EFFECT OF P-DELTA IN SEISMIC ANALYSIS OF MULTISTOREY BUILDINGS

ManikRao[1], Rajendrakumar S Harsoor[2]

[1]*M. Tech Scholar, Department of Civil Engineering, PDA College of Engineering, Kalaburagi, VTU, Karnataka, India*
[2]*Dean & Professor, Department of Civil Engineering, PDA College of Engineering, Kalaburagi, VTU, Karnataka, India*

Abstract

The behavior of structures, when subjected to critical loads is a complex phenomenon and is basically dependent on the type of forces/loads acting on the structure, magnitude of force, direction etc. In this paper the effect of P-Delta on multi storey buildings is studied. The four models i.e. 5, 10, 15, and 20 storey are modelled and analyzed using ETABS v 13.1 software. The non-linear static analysis is performed to account for the P-Delta effect on the four types of building models and is compared with linear static analysis using ETABS v. 13.1. The variation in the axial forces, storey shears, displacements and bending moments with and without the consideration of P-delta effect is compared. The results have shown that, the models analyzed with considering P-delta effect (non-linear static analysis) have significantly more values of displacements, axial forces, bending moments and storey shears when compared with the models without considering the P-delta effect (linear static analysis). Therefore, the P-Delta effect is significant and must be considered in the analysis of multi storey buildings.

Keywords- *Linear static analysis, P-delta effect, nonlinear static analysis, ETABS v. 13.1.*

----------***----------

1. INTRODUCTION

From a structural engineer's point of view tall building or multistoried building is one that, by virtue of its height, is affected by lateral forces to an extent that they play asignificant role in the analysis and design of structures. Due to complexity and lack of knowledge of P-Delta analysis, designers, engineers and architects perform Linear Static analysis, which may eventually become a cause of catastrophic collapse of the multistoried building.

Generally Structural designers are prone to use the linear static analysis, which is also known as first order analysis, to compute design forces, moments and displacements resulting from loads acting on a structure. First order analysis is performed by assuming small deflection where the resulting forces, moments and displacements take no account of the additional effect due to the deformation of the structure under vertical load prior to imposing lateral loads.

The term P-delta refers to the additional actions induced by an axial force (P) when there is a horizontal displacement (delta) on a vertical element. P-Delta is a non-linear (second order) effect that occurs in every structure where elements are subject to axial loads. It is a genuine "effect" that is associated with the magnitude of the applied axial load (P) and a displacement (delta). If a P-Delta affected member is subjected to lateral load, then it will be prone to deflect more which could be computed by P-Delta analysis and not by the linear static analysis. This effect may reduce significantly the flexural capacity of a structure.

The magnitude of P-delta effect is related to the:

- Magnitude of axial load.
- Stiffness/slenderness of the structure as whole.
- Slenderness of individual elements.

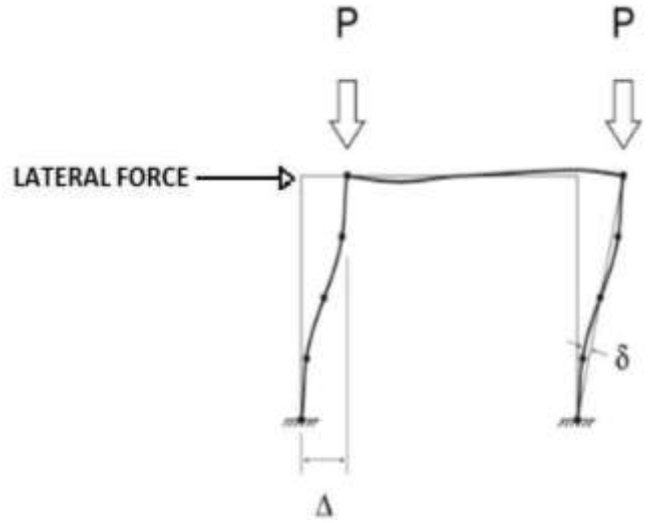


Fig 1 Schematic representation of P-delta effect on a frame

2. LITERATURE REVIEW

Christoph ADAM[1], Luis F. IBARRA[1] (2004), addresses the assessment of destabilizing effects of gravity, usually referred to as P-Delta effects, in highly inelastic structures when subjected to seismic excitations. The proposed approach is based on an equivalent single-degree-of-freedom (ESDOF) system of the actual building.

Appropriate properties of the ESDOF system are defined, based on results of a corresponding global pushover analyses. P-Delta effects are incorporated via an auxiliary backbone curve, which is rotated by a uniform stability coefficient. The procedure is evaluated for several multistorey generic frame structures. The collapse capacity of these structures is derived from a set of Incremental Dynamic Analysis (IDA) studies involving 40 ground motions whose intensity is increased until P-Delta instability occurs. The results are translated from the ESDOF domain into the domain of the multi-degree-of-freedom (MDOF) system, and utilized for the estimation of P-Delta effects in MDOF structures. "Exact" results are contrasted with outcomes of the analyses utilizing ESDOF systems. Assumptions and limitations of the ESDOF system approach are discussed. The emphasis is on the level of response at which the structure approaches dynamic instability (side-sway collapse).

A.S. Moghadam[2], A Aziminezad (2004)[2], evaluated the importance of asymmetry of building on the P-Delta effects in elastic and inelastic ranges of behavior. The contribution of lateral load resisting system, number of stories, degree of asymmetry, and sensitivity to ground motion characteristics are assessed. Four buildings with 7, 14, 20 and 30 storey are designed based on typical design procedures, and then their elastic and inelastic static and dynamic behavior, with and without considering P-Delta effects, are investigated. Each building is considered for 0%, 10%, 20% and 30% eccentricity levels. The results indicate that the type of lateral load resisting system plays an important role in degree that torsion modifies the P-Delta effects. It is also shown that although in the elastic static analyses, torsion always magnifies the P-Delta effects, but the same is not always true for dynamic analyses. The results of dynamic analyses also show high level of sensitivity to ground motion characteristics.

T.J. Sullivan[6], T.H. Pham[6] (2008), the design of a 45-storey reinforced concrete frame-wall case study structure is used to highlight the significance of the p-delta limit within the modal response spectrum analysis procedure of the Euro code 8. It is found that the strength of the structure is dictated by the P-delta limit for seismic actions, despite anticipated storey drifts and ductility demands being relatively low. A series of non-linear time-history analyses using a suite of spectrum-compatible real and artificial accelerograms, indicate that P-delta effects do not have a significant influence on displacements or storey drifts of the tall building. The likely causes of this behavior are identified, making reference to earlier investigations into P-delta behavior and with consideration of substitute structure concepts. To investigate the significance of the P-delta ratio further, a series of SDOF studies are undertaken for systems designed with P-delta ratios of up to 0.85. The results demonstrate that the p-delta ratio has little influence on the behavior of long-period systems subject to real earthquake records and therefore it does not appear appropriate to impose strict limits on the P-delta ratio. Instead, it is recommended that the P-delta effects be evaluated for tall-building systems as part of an overall assessment of their response, using advanced non-linear time-history analyses with real records and within a large-displacement analysis regime.

Jose Antonio Flores Ruiz[8] (2015), studied the effect of P-delta on four, six and twelve storey RC frame building. A series of non-linear time history analyses using Takeda hysteric rule considering the P-delta effect was studied. It was shown that P-delta effects have a significant influence to the response even for the four and six storey structures and concluded that P-delta effect should always be included in the design and analysis of structures.

3. METHODOLOGY

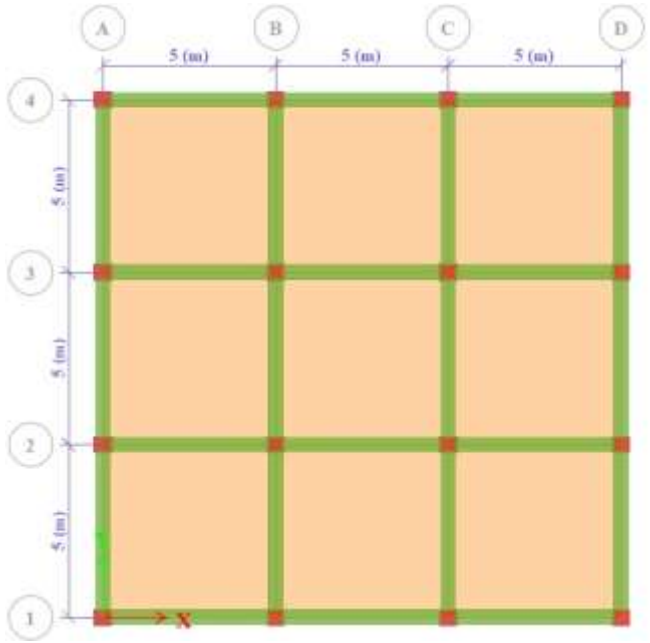


Fig 2 Typical Plan of the models

As mentioned earlier, to observe the effects of P-delta, four different storey cases are taken where storey variation starts from storey 5 to storey 20. Each of the storey case is performed linear Static and P-delta analysis separately with appropriate command. Each storey is 3 metre in height makes Storey 5, storey 10, storey 15 and storey 20 in total height of 15m, 30m, 45m, and 60m. As storey increase so the slenderness increases. Bay length of the buildings in both directions is 5m.

Table 1:- Dimensions, Grade of concrete and grade of steel for different models

Model	Beam size (mmXmm)	Column size (mmXmm)	Slab thickness (mm)	Wall Thickness (mm)	Grade of concrete (N/mm^2)	Grade of steel (Nmm^2)
G+4	400X450	450X550	150	300	M25	FE500
G+9	450X500	500X550	150	300	M25	FE500
G+14	400X450	450X500	150	300	M25	FE500
G+19	500X600	550X650	150	300	M25	FE500

Load Calculations: Following loads are considered for the analysis of the buildings. The loads are taken in accordance with IS: 875 (Part 1) and (Part 2).

3.1.1 Dead Load

3.1.2 Live Load

a) Intensity of live load on intermediate floors = 3 kN/m^2
b) Intensity of live roof load on roof = 1.5 kN/m^2

3.1.3 Lateral Loads for P-Delta Analysis

As per IS 1893:2002 for zone 5,
Zone factor = 0.36
Soil: Type 2
Importance factor = 1

3.2 Load Combinations

As per IS 1893 (Part 1): 2002, the load combinations are considered.

1) 1.5 (DL + IL)
2) 1.2 (DL + IL + ELX)
3) 1.2 (DL + IL - ELX)
4) 1.2 (DL + IL + ELY)
5) 1.2 (DL + IL - ELY)
6) 1.5 (DL + ELX)
7) 1.5 (DL - ELX)
8) 1.5 (DL + ELY)
9) 1.5 (DL - ELY)
10) 0.9 DL + 1.5 ELX
11) 0.9 DL – 1.5 ELX
12) 0.9 DL + 1.5 ELY
13) 0.9 DL – 1.5 ELY

3.3 Analysis Methods

3.3.1 Linear Static Analysis or Equivalent Static Analysis

The linear static analysis for (G+4), (G+9), (G+14) and (G+19) storey building is carried out without considering the P-delta effect in ETABS v13.1 program. From the analysis results, displacements, storey shear, axial force and bending moment at the base and at various structural members are obtained.

3.3.2 Non-Linear Static or P-Delta Analysis:

The nonlinear static analysis for (G+4), (G+9), (G+14) and (G+19) storey building is carried out considering the P-delta effect in ETABS v13.1 program. From the analysis results, displacements, storey shear, axial force and bending moment at the base and at various structural members are obtained.

4. RESULTS AND DISCUSSIONS

4.1 Case 1 - 5 Storey Model

The undeformed shape and deformed shape of the 5 storey model is as shown in fig. 3 and 4 respectively. The values of displacements, storey shear, axial force and bending moments for 5 storey model that are obtained by linear analysis and P-Delta analysis are tabulated in table 2. The values of displacements, storey shear, axial force and bending moments from linear analysis and P-Delta analysis are compared and variations as percent between the two types of analysis are evaluated and tabulated.

The variation of displacements, storey shear, axial force and bending moment obtained from linear static analysis and P-delta analysis are plotted in graphs as shown in fig.5, 6, 7 and 8 respectively.

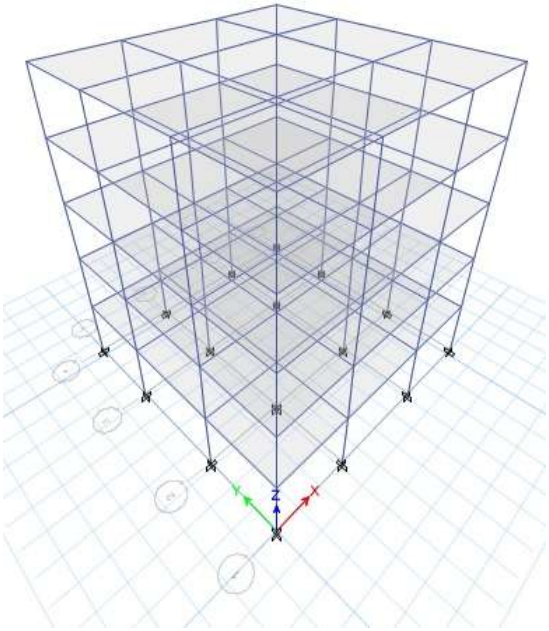


Fig 3. Undeformed shape of 5 storey model

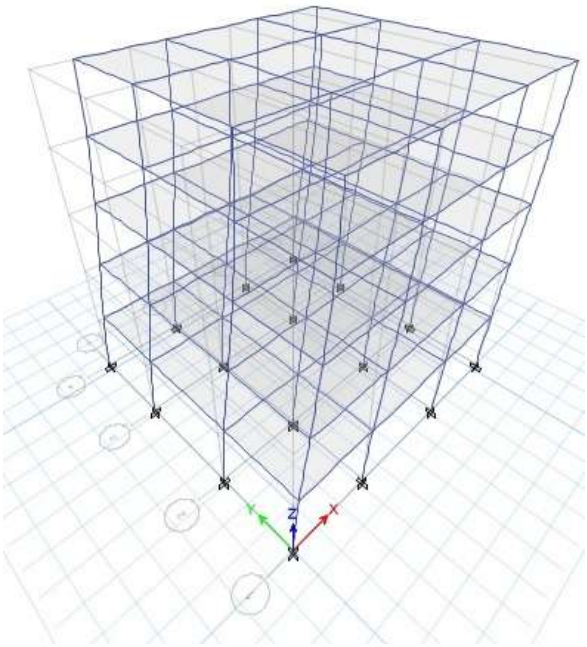


Fig 4. Deformed shape of 5 storey model

Table 2 Values of displacements, Storey shear and bending moment for 5 storey model

NO OF STOREYS	DISPLACEMENT (mm)		STOREY SHEAR(kN)		MOMENT(kN-m)	
	LINEAR STATIC ANALYSIS	P-DELTA ANALYSIS	LINEAR STATIC ANALYSIS	P-DELTA ANALYSIS	LINEAR STATIC ANALYSIS	P-DELTA ANALYSIS
5	15	21.5	315.0487	393.8085	54787	57259
4	13.2	19.2	533.9948	667.4853	109575	116990
3	10.3	15.2	657.152	821.4246	164362	176720
2	6.7	9.8	711.8885	889.8413	219937	236451
1	2.9	3.9	725.5727	906.9532	273937	296182
0	0	0	725.5727	906.9532	273937	296182

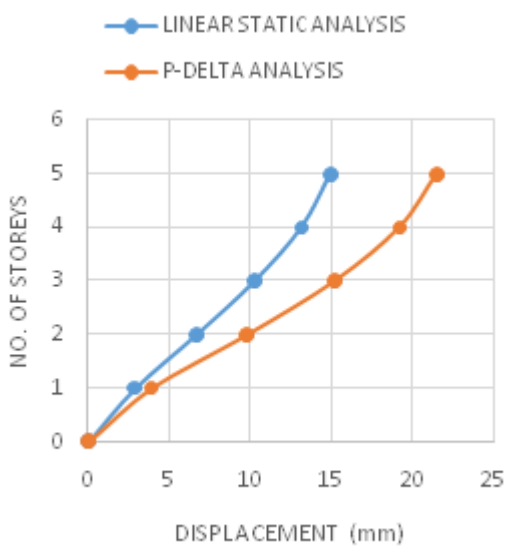


Fig. 5: Variation of displacement for the no. of storeys obtained from linear and P-delta analysis for 5 storey model

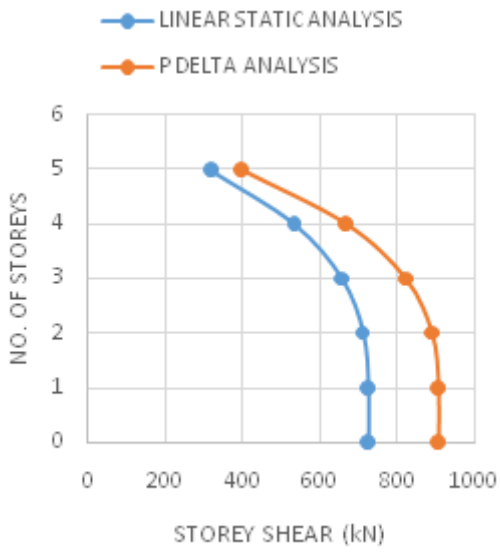


Fig.6: Variation of Storey shear for the no. of storeys obtained from linear and P-delta analysis for 5 storey model

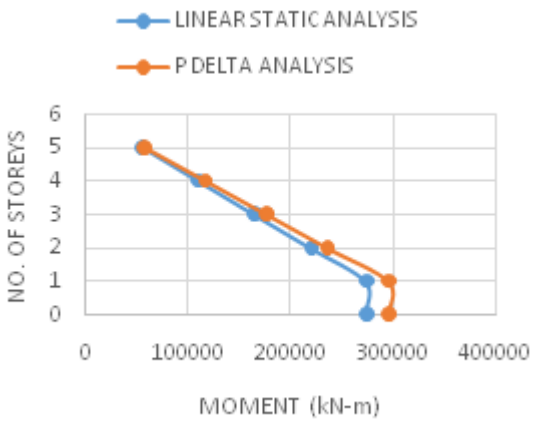


Fig. 7 Variation of Bending moment for the no. of storeys obtained from linear and P-delta analysis for 5 storey model

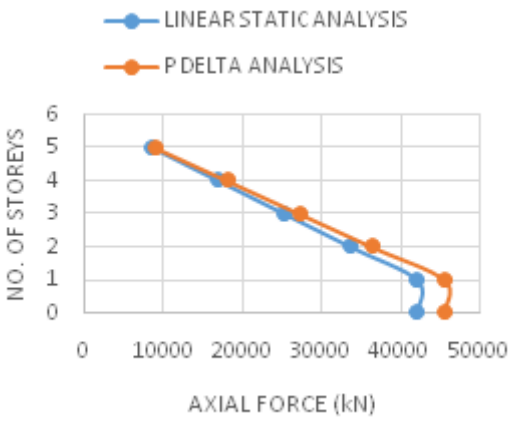


Fig. 8: Variation of Axial force for the no. of storeys obtained from linear and P-delta analysis for 5 storey model

From the fig. 5The maximum displacement of the 5 storey model is 21.5 mm and 15 mm obtained from P-delta analysis and linear analysis respectively and the maximum variation between the two types of analyses is found to be 32.23684211%.

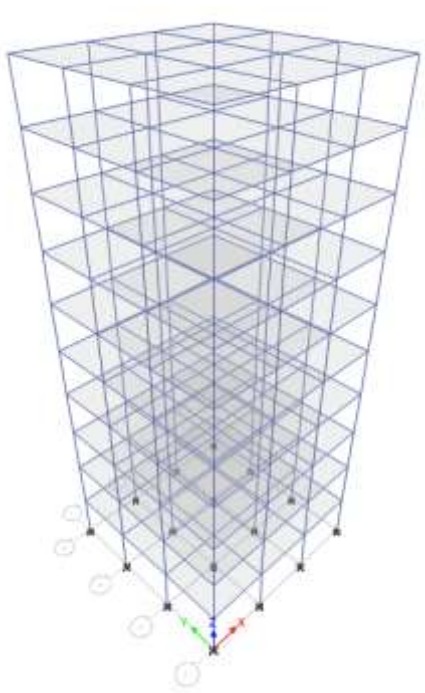
From the fig. 6, the maximum storey shear obtained from P-delta analysis is 393.8085 kN and that from linear analysis is 315.0487 kN and the maximum variation between the two types of analyses is found to be 19.99888197 %.

From the fig. 7, the maximum axial force obtained from P-delta analysis is 45566.55kN and that from linear analysis is 42144.31kN and the maximum variation between the two is found to be 7.510434%.

From the fig. 8, the maximum bending moment obtained from P-delta analysis is 296182kN-m and that from linear analysis is 273937 kN-m and the maximum variation between the two is found to be 7.510584708 %.

4.2 Case 2 - 10 Storey Model

The undeformed shape and deformed shape of the 5 storey model is as shown in fig. 3 and 4 respectively.The values of displacements, storey shear, axial force and bending moments for 10 storey model that are obtained by linear analysis and P-Delta analysis are tabulated in table no. 3. The values of displacements, storey shear, axial force and bending moments from linear analysis and P-Delta analysis are compared and variations as percent between the two types of analysis are evaluated and tabulated.



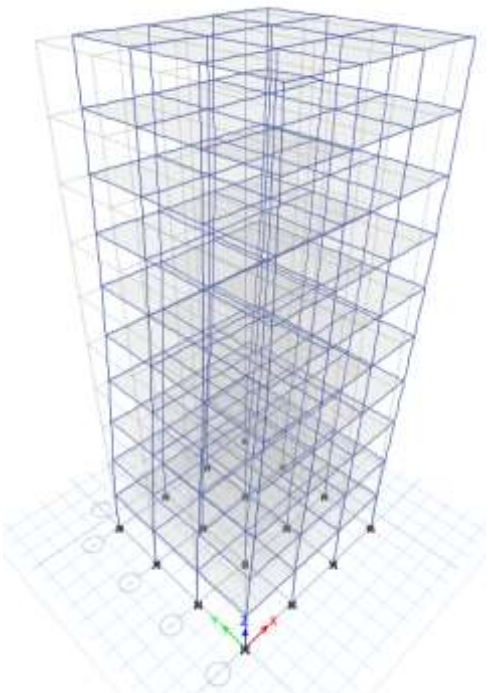


Fig 9. Undeformed shape of 10 storey model**Fig 10**. Deformed shape of 10 storey model

The variation of displacements, storey shear, axial force and bending moment obtained from linear static analysis and P-delta analysis are plotted in graphs as shown in fig.11, 12, 13 and 14 respectively.

Table 3: Values of displacements, Storey shear and bending moment for 10 storey model

NO OF STOREYS	DISPLACEMENT (mm)		STOREY SHEAR(kN)		MOMENT(kN-m)	
	LINEAR STATIC ANALYSIS	P-DELTA ANALYSIS	LINEAR STATIC ANALYSIS	P-DELTA ANALYSIS	LINEAR STATIC ANALYSIS	P-DELTA ANALYSIS
10	28.8	41.4	181.8138	227.2653	53100.012	55044.012
9	27.4	39.8	350.7402	438.4185	106200.02	112032.02
8	25.5	37.4	484.2129	605.25	159300.03	169020.03
7	22.9	34	586.4029	732.9727	212400.04	226008.04
6	19.9	29.9	661.4814	826.8003	265500. 09	282996.06
5	16.5	25.1	713.6191	891.9475	318600.31	339984.07
4	12.9	19.6	746.9873	933.6297	371700.08	396972.53
3	9.3	13.8	765.7569	957.0652	424800.09	453960.75
2	5.6	8	774.099	967.4837	477900.96	510948.10
1	2.1	2.8	776.1845	970.1496	531000.18	567936.18
0	0	0	776.1845	970.1496	531000.12	567936.12

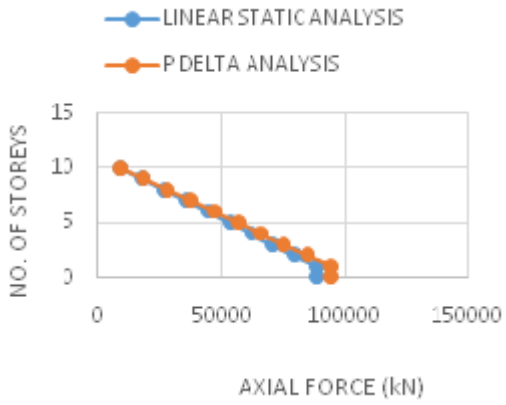


Fig. 11 Variation of Displacement for the no. of storeys obtained from linear and P-delta analysis for 10 storey model

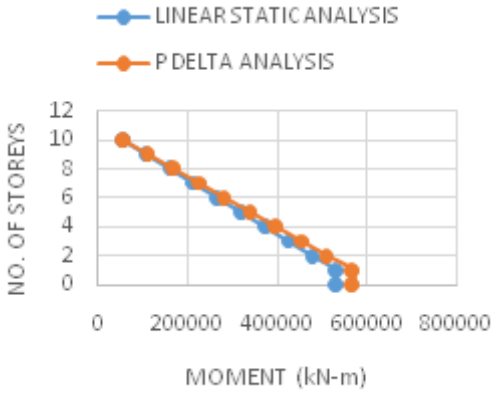


Fig.12 Variation of Storey Shear for the no. of storeys obtained from linear and P-delta analysis for 10 storey model

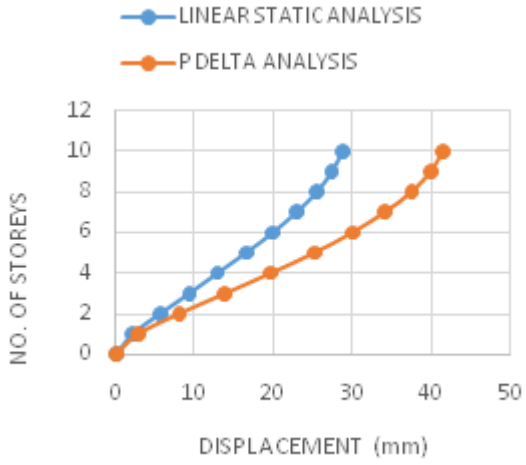


Fig. 13 Variation of Axial Force for the no. of storeys obtained from linear and P-delta analysis for 10 storey model

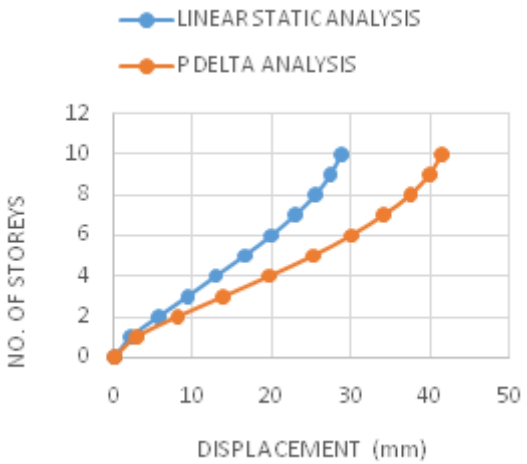


Fig. 14 Variation of Bending Moment for the no. of storeys obtained from linear and P-delta analysis for 10 storey model

From the fig. 11, the maximum displacement of the 10 storey model is 48.4mm and 21.8 mm obtained from P-delta analysis and linear analysis respectively and the maximum variation between the two is found to be 34.26294821%.

From the fig. 12, the maximum storey shear obtained from P-delta analysis is 970.1496kN and that from linear analysis is 776.1845 kN and the maximum variation between the two is found to be 20%.

From the fig. 13, the maximum axial force obtained from P-delta analysis is 94656.0203kN and that from linear analysis is 88500.0203kN and the maximum variation between the two is found to be 6.503548301%.

From the fig. 14, the maximum bending moment obtained from P-delta analysis is 567936.1218kN-m and that from linear analysis is 531000.1218 kN-m and the maximum variation between the two is found to be 6.503548301%.

Bending moments are taken from storey 1 of each of each analysis as a maximum bending moment is found in that position. Like the displacement parameter, here also the P-Delta outcomes over flow the corresponding case of the Linear Static analysis and represent the necessity of P-delta analysis over the Linear Static for reinforced concrete high-rise structures.

4.3 Case 3 - 15 Storey Model

The values of displacements, storey shear, axial force and bending moments for 15 storey model that are obtained by linear analysis and P-Delta analysis are tabulated in table no. 4. The values of displacements, storey shear, axial force and bending moments from linear analysis and P-Delta analysis are compared and variations as percent between the two types of analysis are evaluated and tabulated.

The variation of displacements, storey shear, axial force and bending moment obtained from linear static analysis and P-delta analysis are plotted in graphs as shown in fig.17, 18, 19 and 20 respectively.

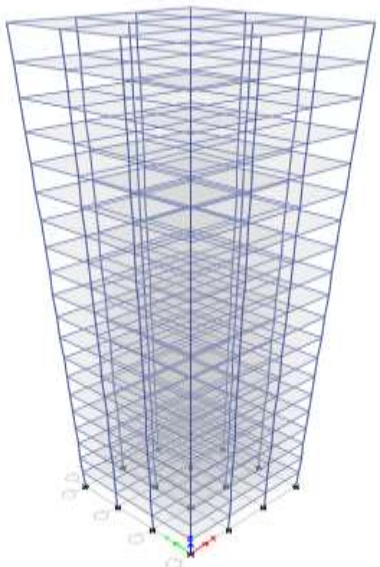


Fig 15. Undeformed shape of 15 storey model

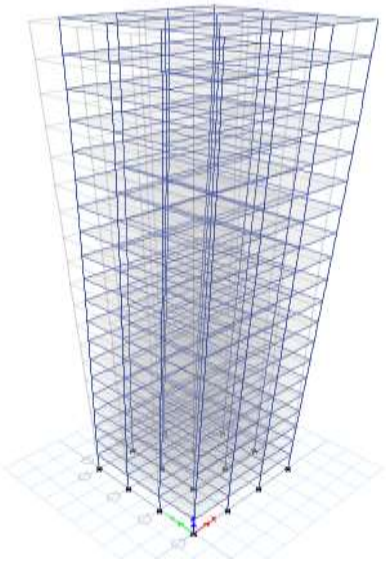


Fig 16. Deformed shape of 15 storey model

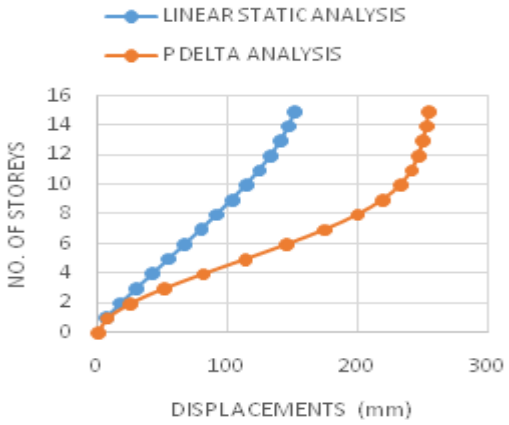


Fig. 17 Variation of Displacement for the no. of storeys obtained from linear and P-delta analysis for 15 storey model

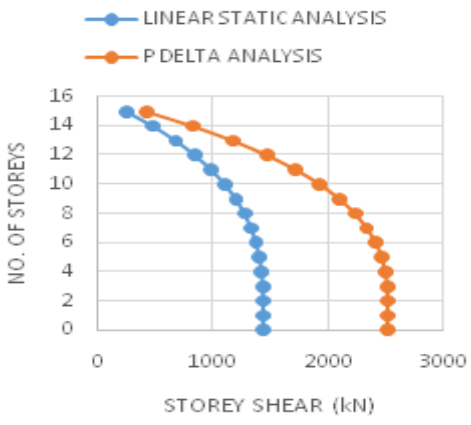


Fig.18 Variation of Storey Shear for the no. of storeys obtained from linear and P-delta analysis for 15 storey model

Table 4: Values of displacements, Storey shear and bending moment for 15 storey model

NO OF STOREYS	DISPLACEMENT (mm)		STOREY SHEAR(kN)		MOMENT(kN-m)	
	LINEAR STATIC ANALYSIS	P-DELTA ANALYSIS	LINEAR STATIC ANALYSIS	P-DELTA ANALYSIS	LINEAR STATIC ANALYSIS	P-DELTA ANALYSIS
15	150.8	254.2	242.6855	424.0821	52261.6718	56058.5468
14	146.3	252.2	472.3788	825.5127	104523.34	115913.96
13	140.2	249.6	670.4301	1171.7746	156785.01	175769.39
12	132.6	246	839.1833	1467.2054	209046.68	235624.81
11	123.7	240.8	980.9823	1716.2115	261308.35	295480.23
10	113.7	232.2	1098.1707	1922.9111	313570.03	355335.65
9	102.8	218.6	1193.0913	2091.1813	365831.70	415191.07
8	91.3	199.3	1268.0851	2224.8957	418093.37	475046.49
7	79.3	174.5	1325.5054	2327.8449	470355.04	534901.92
6	67	145.3	1367.6905	2403.7527	522616.74	594757.34
5	54.6	113.4	1396.9817	2456.3005	574878.39	654612.76
4	42.1	80.9	1415.7126	2489.1659	627140.06	714468.18
3	29.8	50.5	1426.238	2506.0591	679401.73	774323.60
2	17.8	25	1430.8953	2510.6907	731663.40	834179.03
1	6.7	7.2	1431.9097	2506.8362	783925.07	894034.45
0	0	0	1431.9097	2506.8362	783925.07	894034.45

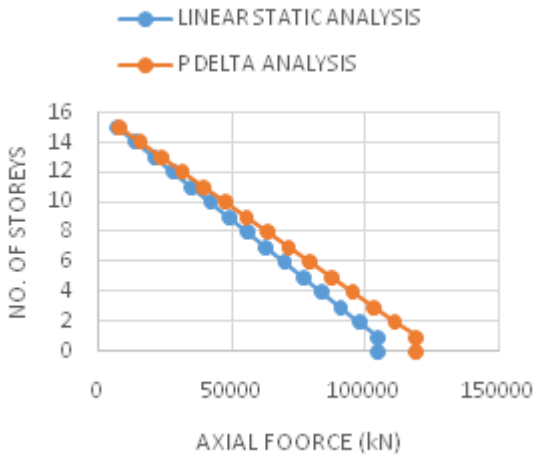


Fig. 19 Variation of Axial force for the no. of storeys obtained from linear and P- delta analysis for 15 storey model

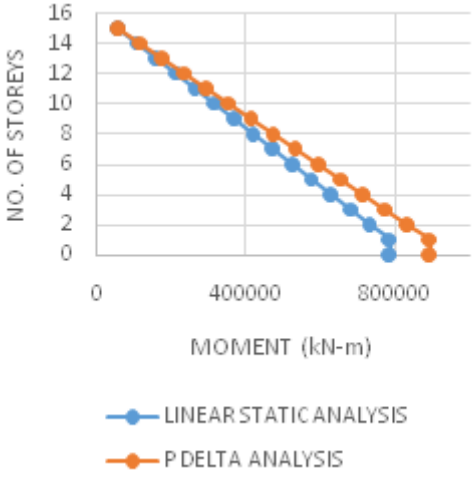


Fig. 20 Variation of Bending Moment forthe no. of storeys obtained from linear and P-delta analysis for 15 storey model

From the fig. 17, the maximum displacement of the 15 storey model is 254.2mm and 150.8 mm obtained from P-delta analysis and linear analysis respectively and the maximum variation between the two is found to be 54.18966382%.

From the fig. 18, the maximum storey shear obtained from P-delta analysis is 2506.8362kN and that from linear analysis is 1431.9097kN and the maximum variation between the two is found to be 43.12659628%. Storey shear are taken from storey 1 to storey 15 of each analysis and it is found that storey shear is maximum in case of P-delta analysis when compared to linear static analysis. Like the displacement and bending moment parameters, the variation in storey shears obtained from linear static analysis and P-delta analysis represent the necessity of P-delta analysis over the Linear Static for reinforced concrete high-rise structures.

From the fig. 19, the maximum axial force obtained from P-delta analysis is 119204.5937kN and that from linear analysis is 104523.3437kN and the maximum variation between the two is found to be 12.31601027%.

From the fig. 20,the maximum bending moment obtained from P-delta analysis is 894034.4526kN-m and that from linear analysis is 783925.0776kN-m and the maximum variation between the two is found to be 12.31601027%.

4.4 Case4: 20 Storey Model

The values of displacements, storey shear, axial force and bending moments for 20 storey model that are obtained by linear analysis and P-Delta analysis are tabulated in table no. 5. The values of displacements, storey shear, axial force and bending moments from linear analysis and P-Delta analysis are compared and variations as percent between the two types of analysis are evaluated and tabulated.

The variation of displacements, storey shear, axial force and bending moment obtained from linear static analysis and P-delta analysis are plotted in graphs as shown in fig. 23, 24, 25 and 26 respectively.

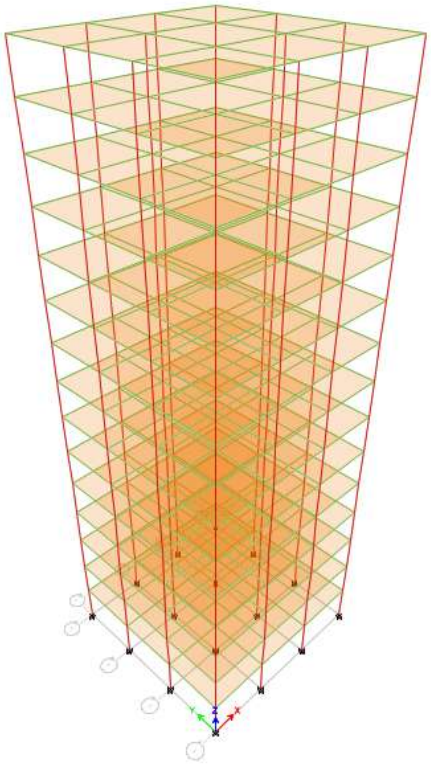


Fig.21 Undeformed shape of 20-storey mode

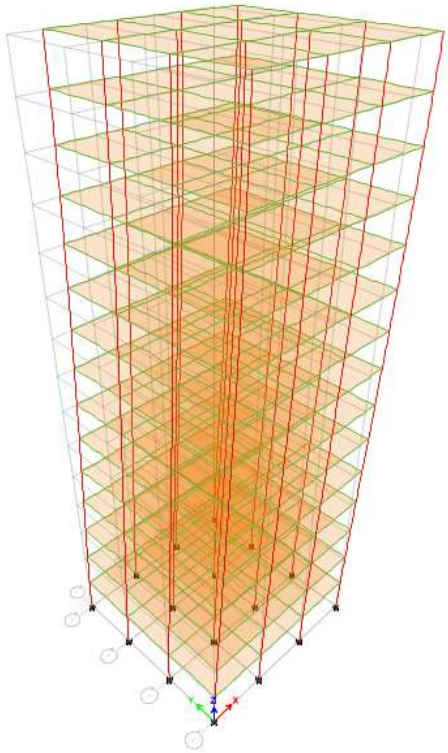


Fig. 22 Deformed shape of 20 storey model

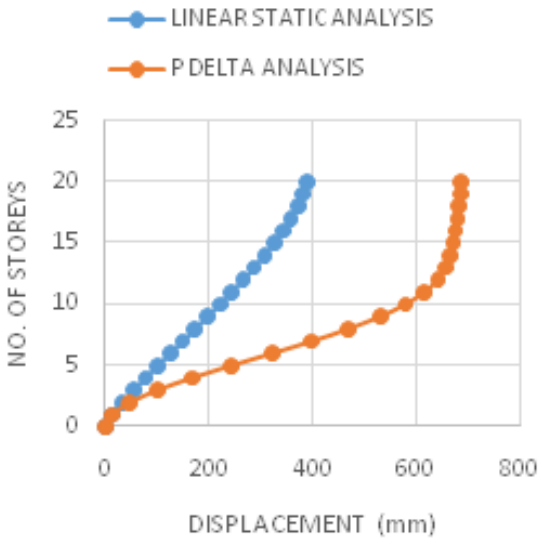


Fig.23 Variation of Displacement for the no. of storeys obtained from linear and P-delta analysis for 20 storey mode

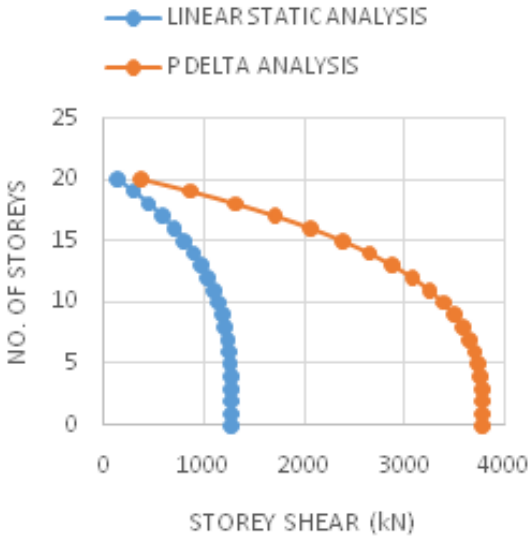


Fig. 24 Variation of Storey Shear for the no. of storeys obtained from linear and P-delta analysis for 20 storey model

Table 5 Values of displacements, Storey shear and bending moment for 20 storey model

NO OF STOREYS	DISPLACEMENT (mm)		STOREY SHEAR(kN)		MOMENT(kN-m)	
	LINEAR STATIC ANALYSIS	P-DELTA ANALYSIS	LINEAR STATIC ANALYSIS	P-DELTA ANALYSIS	LINEAR STATIC ANALYSIS	P-DELTA ANALYSIS
20	390	686.3	122.2906	361.9837	14044.8497	14044.8497
19	381.9	684.4	291.5067	862.8673	42466.5416	44095.468
18	371.4	681.9	443.3802	1312.4139	70888.2335	76400.0629
17	358.5	678.9	578.8486	1713.3983	99309.9254	110727.617
16	343.4	675.4	698.8495	2068.5956	127731.617	146859.601
15	326.3	671.3	804.322	2380.7807	156153.309	184589.974
14	307.6	665.9	896.2153	2652.7287	184575.001	223725.179
13	287.5	657.1	975.5296	2887.2144	212996.693	264084.150
12	266.1	641.3	1043.3707	3087.0129	241418.385	305498.306
11	243.9	615.8	1100.6325	3254.8991	269840.076	347811.556
10	220.9	578.8	1148.049	3393.648	298261.768	390880.294
9	197.3	529.7	1186.5322	3506.0347	326683.460	434573.402
8	173.4	469.1	1216.984	3594.834	355105.152	478772.250
7	149.4	398.8	1240.3059	3662.821	383526.844	523370.695
6	125.3	321.9	1257.3968	3712.7706	411948.536	568275.081
5	101.4	242.9	1269.1549	3747.4578	440370.228	613404.240
4	77.8	167.3	1276.4776	3769.6576	468791.920	658689.492
3	54.6	100.5	1280.2664	3782.145	497213.612	704074.644
2	32.3	47.5	1281.4165	3787.695	525635.304	749515.988
1	11.9	12.9	1280.8582	3789.0825	554056.996	794982.308
0	0	0	1280.8582	3789.0825	554056.996	794982.308

From the fig. 23, the maximum displacement of the 20 storey model is 686.3 mm and 390 mm obtained from P-delta analysis and linear analysis respectively and the maximum variation between the two is found to be 63.03560009%. From the fig. 24, the maximum storey shear obtained from P-delta analysis is 3789.0825kN and that from linear analysis is 1280.8582kN and the maximum variation between the two is found to be 66.21208318%.

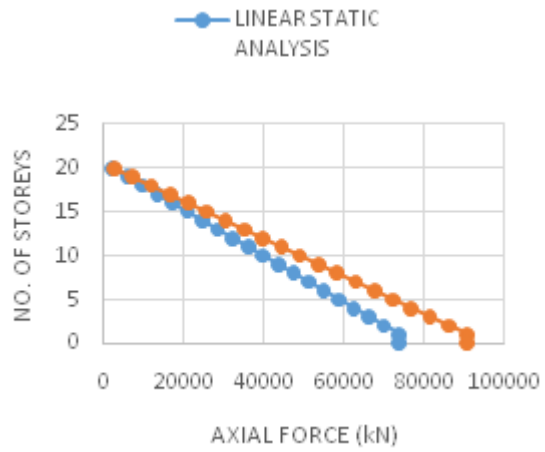


Fig. 25 Variation of Axial Force for the no. of storeys obtained from linear and P-delta analysis for 20 storey model

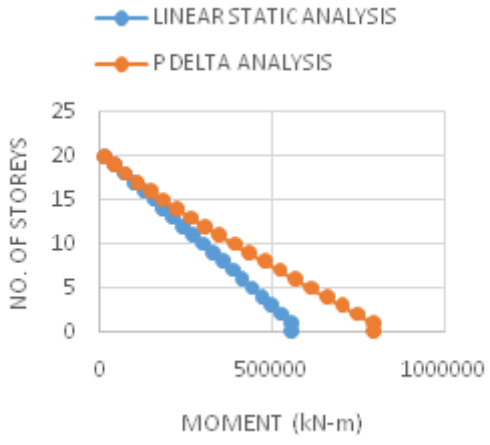


Fig. 26 Variation of Bending Moment for the no. of storeys obtained from linear and P-delta analysis for 20 storey model

From the fig. 25, the maximum axial force obtained from P-delta analysis is 90782.2721kN and that from linear analysis is 73874.2661kN and the maximum variation between the two is found to be 29.47899128%.

From the fig. 26, the maximum bending moment obtained from P-delta analysis is 794982.3083kN-m and that from linear analysis is 554056.9961kN-m and the maximum variation between the two is found to be 30.30574513%.

All the parameters such as displacements, storey shear and bending moments for all the four model considered increases with increasing height or addition of storey. On the other side, analysis conducted without considering P-Delta effects leads to increment of moment with increment of storey as it was expected. Overall high-rise shows higher value then low-rise construction under this analysis.

From the fig 25 and fig 26, the variation of axial force and bending moment obtained from linear static analysis and P-delta analysis in the top storeys have nearly the same values and in the bottom storeys the variation is more and maximum at the base.

The comparison of displacements, base shear, axial force and bending moment that are obtained from linear static analysis and P-Delta analysis for the 5, 10, 15 and 20 storeys are tabulated in table no. 6 and the same is plotted in fig 27, 28, 29 and 30 respectively.

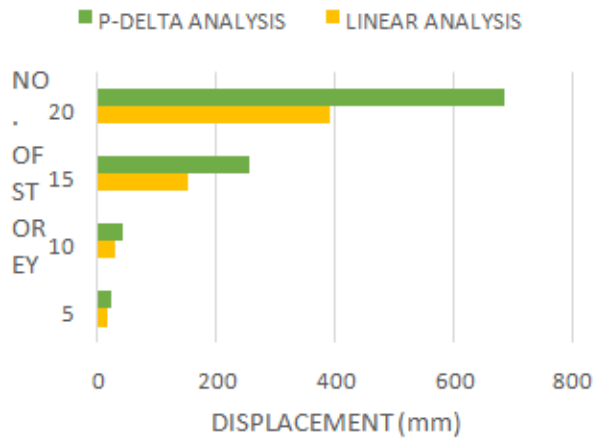


Fig. 27 Comparison of displacements for the no. of storeys obtained from linear and P-delta analysis

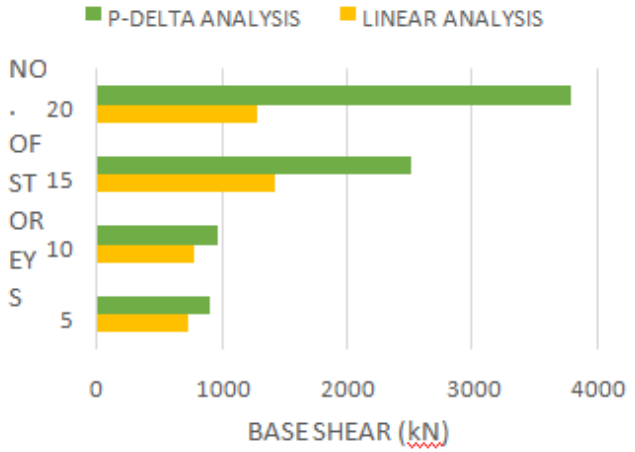


Fig. 28 Comparison of base shear for the no. of storeys obtained from linear and P delta analysis

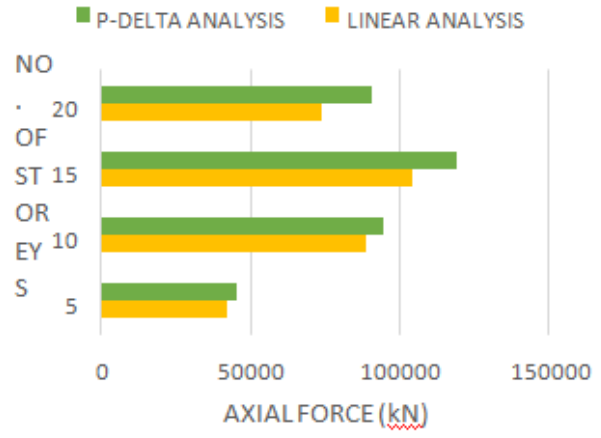


Fig.29 Comparison of axial force for the no. of storeys obtained from linear and P- delta analysis

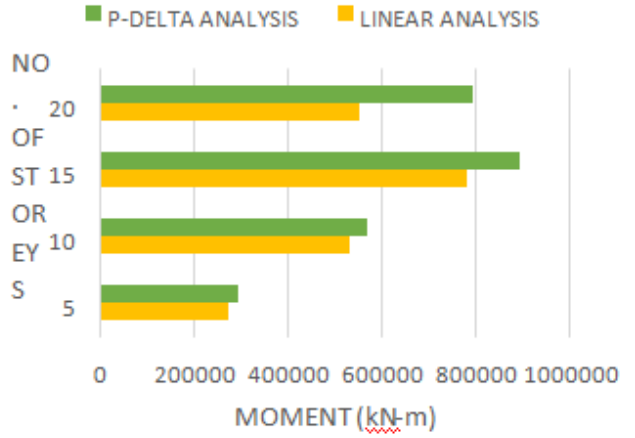


Fig.30 Comparison of bending moment for the no. of storeys obtained from linear and P-delta analysis

Table 6: Variation in axial force, displacement, storey shear and bending moment for various models considered for the study

MODEL	VARIATION (%)			
	Displacement	**Axial force**	**Storey shear**	**Moment**
G+4	32.2368	7.5104	19.9995	6.9841
G+9	34.2629	6.5035	19.9966	6.4679
G+14	54.5558	12.3160	43.1265	12.31
G+19	63.0356	29.4789	66.2153	30.3057

5. CONCLUSION

- The results of storey shear obtained from 20 storey and 15 storey model, when analysed for P-delta effect shows respectively 66.21% and 43.12% more than that obtained from linear static analysis.
- The results of axial force obtained from 20 storey and 15 storey model, when analysed for P-delta effect shows respectively 29.47% and 12.31% more than that obtained from linear static analysis.
- The results of displacements obtained from 20 storey and 15 storey model, when analysed for P-delta effect shows respectively63.03% more than that obtained from linear static analysis.
- The results of bending moments obtained from 20 storey and 15 storey model, when analysed for P-delta effect shows respectively 30.305 % and 12.31% more than that obtained from linear static analysis.
- From the results obtained, it can be concluded that the P-delta effect should be considered in analysis of multi-storied buildings.

REFERENCES

[1] Christoph ADAM, Luis F. Ibarra, Helmut Krawinkler, 2004, "Evaluation of p-delta effects in non-deteriorating MDOF structures from equivalent SDOF systems", 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada, Page no. 3407.

[2] A.S. Moghadam and A. Aziminejad, 2004,"Interaction of torsion and P-delta effects in tall buildings", 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada, Page no. 799.

[3] Shah B.A, Patel P.V, 2005, "Seismic evaluation of RCC framed structures using static pushover analysis", International conference on recent trends in concrete technology and structures", Kumara guru college of technology, Coimbatore, pp. 658-665.

[4] Peng, B.H.H., Dhakal, R.P., Fenwick, R.C., Car, A.J., Bull, D.K.2007, "Flexural, Axial Load and Elongation Response of Plastic Hinges in Reinforced Concrete Member," Proceedings of 8th Pacific Conference of Earthquake Engineering, Singapore. Paper No. 30.

[5] Priestley, M.J.N., Calvi, G.M., Kowalsky, M.J.2007, "*Displacement Based Seismic Design of Structures"*, IUSS Press, Pavia, Italy.

[6] T.J. Sullivan, T.H. Pham and G.M. Calvi, 2008,"P-delta effects on tall RC frame-wall buildings", The 14th World Conference on Earthquake Engineering Beijing, China October 12-17.

[7] Pham, T.H., "Seismic Design Considerations for Tall Buildings" MEEES Masters Dissertation supervised by Sullivan, T.J. and Calvi, G.M., held at ROSE School, University of Pavia, Italy. 85pages, 2008.

[8] Jose Antonio Flores Ruiz,2015,"Study of P-Delta Effect on Tall Steel Structure", International Journal of Allied Practice, Research and Review, Page No. 26-36.