P-DELTA EFFECT ON MULTI-STOREY BUILDINGS

By

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ABSTRACT

The buildings are prone to deform laterally from original position with an eccentricity during an earthquake. When building structures are subjected to seismic loading causing the structure to deform, the resulting eccentricity of the total gravity load due to inclined axes of structure causes the extra moments at the base. The presence of infill, bracing and number of storeys may affect the additional displacement due to P-Delta. In the present study, the design parameters of buildings which are affected by P-Delta, such as lateral displacement, base shear, and moment at the base-columns are discussed. The non-iterative P-Delta analysis is adopted to determine the P-Delta effect for symmetric rectangular regular plan structures. It has been reported that, the bare frame Reinforced Concrete (RC) structures more than 20 stories are required to be analysed and designed for P-Delta effect. The P-Delta effect significantly controlled by the braced systems and masonry infill structures.

Keywords: P-Delta Effects, RC Bare Frame, Masonry Infill, RC Braced Structure, Multi-storey, Seismic Zones.

INTRODUCTION

The P-Δ effect is the second order effect on shears and moments of frame members due to the action of the vertical loads, interacting with the lateral displacement of buildings, resulting from the seismic forces. The structures behave flexible against applied seismic lateral loads as the columns are subjected to compressive loads.

There are two types of P-Delta effects,

- P-δ effect or P- 'small delta' effect.
- P-Δ or P- 'big delta' effect.

The P-δ effect or P- 'small delta' effect is concerned with load displacements of structural elements in between end nodes. The P-Δ or P- 'big delta' effect is associated with the global load-displacement of the structure. In a first-order analysis only gravity loadings are considered. The structures are analysed for each loading to obtain results and superimposed. However, this method does not provide accurate results. In low-rise and medium-rise buildings P-Delta analysis is not essential as the displacements are small. In taller and slender building structures having greater flexibility, the P-Delta effects are more significant. If the P-Delta effects are significant, then it requires larger sectional size of structural components to sustain the augmented moments and shears. In extreme cases such as very flexible, tall building structures subjected to large gravity loading, the P-Delta effects are severe enough to cause catastrophic collapse. In the design of multi-storey building structures, assessment of P-Delta effects is more important to predict whether P-Delta effects are significant, if so, P-Delta effects are accounted for analysis and design of structural elements. The P-Delta effect is critical in case of nonlinear analysis of multi-storey buildings [1, 9]. If the P-Delta effect causes sufficiently large lateral displacements in structures then P-Delta analysis is essential.

The P-Delta effects are not considered in analysis and design of building components of high-rise building structures if the stability coefficient as obtained by the below equation is equal to or less than 0.10 [1].

$$\theta = \frac{P\Delta}{V h C_d} \quad (1)$$

where,

P - total vertical design load (kN),

Δ - design story drift,

v - seismic shear force (kN),

h - height of story (mm),

C_d - deflection amplification factor.

Dinar, Y., et al. [2] studied the 30 storey structure and reported that the displacement and axial forces varies exponentially under P-Delta analysis with the increase in height of the structures.

The RC masonry infill models were analysed against the seismic lateral loads by Mulgund, G. V., and Kulkarni, A. B., [5]. It was inferred that the infill provides lateral stiffness and strength to the structures and reduces the lateral displacements considerably. A simple and accurate second order analysis method was proposed by means of computer programs by Rutenberg, A., [9]. This direct second order approach provided more accurate results including P-Delta effects. The P-Delta effects were investigated for multi-storey buildings adopting matrix formulations by Neuss, C. F., and Maison, B. F., [6] and reported that the values of design quantities were increased with P-Delta analysis at all floor levels of the structure for static analysis. The displacement, base shear and base overturning moments were increased by 6.6, 5.1, and 6.7%, respectively when P-Delta analysis was included. The bare frame structures, infill masonry structures were modelled by Niruba, S., et al. [7]. It was reported as; the infill contributes to the strength, stiffness and ductility of the structures and reduces deflections. The effect of infill reduces as the height of structure increases.

From the reviewed literatures, it is clear that most of the works were carried out on design parameters, such as lateral displacement, storey drift, axial forces, bending moments, and overturning moment of high-rise building structures for seismic force and wind loads using various international codal provisions. The present study includes effect of design parameters like lateral displacement, base shear and overturning moments on analysis and design of multi-storey building structures including P-Delta effect. Also, the study includes the effect of P-Delta on multi-storey braced systems and masonry infill structures.

1. Methodology

1.1 Structural Models

For this study, bare frame, masonry infill, and braced RC multi-storied structures were considered. The built-up area of building structure is 345.6 m^2. The bottom storey height is 3.75 m and other stories height are 3 m and have a uniform mass distribution over their height. Four bays of 3.6 m in Y-direction and four bays of 6 m in X-direction is considered for analysis. The non-iterative P-Delta analysis is carried out using E-TABS software for all models along with non-linear static analysis. An underlying P-Delta investigation in this program considers the P-Delta effect of a solitary stacked state upon the structure. Determine the heap utilizing one of the accompanying choices: a) None Option: Utilize this choice to not consider P-Delta impacts, including expelling already considered impacts, b) Non-Iterative Option: The load considered consequently from the mass at each level as a story-by-story stack upon the structure. This approach is surmised, yet does not require an iterative analysis. This technique is basically suitable for symmetric structural models to consider the P-Delta effect. It is substantially quicker than the iterative method, c) Iterative: This method considers the P-Delta effect on an element by element premise. It catches neighbourhood clasping impacts superior to the non-iterative method. It is to be prescribed that the utilization of this iterative method in all cases aside from those for which no gravity load is determined in the model. The different ETAB models are shown in Figures 1, 2, 3, and 4. The symmetrical bare frame RC structure is modelled for seismic zones II, III, IV, and V in accordance with IS-1893-2002. The 10-storey, 20-storey, 30-storey, and

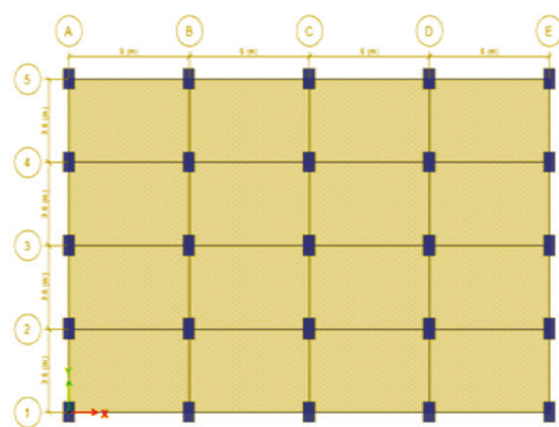

Figure 1. Plan View Figure

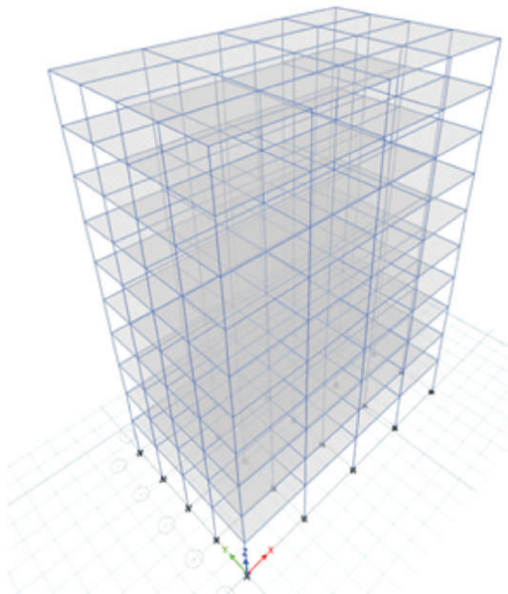

Figure 2. Bare Frame Model

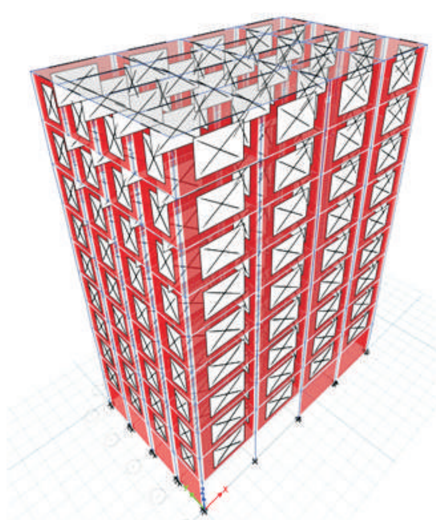

Figure 3. Masonry Infill Model

40-storey bare frame RC building structures are modelled and analysed by non-linear static (pushover analysis) method and P-Delta analysis method. The reinforcement index of all structural components is considered same for all RC frame models. The brick masonry infills are considered for the same RC frame models for the analysis. Every external and internal wall meshed as 3×3 to get more accurate results.

The 40-storey bare frame rectangular plan configuration structure is braced externally and internally using X-bracing. The X-bracings are pin-jointed to the central frames

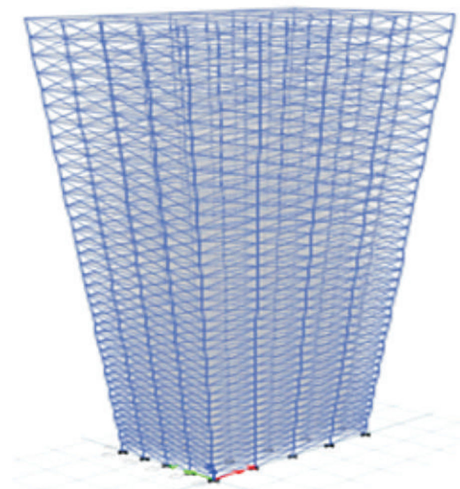

Figure 4. Braced Model

including all the bays in both x and y-directions of the bare frame RC structure. In case of "partially internal braced system", the X-bracing are connected with pin-joint to the middle two bays of central frames in both x and y-directions of the bare frame RC structure. After modelling of these bare frame RC structures, the P-Delta analysis (non-linear static analysis) is carried out. The results obtained from all the bare frame structures with braced system are compared.

1.2 Loading

The loads considered for analysis of models are dead load, imposed load, floor finish, and seismic loads of all the zones in accordance with Indian Standards.

1.2.1 Dead Loads

The dead loads are considered from of IS 875 (Part 1) – 1987.

1.2.2 Imposed Load

The imposed load is adopted from of IS 875 (Part 2) – 1987.

1.2.3 Seismic Load

The structure is assumed to be in all seismic zones, such as zone-II to zone-V as per IS 1893 – 2002 and the parameters are as shown in Table 1.

2. Materials

This section contains data regarding material properties and sectional properties of the structural elements. The modelling of structural forms is carried out for specified analysis methods corresponding to the design parameters.

2.1 Cross-Sections of Elements

The bracing sizes considered for 40-storey bare frame RC structure analysis is ISWB550 at 112.5 kg/m and cross sections of components are shown in Table 2.

2.2 Material Properties

The material properties adopted for modelling structural members are given in Table 3.

Density of concrete : 25 kN/m^3

Slab thickness : 120 mm

Wall thickness : 230 mm

3. Results and Discussion

3.1 Analysis for P-Delta Effect on Multi-Storey Building Structures for Different Seismic Zones

The multi-storey building structures are analysed with P-Delta and without P-Delta (Non-linear static) effect. The displacement, base shear, and overturning moment of different multi storey structures are evaluated. The 10, 20, 30, and 40 storey bare framed building structures are considered for the study. Figure 5 is the graphical representation of the variation of displacement v/s stories for different earthquake zones II, III, IV, V. The analysed models are bare frame RC structures. For 10 storey the P-Delta effect is negligible as the displacements for all four earthquake zones not more than 10% of results obtained from without P-Delta analysis. For zone-II the increased displacement is 2.4% and for zone-V is 2.44% as shown in Table 4. The P-Delta effect is not significant if it is less than 10% [6, 8, 9].

For 20 storey, the results show that the P-Delta analysis values are more than that of without P-Delta analysis. The percentage increases in the displacement for all the seismic zones is 10.8%. As the height of structure increases the slenderness ratio increases and due to this the P-Delta

Parameters	Value
I	1
R	5
Z	0.1, 0.16, 0.24 and 0.36
Sa/G	Type1, Type2 and Type3

Z-Zone, Sa/G- Soil type I, II, III, R-Response reduction factor, I - Importance factor

Table 1. Seismic Parameters

Storey	Column sizes (mm) Bare frame, Masonry infill, and Braced RC Model
10	400×600
20	600×600
30	600×800
40	700×900

Table 2. Sectional Sizes

Structural Members	Concrete Grade	Rebars grade
Column	M40	Fe 500
Beam	M25	Fe 500
Slab	M25	Fe 500

Table 3. Material Properties

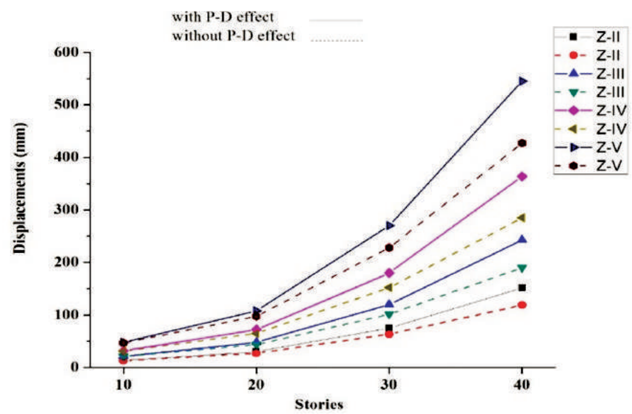

Figure 5. Variation of Displacement for Different Stories of Bare Frame Structures

Storey/Seismic Zone	Analysis	Max. Disp. (mm)	Base Shear (kN)	Moment (kN-m)
Z-II	P-Delta	13.31	301.5	36.02
	W/O P-Delta	12.98	288.03	34.47
	Difference %	2.44	4.67	4.5
Z-III	P-Delta	21.24	482.35	57.62
	W/O P-Delta	20.74	460.86	55.15
	Difference %	2.45	4.63	4.51
Z-IV	P-Delta	31.87	723.52	86.44
	W/O P-Delta	31.11	691.29	82.73
	Difference %	2.44	4.67	4.51
Z-V	P-Delta	47.81	1085	129.66
	W/O P-Delta	46.67	1037	124.09
	Difference %	2.44	4.67	4.49

Table 4. Results of 10 Storey Bare Frame Structures for Different Seismic Zones

effect increases [6, 9]. It is found that the increase in maximum displacements with respect to the zones is comparatively more, as well as the P-Delta effect increases with the displacement is similar with respect to every zone as the difference in with and without P-Delta analysis is 10.68%. Hence it is necessary that the analysis should be carried out for more than 20 storey bare frame RC structures and the values are shown in Table 5.

The 30-storey bare frame RC rectangular regular configuration structures with respect to all four seismic zones are analysed with P-Delta analysis and without P-Delta analysis. The maximum displacement obtained from P-Delta analysis is 18.33%, more than that of without P-Delta analysis as in Table 6. Hence the P-Delta analysis for bare frame RC rectangular regular plan structures for the design of structural components is essential.

The results supported from the analysis carried out by Dinar, and Nazin[3], reported the difference in with P-Delta and without P-Delta analysis is 21.36%. Unlike the current study the value of 18.33% is relatively lesser. This is because the varying slenderness ratio of structures and the design codes referred [6].

In case of 40 storey, referring Table 7, the maximum displacements obtained from P-Delta analysis are 28.3% more than without P-Delta analysis. The maximum displacements of 40 storey bare frame RC rectangular structure is approximately 26%, 16%, and 10% more than 10, 20, and 30 storey bare frame RC structures, respectively. Hence P- Delta analysis is necessary for design of 40 storey bare frame RC rectangular regular plan configuration structure.

Figure 6, is the base shears for 10 storey bare frame RC structures with zone II, III, IV, and V are obtained with and without P-Delta analysis. The base shear increases with

Storey/Seismic Zone	Analysis	Max. Disp. (mm)	Base Shear (kN)	Moment (kN-m)
	P-Delta	29.98	383.4	68.226
Z-II	W/O P-Delta	27.06	331.7	59.23
	Difference %	10.79	15.56	15.18
	P-Delta	47.98	613.4	109.16
Z-III	W/O P-Delta	43.31	530.8	94.76
	Difference %	10.78	15.57	15.20
	P-Delta	71.97	920.1	163.74
Z-IV	W/O P-Delta	64.96	796.2	142.15
	Difference %	10.79	15.57	15.19
	P-Delta	107.95	1380	245.61
Z-V	W/O P-Delta	97.44	1194	213.22
	Difference %	10.8	15.6	15.19

Table 5. Results of 20 Storey Bare Frame Structures for Different Seismic Zones

Storey/Seismic Zone	Analysis	Max. Disp. (mm)	Base Shear (kN)	Moment (kN-m)
	P-Delta	74.98	652.35	130.23
Z-II	W/O P-Delta	63.34	514.02	103.05
	Difference %	18.38	26.91	26.38
	P-Delta	119.97	1044	208.37
Z-III	W/O P-Delta	101.375	822.44	164.89
	Difference %	18.34	26.93	26.36
	P-Delta	179.95	1566	312.57
Z-IV	W/O P-Delta	152.06	1234	247.34
	Difference %	18.34	26.90	26.37
	P-Delta	269.93	2348	468.85
Z-V	W/O P-Delta	228.1	1850	371
	Difference %	18.338	26.91	26.37

Table 6. Results of 30 Storey Bare Frame Structures for Different Seismic Zones

Storey/Seismic Zone	Analysis	Max. Disp. (mm)	Base Shear (kN)	Moment (kN-m)
	P-Delta	151.53	1019	260.30
Z-II	W/O P-Delta	118.72	724.1	186.10
	Difference %	27.63	40.72	39.87
	P-Delta	242.44	1631	416.53
Z-III	W/O P-Delta	189.95	1159	297.80
	Difference %	27.63	40.725	39.86
	P-Delta	363.67	2446	624.73
Z-IV	W/O P-Delta	284.92	1738	446.65
	Difference %	27.63	40.73	39.87
	P-Delta	545.50	3669	937.10
Z-V	W/O P-Delta	427.38	2607	669.98
	Difference %	27.63	40.73	39.87

Table 7. Results of 40 Storey Bare Frame Structures for Different Seismic Zones

increase in seismic zone factors, this is due to severity of earthquake and it also inversely related to time period of structure [4]. The base shears with P-Delta analysis are more than without P-Delta analysis [5, 7]. The percentage increase in the base shear for all seismic zones is 3.34%. Thus, the base shear in P-Delta analysis is insignificant to consider it in designs. For 20 storey bare frames, the percentage increase in the base shear for all seismic zones is 15% for P-Delta analysis than without P-Delta analysis. The base shear values increases with the seismic zone factors. The base shear increase in P-Delta analysis is more than 10% than that of without P-Delta analysis. The 15% of base shear increased in P-Delta analysis is a significant value so, it is considered in the design of bare frame RC rectangular regular configuration structure. Similarly, for 30 storey bare frame, the base shear obtained from P-Delta analysis is 26.91% more than that of without P-Delta analysis. The results were supported by values for base shear obtained by Neuss, and Maison [6], but there is 6% variation in results as the researchers have adopted Applied Technology Council (ATC) dynamic analysis for a 31 storey building structure.

This increase in base shear is approximately 8% more than that of 20 storey bare frame RC structure, which is because of increase in height and weight of the structure. So, the P-Delta analysis is necessary in design of structural components of frame RC rectangular regular configuration structure of 30 storey. For 40 storey, the base shear with P-Delta analysis is 41% more than without P- Delta analysis. The base shear in 40 storey bare frame RC structure is approximately 38%, 28%, and 16% more than 10, 20, and 30 storey bare frame RC structures, respectively. Hence P-Delta analysis is required for the design of 40 storey bare frame RC rectangular regular plan configuration structure.

In Figure 7, the Overturning Moment of 10 storey bare frame RC structures with different seismic zones are obtained. The moments are less than 10% for without P-Delta analysis. Hence the effect of overturning moment is not significant and can be neglected to consider these values for design of 10 storey bare frame RC structure.

The overturning moment for 20 storey bare frame RC rectangular regular plan configuration structure with respect to all four seismic zones are plotted. As the overturning moment is 15.2% (that is >10%) then the P-Delta analysis is necessary for the 20 storey bare frame RC rectangular regular plan configuration structure. For 30 storey building, the overturning moments obtained from P-Delta analysis is 26.4% more than without P-Delta analysis. The overturning moments are approximately 21% and 10% more than 10 storey and 20 storey bare frame RC structures, respectively. Hence the P-Delta analysis is required to carried out for design of structural components. The 30 storey bare frame RC Rectangular regular plan configuration structure must have analysed with P- Delta analysis and designed for results obtained. The overturning moment obtained from P- Delta analysis is 29.24% more than without P- Delta analysis. For 40 storey, the overturning moment in 40 storey bare frame RC rectangular regular plan configuration is approximately 27%, 19%, and 9% more than 10, 20, and 30 storey bare frame RC

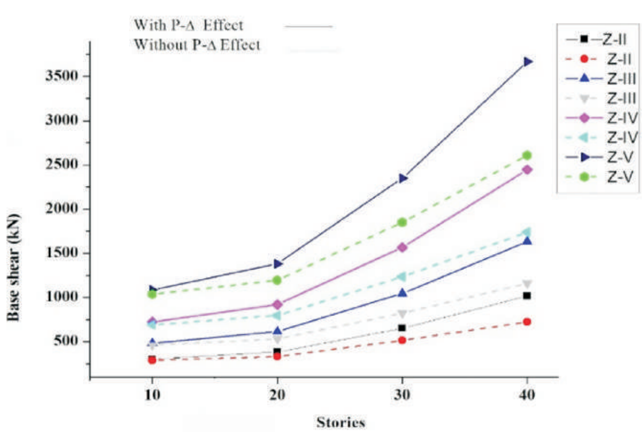

Figure 6. Variation of Base Shear for Different Stories of Bare Frame Structures

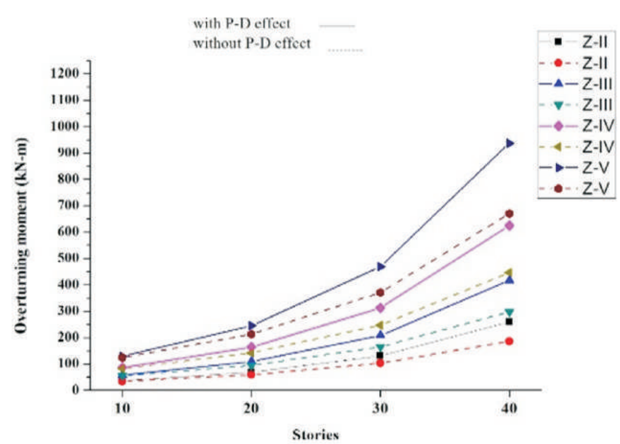

Figure 7. Variation of Overturning Moment for Different Stories of Bare Frame Structures

rectangular structure. Analysis values of 40 storey building are shown in Table 7. The P- Delta analysis is necessary for the design of 40 storey bare frame RC structure.

The P-Delta effect on 10 storey bare frame RC structure with rectangular regular configuration is negligible so the structures can be analysed without P-Delta analysis and obtained results are adopted for the design of structural components.

The 20 and more than 20 storey bare frame RC rectangular regular plan configuration structure have to be analysed with P-Delta analysis and designed for the results obtained.

3.2 To Study the Effect of Infill Masonry on High Rise Structure for P-Delta Effect

For masonry infill (brickwork) model, the thickness of 230 mm and 120 mm are adopted as external walls and as internal walls, respectively. From Figure 8, it is found that the maximum displacements, with and without P-Delta analysis are nearly same for 10 storey masonry RC structures.

The P- Delta analysis is not found significant for masonry RC structures, so P-Delta analysis for masonry RC structure of storey -10 is not necessary for design. Even for 20, 30, and 40 storey masonry RC structures, the P-Delta analysis is not necessary as the displacement obtained from P-Delta analysis is same as without P-Delta analysis. The base shear and overturning moments are also nearly same for with and without P-Delta analysis in masonry RC Structure. The obtained values are tabulated in Table 8. Hence the P-Delta analysis for 10, 20, 30, and 40 storey masonry RC structures is not necessary for design of structural components. The infill acts as stiffening element in masonry structures and thus, increases lateral stiffness of the structure [3, 4, 10].

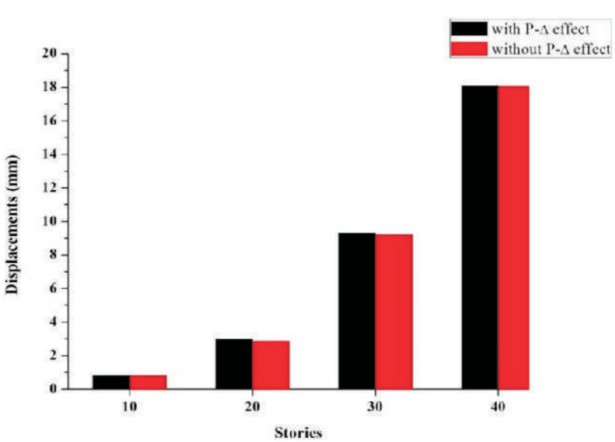

Figure 8. Variation of Displacement for Different Stories of Infill Masonry Structures

When masonry structure subjected to seismic loading, the infill behaves as a diagonal compression strut member and this reduces the lateral displacement of the masonry structures.

However, the additional weight of infill increases the base shear of the structure but the lesser displacement of masonry structure will not produce significant overturning moment at the base [2].

Figures 8, 9, and 10 show that for 40 storey structure, the displacement base shear and overturing moment are increasing suddenly, which is caused due to increase in slenderness ration and the increase in effective seismic weight of the masonry structure [2, 9].

3.3 To Study the Effect of Bracing Systems on High Rise Structures for P-delta Effect

The 40 storey bare frame rectangular regular plan configuration structure is braced externally and internally considering X-bracings of section ISWB 112.5 kg/m. The plan configurations of braced systems adopted for analysis of structures are as shown in Figure 11.

As shown in Figure 12 and Table 9, the maximum displacement for Fully External Braced System (FEBS) is

Storey/Seismic Zone	Analysis	Max. Disp. (mm)	Base Shear (kN)	Moment (kN-m)
	P-Delta	0.81	13651	54.14
Storey-10	W/O P-Delta	0.81	13650	54.10
	Difference %	0.012	0.007	0.081
	P-Delta	2.99	13813	95.95
Storey -20	W/O P-Delta	2.98	13807	95.88
	Difference %	0.34	0.04	0.07
	P-Delta	9.33	20807	130.59
Storey -30	W/O P-Delta	9.32	20789	130.2
	Difference %	0.11	0.09	0.30
	P-Delta	18.09	23974	162.55
Storey -40	W/O P-Delta	18.07	23952	162.46
	Difference %	0.11	0.09	0.06

Table 8. Results of 40 Storey Infill Masonry Structure for Different Stories

minimum compared to Partially External Braced System (PEBS), Fully Internal Braced System (FIBS), and Partially Internal Braced System (PIBS). As the external peripheral frames are X-braced, the lateral stiffness of the structure increases considerably. The increased lateral stiffness reduces the lateral displacement of the structures and hence the P-delta effect will be reduced. In all stories, i.e

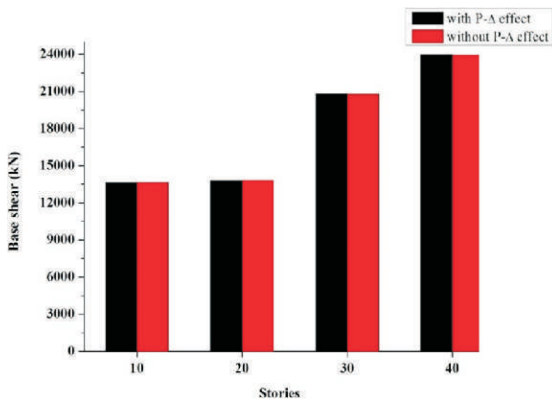

Figure 9. Variation of Base Shear for Different Stories of Infill Masonry Structures

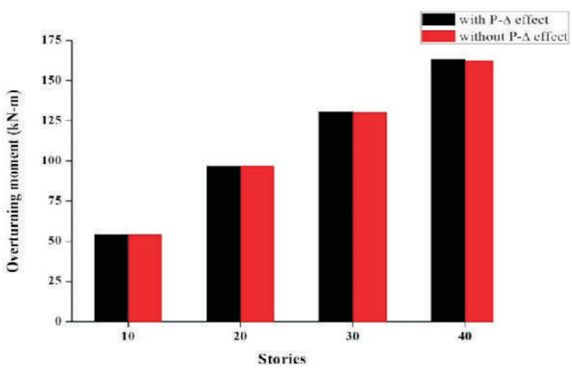

Figure 10. Variation of Overturning Moment for Different Stories of Infill Masonry Structures

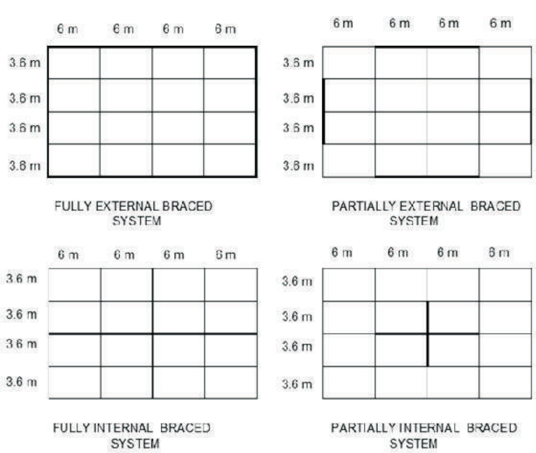

Figure 11. Configurations of Braced Systems

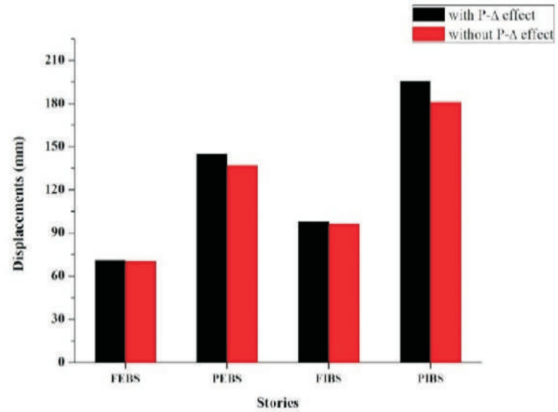

Figure 12. Variation of Displacement for Different Stories of Braced Structures

Braced System	Max. Displacement (mm)	Base Shear (kN)	Moment (kN-m)
FEBS	70.93	4387	142.17
FIBS	97.85	3135	171.43
Diff. in %	-27.51	39.936	-17.06
PEBS	144.72	2864	173.13
PIBS	195.66	2934	265.77
Diff. in %	-26.03	-2.38	-34.8

Table 9. Comparison of Different Braced Systems for P-Delta Analysis

10, 20 storey and braced systems, the P-Delta effect is not significant as the maximum lateral displacement at the structure is more compared to that of FEBS and FIBS, respectively.

Figure 13 and Figure 14 show that the base shear and overturning moment in FEBS are approximatly 39.93% more and 17.08% less than FIBS, but lateral displacement is lesser in case of FEBS by 27.5% as the base shear and overturning moment are major factors for the design consideration, the FEBS are more preferred practically than the FIBS. Similarly, PEBS are more preferred for the practical cases as it has lesser base shear and overturning momemt compared to that of PIBS.

The P-Delta analysis is essential for PIBS for seismic zone-V as the base shear and overturning moment is greater than 10%, that is 11.16%.

3.4 Comparison of Bare Frame, Masonry Structure, and Braced Frame Structures

As shown in Table 7 and Table 10, the P-Delta effect for 40 storey rectangular bare frame, RC structure is about

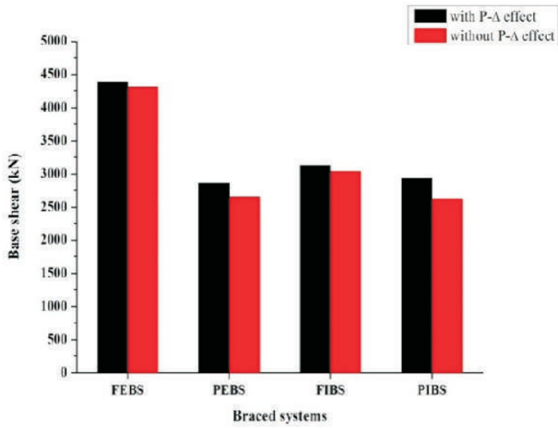

Figure 13. Variation of Base Shear for Different Stories of Braced Structures

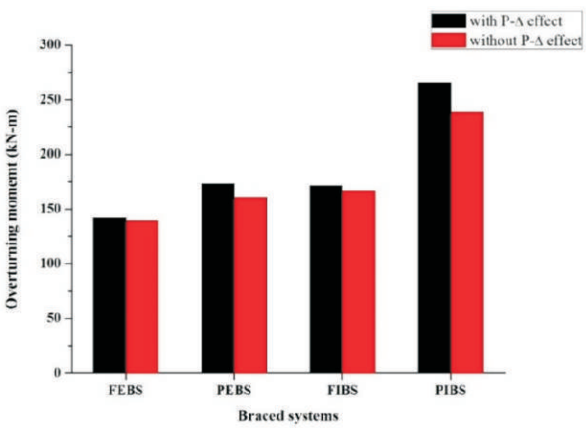

Figure 14. Variation of Overturning Moment for Different Stories of Braced Structures

Type of Braced System	Braced system	Max. Disp. (mm)	Base Shear (kN)	Moment (kN-m)
	P-Delta	70.93	4387	142.17
FEBS	W/O P-Delta	70.34	4319	140.01
	Difference %	0.84	1.57	1.54
	P-Delta	144.725	2864	173.13
PEBS	W/O P-Delta	136.98	2655	160.87
	Difference %	5.65	7.87	7.62
	P-Delta	97.86	3135	171.43
FIBS	W/O P-Delta	96.26	3040	166.58
	Difference %	1.66	3.12	2.91
	P-Delta	195.66	2934	265.77
PIBS	W/O P-Delta	181	2631	239.08
	Difference %	8.09	11.51	11.16

Table 10. Results of 40 Storey Braced Structures for Different Seismic Zones

27.638%, but in case of masonry infill and braced frame structure the effect is negligible. It has been found from the study that infill masonry is a more efficient structure for reducing P-delta effect compared to bare frame and braced frame structures. The infill reduces the displacement and overturning moment drastically, this is because of the direct contact of infill panels with column and beams. As the infill panels acts as a large web section between the columns and beams of the building structure, it contributes the effective reduction of lateral deformation of the structure [3, 4, 10].

The values for the displacement and base shear obtained in the current study are supported by the study reported by Mulgund and Kulkarni [5]. This is because, for 8 storey RC building they have adopted 40%-60% of masonry infill with different plan configuration of infill panels and also considered openings at every storey [4].

The reduction in the lateral displacements is also considerably minimized as shown in Figure 15. As the building structure is fully infilled with walls, the weight of the structure also greatly increases. Because of this, there is huge difference in displacement, base shear, and overturning moments between the masonry and bare frame RC structures. The variation of base shear and overturning moment values are as represented in Figure 16 and Figure 17.

For every ten storey, the weight of the infill is increased by 48.4% than that of bare frame RC structure, even though P-Delta effect is not significant for the masonry infill structure.

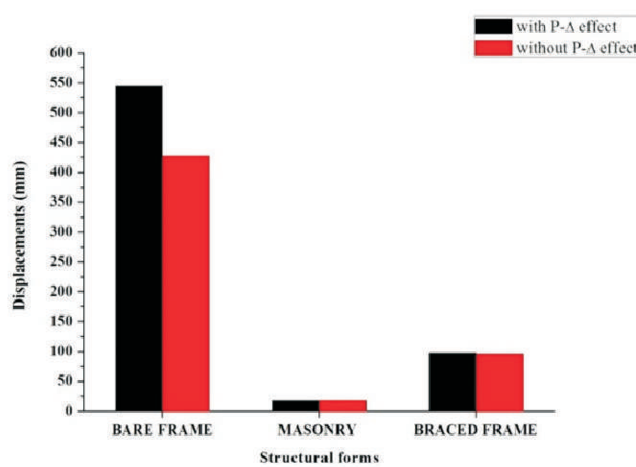

Figure 15. Variation of Displacement for Different Structural Forms

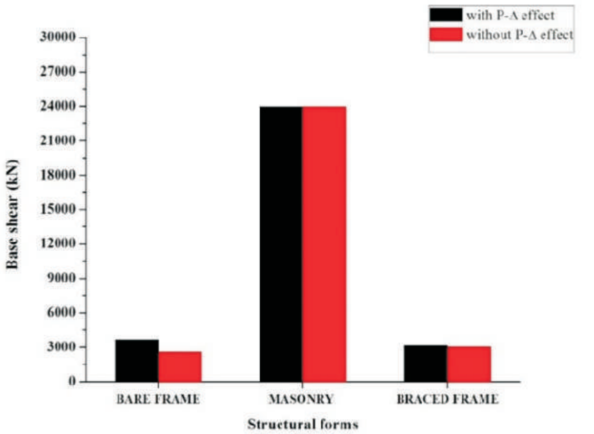

Figure 16. Variation of Base Shear for Different Structural Forms

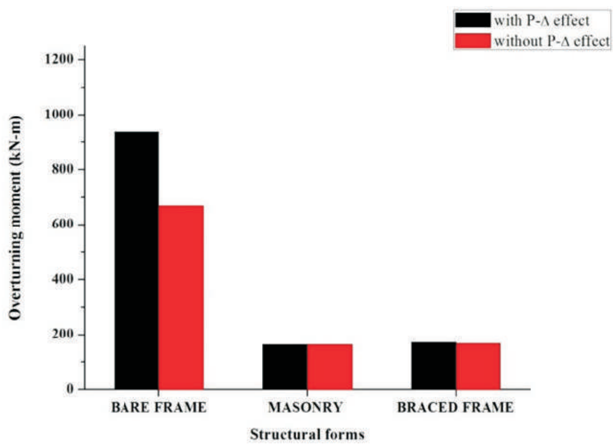

Figure 17. Variation of Overturning Moment for Different Structural Forms

Thus, it can be inferred that the masonry structure has larger gravity loading compared to other structural forms, but the displacement is negligible and thus the P-Delta effect is not significant [3, 4, 10]. The braced frame structures are efficient in reducing the displacement of structures. The overturning moment is directly related to the displacement of the structure, if the displacement of the structurers is reduced, the overturning moment can be minimized. The masonry and braced systems contribute to reduction in lateral displacement and increase in lateral stiffness. The P-Delta effect in multi-storey building structures can be controlled by braced systems masonry infill structures.

Conclusions

The following conclusions are drawn from the results obtained from the study carried out,

- The rectangular bare frame RC structures which are more than 20 stories are required to be analysed and designed for P-Delta effects.
- The P-Delta analysis is not necessary for infill masonry structures up to 40 storey building structures. From 30 storey onwards it has been observed that there is a sudden increase in lateral displacements and overturning moments in infill masonry structures.
- Fully external braced systems are more efficient structures than fully internal braced systems, because displacements and overturning moments of fully external braced systems is lesser than the fully internal braced systems by 27.5% and 17.06%, respectively. Similarly, the partially external braced systems are more efficient structures than partially internal braced systems, because displacements and overturning moments of partially external braced systems is lesser than partially internal braced systems by 26.03 % and 34.80%, respectively.
- The rectangular bare frame RC structures are more vulnerable to P-Delta effect than the masonry infill structures and braced structures. However, bare frame RC structures more than 40 stories has very much larger displacements and even design for P-Delta effect will not be economical. So, for more than 40 stories the braced systems can be adopted to reduce P-Delta effects.
- The infill masonry structures have the negligible P-Delta effects compared to bare frame RC structures. The displacements and overturning moments in masonry structure is lesser than the bare frame structures and braced structures, but base hear in masonry structure is very much higher than other structural forms.

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