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"P-Delta Effect in the Structural Design of Multi-storey RCC Building Subjected to Seismic Loads"

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Abstract: P-delta effect is secondary or second order effect on structure. It is also known as geometric nonlinearity effect. As number of storey increases, P-delta effect becomes more important. If the change in bending moments, shear forces and displacements is more than 10%, P-delta effect should be considered in design. In this study the P-delta effect on high rise building is studied. First order analysis (without P-delta effect) and second order analysis (with P-delta effect) on high rise buildings with different number of storey is carried out. For this multi-story R.C.C. framed buildings are modeled and analyzed for earthquake load and also for load combinations as per IS-1893(2002) for zone III using ETABS software.

1. Introduction

Generally Structural designers are prone to use 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 behaviour 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. P-delta is a geometrical non-linearity (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 not the linear static analysis. P-Delta is a non-linear effect that occurs in every structure where elements are subject to axial load. It is a genuine "effect" that is associated with the magnitude of the applied axial load (P) and a displacement (delta).

2. Methodology

2.1 GENERAL

Procedure adopted to incorporate the P-Delta effect in the analysis consists of the following steps.

1) Modeling of multi-storey structures for different configuration using ETABS.
2) Modeling of beam and column using frame elements and slab using shell elements for static analysis of structures.
3) Seismic analysis using equivalent static method is carried out as per IS 1893(2002).
4) Different types of loads considered for the analysis are dead load, live load and earthquake load.
5) Load combinations for analysis are set as per IS 875(1987).
6) Analytical study of P-delta (second order analysis) is carried out using ETABS.
7) Comparison of the results with and without P-delta effect.

2.2 METHOD OF MODELLING AND ANALYSIS OF BUILDING

In the present study, buildings having same plan but with different number of stories are analyzed in ETABS with and without P-delta effect and their result are compared.
Model results are compared for 10 storey, 20 storey, 30 storey, 40 storey, 50 storey.

2.2.1 Plan of building:-

1) RCC framed structure.
2) Storey height is 3.5m, base height 4m
3) Length of building in X-direction = 25m
4) Length of building in Y-direction = 20m

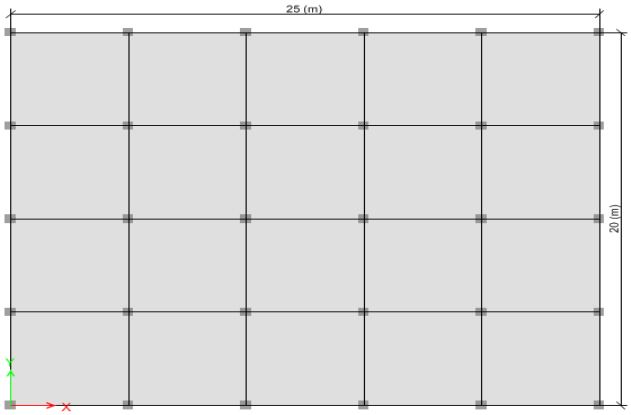


Fig 1: Typical floor plan of a building

2.2.2 Material properties:-

1) Concrete: M30
Density: 25 KN/m3
Modulus of Elasticity: 25000 N/mm2
Poisson's ratio: 0.2

2) Rebar : HYSD500
Density: 7849 Kg/m3
Modulus of Elasticity: 200000N/mm2

2.2.3 Section Properties:

1) Column :

Table 1: Size of columns (mm)

No. of storey	1-10 Storey	11-20 Storey	21-30 Storey	31-40 Storey	41- 50 Storey
10	450x450	-	-	-	-
20	550x550	350x350	-	-	-
30	650x650	450x450	450x450	-	-
40	850x850	650x650	450x450	450x450	-
50	950x950	750x750	550x550	350x350	350x350

2) Beam :
For 10, 20, 30 and 40 storey 230x550(mm)
For 50 storey 300x600(mm)

3) Slab: With Thickness of 150mm.

2.2.4 Loads considered

1) Dead load:
Self weight
Floor finish for storey: 1.25 KN/m2
Floor finish for roof: 1.75 KN/m2

2) Live load:
Floor = 3.5KN/m2
Roof = 1.5 KN/m2

3) Earthquake loads: As per IS1893:2002 for Zone III
EQX: Earthquake load in X-direction
EQY: Earthquake load in Y-direction
Zone factor = 0.16
Soil = Type II
Importance factor = 1

Response reduction factor = 3

2.2.5 Load combinations

P-delta load combinations:-

1) 1.4 DL
2) 1.2 DL + 1.6 LL
3) 1.2 DL + 0.5 LL + 1.3 EQX
4) 1.2 DL + 0.5 LL - 1.3 EQX
5) 0.9 DL + 1.3 EQX
6) 0.9 DL - 1.3 EQX

As per IS-875(1987) in which both gravity and lateral loads are included.

1) 1.2 (DL + LL + EQX)
2) 1.2 (DL + LL – EQX)
3) 1.2 (DL + LL + EQY)
4) 1.2 (DL + LL - EQY)
5) 1.5(DL + EQX)
6) 1.5(DL - EQX)
7) 1.5(DL + EQY)
8) 1.5(DL - EQY)
9) 0.9DL + 1.5EQX
10) 0.9DL - 1.5EQX
11) 0.9DL + 1.5EQY
12) 0.9DL - 1.5EQY

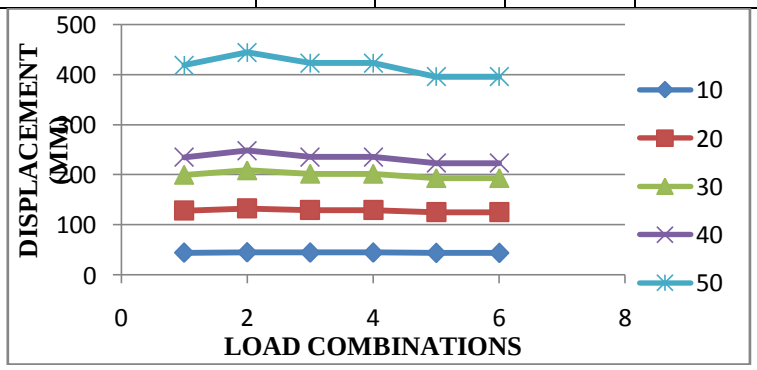
3. Result and Discussion

3.1 Displacements for P-delta load combinations

Analysis results of displacement for P-delta load combinations for all storey buildings.

Table 2: Displacement results for P- delta load combinations for all 5 models

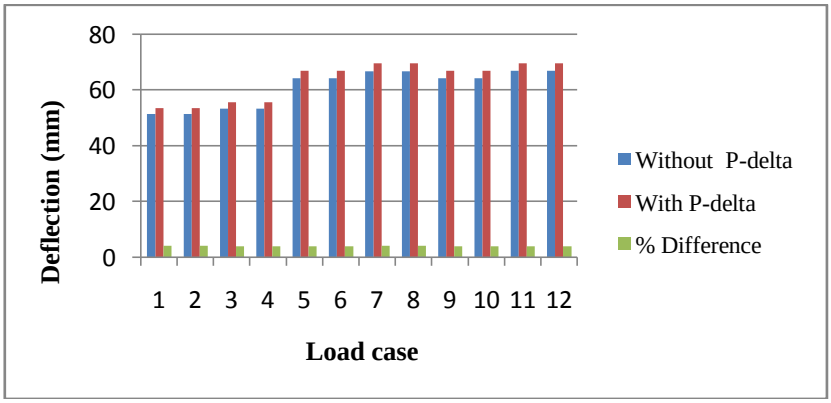
Load combinations	Displacement (mm)				
	10 storey	20 storey	30 storey	40 storey	50 storey
1.4 DL	44.68	128.76	200.13	235.18	418.8
1.2 DL + 1.6 LL	45.34	132.96	209.13	248.18	444.2
1.2 DL + 0.5 LL + 1.3 EQX	44.8	129.61	202.29	235.68	423.11
1.2 DL + 0.5 LL - 1.3 EQX	44.8	129.61	202.17	235.68	423.11
0.9 DL + 1.3 EQX	44.12	125.61	193.46	223.4	395.83
0.9 DL - 1.3 EQX	44.12	125.61	193.46	223.4	395.83



Graph 1: Displacement for P-delta load combinations for all models

3.2 Analysis results for 10 storey RC building.

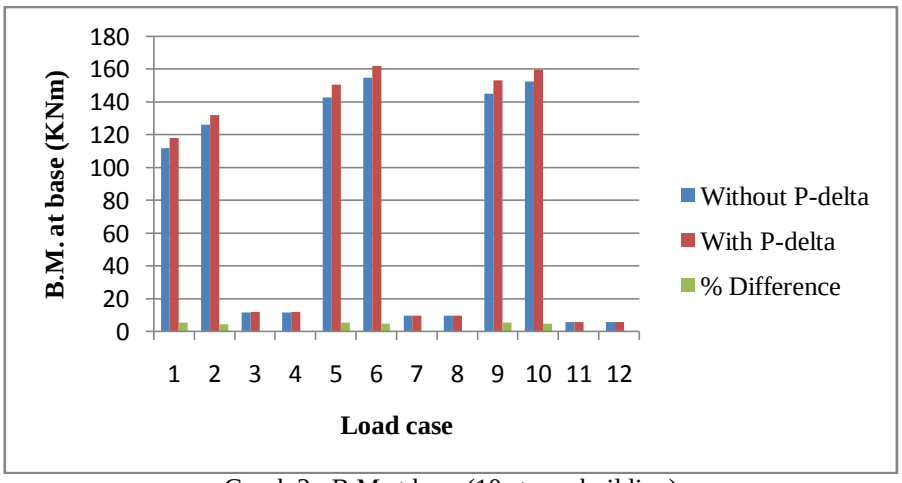
Load cases	Deflection at top (mm)		
	Without P-delta	With P-delta	% of Difference
1.2(DL+LL+EQX)	51.4	53.6	4.19047619
1.2(DL+LL-EQX)	51.4	53.6	4.19047619
1.2(DL+LL+EQY)	53.4	55.6	4.036697248
1.2(DL+LL-EQY)	53.4	55.6	4.036697248
1.5(DL+EQX)	64.3	67	4.112718964
1.5(DL-EQX)	64.3	67	4.112718964
1.5(DL+EQY)	66.8	69.7	4.249084249
1.5(DL-EQY)	66.8	69.7	4.249084249
0.9DL+1.5EQX	64.3	67	4.112718964
0.9DL-1.5EQX	64.3	67	4.112718964
0.9DL+1.5EQY	66.9	69.7	4.099560761
0.9DL-1.5EQY	66.9	69.7	4.099560761



Graph 2 : Deflection at top storey (10 storey building)

Load cases	B.M. at base (kN-m)		
	Without P-delta	With P-delta	% of Difference
1.2(DL+LL+EQX)	111.862	118.155	5.471769478
1.2(DL+LL-EQX)	126.389	132.2	4.494390713
1.2(DL+LL+EQY)	11.88	11.917	0.310963567
1.2(DL+LL-EQY)	11.88	11.898	0.151400454
1.5(DL+EQX)	142.88	150.763	5.369104661
1.5(DL-EQX)	154.932	162.176	4.568790444
1.5(DL+EQY)	9.853	9.884	0.31413082
1.5(DL-EQY)	9.853	9.868	0.152122103
0.9DL+1.5EQX	145.292	153.183	5.287545021

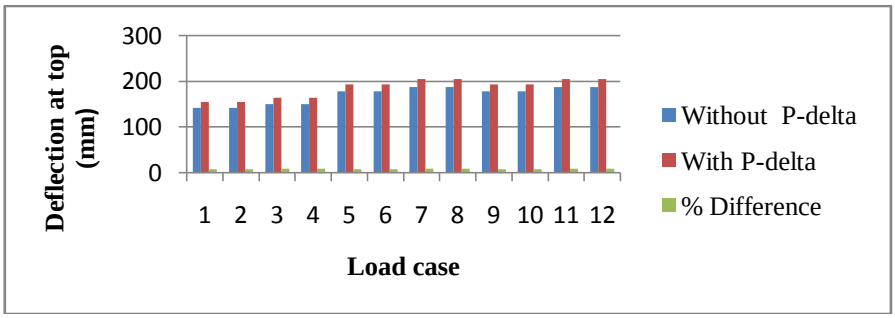
0.9DL-1.5EQX	152.522	159.744	4.625543607
0.9DL+1.5EQY	5.912	5.9	0.203183204
0.9DL-1.5EQY	5.912	5.921	0.152116961



Graph 3 : B.M at base (10 storey building)

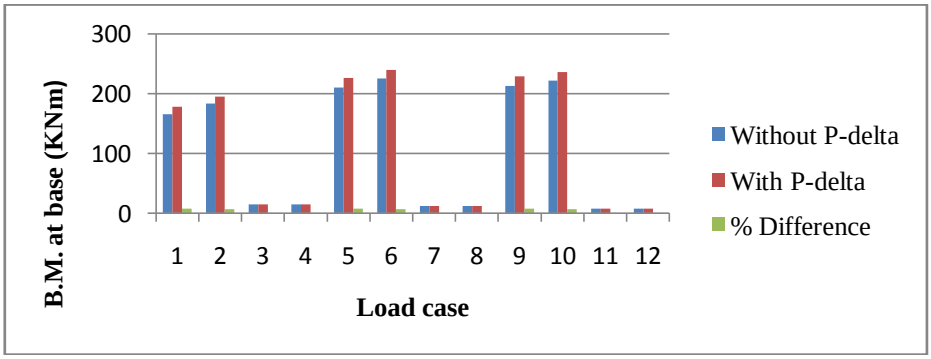
3.3 Analysis results for 20 storey RC building

Load case	Deflection at top (mm)		
	Without P-delta	With P-delta	% of Difference
1.2(DL+LL+EQX)	142.6	154.8	8.204438467
1.2(DL+LL-EQX)	142.6	154.7	8.139926001
1.2(DL+LL+EQY)	150.2	164.6	9.14866582
1.2(DL+LL-EQY)	150.2	164.6	9.14866582
1.5(DL+EQX)	178.2	193.4	8.180839612
1.5(DL-EQX)	178.2	193.4	8.180839612
1.5(DL+EQY)	187.7	205.8	9.199491741
1.5(DL-EQY)	187.7	205.8	9.199491741
0.9DL+1.5EQX	178.2	193.4	8.180839612
0.9DL-1.5EQX	178.2	193.4	8.180839612
0.9DL+1.5EQY	187.8	205.8	9.146341463
0.9DL-1.5EQY	187.8	205.8	9.146341463



Graph 4 : Deflection at top storey (20 storey building)

Load cases	B.M. at base (kN-m)		
	Without P-delta	With P-delta	% of Difference
1.2(DL+LL+EQX)	165.45	178.205	7.423142396
1.2(DL+LL-EQX)	183.206	194.814	6.141473996
1.2(DL+LL+EQY)	14.283	14.329	0.321543408
1.2(DL+LL-EQY)	14.109	14.157	0.339630652
1.5(DL+EQX)	210.58	226.54	7.302342606
1.5(DL-EQX)	225.241	239.714	6.225548709
1.5(DL+EQY)	11.84	11.874	0.286750443
1.5(DL-EQY)	11.624	11.672	0.412087912
0.9DL+1.5EQX	213.51	229.456	7.199649635
0.9DL-1.5EQX	222.3	236.753	6.296876396
0.9DL+1.5EQY	7.147	7.161	0.195694716
0.9DL-1.5EQY	6.931	6.971	0.575456769



Graph 5 : B.M at base (20 storey building)

B.M. of member 305 at storey 10 (20 storey building)

Load cases	B.M. at base (kN-m)		
	Without P-delta	With P-delta	% of Difference
1.2(DL+LL+EQX)	23.36	23.65	1.23378
1.2(DL+LL-EQX)	-98.61	-102.35	3.72213
1.2(DL+LL+EQY)	50.33	50.309	0.041733
1.2(DL+LL-EQY)	-50.65	-50.37	0.554346
1.5(DL+EQX)	18.98	23.61	21.7422
1.5(DL-EQX)	-101.31	-105.97	4.49633
1.5(DL+EQY)	40.96	40.91	0.122145

1.5(DL-EQY)	-40.35	-40.44	0.2228
0.9DL+1.5EQX	35.45	40.08	12.26
0.9DL-1.5EQX	-84.84	-89.5	5.34588
0.9DL+1.5EQY	24.49	24.44	0.204374
0.9DL-1.5EQY	-24.89	-24.97	0.3209

B.M. of member 155 at storey 15 (20 storey building)

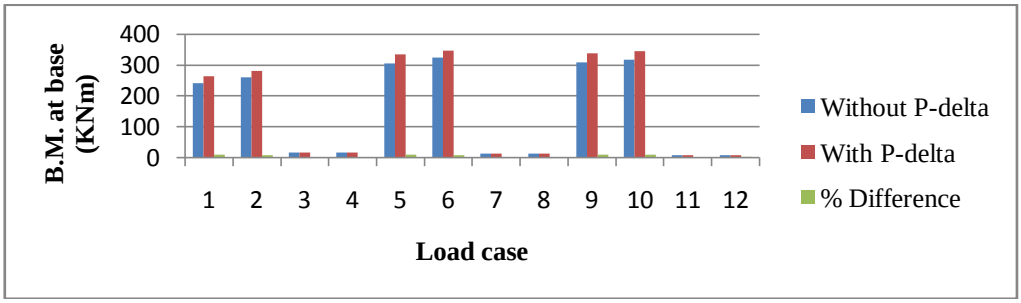
Load cases	**B.M. at base (kN-m)**		
	Without P-delta	**With P-delta**	**% of Difference**
1.2(DL+LL+EQX)	-4.01	-3.37	17.34417
1.2(DL+LL-EQX)	87.61	84.51	3.602138
1.2(DL+LL+EQY)	40.98	41.05	0.17067
1.2(DL+LL-EQY)	41	41.05	0.12188
1.5(DL+EQX)	-24.8	-20.81	17.49616
1.5(DL-EQX)	91.71	87.84	4.310777
1.5(DL+EQY)	-33.46	-33.51	0.14932
1.5(DL-EQY)	33.47	33.51	0.11944
0.9DL+1.5EQX	38.18	34.21	10.96837
0.9DL-1.5EQX	78.35	74.43	5.131562
0.9DL+1.5EQY	20.07	20.11	0.1991
0.9DL-1.5EQY	20.08	20.107	0.13437

3.4 Analysis results for 30 storey RC building.

Load case	**Deflection at top (mm)**		
	Without P-delta	**With P-delta**	**% of Difference**
1.2(DL+LL+EQX)	214.9	240.7	11.32572432
1.2(DL+LL-EQX)	214.9	240.7	11.32572432
1.2(DL+LL+EQY)	233.5	263.7	12.14802896
1.2(DL+LL-EQY)	233.5	263.7	12.14802896
1.5(DL+EQX)	268.6	300.8	11.31015104
1.5(DL-EQX)	268.6	300.8	11.31015104
1.5(DL+EQY)	291.9	329.7	12.16216216
1.5(DL-EQY)	291.9	329.7	12.16216216
0.9DL+1.5EQX	268.6	300.8	11.31015104
0.9DL-1.5EQX	268.6	300.8	11.31015104
0.9DL+1.5EQY	291.9	329.6	12.13193886

Load case	**B.M. at base (kNm)**		
	Without P-delta	**With P-delta**	**% of Difference**
1.2(DL+LL+EQX)	241.29	265.06	9.388762714
1.2(DL+LL-EQX)	260.283	282.058	8.030003264
1.2(DL+LL+EQY)	15.147	15.227	0.526766313
1.2(DL+LL-EQY)	14.845	14.965	0.80509896

1.5(DL+EQX)	305.663	335.387	9.273535606
1.5(DL-EQX)	325.361	348.49	6.86472232
1.5(DL+EQY)	12.569	12.627	0.460390538
1.5(DL-EQY)	12.19	12.313	1.003958699
0.9DL+1.5EQX	308.793	338.531	9.187980053
0.9DL-1.5EQX	318.182	345.33	8.183122536
0.9DL+1.5EQY	7.617	7.642	0.32767547
0.9DL-1.5EQY	7.238	7.34	1.399368912



Graph 6 : B.M at base (30 storey building)

B.M. of member 605 at storey 10 (30 storey building)

Load case	B.M. at base (kN-m)		
	Without P-delta	With P-delta	% of Difference
1.2(DL+LL+EQX)	15.73	24.48	43.5215
1.2(DL+LL-EQX)	-111.92	-120.69	7.54052
1.2(DL+LL+EQY)	47.83	48.71	1.82308
1.2(DL+LL-EQY)	-48.35	-47.48	1.815715
1.5(DL+EQX)	40.79	51.73	23.6489
1.5(DL-EQX)	-118.77	-129.73	8.82093
1.5(DL+EQY)	38.67	39.76	2.77955
1.5(DL-EQY)	-39.31	-38.23	2.785659
0.9DL+1.5EQX	56.38	67.33	17.7027
0.9DL-1.5EQX	-103.17	-114.13	10.0874
0.9DL+1.5EQY	23.07	24.16	4.61571
0.9DL-1.5EQY	-23.71	-22.63	4.6612

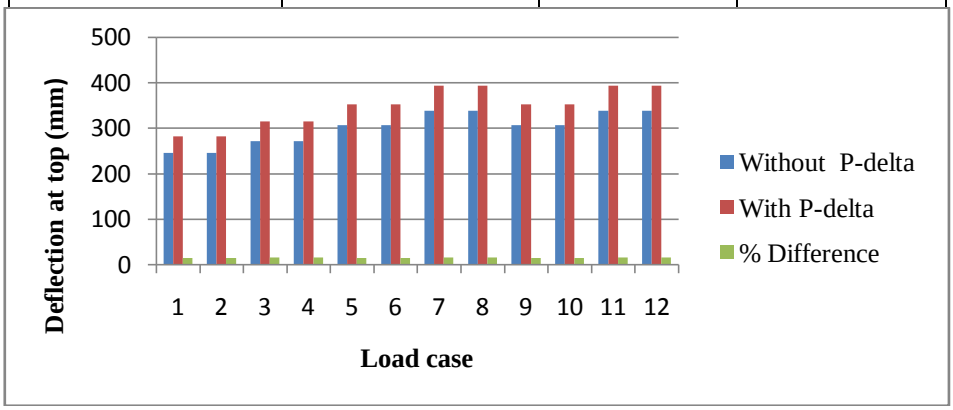
B.M. of member 305 at storey 20 (30 storey building)

Load case	B.M. at base (kNm)		
	Without P-delta	With P-delta	% of Difference
1.2(DL+LL+EQX)	11.36	6.93	48.44177
1.2(DL+LL-EQX)	109.78	114.16	3.91176

1.2(DL+LL+EQY)	60.57	60.86	0.47764
1.2(DL+LL-EQY)	60.57	60.23	0.562914
1.5(DL+EQX)	12.62	18.15	35.9441
1.5(DL-EQX)	110.39	115.88	4.85261
1.5(DL+EQY)	48.88	49.25	0.7541
1.5(DL-EQY)	48.88	48.47	0.842322
0.9DL+1.5EQX	32.18	37.702	15.8038
0.9DL-1.5EQX	-90.84	-96.33	5.86632
0.9DL+1.5EQY	29.33	29.7	1.2536
0.9DL-1.5EQY	29.32	28.92	1.373626

3.5 Analysis results for 40 storey RC building.

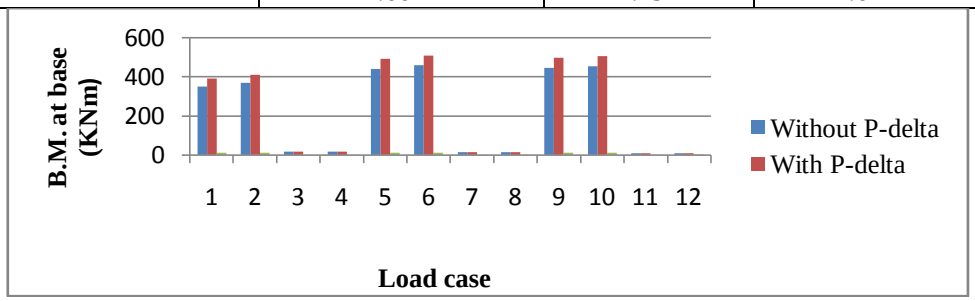
Load case	**Deflection at top (mm)**		
	Without P-delta	**With P-delta**	**% of Difference**
1.2(DL+LL+EQX)	246.1	282.9	13.91304348
1.2(DL+LL-EQX)	246.1	282.9	13.91304348
.2(DL+LL+EQY)	271.2	315.5	15.10141469
1.2(DL+LL-EQY)	271.2	315.5	15.10141469
1.5(DL+EQX)	307.6	353.5	13.88594766
1.5(DL-EQX)	307.6	353.5	13.88594766
1.5(DL+EQY)	338.9	394.4	15.13705168
1.5(DL-EQY)	338.9	394.4	15.13705168
0.9DL+1.5EQX	307.6	353.5	13.88594766
0.9DL-1.5EQX	307.6	353.5	13.88594766
0.9DL+1.5EQY	338.9	394.3	15.11183852
0.9DL-1.5EQY	338.9	394.3	15.11183852



Graph 7 : Deflection at top storey (40 storey building)

Load case	**B.M. at base (kNm)**		
	Without P-delta	**With P-delta**	**% of Difference**
1.2(DL+LL+EQX)	350.389	391.96	11.1999

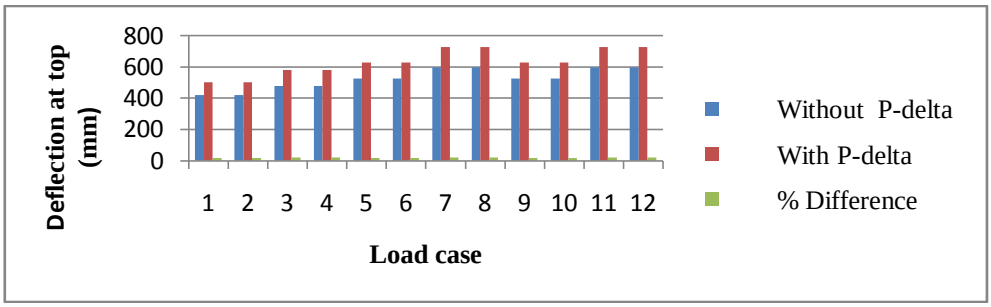
1.2(DL+LL-EQX)	371.226	410.878	10.1398
1.2(DL+LL+EQY)	16.185	16.188	0.01853
1.2(DL+LL-EQY)	15.785	15.901	0.73218
1.5(DL+EQX)	442.44	492.427	10.6939
1.5(DL-EQX)	459.574	509.119	10.2292
1.5(DL+EQY)	13.434	13.423	0.08192
1.5(DL-EQY)	12.935	13.0715	1.04974
0.9DL+1.5EQX	445.87	497.863	11.0186
0.9DL-1.5EQX	456.148	505.677	10.299
0.9DL+1.5EQY	8.1603	8.136	0.29823
0.9DL-1.5EQY	7.6614	7.791	1.67741



Graph 8 : B.M at base (40 storey building)

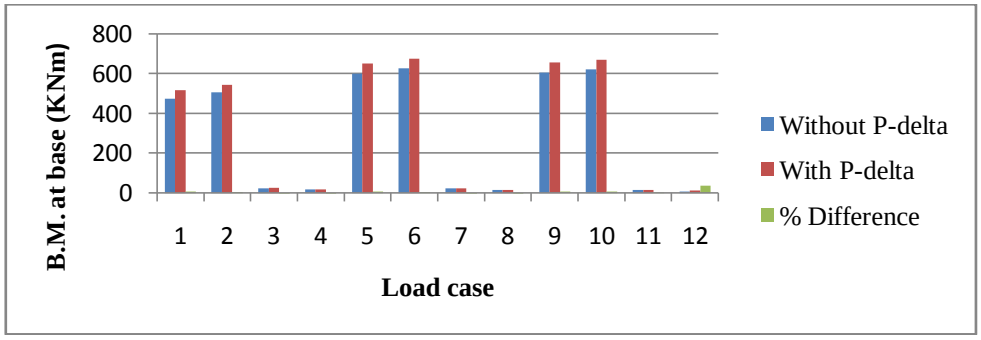
3.6 Analysis results for 50 storey RC building.

Load case	Deflection at top (mm)		
	Without P-delta	With P-delta	% of Difference
1.2(DL+LL+EQX)	422.2	502.1	17.28875906
1.2(DL+LL-EQX)	422.2	502.1	17.28875906
1.2(DL+LL+EQY)	479.9	582.8	19.36576644
1.2(DL+LL-EQY)	479.9	582.8	19.36576644
1.5(DL+EQX)	527.7	627.5	17.27839335
1.5(DL-EQX)	527.7	627.5	17.27839335
1.5(DL+EQY)	599.5	728.2	19.38690969
1.5(DL-EQY)	599.5	728.2	19.38690969
0.9DL+1.5EQX	527.7	627.5	17.27839335
0.9DL-1.5EQX	527.7	627.5	17.27839335
0.9DL+1.5EQY	599.8	728.5	19.37815253
0.9DL-1.5EQY	599.8	728.5	19.37815253



Graph 9 : Deflection at top storey (50 storey building)

Load case	B.M. at base (kNm)		
	Without P-delta	With P-delta	% of Difference
1.2(DL+LL+EQX)	476.366	517.681	8.312484219
1.2(DL+LL-EQX)	507.047	545.263	7.263258926
1.2(DL+LL+EQY)	25.282	25.631	1.370966158
1.2(DL+LL-EQY)	20	19.87	0.652119388
1.5(DL+EQX)	601.361	653.02	8.236572461
1.5(DL-EQX)	627.906	675.636	7.323124226
1.5(DL+EQY)	22.954	23.36	1.753249557
1.5(DL-EQY)	16.351	16.183	1.032765722
0.9DL+1.5EQX	606.67	658.343	8.169560313
0.9DL-1.5EQX	622.597	670.3	7.379242121
0.9DL+1.5EQY	15.093	15.48	2.53164557
0.9DL-1.5EQY	8.49	8.311	2.64402161



Graph 10 : B.M at base (50 storey building)

4. Discussion

For P-delta load combinations :

Analysis results of displacement for P-delta load combinations for all storey buildings.

For this case, the P-delta effect due to the overall sway of the structure can usually be accounted for, conservatively, by specifying the P-delta load combination to be 1.2 times dead load plus 0.5 live load. This will accurately account for this effect in load combinations 3 and 4 which are used above for analysis. So, the load combination 3 is used for the further second order analysis.

For 10 and 20 storey building :

Analysis results for 10 storey and 20 storey RC buildings.

1. Change in B.M. at base is 0.15-7.42%.
2. Change in the deflection is 4-8%.
3. Change in the B.M. of beams is less than 10%.
4. Change in the B.M. of column is up to 20% for some members in some load cases. But it is found that their initial values are very small (i.e. not more than 30KNm.So we can say that practically it is not necessary to consider P-delta effect.
5. Hence for 10 storey and 20 storey building, it is not necessary to consider P-delta effect. So building can be designed by performing 1st order analysis.

For 30, 40 and 50 storey buildings:

Analysis results for 30, 40 and 50 storey buildings.

1. Change in B.M. at base is 0.32-11.19%.
2. Change in the deflection is 11-19%.
3. Change in the B.M. of beams is more than 10%.
4. Change in the B.M. of column is up to 35%. It is more observed at the exterior and their nearby beams. Also it is more observed at intermediate stories.
5. So it is necessary to consider P-delta effect for designing 30, 40 and 50 storey buildings.

Conclusion

In this study, the five building models with different number of stories are analyzed with and without considering P-delta effect for seismic loads. By studying the results of analysis, following conclusions are drawn.

1) As number of storey increases P-delta effect becomes more important.
2) P-delta effect is only observed in some of the beams and columns (Exterior columns and their adjacent beams) in some load cases. If these load cases are governing load cases for design of member, then only we can say that it is considerable. This condition is observed in 30, 40 and 50 storey buildings and mostly in 50 storey building.
3) So it can be said that, at least it is necessary to check the results of analysis with and without considering P-delta effect for the buildings with 30 stories.
4) Iterative P-delta analysis method is used. Building is analyzed for 10 numbers of iterations. But it is found that the results are converged after 2 iterations. So there is no change in the results by increasing the number of iterations.
5) So it is necessary to perform P-delta analysis for designing a 30 storey building. And buildings up to 20 stories can be designed by conventional primary analysis or linear analysis.