Stability Analysis of Multi-Story Building with Underneath Satellite Bus Stand Having Intermediate Soft-Story and Floating Columns using P-Delta

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Abstract— The masonry infill walls are considered as non-structural element and their stiffness contribution are ignored in the analysis when building is subjected to seismic loads, but it is considered while we studying stability analysis. RC frame building with open ground storey, and similar soft storey effect can be observed when soft storey at different levels of structure are constructed. The method used for stability analysis of columns, shear walls, coupled and coupled components, cores, single storey and multi storey structures are studying. Buildings and structures are considering stable with lateral supports by using either bracing systems or shear system or both such as wall to ensure the stability of the building. One of the problems is affected from wind load. The calculation methods are computer assisted through the use of the software, ETAB. Comparisons of results are made between the methodologies, and different models with different parameters. This is how the soft storey effects are managed to overcome the future damages of the storied structures.

Key words: Satellite Bus Stop, Soft-Storey, Non-Linear Time History Analysis, P-Delta, Floating Columns

I. Introduction

Satellite bus stop is the new term that has come in the recent years in cities like Bengaluru because, due to increasing population and the land value since the past few years' bus stands in populated cities is a matter of major problem. So that constructions of multi-storeyed buildings with open first storey. Hence it has been utilizing for the moment of the buses and people can use this as bus terminals. These type of buildings having no infill walls in ground storey, but all upper storeys infilled with masonry walls. Soft storeys at different levels of structure are constructed for other purposes like lobbies conference halls and for the service storeys. This storey is known as weak storey because storey stiffness is lower compare to above storeys. So, importance to be given for the earthquake resistant design. Consideration of infill and shear walls and correct shape can improve the performance of the building in analysis.

II. Description of Structural Model

A. Geometry:

For the study, four different models of a 12 storey building are considered. The building has four bays in X direction with spacing of 11m and seven bays in Y direction with spacing of 7m. The plan dimension 44 m × 49 m. Typical storey height is 3.65 m for each floor up to intermediate soft storey their after that 3.2 m for remaining storeys and bottom soft-storey and intermediate soft-storeys are of height 7m and 3m respectively. Floating columns are used after intermediate soft story as shown in figure below. This geometry remains same throughout the study. The only influencing factor is change in the models and parameters, dimensions remains same. The column size decreases from Bottom to Top.

Column size	
From Storey 1 to Storey 6	1.5m x 0.6m
Storey 7 to Storey 10	1.2m x 0.8m
Storey 11 to Storey 15	0.8m x 0.4m
Floating columns	0.8m x 0.4m
Beam size	
From storey 1to storey7	0.4m x 0.8 m
Storey 7th in X direction	1m x 1m
Slab thickness	
Storey 1 to 7	0.150m
Storey 8 to 12	0.125m

Following 2 models are analyzed by equivalent static method, response spectrum method and Non-Linear Time History analysis using ETABS software.

Model 1: Bare frame model, however masses of brick masonry infill walls are included in the model with and without P-Delta option for equivalent static method, response spectrum method and Time history nonlinear analysis.

Model 2: Masonry frame model, however masses of brick masonry infill walls and stiffness are included in the model with and without P-Delta option for equivalent static method, response spectrum method and Time history nonlinear analysis.

B. Analysis Data:

Following data is used in the analysis of the RC frame building models for equivalent static method and response spectrum method.

C. Material Properties:

E for (M20) concrete = 25.00×10^6 KN/m²
E for (M30) concrete = 29.58×10^6 KN/m²
Density of RCC = 25kN/m³
E for brick masonry = 3500×10^3kN/m²
Density of brick masonry = 20kN/m³
Floor finishes = 1.5kN/m²
Live load intensities: = 4.0KN/ m²

D. Seismic Data:

(as per IS:1893-2002)
Zone factor (table 2) = 0.36(Zone–V)
Importance factor I (Table 6) = 1.5
Response reduction factor R (Table 7) = 5.0(SMRF)
Soil type (Figure 2) = Type II (Medium soil)

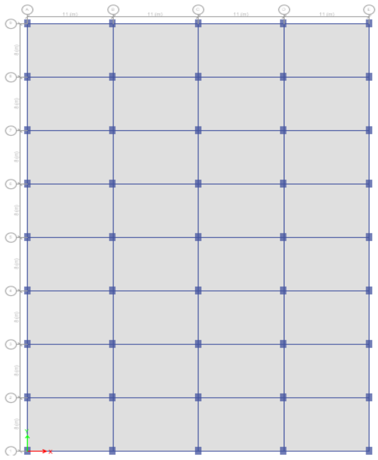
Fig. 1: Floor Plan up to intermediate soft-story

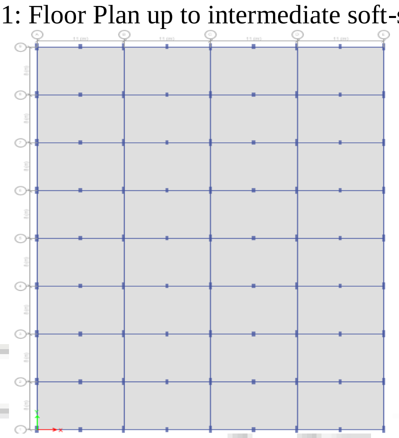
Fig. 2: Floor Plan after intermediate soft story

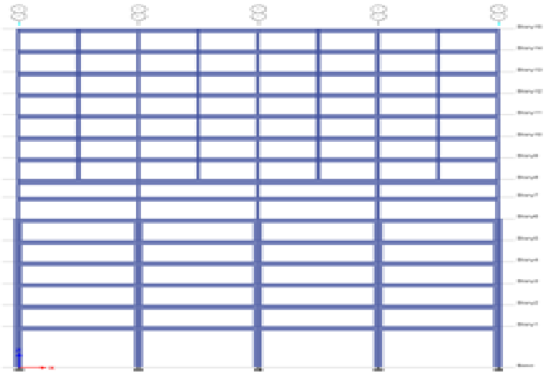
Fig. 3: Elevation of Building Model-1 along y-dir.

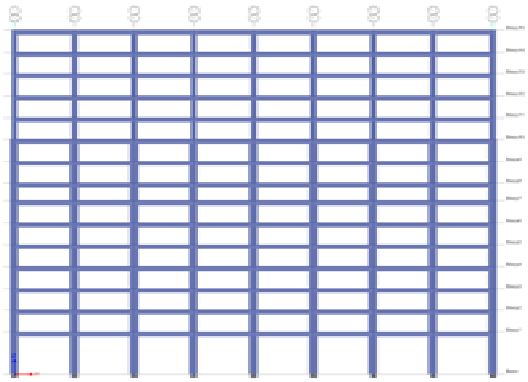
Fig. 4: Elevation of Building Model-1 along x-dir

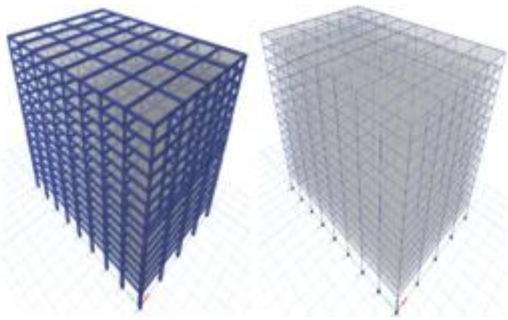
Fig. 5: 3D View of Model-1

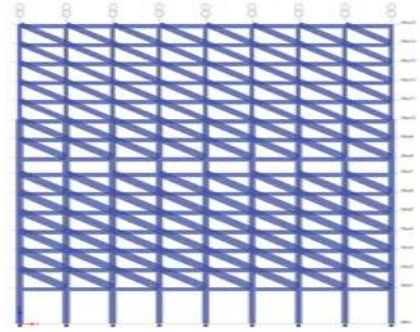
Fig. 6: Elevation of Building Model-2 along y-dir

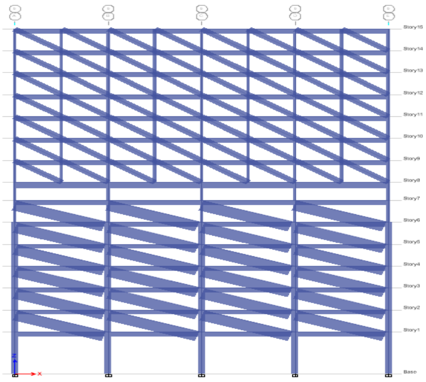
Fig. 7: Elevation of Building Model-2 along x-dir.

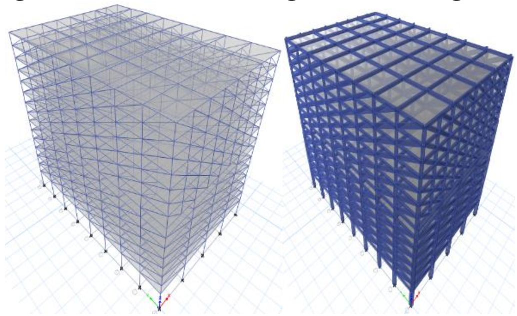
Fig. 8: 3D View of Model-2

III. RESULTS AND DISCUSSIONS

Most of the past studies on different buildings such symmetrical and unsymmetrical have adopted idealized structural systems without considering the effect of concrete shear and core walls. Although these systems are sufficient to understand the general behaviour and dynamic characteristics, it would be interesting to know how real building will respond to Earthquake forces and Wind forces. For this reason, a hypothetical building, located on a plane ground having similar ground floor plan have been taken as structural systems for the study.

In this chapter, the results of natural period of vibration, base shear, lateral displacements, storey drifts of different building models are presented and compared. An effort has been made to study the effect of shear wall both at Centre and corners on exterior side in longitudinal & transverse direction respectively.

A. Fundamental Natural Time Period:

Table 3.1 shows the time period and frequency obtained by ETABS without P-delta options for analysis, time period and frequency for model 2 reduces by 61.51% as compared to bare frame model-1. Model-1 with P-Delta increases time period by 5.45% as compared to model-1 without P-delta. Similarly, for model-2 with P-Delta increases by 2.47% as compared to model-2 without P-delta. From that it can be clear that the presence of p-delta in the building will increases the time period and decreases the frequency of the structure. From table 3.1.1 and chart 3.1.1 to 3.1.2 is obtained time period by ETABS analysis values are differing for different models. Thus it can be clearly understanding that, presence of brick infill wall stiffness considerably reduces the time period of building.

	PERIOD IN SEC		FREQUENCY IN CYC/SEC	
MODEL	Without P-Delta	With P-Delta	Without P-Delta	With P-Delta
1	3.266	3.444	0.306	0.290
2	1.257	1.288	0.796	0.776

Table 3.1: Fundamental natural time period and Frequency using ETABS software for various models.

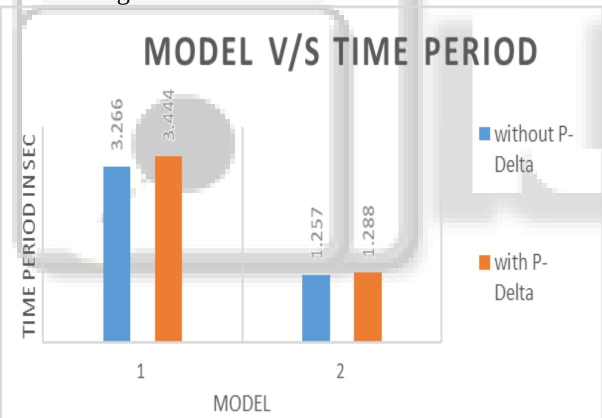

Fig. 9: Chart 3.1.2: Model Vs Time period for Different models without and with P-delta.

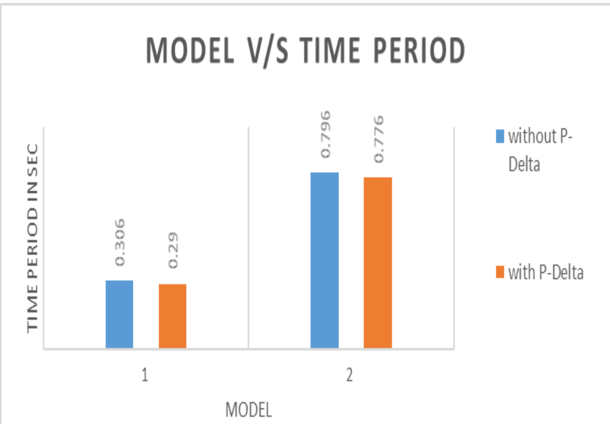

Fig. 10: Chart 3.1.2: Model Vs frequency for Different models without and with P-delta

B. Storey Drifts:

The permissible storey drift according to IS1893(part1)-2002 is limited to 0.004 times the storey height. The maximum storey drifts for various building models along longitudinal and transverse direction obtained from Non-linear time history analysis from ETABS are shown in tables below, from the table 3.2.1 to 3.2.2 and chart 3.2.1 to 3.2.4. From that it can be seen that the storey drift in all storey for model-1 has higher values as compare to that for model-2. The drift values gradually decrease from storey 1 to 15th storey in both directions. All the values of drift are within the limit as per IS:1893-2002 i.e., 0.004x3.5=0.014m, 0.004x3=0.012m and 0.004x7=0.028m.

Story No	Without P-Delta along X	With P-Delta along X	Without P-Delta along Y	With P-Delta along Y
1	0.002079	0.002235	0.002257	0.002178
2	0.002785	0.002998	0.003316	0.003170
3	0.002693	0.002931	0.003270	0.003163
4	0.002594	0.002735	0.003062	0.003081
5	0.002549	0.002413	0.002919	0.002918
6	0.002453	0.002270	0.002727	0.002775
7	0.003313	0.003099	0.002822	0.003080
8	0.002287	0.001945	0.002867	0.003066
9	0.001589	0.001347	0.003098	0.003226
10	0.001845	0.001574	0.003254	0.003335
11	0.001992	0.001709	0.003723	0.003789
12	0.001761	0.001563	0.003498	0.003527
13	0.001415	0.001355	0.002968	0.002959
14	0.000970	0.000971	0.002189	0.002163
15	0.000479	0.000480	0.001366	0.001340

Table 3.2.1: Comparison of Storey Drifts for with and without P-Delta Non-Linear Time History analysis of Model-1 in x and y-direction.

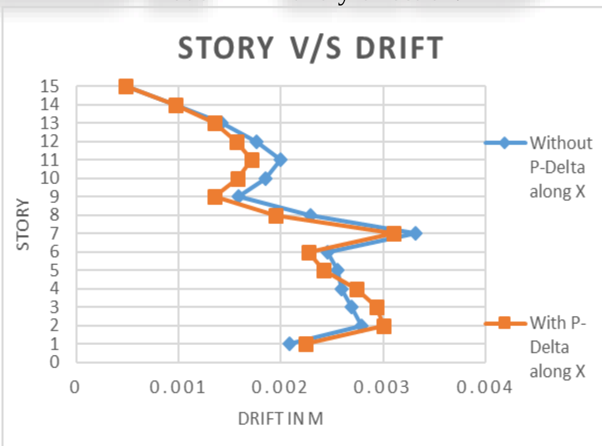

Fig. 10: Chart 3.2.1: Storey drift Vs. Storey for model-1 along X-direction by THNA with and without P-delta.

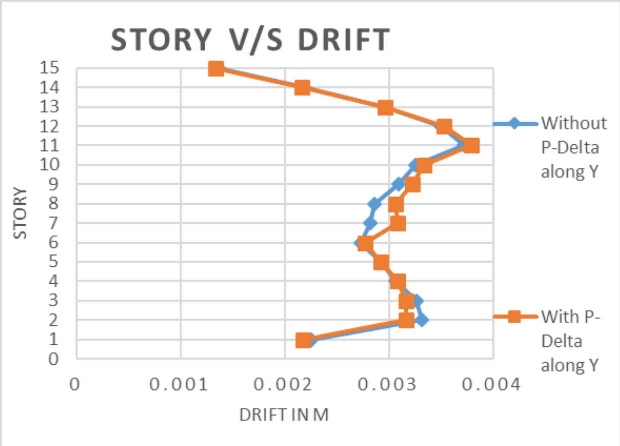

Fig. 11: Chart 3.2.2: Storey drift Vs Storey for model-1 along Y-direction by THNA with and without P-delta.

Story No	Without P-Delta along X	With P-Delta along X	Without P-Delta along Y	With P-Delta along Y
1	0.008407	0.008102	0.006174	0.006152
2	0.000627	0.000545	0.000691	0.000692
3	0.000426	0.000369	0.000368	0.000364
4	0.000403	0.000358	0.000348	0.000346
5	0.000392	0.000374	0.000311	0.000312
6	0.000409	0.000387	0.00031	0.000305
7	0.000423	0.000416	0.000341	0.000345
8	0.006916	0.006683	0.002136	0.002099
9	0.000302	0.000300	0.000436	0.000431
10	0.000291	0.000288	0.000318	0.000315
11	0.000287	0.000284	0.000295	0.000296
12	0.000277	0.000274	0.000265	0.000266
13	0.000268	0.000266	0.000247	0.000248
14	0.000262	0.000259	0.000233	0.000233
15	0.000258	0.000255	0.000228	0.000227

Table 3.2.2: Comparison of Storey Drifts for with and without P-Delta Non-Linear Time History analysis of Model-1 in x and y-direction.

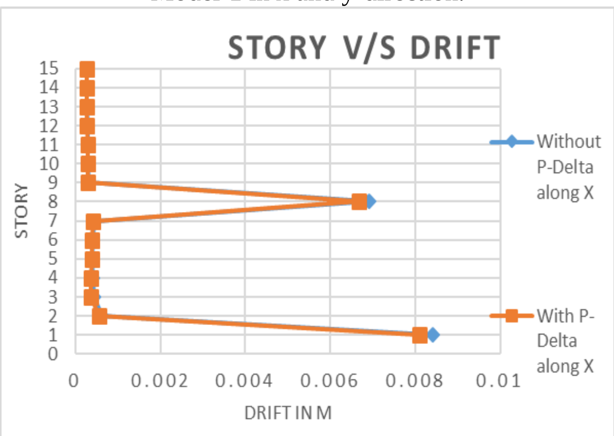

Fig. 12: Chart 3.2.3: Storey drift Vs Storey for model-2 along X-direction by THNA with and without P-delta.

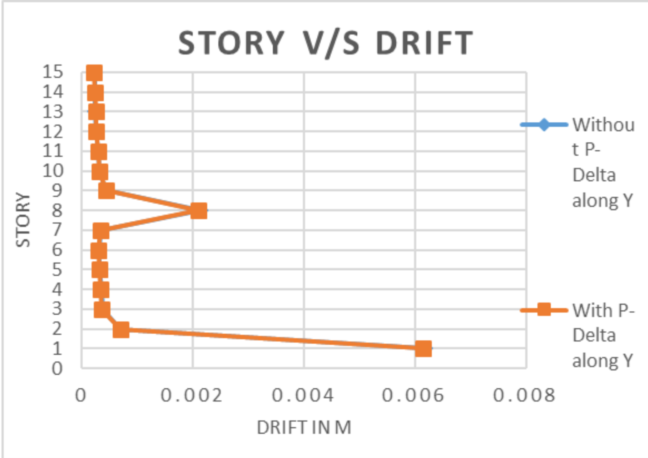

Fig. 13: Chart 3.2.4: Storey drift Vs Storey for model-2 along Y-direction by THNA with and without P-delta.

C. Storey Displacements:

The maximum displacement at each storey with respective to ground level are presented in tables obtained from Non-Linear Time history analysis for different models. To understand in a better way, the displacements for each model along the longitudinal direction and transverse direction are plotted in charts below. Table 3.3.1 to 3.3.2 and chart 3.3.1 to 3.3.4 shows all Model storey displacements. The bare frame model-1 has highest storey displacement values as compared to model-2.

Story No	Without P-Delta along X	With P-Delta along X	Without P-Delta along Y	With P-Delta along Y
0	209.208	209.208	209.208	209.208
1	211.299	210.505	209.809	209.701
2	213.074	212.04	210.346	210.132
3	214.846	213.667	210.916	210.606
4	216.568	215.255	211.481	211.079
5	218.209	216.752	212.029	211.536
6	219.773	218.161	212.557	211.973
7	221.785	219.941	213.077	212.399
8	222.715	220.714	213.464	212.714
9	223.346	221.183	213.916	213.087
10	224.002	221.641	214.350	213.450
11	224.65	222.064	214.807	213.835
12	225.186	222.387	215.207	214.169
13	225.597	222.621	218.062	221.600
14	225.872	222.772	224.179	228.414
15	226.011	222.851	228.136	232.740

Table 3.3.1: Comparison of Storey Displacement for with and without P-Delta Non-Linear Time History analysis of Model-1 in x and y-direction.

Story No	Without P-Delta along X	With P-Delta along X	Without P-Delta along Y	With P-Delta along Y
0	209.208	209.208	209.208	209.208
1	210.424	210.477	209.349	209.349
2	210.447	210.5	209.355	209.356
3	210.474	210.527	209.359	209.361
4	210.5	210.553	209.364	209.367
5	210.525	210.578	209.369	209.372
6	210.55	210.603	209.374	209.378
7	210.576	210.628	209.38	209.384

8	211.137	211.206	209.433	209.435
9	211.161	211.231	209.44	209.442
10	211.184	211.254	209.447	209.449
11	211.209	211.279	209.453	209.455
12	211.233	211.303	209.459	209.461
13	211.258	211.328	209.465	209.467
14	211.282	211.352	209.471	209.473
15	211.306	211.376	209.477	209.478

Table 3.3.2: Comparison of Storey Displacement for with and without P-Delta Non-Linear Time History analysis of Model-2 in x and y-direction.

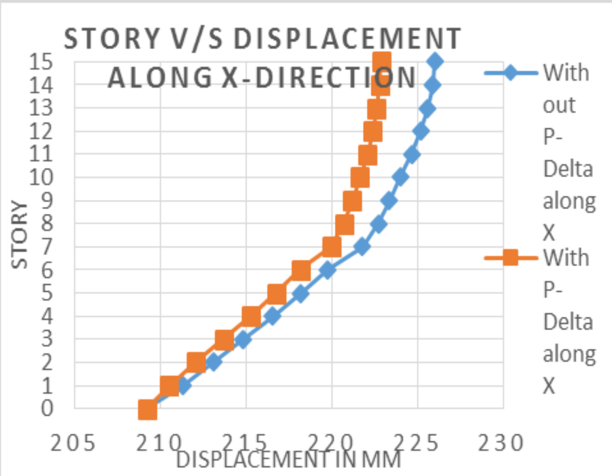

Fig. 14: Chart 3.3.1: Storey Displacement Vs Storey for model-1 along X-direction by THNA with and without P-delta.

The effect of p-delta will reduce the displacement values of all models in both x and y direction. Model-2 (full brick infill) shows considerable reduction in storey displacement with a reduction compared with model-1. Thus it can be concluded that addition of infill wall stiffness act as drift and displacement controlled elements in RC buildings.

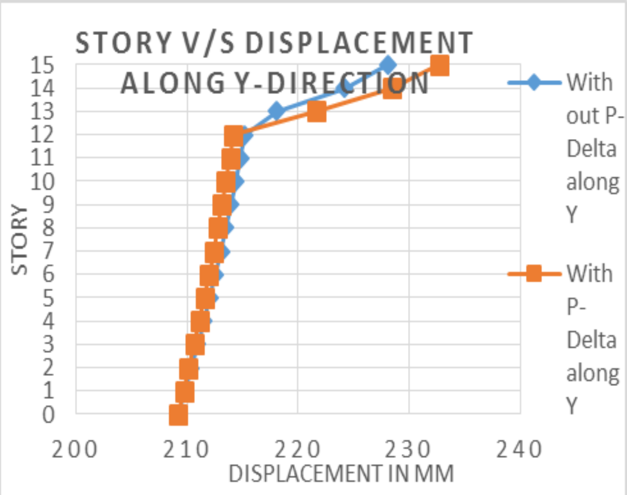

Fig. 15: Chart 3.3.2: Storey Displacement Vs Storey for model-1 along Y-direction by THNA with and without P-delta.

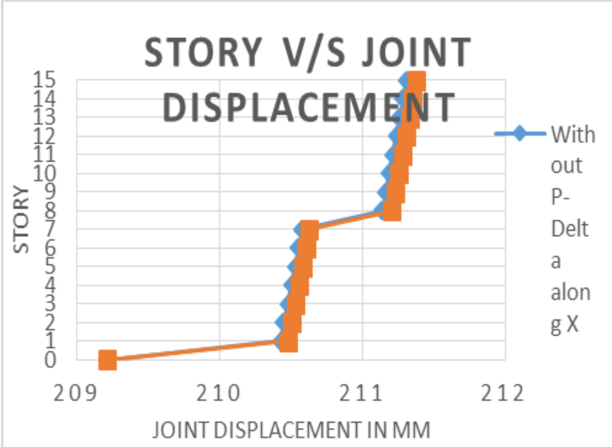

Fig. 16: Chart 3.3.3: Storey Displacement Vs Storey for model-2 along X-direction by THNA with and without P-delta.

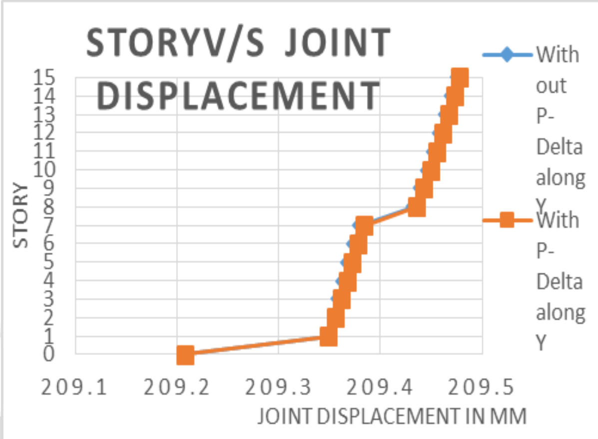

Fig. 17: Chart 3.3.4: Storey Displacement Vs Storey for model-2 along Y-direction by THNA with and without P-delta.

D. Storey Acceleration:

The maximum acceleration at each floor level with respect to ground are presented in tables from 6.6.1 to 6.6.5 obtained from Non-Linear Time History Analysis along x-direction and y-direction. Table 6.6.1 to 6.6.5 shows the comparison of the storey acceleration values of all models in x and y-direction of all storeys by NTHA, the acceleration value is lower for the bare frame model as compare to the other models. When masonry infill stiffness taken into consideration, Model-2 (full brick infill) shows considerable increase in storey acceleration than model-1,4 and 5. It is observed that, the model with shear wall yields comparatively greater storey acceleration which is represented in chart 6.6.1 to 6.6.10. Hence it can be concluded that by providing shear walls at corners in X and Y direction significantly increases the storey acceleration in the storeys. 'L' type shear wall reduces the storey acceleration compared to all other models. And consideration of P-delta will reduce the acceleration values in all the models.

Story No	Without P-Delta along X	With P-Delta along X	Without P-Delta along Y	With P-Delta along Y
1	591.25	563.22	821.52	812.32
2	623.68	646.94	888.62	862.64
3	695.74	734.02	878.00	879.84

4	688.18	702.42	1026.46	881.8
5	699.34	719.59	1046.07	860.88
6	799.86	723.57	996.86	893.27
7	759.04	692.67	1041.48	955.3
8	605.07	551.53	1011.93	955.94
9	475.67	432.74	960.95	937.52
10	472.81	472.19	939.36	885.99
11	519.66	506.69	848.07	887.96
12	569.96	517.35	1015.53	1004.21
13	707.94	672.51	958.89	917.23
14	894.47	850.5	1246.19	1114.32
15	997.43	944.24	1484.50	1340.36

Table 3.4.1: Comparison of Storey Acceleration for with and without P-Delta Non-Linear Time History analysis of Model-1 in x and y-direction

Story No	Without P-Delta along X	With P-Delta along X	Without P-Delta along Y	With P-Delta along Y
1	1705.3	1451.75	2784.01	2799.85
2	1749.62	1493.75	2834.52	2850.21
3	1775.21	1521.74	2875.79	2891.19
4	1799.42	1549.73	2912.84	2927.49
5	1821.37	1575.32	2947.38	2960.62
6	1843.62	1600.5	2979.6	2990.64
7	1874.31	1631.82	3010.75	3018.56
8	2385.78	2247.88	3095.99	3047.87
9	2405.16	2261.66	3136.23	3068.28
10	2422.11	2274.45	3176.94	3091.1
11	2438.54	2286.65	3219.04	3116.98
12	2454.43	2299.27	3262.49	3146.06
13	2470.03	2312.38	3306.79	3177.88
14	2485.08	2325.79	3352.3	3211.99
15	2499.69	2339.96	3398.25	3248.22

Table 3.4.2: Comparison of Storey Acceleration for with and without P-Delta Non-Linear Time History analysis of Model-2 in x and y-direction

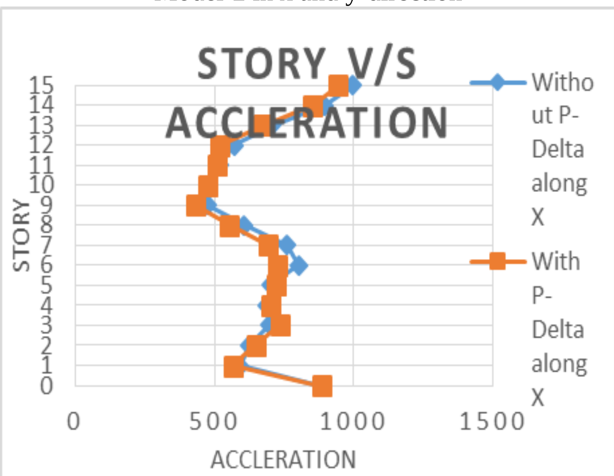

Fig. 18: Chart 6.6.1: Storey Acceleration Vs Storey for model-1 along X-direction by THNA with and without P-delta.

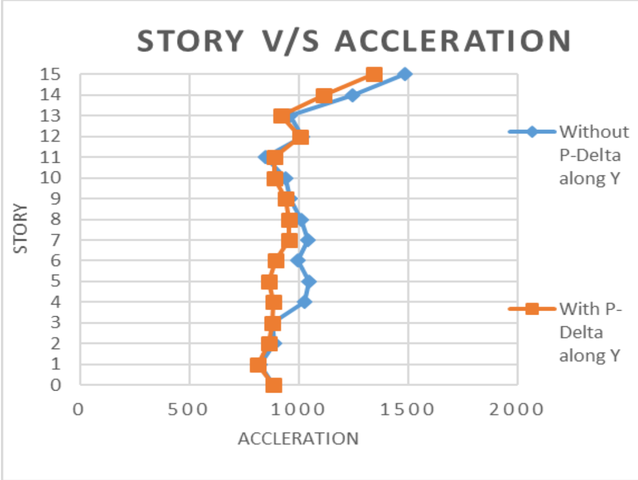

Fig. 19: Chart 6.6.2: Storey Acceleration Vs Storey for model-1 along Y-direction by THNA with and without P-delta.

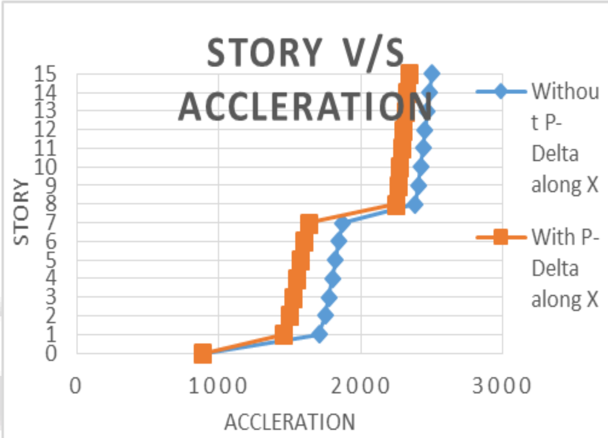

Fig. 20: Chart 6.6.3: Storey Acceleration Vs Storey for model-2 along X-direction by THNA with and without P-delta.

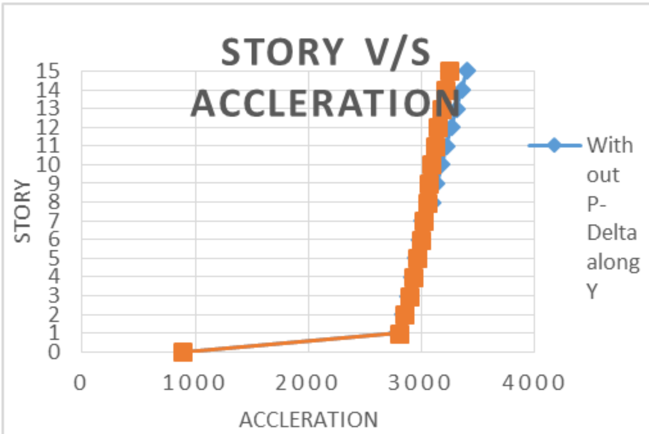

Fig. 21: Chart 6.6.4: Storey Acceleration Vs Storey for model-2 along Y-direction by THNA with and without P-delta.

E. Seismic Base Shear:

Table 3.5.1 shows comparison of highest values of seismic base shear of different models by Non-linear time history analysis using Bhuj Earthquake data. From the table it can be seen that the seismic base shear for all model-2 has larger values then model-1(bare frame). Model-2 increased by 85.9% along x-direction and 85.32% along y-direction as compared to bare frame model-1. The use of p-delta in the analysis increases the base shear value by 4.5% to 15% when compared without p-delta values

Story No	Without P-Delta along X	With P-Delta along X	Without P-Delta along Y	With P-Delta along Y
1	13236	12353	24997	21449
2	93870	84144	131205	131828

Table 3.5.1: Seismic Base shear by Non-linear Time-History analysis

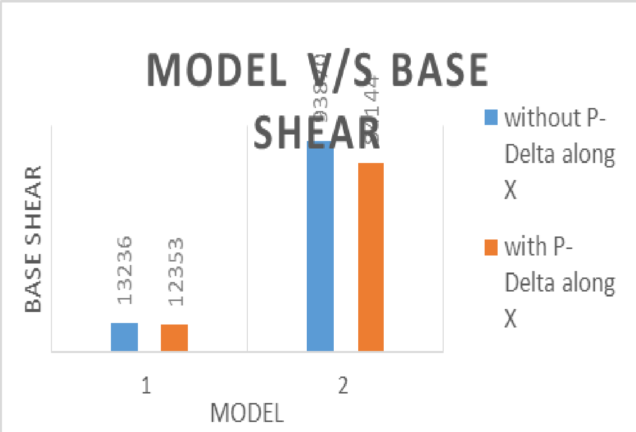

Fig. 22: Chart 3.5.1: Model Vs Base shear for different models along x-direction.

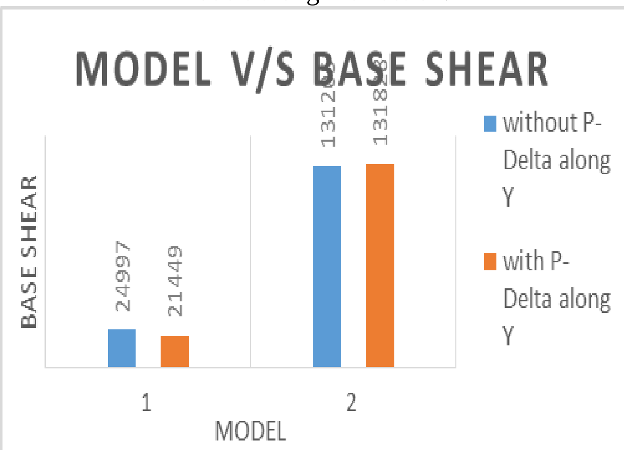

Fig. 23: Chart 3.5.2: Model Vs Base shear for different models along y-direction.

IV. CONCLUSIONS

1) Time period of the structure increases with use of p-delta in the analysis and frequency of the structure decreases.
2) Storey drift of all the storeys found within the limit.
3) Storey drift increases in longer direction and decreases in shorter direction when considered p-delta effect to the building.
4) P-delta not effect more on drift, so it can be negligible.
5) Storey displacement are decreases when shear walls are considered in to the building.
6) Storey acceleration are increases when shear walls are added to the structure.
7) Base shear decreases when p-delta is considered in the building.
8) The soft story effect is less at intermediate location of the building. A service storey of lesser height can be safer for building at higher level.
9) Models with soft stories have got highest storey drift values at soft stories levels, which leads to dangerous sway mechanism. Therefore, providing shear wall is essential so as to avoid soft storey failure.
10) As the number of soft stories increases, the fundamental time period of the structure also increases hence existence of soft stories can make the structure to be flexible in nature.
11) Fundamental time period decreases when the stiffness of masonry infill wall is considered.

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