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Analysis of Multistory RCC Structures Using P-Delta

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ABSTRACT

In developing countries like India, population is a major issue that challenges the development of the nation especially in cities where very few land is left for construction purpose. To cater the need of the population in the existing habitable area it is the only option to construct high rise buildings that can house large number of people on a very small piece of land. But again, India is a developing country where construction of such high-rise building is a big challenge and their performance during earthquakes is a serious matter of concern. Most of the structural engineers follow traditional methods like first order analysis to construct tall buildings but that result in serious damage and collapse of buildings during earthquake. So, there is a need of modern techniques that are second order analysis like P-Delta analysis that provide better insight of the structure's performance and behavior. Due to the complex nature and lack of knowledge of P-Delta effect engineers usually neglect this. In this thesis five models of 10 str, 15 str, 20 str, 25 str, and 30 str. buildings are taken for designing and the effect of P-Delta is observed analyzed and concluded. For the analysis SAP 2000 V 20.0.0 is used. After analysis results are chosen at selected sections and locations to examine the difference of results obtained. For the buildings in which displacement, axial forces, shear force, moment, and stresses exceeded the requirements laid as per the codal provision are redesigned. For redesigning there are two methods first is to increase the load bearing capacity of structure and the second is to increase lateral stiffness of the structure here structural stiffness is increased by providing beam column joint with end length offset assigned to frame at rigid zone factor 1. While using P-Delta analysis NSA (Non- Linear Static Analysis) is used. This thesis focus on the importance of P-delta effect for high rise RCC structures especially in areas having high risk of earthquakes.

Keywords:- P-delta, RCC, Earthquake, Multistory Building.

1. INTRODUCTION

There are broadly two common procedures of structural analysis namely, first order analysis and second order analysis. First order analysis is a kind of analysis in which the deformed shape of a structure due to applied loads are not considered to determine the behavior of the structure, this analysis includes conventional methods like moment distribution, slope deflection, stiffness methods etc. On the other hand, second order analysis like P-Delta analysis, pushover analysis includes stresses that generates due to the deformation of the tall structure in the presence of applied loads. In this analysis the changes occurred in the geometric property and strength of a structure due to axial load is also taken into account. In this method calculations are iterated according to the deformed shape again and again till convergence is reached. For stability design of structures 2^{nd} order analysis is used. In first order analysis we get smaller values of stresses and hence sections are provided according to that values that are lower than the actual values, therefore lighter sections may result in side way collapse as shown in the figure below. But in second order analysis we are getting extra stress values by the additional moments generated due to axial loads, which are accurate values, so for these increased values we need to provide heavier sections or some arrangement which may increase the cost of construction but prove to be safer and perform better during earthquakes.

1.1 SCOPE OF THE PRESENT STUDY

In this research RCC moment resisting frames are created with different number of storeys (ranging from 10-30 storeys) and analyses with and without P- Delta effect by using SAP 2000 and the results obtained are carefully studied with the help of tables and graphs created in MS excel. Scope of this thesis is limited to only RCC frames and for the mentioned conditions provided in the next chapters. P-Delta effect considered here is analyses for only P- Large Delta and not for P-Small delta. Buildings are analyses as per IS 456- 2000 and seismic loading is taken as per IS 1893- 2016 and other parameters are taken default as per SAP 2000 V 20.0.0. unless specified. In building model having significant role of P- Delta, changes are made by increasing stiffness of members with proper arrangement of beam – column joint.

2. OBJECTIVES OF THE PRESENT STUDY

1. Theoretical study of P-Delta effect.

2. Modeling of 10, 15, 20, 25, 30 story R.C.C. buildings.
3. Linear static Analysis procedure is performed by using SAP 2000, to determine the seismic capacity of RCC structures.
4. Nonlinear static analysis (NSA) with P-Delta procedure is performed by using SAP 2000 to determine the seismic load carrying capacity of buildings.
5. To calculate the minimum height of the structure where the inclusion of P-delta effect is necessary.
6. To calculate the percentage change in the value of axial force, displacement, moment, stress and shear force with the consideration of P-Delta effect and without the consideration of P-Delta effect in structures.
7. For models with significant changes in P-Delta effect redesign is carried out to bring the displacement and other stresses values within the acceptable limit according to the IS1893- 2002 by improving lateral stiffness.

3. P-DELTA EFFECT

P-Delta is a type of second order effect which is also known as geometric nonlinearity. It is coined by two terms 'P' and 'Δ' (Delta), where P is applied axial load and Δ is horizontal displacement due to lateral force. Now due to the horizontal displacement the load P is now an eccentric load which will now create an 'additional moment'. Here lateral loads are mainly due to wind loads and seismic loads, since seismic loads are more dominant so this thesis work is limited for seismic loads only.

In the an example of a column of length L, axial load P, lateral load V and Δ is the horizontal displacement after the application of load V as shown in Figure 1 (b).

$$P\times\Delta = V\times L$$

$$\Delta = \frac{V\times L}{P}$$

In linear static analysis lateral deflection Δ is given by

$$\Delta = \frac{M\times L^2}{3EI} \quad \text{where Moment, } M = V\times L \quad \Delta = \frac{V\times L^3}{3EI}$$

Now, due to P-Delta effect there is secondary moment that is an additional moment

generated due to the deformed shape and its value is P × Δ.

Here additional moment is directly proportional to the applied axial load P which means increase in axial load will increase in the stresses generated in a structure due to P-Delta effect. In short more P means more drift. And lesser P will result in smaller impact of P-Delta effects. This behavior is illustrated in Appendix -II -Effect of displacement with change in axial load.

Now, overall moment due to initial loadings and with secondary effect is

$$\sum M = VL + P\Delta \quad \Delta NEW = \frac{\sum M\times L^2}{3EI}$$

$$\Delta NEW = \frac{(VL + P\Delta)\times L^2}{3EI} \quad \Delta NEW = \frac{V\times L^3}{3EI} \quad \frac{P\times\Delta\times L^2}{3EI} +$$

This additional term $\frac{P\times\Delta\times L^2}{3EI}$ signifies the presence of secondary effect whichwas absent in linear static analysis that clearly indicates that moment values are underestimated in linear static analysis. In the figure 1(c) the displacement up to point B is due to the term $\frac{V\times L^3}{3EI}$ which we get from linear static analysis and the displacement between point B & C is due to the term $\frac{P\times\Delta\times L^2}{3EI}$ which we get in addition to linear static analysis so this extra term is usually ignored which in turn result in lower strength building that collapse during earthquakes.

Linear static analysis - displacement - between points A &B (figure 1 c)

- value = $\frac{V \times L^3}{3EI}$

Nonlinear static analysis - displacement - between points A &C (figure 1 c)

- value = $\frac{V \times L^3}{3EI}$ + $\frac{P \times \Delta \times L^2}{3EI}$

4. COMPARISON OF RESULT AND REDESIGNING

The comparison between linear static and nonlinear static analysis is made to show that how P-Delta effect alters the structural response of a structure in the presence of applied vertical and lateral loads. Since, in seismic analysis the concept of strong column and weak beam is usually adopted so, comparison is made according to the behavior of exterior left columns present in the models. Values of displacement, axial force, shear force, moment and stress are taken at plane X-Z @ 10, because at this location the displacement values are highest. The column height is equal to storey height that is 3m (neglecting slab thickness).

a) Displacement values are taken at 0m with respect to the lower joint, its unit is m and absolute value is taken. It is taken at translation in direction1 i.e. U1.

b) Axial force values are all – ve having unit kN, and taken @ 3m with respect to the lower joint.

c) Shear force values, V2 are taken at major axis having unit kN and taken @ 3m with respect to the lower joint.

d) Moment values, M3 are taken at point where it is maximum either – ve or +ve and it is taken along major axis having unit kNm and taken @ 3m with respect to the lower joint.

e) Stress values are taken at S max having unit kN/m^2, and selected @ 3m with respect to the lower joint.

5. COMPARISON OF PARAMETERS BETWEEN LS AND PD FOR ALL MODELS

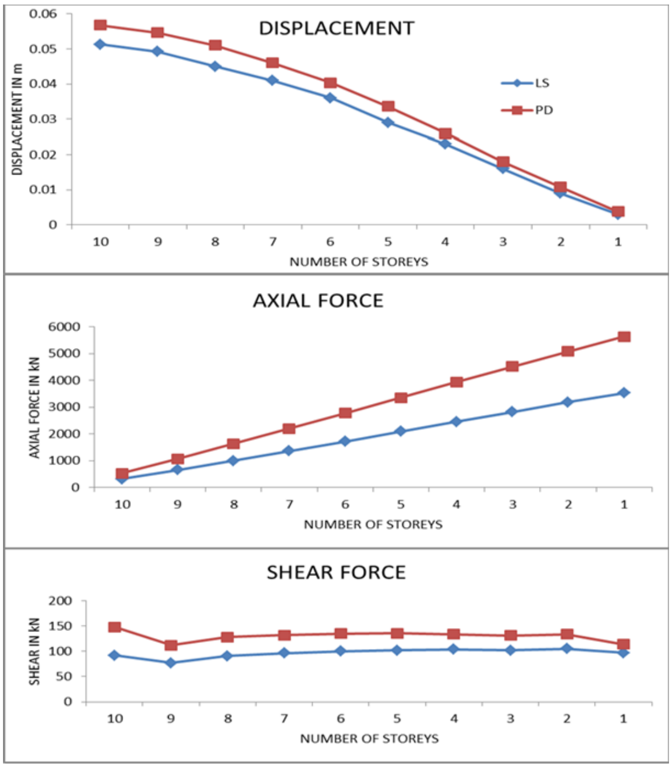


CHART 5.1 Comparison of displacement, axial force and shear force between linear static analysis (LS) and P-Delta analysis (PD) for 10 storey model.

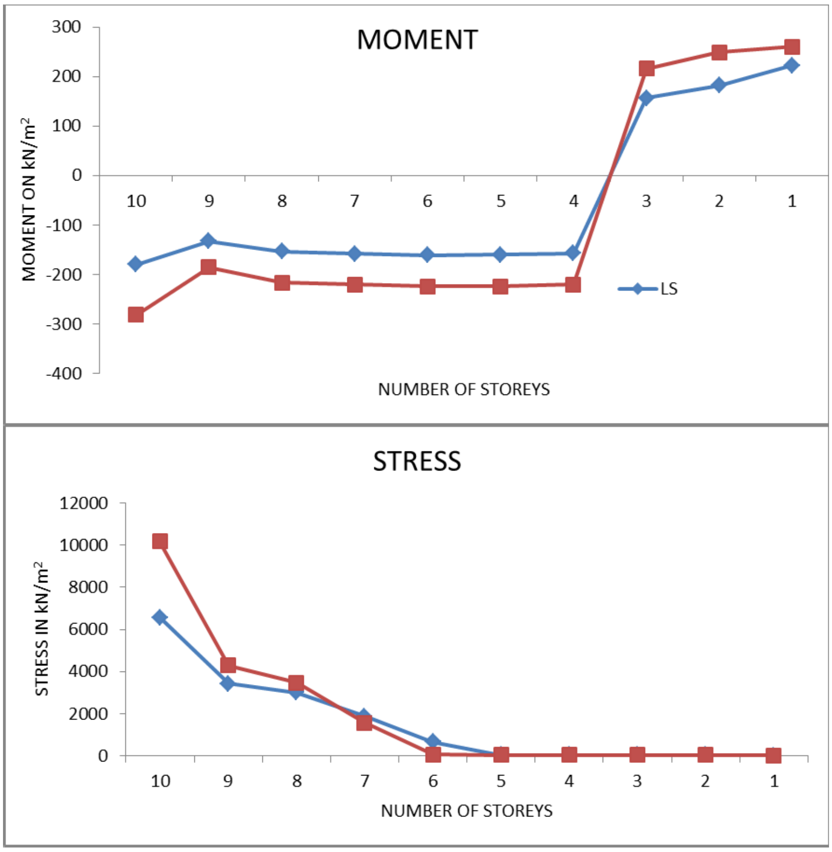
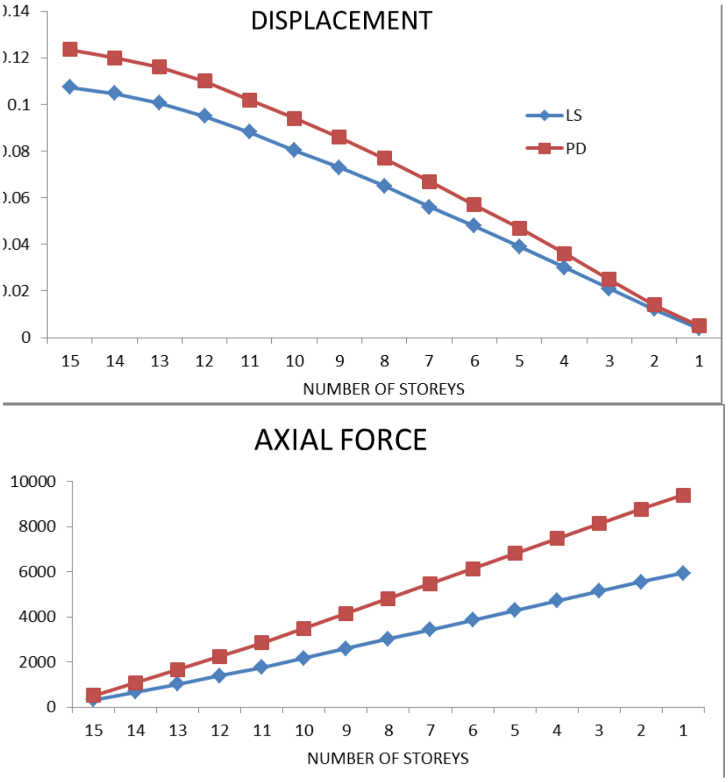


CHART 5.2 Comparison of moment and stress between linear static analysis (LS) and P-Delta analysis (PD) for 10 storey model.



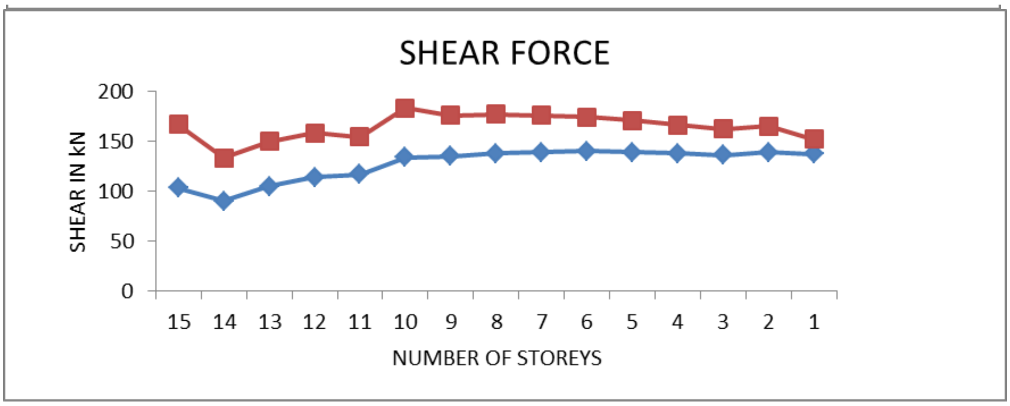


CHART 5.3 Comparison of displacement, axial force and shear between linear static analysis (LS) and P-Delta analysis (PD) for 15 storey model.

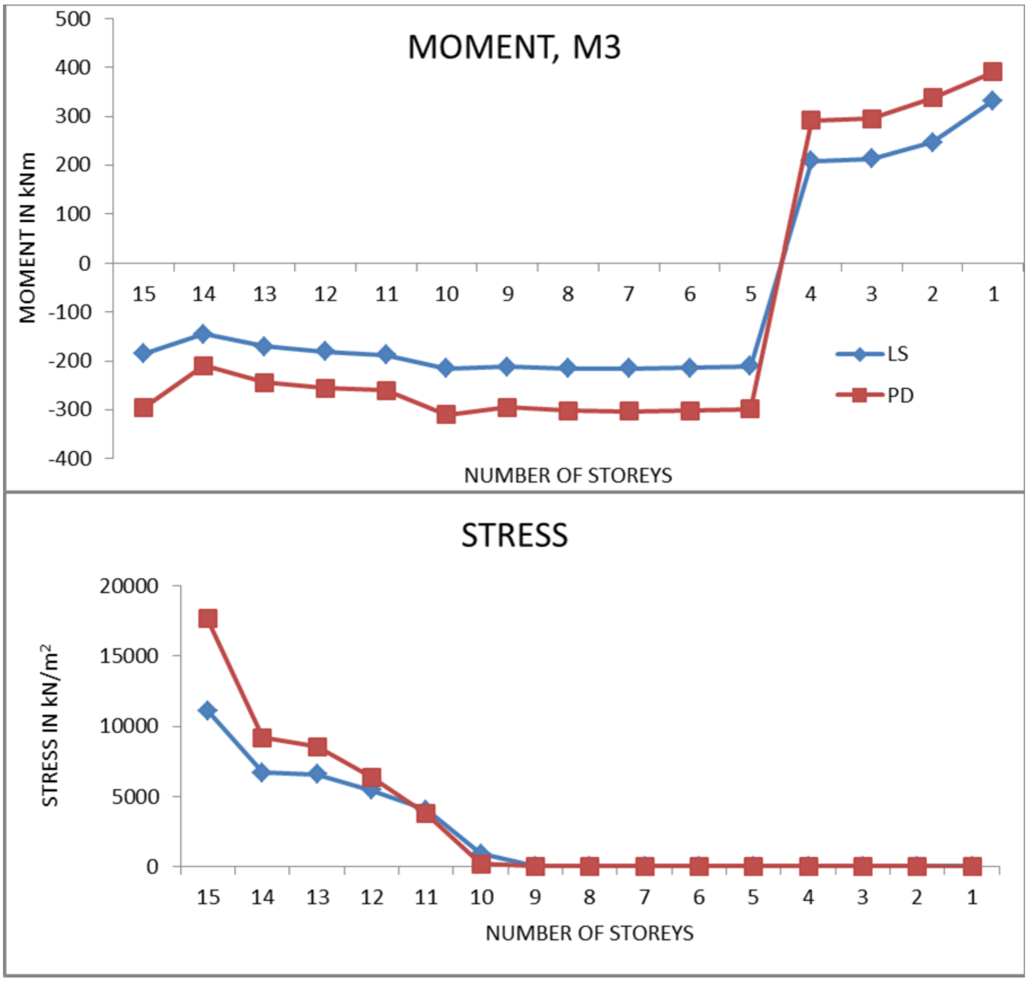


CHART 5.4 Comparison of moment and stress between linear static analysis (LS) and P-Delta analysis (PD) for 15 storey model.

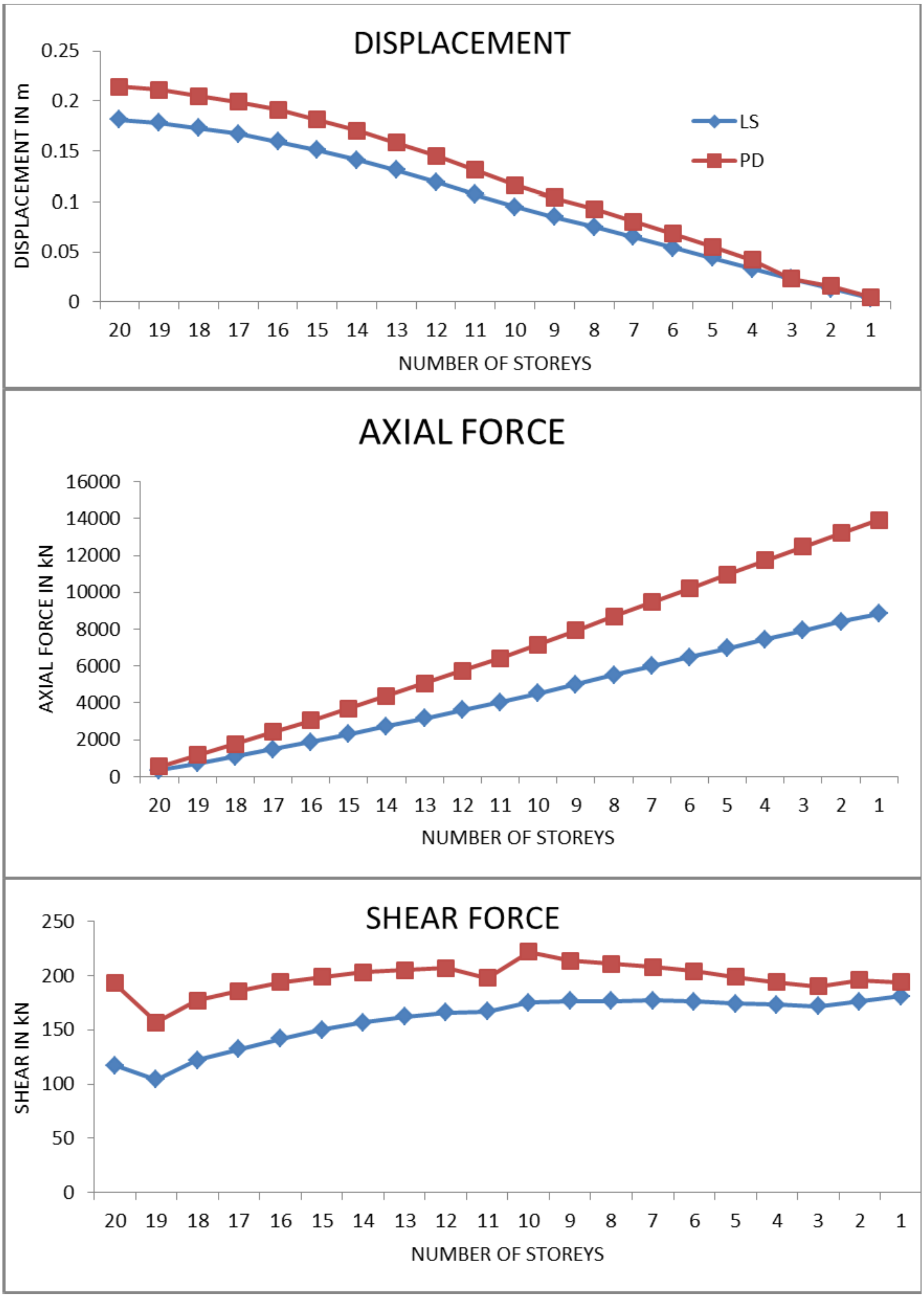


CHART 5.5 Comparison of displacement, axial force and shear force between linear static analysis (LS) and P-Delta analysis (PD) for 20 storey model.

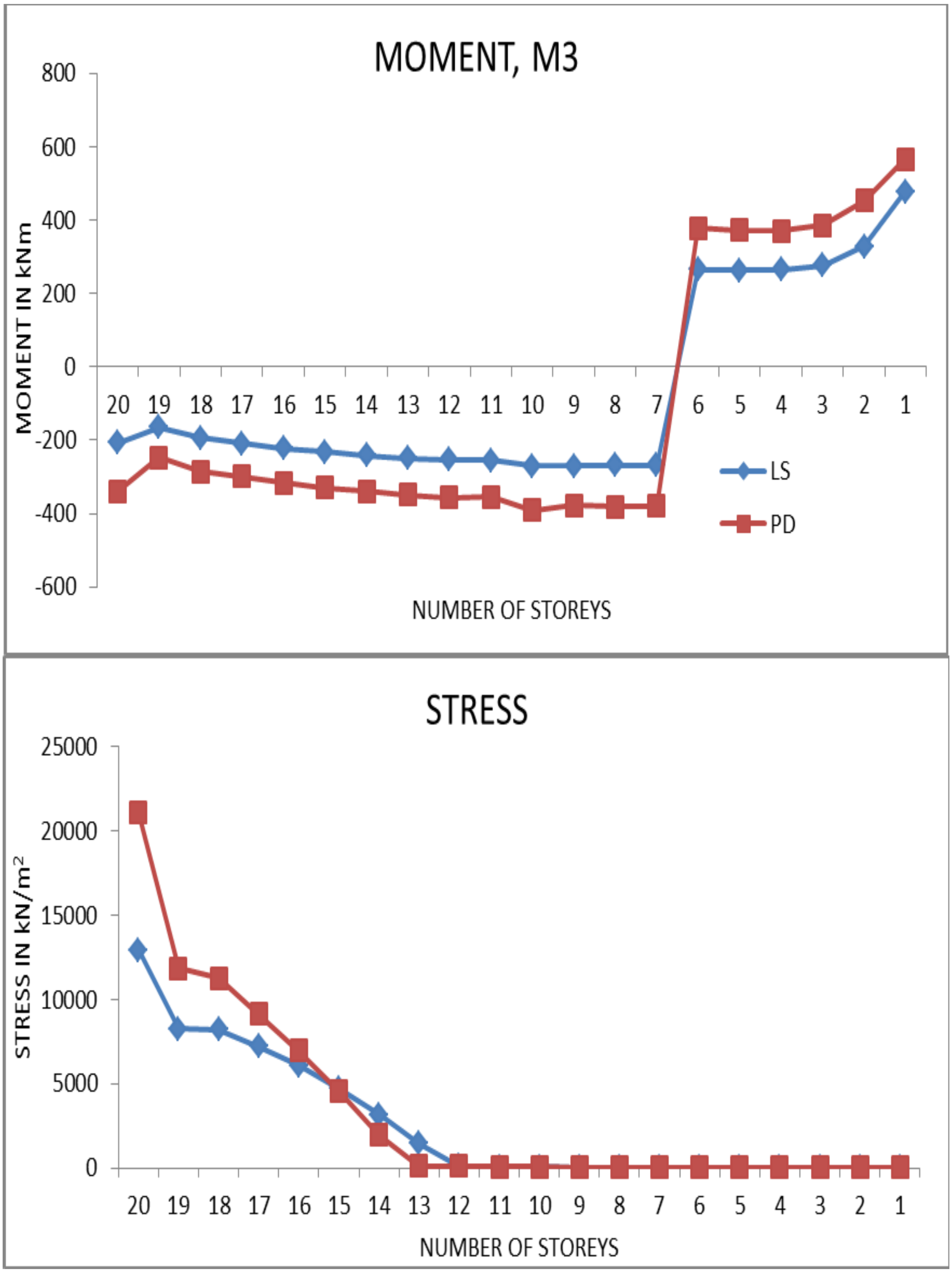


CHART 5.6 Comparison of moment and stress between linear static analysis (LS) and P-Delta analysis (PD) for 20 storey model.

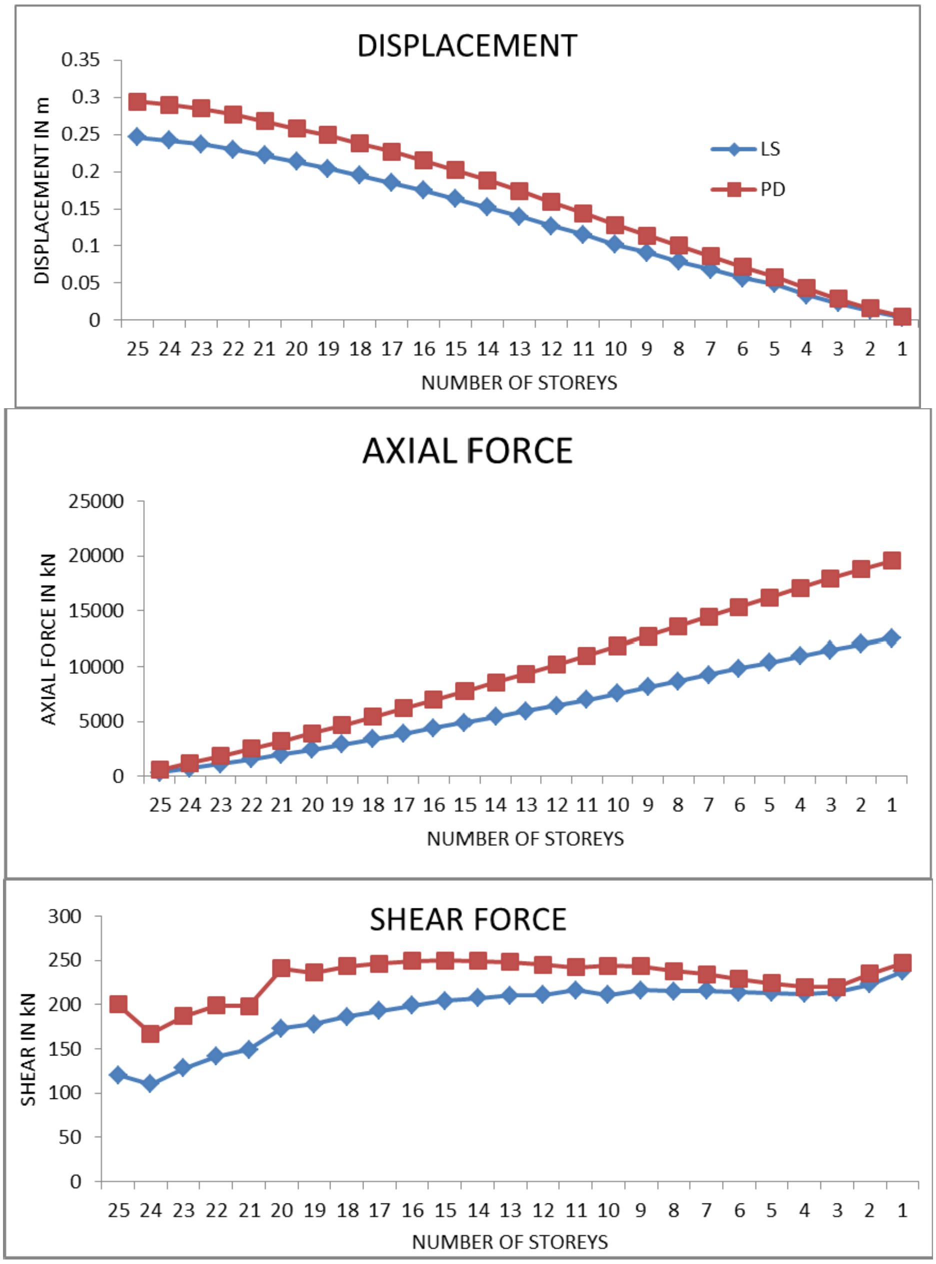
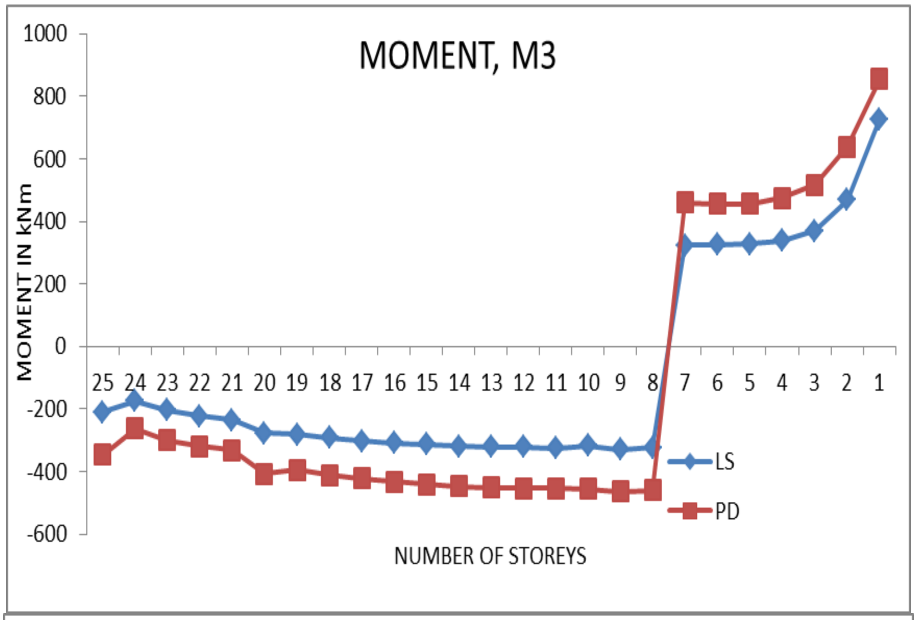


CHART 5.7 Comparison of displacement, axial force and shear force between linear static analysis (LS) and P-Delta analysis (PD) for 25 storey model.



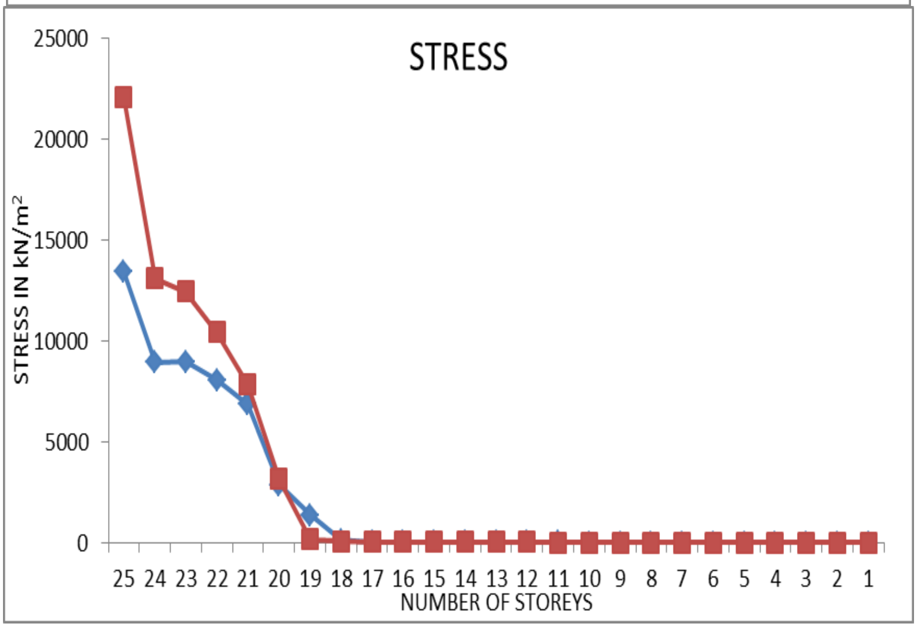


CHART 5.8 Comparison of moment and stress between linear static analysis (LS) and P-Delta analysis (PD) for 25 storey model.

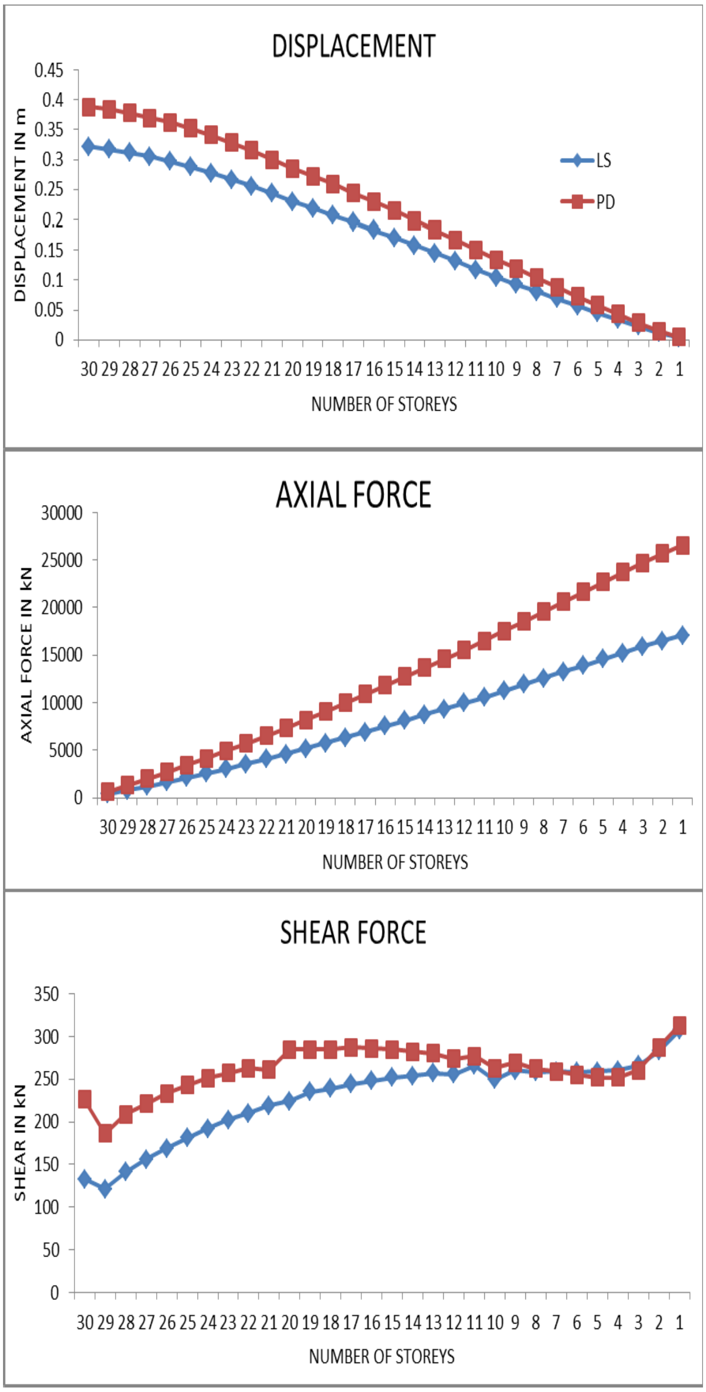


CHART 5.9 Comparison of displacement, axial force and shear force between linear static analysis (LS) and P-Delta analysis (PD) for 30 storey model.

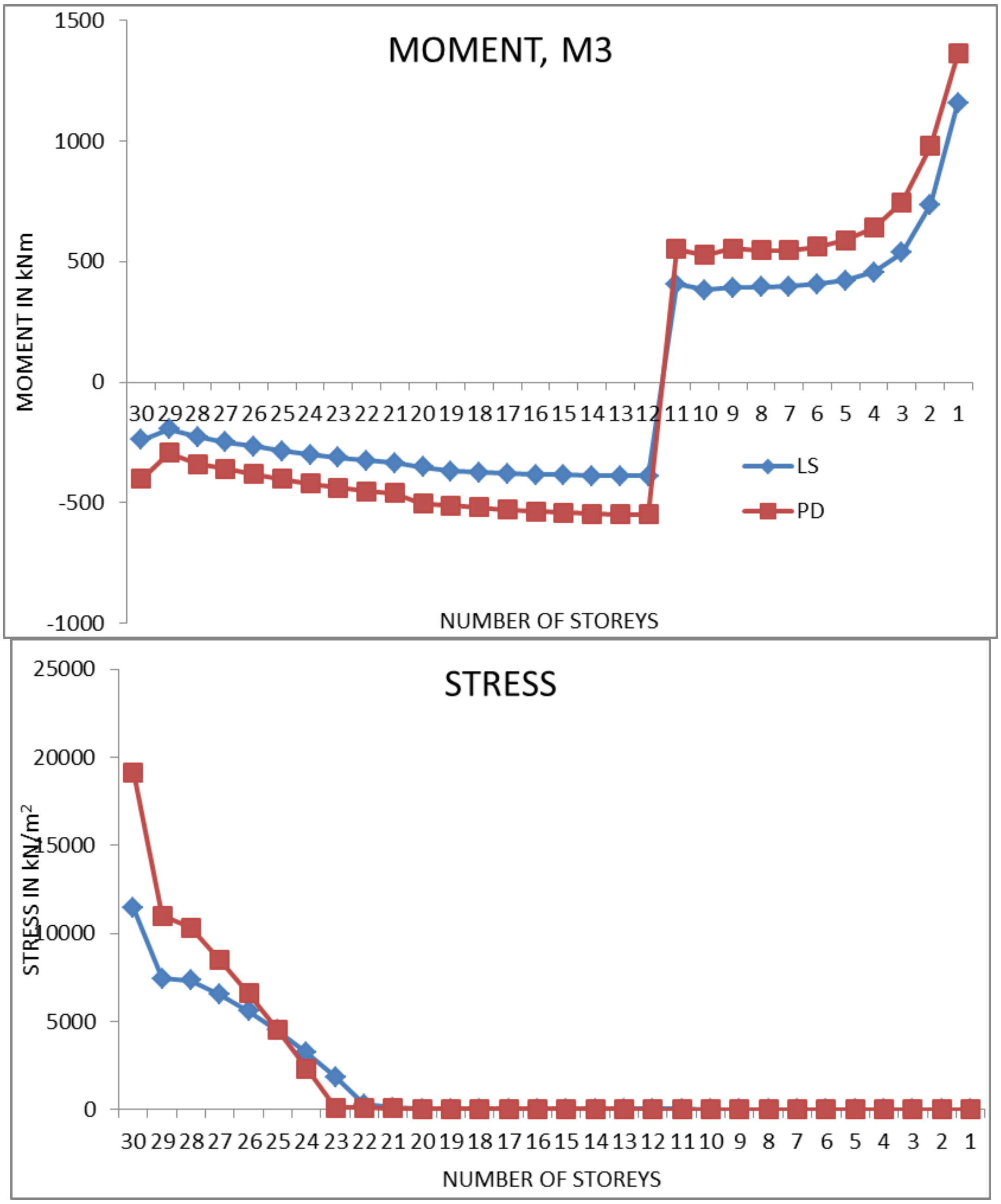


CHART 5.10 Comparison of moment and stress between linear static analysis (LS) and P-Delta analysis (PD) for 30 storey model.

5.1 REDESIGNING

All models have passed the design check according to IS load combination and LS load case is equivalent to IS load combination, but with that software check it is not clear that the structure is safe for PD load case. According to IS 1893 -2002 Clause

7.11.1 the storey drift should not exceed 0.04×storey height due to the lateral force with load factor 1. Here the storey height is 3m so storey drift should not exceed -

Max storey drift allowed = 0.004 ×3 m = 0.012m

Chart of storey drift is showing the maximum drift values and it is clear that 10, and 15 storey model are safe but 20, 25, 30 storey building have 0.015m, 0.016m, 0.017m storey drift respectively which is greater than 0.012m. It means they do not fulfill the codal requirement and there is a need to redesign. Now we have two methods of redesigning-

a) Increase the strength – This can be achieved by providing heavier cross section and/or increasing the grade of concrete and steel. But this result in increase in dead load and then axial load also, which in turn increase P-Delta effect so, this method is not used in the present study.

b) Increase the stiffness – It can be increased by various methods like bracing, shear walls, suitable damping system. In this work the stiffness is increased by providing beam - column joint with end length offset at rigid zone factor 1. Rigid zone factor =1 mans the joints are fully rigid. In SAP 2000 the steps followed to use this method are described below-

i) Select all frame members – click assign - frame- end (length) offset

ii) Select - end offset along length - automatic from connectivity then select- parameters - rigid zone factor =1, finally apply.

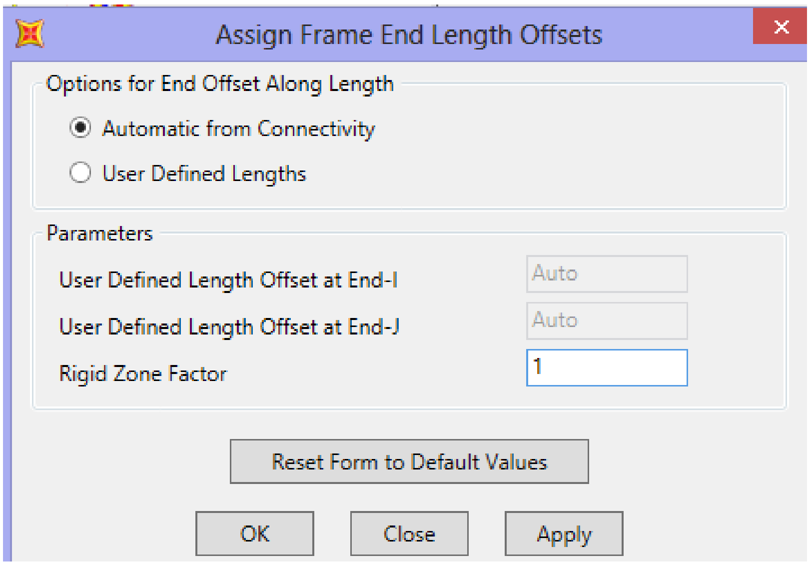


Figure 5.3 Beam column joint with end length offset used in SAP 2000

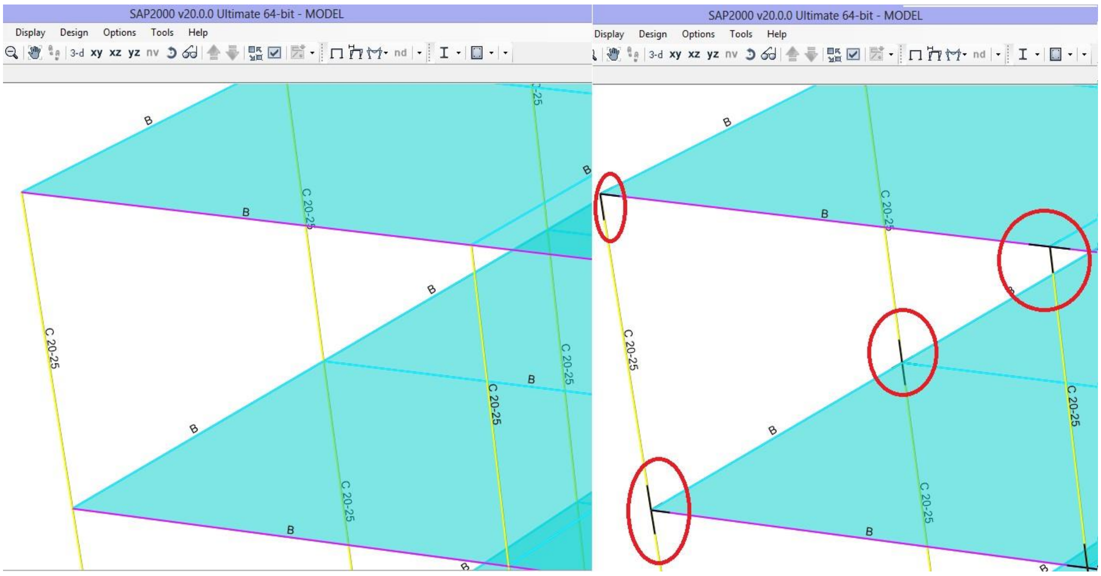


Figure 5.4 Showing screenshot of model without beam- column joint and with beam column joint with end length offset in red bubbles.

Table 5.16 Displacement and drift before and after redesigning for 20 storey model

STR.	DISPLACEMENT AFTER REDESIGNING	DRIFT AFTER REDESIGNING	DRIFT BEFORE REDESIGNING	PERCENTAGE DECREASE IN DRIFT AFTER REDESIGNING
20	0.151	0.003	0.003	0
19	0.148	0.004	0.006	-33.3333

18	0.144	0.005	0.006	-16.6667
17	0.139	0.006	0.008	-25
16	0.133	0.007	0.01	-30
15	0.126	0.008	0.011	-27.2727
14	0.118	0.009	**<u>0.012</u>**	-25
13	0.109	0.01	**<u>0.013</u>**	-23.0769
12	0.099	0.009	**<u>0.014</u>**	-35.7143
11	0.09	0.01	**<u>0.015</u>**	-33.3333
10	0.08	0.008	0.011	-27.2727
9	0.072	0.0085	**<u>0.012</u>**	-29.1667
8	0.0635	0.0085	**<u>0.013</u>**	-34.6154
7	0.055	0.009	**<u>0.012</u>**	-25
6	0.046	0.008	**<u>0.013</u>**	-38.4615
5	0.038	0.008	**<u>0.013</u>**	-38.4615
4	0.03	0.01	**<u>0.013</u>**	-23.0769
3	0.02	0.008	**<u>0.013</u>**	-38.4615
2	0.012	0.0076	0.011	-30.9091
1	0.0044	0.0044	0.005	-12

Table 5.17 Displacement and drift before and after redesigning for 25 storey model

STR.	DISPLACEMENT AFTER REDESIGNING	DRIFT AFTER REDESIGNING	DRIFT BEFORE REDESIGNING	PERCENTAGE DECREASE IN DRIFT AFTER REDESIGNING
25	0.203	0.003	0.004	-25
24	0.2	0.005	0.005	0
23	0.195	0.005	0.008	-37.5
22	0.19	0.007	0.009	-22.2222
21	0.183	0.007	0.009	-22.2222
20	0.176	0.009	0.011	-18.1818
19	0.167	0.006	0.01	-40
18	0.161	0.008	0.011	-27.2727
17	0.153	0.009	**<u>0.012</u>**	-25
16	0.144	0.009	**<u>0.013</u>**	-30.7692
15	0.135	0.01	**<u>0.014</u>**	-28.5714
14	0.125	0.01	**<u>0.014</u>**	-28.5714
13	0.115	0.01	**<u>0.015</u>**	-33.3333
12	0.105	0.01	**<u>0.015</u>**	-33.3333
11	0.095	0.011	**<u>0.016</u>**	-31.25
10	0.084	0.009	**<u>0.014</u>**	-35.7143
9	0.075	0.009	**<u>0.014</u>**	-35.7143
8	0.066	0.009	**<u>0.014</u>**	-35.7143
7	0.057	0.01	**<u>0.014</u>**	-28.5714
6	0.047	0.009	**<u>0.014</u>**	-35.7143
5	0.038	0.009	**<u>0.015</u>**	-40
4	0.029	0.009	**<u>0.014</u>**	-35.7143
3	0.02	0.0085	**<u>0.013</u>**	-34.6154
2	0.0115	0.0075	0.0107	-29.9065
1	0.004	0.004	0.0053	-24.5283

Table 5.18 Displacement and drift before and after redesigning for 30 storey model

STR.	DISPLACEMENT AFTER REDESIGNING	DRIFT AFTER REDESIGNING	DRIFT BEFORE REDESIGNING	PERCENTAGE DECREASE IN DRIFT AFTER REDESIGNING
30	0.26	0.004	0.004	0
29	0.256	0.005	0.006	-16.6667
28	0.251	0.005	0.008	-37.5
27	0.246	0.007	0.008	-12.5
26	0.239	0.007	0.01	-30
25	0.232	0.009	0.011	-18.1818
24	0.223	0.009	**0.013**	-30.7692
23	0.214	0.01	**0.013**	-23.0769
22	0.204	0.01	**0.015**	-33.3333
21	0.194	0.011	**0.015**	-26.6667
20	0.183	0.009	**0.013**	-30.7692
19	0.174	0.009	**0.013**	-30.7692
18	0.165	0.01	**0.015**	-33.3333
17	0.155	0.01	**0.014**	-28.5714
16	0.145	0.01	**0.015**	-33.3333
15	0.135	0.011	**0.016**	-31.25
14	0.124	0.01	**0.016**	-37.5
13	0.114	0.011	**0.016**	-31.25
12	0.103	0.011	**0.016**	-31.25
11	0.092	0.01	**0.017**	-41.1765
10	0.082	0.01	**0.015**	-33.3333
9	0.072	0.009	**0.015**	-40
8	0.063	0.009	**0.016**	-43.75
7	0.054	0.009	**0.015**	-40
6	0.045	0.009	**0.015**	-40
5	0.036	0.009	**0.015**	-40
4	0.027	0.009	**0.015**	-40
3	0.018	0.008	**0.013**	-38.4615
2	0.01	0.0065	0.0103	-36.8932
1	0.0035	0.0035	0.0047	-25.5319

Note- In the above three tables the values shown in column ‘ Drift before redesigning’ which are bold and underlined are the drift values which do not fulfill the maximum storey drift limit criteria laid by IS 1893 -2002. These highlighted values are > 0.012. Now after redesign the values in column ‘ Drift after redesigning’ adjoining the highlighted values are under 0.012, which means that the models are safe according to the storey drift limitation laid by the code.

After redesign the percentage decrease in storey drift are as follows-

20 storey - 12 to 38.5%

25 storey - 18 to 40%

30 storey - 12 to 37.5 %

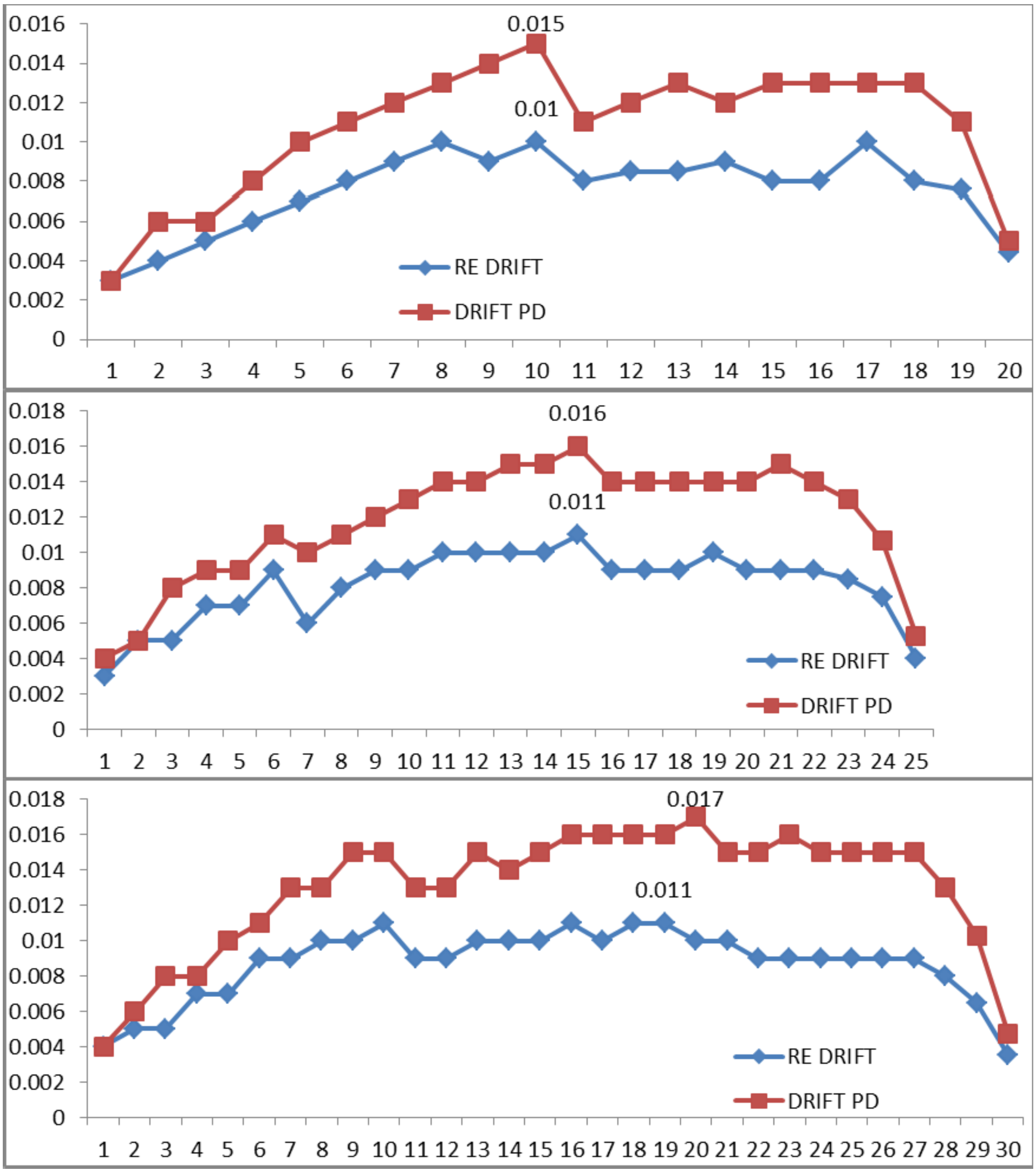


Chart 5.11 Showing decrease in storey drift for PD case of 20, 25, and 30 storey models after redesigning. X-axis showing no. of storeys and Y-axis showing storey Drift with indication of maximum drift value.

Here RE DRIFT means results after redesigning and DRIFT PD means results before redesigning. The charts show that after redesigning building by applying End Length Offset to the frame elements at rigid zone factor 1. From the above charts it is clear that now models are theoretically safe according to the limit laid by IS 1893- 2002 for storey drift. The 20 storey models was also designed at rigid zone factor =0.5 but that gave storey drift =0.012 at some location so for subsequent study rigid zone factor

=1 is adopted.

This redesigning chapter of this thesis is the up-gradation of various research works mentioned in the Literature Review section by various PG students, as they all have mentioned that P- Delta affects tall RCC structures significantly but none of them have mentioned the ways to counter this additional moment generated by this force, and in this thesis providing extra strength at beam – column joint provided the sufficient stiffness that balanced the structure and the building model' s performance improved in the EQ excitation force for zone V.

6. CONCLUSION AND FURTHER RESEARCH

6.1 CONCLUSION

From the result obtained after the study conducted it has been concluded that P- Delta effect is very crucial in the designing of earthquake resistant structures. In the conditions provided in the study models with 10 and 15 storeys are not so much influenced by P-Delta effect and it can be ignored for that type of models. But models with 20, 25 and 30 storeys must be designed for P-Delta effect because they are not safe as per the storey drift limitation laid by the IS 1893- 2002. Five parameters for the comparison are chosen and are summarized below.

6.1.1 Displacement

The percentage changes in displacement for the models are –

10 storey	-	10.72 %
15 storey	-	15 %
20 storey	-	18.2 %
25 storey	-	19.5 %
30 storey	-	20.7 %

6.1.2 Axial Force

The percentage changes in axial force for the models are –

10 storey	-	64.4 %
15 storey	-	65.4 %
20 storey	-	66 %
25 storey	-	67 %
30 storey	-	67.3 %

6.1.3 shear Force

The percentage changes in Shear force for the models are – 10 storey - 60.8 %

15 storey	-	62 %
20 storey	-	65.7 %
25 storey	-	67 %
30 storey	-	70 %

6.1.4 Moment

The percentage changes in Moment for the models are –

10 storey	-	56.7 %
15 storey	-	59.7%

20 storey - 63.5 %

25 storey - 64.5 %

30 storey - 67.4 %

6.1.5 Stress

The percentage changes in Stress for the models are –

10 storey - 55 %

15 storey - 58.9%

20 storey - 62.7 %

25 storey - 64 %

30 storey - 67 %

6.1.6 Storey Drift

The maximum Storey drift due to P-Delta analysis of all the models are given below-

10 storey - 0.008

15 storey - 0.009

20 storey - 0.013

25 storey - 0.016

30 storey - 0.017

Here, models of 20, 25 and 30 storey have storey drift greater than 0.012. So, they are redesigned and after providing beam-column joint with end length offset at rigid zone factor 1 the models with storey drift values are as follows-

20 storey - 0.01

25 storey - 0.011

30 storey - 0.011

Now, displacement values are within prescribed limit as per IS 1893 -2002.

6.2 FUTURE SCOPE

- To study the behavior of this effect studies can also be made for detailed building design including all types of load pattern and loads of non-structural components.
- The results obtained can also be compared with the same parameters but with change in geometric non-linearity as 'large P-Delta' instead of P-Delta. The results obtained with 'large P-Delta' will show negligible changes for buildings with lesser heights when compared with taller buildings.
- The study can also be made with irregular and asymmetric building with change in slenderness.
- Dynamic Nonlinear study i.e time history analysis can also be made to know the exact behavior of building with P-Delta effect but seismic analysis is made on various assumption and time history analysis is a very sensitive analysis in which even a minor assumption can alter the results significantly and results obtained will be just an approximate value.

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