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Assessment Of P-Delta Effect On High Rise Building

Mr. Sagar Anil Bhosale.

Prof. Shrisahil B. Tanwade, Prof. Rameez R. Badeghar, Prof. Amruta G. Dhanashetti

ABSTRACT

In this study the P-delta effect on high rise building is studied. Linear static analysis (without P-delta effect) and nonlinear static analysis (with P-delta effect) on high rise buildings having different number of storey is carried out. For the analysis G+19, G+24 and G+29 (i.e. 20, 25 and 30 storey) R.C.C. framed buildings are modelled. Earthquake load is applied on model of structure as per IS-1893(2002) for zone III in SAP2000-12 software. Load combinations for analysis are set as per IS-456(2000). All analysis is carried out in software SAP 2000-12. Bending moment, story displacement with and without P-delta effect is calculated and compared for all the models.

1.1 INTRODUCTION

Engineers today typically use linear elastic static (first order) analysis to determine design forces and moments resulting from loads acting on a structure. First order analysis assumes small deflection behaviour; the resulting forces and moments take no account of the additional effect due to the deformation of the structure under load. Second order analysis combines two effects to reach a solution:-

- Large displacement theory; the resulting forces and moments take full account of the effects due to the deformed shape of both the structure and its members.
- “Stress stiffening”; the effect of element axial loads on structure stiffness, tensile loads stiffening an element and compressive loads softening an element.

As the structure becomes more slender and less resistant to deformation, it is necessary to consider 2nd order and to be more specific, P-delta effects arises. As a result, Codes of Practice are referring engineers more and more to the use of 2nd order analysis in order that P-delta and “stress stiffening” effects are accounted for when appropriate in design. This is as true in concrete and timber design as it is in the design of steelwork.

OBJECTIVE OF THE STUDY

1. To validate the results of Etabs16.

2. To perform non-linear analysis on the structure.

3. To Design/Check the RCC Members.

4. To perform static Non-linear P-Delta on the structure.

5. To study effect of P-DELTA on the lateral deflection of the high-rise structure.

6. To consider the P-delta effect for 25 storey building.

7. So buildings having height more than or equal to 75m, should be designed

considering P-delta effect.

8. Also we can say that up to 25 storey building, it is not necessary to consider P-delta

effect in design and primary or first order analysis is sufficient for design.

1.2 SCOPE OF THE STUDY

1. Scope of this project includes analysis of 20, 25 and 30 storey R.C.C. buildings with and without considering P-delta effects.
2. Analysis can be done using SAP 2000.
3. Lateral load is seismic load for zone III.
4. If the change in the values of forces, deflections and moments considering P-delta effect is not more than 10%, they can be neglected.
5. From this analysis we can decide the minimum height of building for which it is necessary to include P-delta effect in analysis.

2.1 LITRATURE SURVEY

Experimental Study of P-Delta effect in High rise building

M.A.A Mollick ,

There are very few experimental studies on P-delta effect. This paper reports the P-delta effect through the test on frame structures models which represent the lower part of high rise building subject to seismic force.

Whenever a high rise building is shaken by earthquake excitation, the exterior columns are subjected to lateral force and also the fluctuating axial force both in compression and tension. Naturally the lowest parts of exterior columns are more severely subjected to highest intensity of axial force. The combine effect of storey drift in the lateral direction due to lateral and axial force causes P-Delta effect.

The test results revealed that it is most essential to include P-Delta effect in analysis for the design of high rise building subject to seismic force.

Especially the P-Delta effect becomes more important to take into account if the storey drift exceed 1/85 rad during earthquake excitation.

Comparison of P-delta analyses of plane frames using commercial structural analysis programs and current AISC design specifications [2]

Angela M. Schimizze

Several different approaches to determining second-order moments in plane frames were studied during this research. The focus of the research was to compare the moments predicted by four different commercially available computer analysis programs and the current design specification, the AISC LRFD moment magnification method. For this research, the second order moments for ten commonly designed frames were compared.

An overview of various second-order analysis procedures is presented first. The solution procedure utilized by each computer program and the AISC moment magnification method are explained. Also, the frames considered in the research are described.

Next the frames are analyzed and the results between each of the computer programs and the current design specifications are compared.

Finally, conclusions are drawn concerning the consistency of the second-order moments predicted by each of the solution procedures and recommendations for their use are discussed. In general, each of the four computer analysis programs evaluated and the AISC moment magnification method can consistently and adequately predict the second-order moments in plane frames.

RECOMMENDATIONS

Since different computer programs can produce varying results for second-order analyses of certain structures, caution must be used when relying on the results for design purposes.

The limitations and reliability of the AISC procedure as well as each of the computer programs should be fully understood so that adequate conservatism can be incorporated into a design.

A second-order analysis is necessary for a thorough analysis and appropriate design of a structure and while computer programs ease the intensity of the analysis, it is important for the engineer to understand the solution procedure and carefully evaluate the second-order moments.

Effect of P-delta analysis for slender building structures [3]

T.K. Bandyopadhyay, D. Datta Saha, A. Chaudhuri

High-rise buildings are essential in metro cities of developing countries. One of the important aspect of design of tall buildings/frames is to ensure its lateral stability taking care of maximum drift stipulation.

This paper includes guidelines stipulated in various codes [such as UBC – Vol. 3 (1997), IS: 800 Draft (2006), IS: 1893 (2002 Part-1), etc.] to restrict the P-delta effect. According to the recent trends for economic limit state design, it is necessary to carry out the nonlinear dynamic analysis in seismic condition for highly ductile material. This also helps to avail advantage of high strength within elastic range. As steel is more ductile than reinforced concrete, geometric non-linearity including stress softening P-delta effect is an important factor in the design of tall slender steel structures. This also ensures suitability of steel intensive construction including steel concrete composite construction over the conventional RCC framed construction

CONCLUSIONS

Effects of P-delta analysis due to large lateral deformation of tall building are discussed here. It is shown that increase in deflection and moments due to second order analysis is very high for very slender structure. Also, the deflections are checked in serviceability conditions. If serviceability condition is fulfilled then only the moments shall be checked in limit state condition considering the second order effects. This also ensures suitability of steel framed construction (since the ductile behavior of steel is advantageous) over the conventional RCC construction

Interaction of Torsion and P-Delta Effects in Tall Buildings [4]

A.S. Moghadam and A. Aziminejad

In this paper the importance of asymmetry of building on the P-Delta effects in elastic and inelastic ranges of behavior are evaluated. The contributions 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 story 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.

CONCLUSIONS

1. In the elastic static analyses, effect of P-Delta always is increasing, as number of stories of buildings or their eccentricity increases.
2. In the elastic or inelastic dynamic analyses, the effects of P-Delta sometimes increase the responses and sometimes decrease the responses.
3. “Importance of interaction of torsion and P-Delta effect” mainly depends on the type of lateral load resisting system of building. It is concluded that the characteristics of lateral load resisting system has far more importance compare with the number of stories in building.
4. It is seen that the effects of P-Delta is quite sensitive to ground motion characteristics such as the frequency content of earthquake. In general, the sensitivity to ground motion increases, as the eccentricity increases.
5. In elastic or inelastic dynamic analyses, increase in eccentricity causes change in the effect of P-Delta.

However, the variation does not have a constant increasing or decreasing trend.

Modification to Current P-Delta Implementation for Rigid Diaphragms in RAM Frame [5]

Author: Bulent N. Alemdar

Effects of gravity loads on lateral members are the primary source of the P-Delta effects. In addition to dead loads, live loads are also needed for P-Delta calculations. Currently, two alternative methods can be followed in the RAM Frame program to account for live loads:

1) By using P-Delta scale factor
2) To directly increase values of mass loads

The first method is recommended method since if one uses the second method, building's dynamic properties (such as structural periods and mode shapes) are also altered. Briefly, the P-Delta scale factor is only applied to P-Delta effects and no building mass components are altered.

With the new implementation, the program uses dead load (DL) and live loads (LL) instead of mass loads. The procedure follows the same steps with only changes of using gravity loads instead of mass loads.

Gravity loads are already calculated for notional loads. They are tabulated in Diaphragm Gravity Loads dialog as well as reported in Criteria, Mass and Exposure report. The same loads are also used for this new feature.

Note that the previous implementation using mass loads is also retained in the dialog so that two alternative options are provided to users. In fact, both options lead to the same answer.

In summary:

Instead of using building mass loads, live loads and dead loads are used to calculate P-Delta effects. Thus, the above scale factors are separately applied to dead and live loads. This approach removes (somewhat confusing) relationship between building mass and P-Delta effects. Thus, mass loads are only used for calculating dynamic properties of building masses in this new approach. The new approach also lessens the difficulty in determining a single factor that reflects ratios between DL and LLs.

1.1 METHODOLOGY

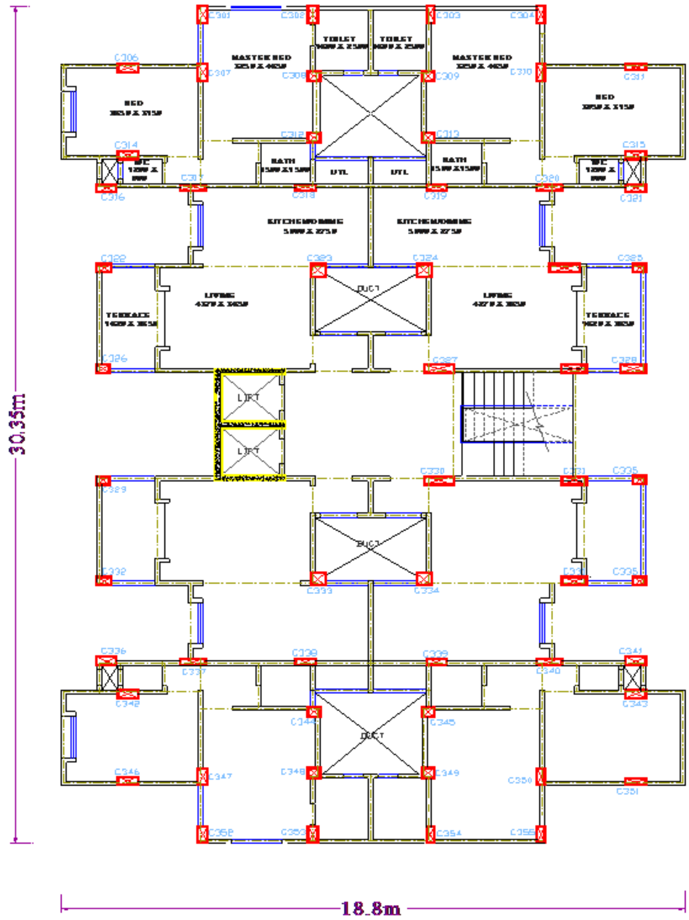
Buildings having same plan but with different number of stories are analyzed in SAP2000 with and without considering P-delta effect and their results are compared.

1) 20 storey
2) 25 storey
3) 30 storey

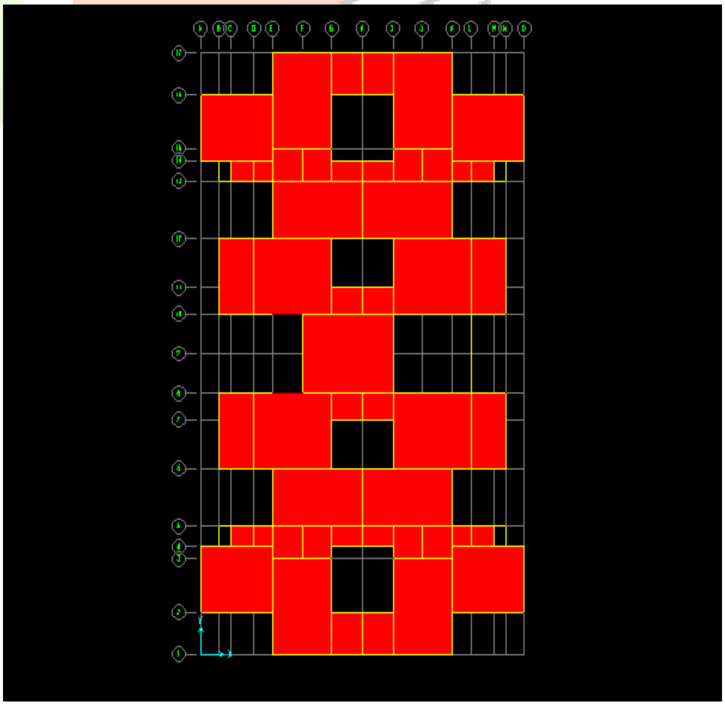
Details of building:-

1) Residential building
2) RCC framed structure
3) Storey height is 3m.
4) Length of building in X-direction = 18.8m
5) Length of building in Y-direction = 30.35m

Other details are also shown below.



Typical floor plan of building



ETAB Model (Plan View)

Material properties:-

1) **Concrete:** M30

Density: 25 KN/m^3

Modulus of Elasticity: 27386 N/mm^2

Poissons ratio: 0.2

2) **Steel:** Fe500, Fe250

Density: 7850 Kg/m^3

Modulus of Elasticity: 2.1×10^5 N/mm^2

Poisson's ratio: 0.3

3) **Masonry:** Brick

Density= 20 KN/m^3

Section Properties:-

1) **Beam:**

230X300, 230X450, 230X600, 230X700

2) **Column:**

230X450, 230X525, 230X600, 230X675, 230X750

300X750, 300X825, 300X900, 375X900.

3) **Slab:** various sections with thickness varying from 100mm to 200mm.

4) **Shear wall:** with thickness of 200mm.

1) **Dead load:**

a) Self weight

b) Floor finish: 1.25 KN/m^2

c) Wall load:

Load = Height x thickness x density of masonary.

For 3m height of wall:

For 230mm thick wall, Load = 15 KN/m

For 150mm thick wall, Load = 10 KN/m

For 1.2m height of wall (Parapet wall):

Load = 5 KN/m^2

2) **Live load:**

i) Floor = 2 KN/m^2

ii) Roof = 1.5 KN/m^2

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

Load cases:-

As per IS-456(2000) in which both gravity and lateral loads are included.

A) Linear (Without P-Delta):

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

B) Non-Linear (With P-Delta):

1-1) 1.2 (DL + LL + EQX)

2-1) 1.2 (DL + LL – EQX)

3-1) 1.2 (DL + LL + EQY)

4-1) 1.2 (DL + LL - EQY)

5-1) 1.5(DL + EQX)

6-1) 1.5(DL - EQX)

7-1) 1.5(DL + EQY)

8-1) 1.5(DL - EQY)

9-1) 0.9DL + 1.5EQX

10-1) 0.9DL - 1.5EQX

11-1) 0.9DL + 1.5EQY

12-1) 0.9DL - 1.5EQY

Analysis Results:-

For 20 storey building:-

(i) B.M. at base:

Storey no.	B.M. (KNm)	Load case No.					
		1	2	3	4	5	6
5	Initial	78.0	-107.9	39.3	-61.2	98.2	-134.2
	With P-delta	82.4	-110.8	46.4	-68.2	104.4	-139.0
	%	**5.6**	**2.6**	**18.1**	**11.5**	**6.2**	**3.6**
10	Initial	66.6	-104.2	25.5	59.8	84.5	-129.1
	With P-delta	70.7	-106.5	30.3	64.8	90.1	-132.4
	%	**6.0**	**2.1**	**18.9**	**8.4**	**6.6**	**2.6**
15	Initial	-37.4	83.0	20.4	47.7	-48.1	102.3
	With P-delta	-39.9	83.9	18.9	49.0	-51.6	103.3
	%	**6.7**	**1.2**	**-7.5**	**2.8**	**7.1**	**1.0**
20	Initial	-6.8	32.3	-16.1	-14.1	-7.5	39.2
	With P-delta	-6.3	31.9	-16.8	-13.1	-6.9	38.7
	%	**-6.9**	**-1.3**	**4.7**	**-6.9**	**-7.7**	**-1.2**

Sr. No.	Load Case	B.M. at base (KNm)		
		Without P-delta	With P-delta	% Difference
1)	1.2 (DL + LL + EQX)	-201.82	-206.4	**2.27**
2)	1.2 (DL + LL – EQX)	159.7	162.46	**1.73**
3)	1.2 (DL + LL + EQY)	67.75	71.7	**5.83**
4)	1.2 (DL + LL – EQY)	-65.26	-69.36	**6.28**
5)	1.5(DL + EQX)	-249.8	-256.15	**2.54**
6)	1.5(DL - EQX)	202.1	206.2	**2.03**
7)	1.5(DL + EQY)	84.7	90.3	**6.61**
8)	1.5(DL - EQY)	-81.5	-87.4	**7.24**
9)	0.9DL + 1.5EQX	-240.6	-243.87	**1.36**
10)	0.9DL - 1.5EQX	211.63	214.24	**1.23**
11)	0.9DL + 1.5EQY	84.07	87.26	**3.79**
12)	0.9DL - 1.5EQY	-82.2	-85.7	**4.26**

B.M. at joint at base with and without P-delta effect (20 storey building

Deflection at top:

Sr. No.	Load Case	Deflection at top(mm)		
		Without P-delta	With P-delta	% Difference
1)	1.2 (DL + LL + EQX)	73.4	76.6	**4.36**
2)	1.2 (DL + LL – EQX)	-62.9	-64	**1.75**
3)	1.2 (DL + LL + EQY)	105.3	115.6	**9.78**
4)	1.2 (DL + LL – EQY)	-103.24	-113.43	**9.87**
5)	1.5(DL + EQX)	91.5	95.8	**4.70**
6)	1.5(DL - EQX)	-78.9	-80.6	**2.15**
7)	1.5(DL + EQY)	131.5	146.3	**11.25**
8)	1.5(DL - EQY)	-129.17	-143.85	**11.36**
9)	0.9DL + 1.5EQX	89	91.5	**2.81**
10)	0.9DL - 1.5EQX	-81.4	-82.5	**1.35**
11)	0.9DL + 1.5EQY	131.05	139.55	**6.49**
12)	0.9DL - 1.5EQY	-129.6	-138.06	**6.53**

Deflection at joint at top storey with and without P-delta effect (20 storey building)

B.M. of members at different storey levels:-B.M. in members with and without P-delta effect (20 storey building)

Storey no.	B.M. (KNm)	Load case No.					
		7	8	9	10	11	12

5	Initial	50.1	-75.6	105.4	-126.9	55.2	-70.5
	With P-delta	60.4	-85.7	109.0	-129.5	61.1	-76.1
	%	**20.7**	**13.5**	**3.4**	**2.1**	**10.7**	**8.1**
10	Initial	33.4	73.1	93.4	-120.2	41.1	65.0
	With P-delta	40.4	80.3	96.7	-122.2	45.3	69.1
	%	**20.8**	**9.8**	**3.5**	**1.7**	**10.2**	**6.3**
15	Initial	24.1	57.5	-59.0	91.5	13.2	47.8
	With P-delta	22.1	59.4	-61.0	92.1	12.1	49.0
	%	**-8.3**	**3.3**	**3.4**	**0.7**	**-8.4**	**2.4**
20	Initial	-18.6	-16.1	-3.4	30.2	-11.6	-9.2
	With P-delta	-19.7	-14.8	-3.9	30.0	-12.3	-8.4
	%	**6.1**	**-8.4**	**12.6**	**-0.9**	**5.5**	**-8.5**

B.M. in members with and without P-delta effect (20 storey building) continued

For 25 storey building:-

B.M. at base:

Sr. No.	Load Case	B.M. at base (KNm)		
		Without P-delta	With P-delta	% Difference
1)	1.2 (DL + LL + EQX)	-234.4	-240.7	**2.69**
2)	1.2 (DL + LL – EQX)	183.9	187.52	**1.97**
3)	1.2 (DL + LL + EQY)	83.79	87.9	**4.91**
4)	1.2 (DL + LL – EQY)	-80.5	-84.7	**5.22**
5)	1.5(DL + EQX)	-290.16	-298.9	**3.01**
6)	1.5(DL - EQX)	232.8	238.17	**2.31**
7)	1.5(DL + EQY)	104.72	110.58	**5.60**
8)	1.5(DL - EQY)	-100.64	-106.68	**6.00**
9)	0.9DL + 1.5EQX	-278.68	-283.64	**1.78**
10)	0.9DL - 1.5EQX	244.26	247.7	**1.41**
11)	0.9DL + 1.5EQY	103.9	107.25	**3.22**
12)	0.9DL - 1.5EQY	-101.45	-105.04	**3.54**

B.M. at base with and without P-delta effect (25 storey building)

Deflection at top:

Sr. No.	Load Case	Deflection at top(mm)		
		Without P-delta	With P-delta	% Difference
1)	1.2 (DL + LL + EQX)	104.45	110.54	**5.74**
2)	1.2 (DL + LL – EQX)	-84.6	-86.8	**2.6**
3)	1.2 (DL + LL + EQY)	138.66	155.09	**11.85**
4)	1.2 (DL + LL – EQY)	-136.2	-152.45	**11.94**
5)	1.5(DL + EQX)	130	138.51	**6.55**
6)	1.5(DL - EQX)	-106.22	-109.65	**3.23**
7)	1.5(DL + EQY)	173.18	196.87	**13.68**
8)	1.5(DL - EQY)	-170.38	-193.86	**13.78**
9)	0.9DL + 1.5EQX	125.3	130.19	**3.90**
10)	0.9DL - 1.5EQX	-111	-113.12	**1.91**
11)	0.9DL + 1.5EQY	172.62	186.07	**7.79**
12)	0.9DL - 1.5EQY	-170.94	-184.26	**7.79**

Deflection at joint at top storey with and without P-delta effect (25 storey building)

B.M. of members at different storey levels:-

Storey no.	B.M. (KNm)	Load case No.					
		1	2	3	4	5	6
5	Initial	82.79	-110.3	38.67	-71.76	101.18	-137.1
	With P-delta	88.65	-114.3	45.04	-78.4	112.43	-143
	%	**7.08**	**3.63**	**16.47**	**9.25**	**11.12**	**4.24**
10	Initial	69.51	-111.4	29.56	67.54	88.24	-137.9
	With P-delta	75.31	-115.1	39.01	76.16	96.39	-143.3
	%	**8.34**	**3.26**	**31.97**	**12.76**	**9.24**	**3.87**
15	Initial	53.38	-95.24	16.27	-59.92	68.24	-117.9
	With P-delta	58.09	-97.85	21.14	-64.96	74.81	-121.4
	%	**8.82**	**2.74**	**29.93**	**8.41**	**9.63**	**2.93**
20	Initial	29.65	56.88	12.77	-42.06	-37.97	70.19
	With P-delta	32.38	57.27	11.18	-43.2	-41.7	70.91
	%	**9.21**	**0.69**	**-12.45**	**2.71**	**9.82**	**1.03**
25	Initial	-7.61	29.84	-19.72	-16.74	-8.42	36.06
	With P-delta	-6.97	29.32	-20.6	-15.58	-7.6	35.42
	%	**-8.41**	**-1.74**	**4.46**	**-6.93**	**-9.74**	**-1.77**

B.M. in members with and without P-delta effect (25 storey building)

(30 storey building)

Storey no.	B.M. (KNm)	Load Case No.					
		7	8	9	10	11	12
5	Initial	49.7	-88.28	110.77	-130.6	57.46	-80.58
	With P-delta	58.98	-97.82	115.57	-134	62.76	-88.97
	%	**18.67**	**10.81**	**4.33**	**2.67**	**9.22**	**10.41**
10	Initial	38.8	82.46	98.18	-128	47.42	73.39
	With P-delta	52.51	95.03	102.91	-131.2	55.08	80.4
	%	**35.34**	**15.24**	**4.82**	**2.52**	**16.15**	**9.55**
15	Initial	22.43	-72.82	78.18	-107.6	32.5	-62.74
	With P-delta	29.45	-80.06	81.97	-110.1	36.5	-66.84
	%	**31.30**	**9.94**	**4.85**	**2.34**	**12.31**	**6.53**
20	Initial	15.5	-50.43	-44.42	63.75	10.45	-40.44
	With P-delta	12.94	-52.03	-46.55	64.24	11.17	-41.39
	%	**-16.52**	**3.17**	**4.80**	**0.77**	**6.89**	**2.35**
25	Initial	-22.86	-19.15	-1.81	27.49	-14.46	-10.74
	With P-delta	-24.18	-17.5	-2.4	27.13	-15.18	-9.77
	%	**5.77**	**-8.62**	**32.60**	**-1.31**	**4.98**	**-9.03**

B.M. in members with and without P-delta effect (25 storey building) continued

For 30 storey building:-

B.M. at base:

Sr. No.	Load Case	B.M. at base (KNm)		
		Without P-delta	With P-delta	% Difference
1)	1.2 (DL + LL + EQX)	-255.84	-264.13	**3.24**
2)	1.2 (DL + LL – EQX)	204.75	209.59	**2.36**
3)	1.2 (DL + LL + EQY)	105.19	110.29	**4.85**
4)	1.2 (DL + LL – EQY)	-101.63	-106.83	**5.12**
5)	1.5(DL + EQX)	-316.97	-328.49	**3.63**
6)	1.5(DL - EQX)	258.77	266.05	**2.81**
7)	1.5(DL + EQY)	131.49	138.78	**5.54**
8)	1.5(DL - EQY)	-127.04	-134.55	**5.91**
9)	0.9DL + 1.5EQX	-305.33	-311.86	**2.14**
10)	0.9DL - 1.5EQX	270.4	275	**1.70**
11)	0.9DL + 1.5EQY	130.6	134.75	**3.18**
12)	0.9DL - 1.5EQY	-127.9	-132.37	**3.49**

B.M. at base with and without P-delta effect

Storey no.	B.M. (KNm)	Load case No.					
		1	2	3	4	5	6
5	Initial	88.02	-116.6	39.23	-77.13	110.75	-145
	With P-delta	95.27	-121.6	44.94	-83.31	121	-152.3
	%	**8.24**	**4.30**	**14.56**	**8.01**	**9.26**	**5.03**
10	Initial	78.87	-119.7	25.43	-77.32	100.03	-148.2
	With P-delta	86.28	-124.8	32.5	-84.09	110.5	-155.6
	%	**9.40**	**4.20**	**27.80**	**8.76**	**10.47**	**4.96**
15	Initial	64.74	-112.3	25.66	74.43	82.65	-138.6
	With P-delta	71.55	-116.3	35.42	84.18	92.24	-144.7
	%	**10.52**	**3.56**	**38.04**	**13.10**	**11.60**	**4.34**
20	Initial	47.74	92.06	12.23	62.92	61.38	113.31
	With P-delta	53.08	94.61	17.3	68.24	68.82	117.14
	%	**11.19**	**2.77**	**41.46**	**8.46**	**12.12**	**3.38**
25	Initial	-25.72	52.68	5.52	-43.3	-33.1	64.89
	With P-delta	-28.85	52.85	4.45	-44.48	-37.35	65.36
	%	**12.17**	**0.32**	**-19.38**	**2.73**	**12.84**	**0.72**
30	Initial	-8.65	28.28	-21.44	-18	-9.69	34.09
	With P-delta	-7.85	27.56	-22.35	-16.66	-8.67	33.21
	%	**-9.25**	**-2.55**	**4.24**	**-7.44**	**-10.53**	**-2.58**

Sr. No.	Load Case	Deflection at top(mm)		
		Without P-delta	With P-delta	% Difference
1)	1.2 (DL + LL + EQX)	131.65	141.01	**7.11**
2)	1.2 (DL + LL – EQX)	-108.32	-111.87	**3.28**
3)	1.2 (DL + LL + EQY)	170.72	192.64	**12.84**
4)	1.2 (DL + LL – EQY)	-167.78	-189.46	**12.92**
5)	1.5(DL + EQX)	164.2	177.16	**7.89**
6)	1.5(DL - EQX)	-135.76	-141.28	**4.07**
7)	1.5(DL + EQY)	213.23	245.06	**14.93**
8)	1.5(DL - EQY)	-209.9	-241.44	**15.03**
9)	0.9DL + 1.5EQX	158.51	166	**4.73**
10)	0.9DL - 1.5EQX	-141.45	-144.85	**2.40**
11)	0.9DL + 1.5EQY	212.5	230.4	**8.42**
12)	0.9DL - 1.5EQY	-210.57	-228.29	**8.42**

Deflection at top storey with and without P-delta effect (30 storey building)

B.M. of members at different storey levels:-

B.M. in members with and without P-delta effect (30 storey building)

Storey no.	B.M. (KNm)	Load case No.					
		7	8	9	10	11	12
5	Initial	50.6	-94.8	117.6	-138.1	59.45	-86
	With P-delta	58.9	-103.7	123.54	-142.6	64.24	-91.05
	%	**16.40**	**9.39**	**5.05**	**3.19**	**8.06**	**5.87**
10	Initial	34.17	-94.27	109.67	-138.6	46.19	-82.25
	With P-delta	44.49	-105.2	115.75	-143	52.04	-88.38
	%	**30.20**	**11.64**	**5.54**	**3.18**	**12.67**	**7.45**
15	Initial	34.4	90.61	93.85	-127.4	45.45	89.1
	With P-delta	48.74	104.92	99.39	-131.1	53.36	86.96
	%	**41.69**	**15.79**	**5.90**	**2.86**	**17.40**	**-2.40**
20	Initial	17.74	76.14	71.72	-102.7	29.26	64.35
	With P-delta	25.11	83.84	76.01	-104.9	33.4	68.69
	%	**41.54**	**10.11**	**5.98**	**2.14**	**14.15**	**6.74**
25	Initial	4.09	-51.7	-39.46	58.53	7.54	-40.66
	With P-delta	3.01	-53.34	-41.89	58.89	8.25	-41.64
	%	**-26.41**	**3.17**	**6.16**	**0.62**	**9.42**	**2.**
30	Initial	-24.84	-20.53	-1.66	25.6	-15.76	11
	With P-delta	-26.22	-18.64	-1.07	25.1	-16.5	10
	%	**5.56**	**-9.21**	**-35.54**	**-1.95**	**4.70**	**-9**

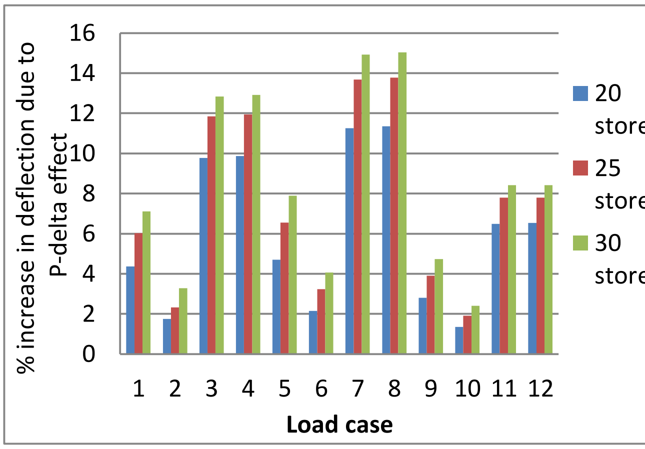
B.M. in members with and without P-delta effect (30 storey building) continued

RESULTS

Graphical Representation of % increase in deflection and B.M. values due to all load cases with and without P-delta effect:-

1) **Graph 1:-**

- Graph 1 represents % increase in deflection for various load cases for 20, 25 and 30 storey buildings.
- From graph, we can observe that increase in deflection is more as number of storey increased.
- Also, P-delta effect is more observed in load cases 3,4,7,8,11,12 (the cases in which earthquake load is in y-direction). So P-delta effect is more observed in y-direction.

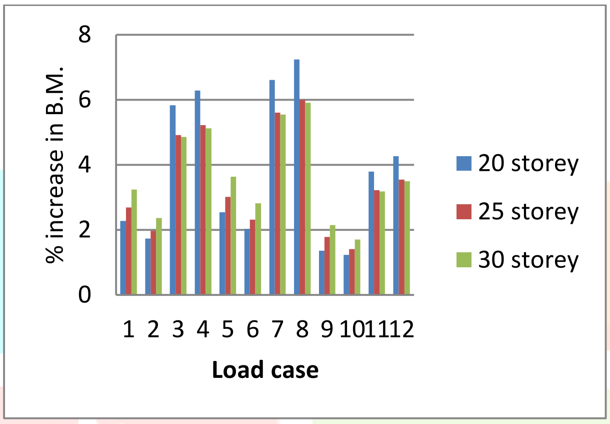


Graph 1: % increase in deflection due to P-delta effect for all load cases

Graph 2:-

- Graph 2 represents % increase in B.M. at base for various load cases for 20, 25 and 30 storey bu`dings.
- From graph, we can observe that increase in B.M. is in the range of 1-8% , so it is not considerable.

Here also, P-delta effect is more observed in load cases 3,4,7,8,11,12 (the cases in which earthquake load is in y-direction). So P-delta effect is more observed in y-direction. As the increase is less than 10%, it is not considerable.

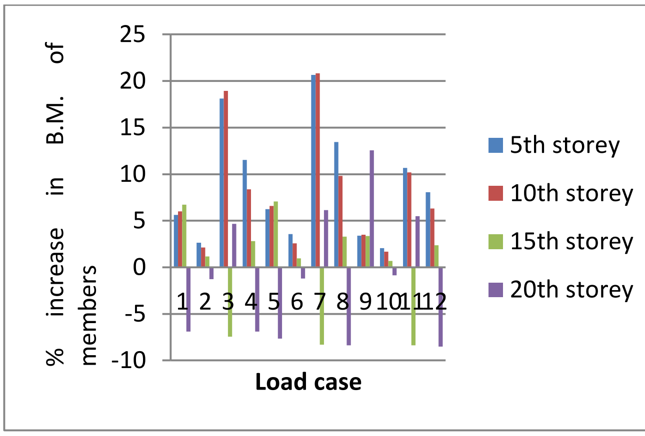


Graph 2: % increase in B.M. at base due to P-delta effect for all load cases

1) **Graph 3:-**

- Graph 3 represents % increase in B.M. of members at different storey levels for various load cases for 20 storey building.
- From graph, we can observe that increase in deflection is more for members at 5th and 10th storey levels as compared to 15th and 20th storey levels. Hence P-delta effect is more observed in bottom storeys.
- Decrease in B.M. is observed at top storeys.

Also, P-delta effect is more observed in load cases 3,4,7,8,11,12 (the cases in which earthquake load is in y-direction). So P-delta effect is more observed in y-direction

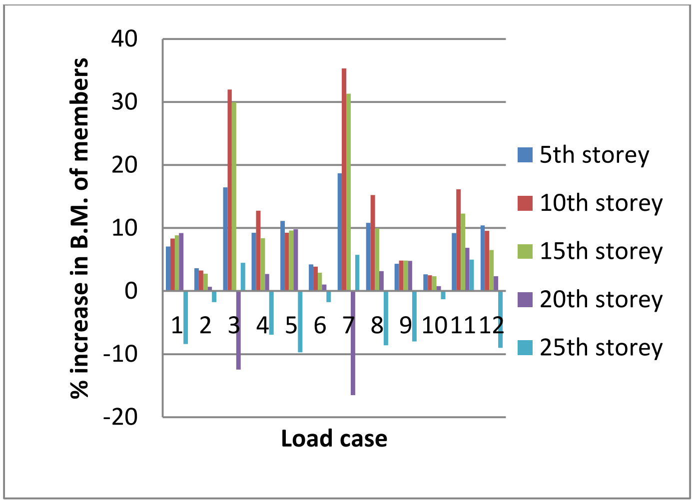


Graph 3: % increase in B.M. of members due to P-delta effect at different storey levels for all load cases (For 20 storey building)

Graph 4:-

- Graph 4 represents % increase in B.M. of members at different storey levels for various load cases for 25 storey building.
  - From graph, we can observe that increase in deflection is more for members at 5th , 10th and 15th storey levels as compared to 20th and 25th storey levels. Hence P-delta effect is more observed in bottom storeys but specially in 10th and 15th storey.
  - Decrease in B.M. is observed at top storeys.

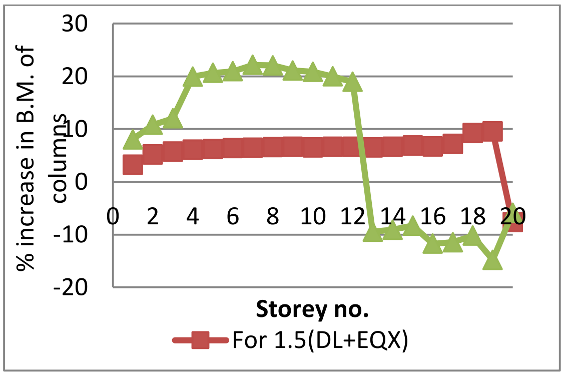
Also, P-delta effect is more observed in load cases 3,4,7,8,11,12 (the cases in which earthquake load is in y-direction). So P-delta effect is more observed in y-direction.



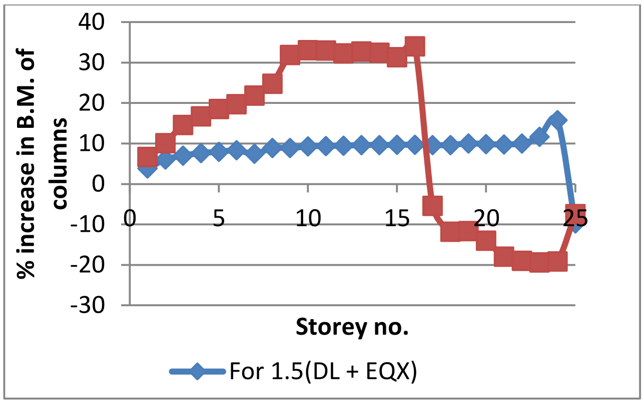
Graph 4: % increase in B.M. of members due to P-delta effect at different storey levels for all load cases (For 25 storey building)

2) Graph 5,6,7:-

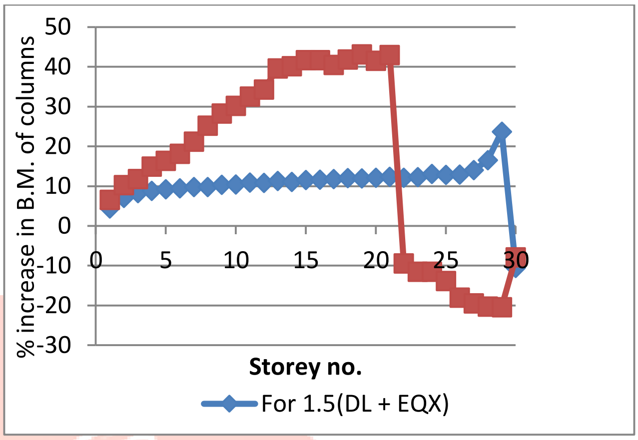
- Represent % increase in B.M. of columns due to P-delta effect at each storey level for load cases shown in graph for 20, 25 and 30 storey building.
- Load case no. 5 is 1.5(DL+EQX) and load case no. 7 is 1.5(DL+EQY).
- In 20 storey building, the increase is less than 10% for 5th load case and up to 22% for 7th load case. But their initial values are very small. So practically it is not necessary to consider P-delta effect.
- For 25 and 30 storey buildings, the increase is up to 15% and 20% respectively for load case 5 and up to 40% in load case 7. So considerable increase in B.M. of columns is observed in both the directions. So it is necessary to consider P-delta effect for 25 and 30 storey buildings.



Graph 5. % increase in B.M. of columns at each storey for load case 5 and 7 (20 storey building)



Graph 6 % increase in B.M. of columns at each storey for load case 5 and 7 (25 storey building)



Graph 7: % increase in B.M. of columns at each storey for load case 5 and 7(30 storey building)

Discussion:

1) For 20 storey building:-

1. Change in B.M. at base is 2-6%.
2. Change in the deflection is 1-11%.
3. Change in the B.M. of beams is less than 10%.
4. Change in the B.M. of columns 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 20 storey building, it is not necessary to consider P-delta effect. So building can be designed by performing 1st order analysis.

2) For 25 storey building:-

1. Change in B.M. at base is 2-4% .
2. Change in the deflection is 2-14%.
3. Change in the B.M. of beams which are parallel to y-direction is up to 15%.

4. Change in B.M. of columns is 8-30%. It is more observed at the exterior columns and their nearby beams. Also it is more observed at intermediate stories.
5. So P-delta effect is observed in some load cases for 25 storey building.
6. So it is necessary to consider P-delta effect while designing a 25 storey building.

3) For 30 storey building:-

1. Change in B.M. at base is 2-4%.
2. Change in the deflection is 3-15%.
3. Change in the B.M. of some beams is up to 15%.
4. Change in B.M. of some columns is 10-35%. It is more observed at the exterior columns and their nearby beams. Also it is more observed at intermediate stories.
5. So it is necessary to consider P-delta effect for designing a 30 storey building.

CONCLUSION :

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

- As number of storey increases P-delta effect becomes more important.
- 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 25 and 30 storey buildings and mostly in 30 storey building.
- So we can say that, at least it is necessary to check the results of analysis with and without considering P-delta effect for the buildings with 25 stories (height = 75m).
- Iterative P-delta analysis method is used. Building is by default analyzed for 10 numbers of iterations in SAP2000. But the same results are observed for single iteration also. So there is no change in the results by increasing the number of iterations.
- Also the analysis is performed by considering the seismic loading in other zones in India. Similar results are observed in the form of increase in internal forces.
- So we should perform P-delta analysis for designing a minimum of 25 storey building considering seismic loads. And buildings up to 25 stories can be designed by conventional primary analysis or linear analysis.
- This conclusion is valid for RCC residential buildings for seismic loading in all the zones in India and may not be applicable for commercial, educational or industrial buildings.

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Author No. 1 : Mr. S.A. Bhosale.

Email. sagarbhosale09.sb@gmail.com

Author No.2 : Prof. S. B. Tanwade.

Email : shritanwade@rediffmail.com

Author No. 3 : Prof. R. R. Badeghar

Author No. 4 : Prof. A. G. Dhanashett