment is applied to the element, causing the element to bend.

According to Indian code Guidelines the variation in Bending moment varies more than 10 percent P-Delta effect should be considered.



	G+10	G+20	G+30
Bending Moments (kN-m) WITHOUT P-DELTA	158.937	445.077	672.869
Bending Moments (kN-m) WITH P-DELTA	163.634	487.156	748.697

Figure 16: Max Bending moment in X-Direction

The maximum bending moment at column 13 at ground floor, column 13 at ground floor and column 7 at ground floor in G+10, G+20, G+30 building model respectively.
When the P-delta effect is considered, the bending moment obtained from the 10,20 and 30 storey braced model are, respectively, 2.87%, 8.63% and 10.12% higher than the standard building model (without P-delta).

V. Conclusions

From the above results and discussions, the following conclusions are drawn.

- The eccentricity ratio increases maximum torsional moment also increases because torsion generated depends upon the position of centre of rigidity and centre of mass of the structures.
- The bare frame structure with G+10, G+20 and G+30 storey building shows maximum variation in displacement, drift, shear force and bending moment due to P-Delta effect. This is because of additional moment generated during second order effect.
- The results storey displacement obtained from P-Delta effect of G+10, G+20 and G+30 storey bare frame models are respectively 18.65%, 10.73% and 14.39% higher than those obtained from standard building model (without P-delta).
- The results of storey drift from P-Delta effect of G+10, G+20 and G+30 storey bare frame models are, respectively, 14.31%, 13.21% and 14.31% higher than the standard building model (without P-delta).
- The P-Delta analysis is necessary for bare frame structure which the floors of building is more than 10 storeys.
- The results storey displacement obtained from P-Delta effect of G+10, G+20 and G+30 storey braced frame models are respectively 4.64%, 6.53% and 12.96% higher than those obtained from standard building model (without P-delta).
- The results of storey drift from P-Delta effect of G+10, G+20 and G+30 storey braced frame models are, respectively, 4.34%, 6.15% and 10.43% higher than the standard building model (without P-delta).
- The shear force obtained from the G+10, G+20 and G+30 storey braced models are, respectively, 3.6%, 9.23% and 11.58% higher than the standard building model (without P-delta).
- The bending moment obtained from the G+10, G+20 and G+30 storey braced models are, respectively, 2.87%, 8.63% and 10.12% higher than the standard building model (without P-delta).
- From above results, the P-Delta analysis is not necessary for corner braced structure up to 20 storey building structures because it shows minimum variation to P-Delta effect.
- From overall analysis, the P-delta effect becomes more significant as the number of storeys increases.

VI. References

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