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ANALYSIS OF BUILDING FRAMES WITH FLOATING COLUMNS AND SOFT STOREYS UNDER WIND LOADS

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Abstract- With the rapid urbanization, the space constraints are always accountable in case of tall buildings. Wind has gust effects that make the building to be affected not only along wind direction but also across wind direction. In recent years, to enhance aesthetic view, various architects have started using floating columns in their designs. The rigidity of the structure is discontinuous at the soft storey level due to variation in the floor height. This discontinuity may give birth to structural failure of buildings under the effects of winds. In this study, equivalent static analysis of 3-D building frames of G+7 storeys along with floating columns as well as soft storey effects have been carried out. A total of 73 cases have been considered in which 8 cases have central floating columns on any one of the storey, whereas 64 other cases have the floating columns at a particular storey with the soft storey being varied right from ground (G) storey to G+7 storey. Apart from the above cases a simple case is formed in which any storeys is not soft nor are any columns floating. Nine load combinations have been considered. Soft storeys have been created by varying the floor heights. STAAD.Pro software has been used for analysis purpose. Results are collected in terms of max. node displacements (resultant), max. moments, max. shear force, max. axial force, maximum storey drift. Results are analyzed to draw technical conclusions.
Keywords – Wind Loads, Soft Storey, Floating columns, and Design wind speed, Storey drift.

I. INTRODUCTION

Definition suggests that any storey for which the lateral stiffness is less than 60 percent that of the storey immediately above, or less than 70 percent of the combined stiffness of the three storeys above, is classified as a soft storey. Generally soft storey usually exists at the ground storey level, but it could be at any other storey level as well. A floating column is a vertical element which ends at upper storey level but do not continue to the ground. The commercial buildings need large column free spaces. Architects and designers use floating columns in their structural and architectural designs. Behavior of buildings subjected to floating columns at a particular storey or the presence of both the floating columns as well as soft storey in a specific case are analytically examined to draw relevant conclusions. U. Arya et al. [1] carried out wind analysis of building frames on sloping ground, in their study they concluded that maximum axial

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force increases with increase in the ground slopes, also maximum support reaction can be decreased at the windward column with increase in wind velocity. P. Kheyari and S.K. Dalui [2] did the estimation of wind load on a tall building under interference effects using computational fluid dynamics package of ANSYS. In their case study it has been observed that the most significant interference effects are found on the downwind structure. It is also found that present IS: 875 (Part III)-1987, has no provision about the oblique wind incidence angle. L. Saad and S. S. Jamkar [3] did the comparative study of Wind load analysis of buildings of various shapes and sizes as per IS: 875 (Part III) and ASCE 7-02 using STAAD.Pro .They concluded that for the design of low height and medium height (upto 10 stories) it would be more economical to design using the coefficients given in IS: 875 (Part III) and for designing high rise buildings (above 10 stories) it is safer to design with coefficients given in IS: 875 (Part III). B. D. Prajapati et al., [4] studied seismic and wind effect on multi-storey R.C.C., steel and composite building and concluded that displacement is within the limits for all buildings of three types considered. Keeping span and loading unaltered, smaller structural steel sections are required in composite construction compared to non-composite construction. This reduction in overall weight of the composite structure compared to other structure results in less cost of structure and foundation. M. Vinayak and B. S. S. Chandra [5] analyzed the response of tall RC structures under the effect of wind loads. They checked the response and concluded that storey moment and storey shear due to gust factor method is more than static method. Displacement is found to increase in both static and gust factor method with increase in storey height. In this study the provisions of IS 875 (Part III): 1987 code has been taken into consideration for defining wind parameters to perform an equivalent static analysis of soft storey with floating columns as well as buildings with floating columns without any soft storey.

The rest of the paper is organized as follows. Structural modelling and analysis are explained in section II. Result and discussion are presented in section III. Concluding remarks are given in section IV.

II. STRUCTURAL MODELLING AND ANALYSIS

A. Classification of Cases –

Following are the group's classification with detail:

- Group 1: In this group only a normal case of G+ 7 storeys has been analyzed. Normal case in which neither floating columns are present nor any soft storey is present. Height of buildings is 24 m.

- Group 2: In this group**,** buildings in which only a particular storey level has floating columns. No soft storey at any level in any case of this group. Height of buildings is 24 m.

CASE 1: When floating columns are at G Storey.
CASE 2: When floating columns are at G+1 Storey.
CASE 3: When floating columns are at G+2 Storey.
CASE 4: When floating columns are at G+3 Storey.
CASE 5: When floating columns are at G+4 Storey.
CASE 6: When floating columns are at G+5 Storey.
CASE 7: When floating columns are at G+6 Storey.
CASE 8: When floating columns are at G+7 Storey.

- Group 3: In this group, buildings in which a particular storey has floating columns with soft storey being varied from ground storey to G+7 storey level. Height of buildings is 25 m.

CASE 1-8: In all these cases ground (G) storey has floating columns with Soft storey being varied from G to G+7.
CASE 9-16: In all these cases G+1 storey has floating columns with Soft storey being varied from G to G+7.
CASE17-24: In all these cases G+ 2 storey has floating columns with Soft storey being varied from G to G+7.
CASE 25-32: In all these cases G+3 storey has floating columns with Soft storey being varied from G to G+7.
CASE 33-40: In all these cases G+4 storey has floating columns with Soft storey being varied from G to G+7.
CASE 41-48: In all these cases G+5 storey has floating columns with Soft storey being varied from G to G+7.
CASE 49-56: In all these cases G+6 storey has floating columns with Soft storey being varied from G to G+7.
CASE 57-64: In all these cases G+7 storey has floating columns with Soft storey being varied from G to G+7.

Hence in whole analysis total cases (All Groups): 73 (including one normal case of Group 1)

B. Material and Geometrical Properties –

Following material properties have been considered in modelling:
Specific weight of RCC: 25 kN/m^3
Size of Columns (Constant) = 550×250 mm.
Size of beams (Constant) = 450×250 mm.

C. Loading conditions –

1. Dead Load:
   Self-weight of slab= 25×0.12= 3 kN/m^2.
2. Live Loads:
   Live load as per IS 875 (Part 2):1987
   Loading Class III (assumed)
   Live Load on typical floors = 3kN/m^2
3. Wind Loads:
   As per IS: 875 (Part III): 1987

For calculation of design wind speed and design wind pressure, parameters considered as per above code are as follows for all cases irrespective of any group.

i. Wind Zone: V
ii. Terrain Category: 4
iii. Design wind speed (V_z)

$$V_z = V_b \times K_1 \times K_2 \times K_3$$

For all cases:
V_b (Zone V) = 50 m/s
K_1 (Important building) = 1.08
K_3 (Plain ground) = 1.0

K_2 = to be determined as per height. Also it is considered significant at or above height of 10 m. for Group 3. Whereas for regular geometry cases of, group 1 and group 2, it is calculated for 12 m or above height. Apart from above considerations, wind is assumed not much significant for storey up to G+2 in Group 1 and Group 2. Using above design wind velocity, design wind pressure is obtained as $P_z = 0.6 \times (V_z)^2$.

D. Model details –

STAAD.Pro software is used for structural modeling and analysis. The plan of 72 m^2 (12m×6m) shown in Figure 1, is considered common to all cases of Group 1, Group 2 and Group 3. Models of building frames for different groups are shown in Fig. 2, 3, 4 and 5.All columns are rigidly supported at ground and 9 load combinations have been considered for the purpose of analysis (Table 1).

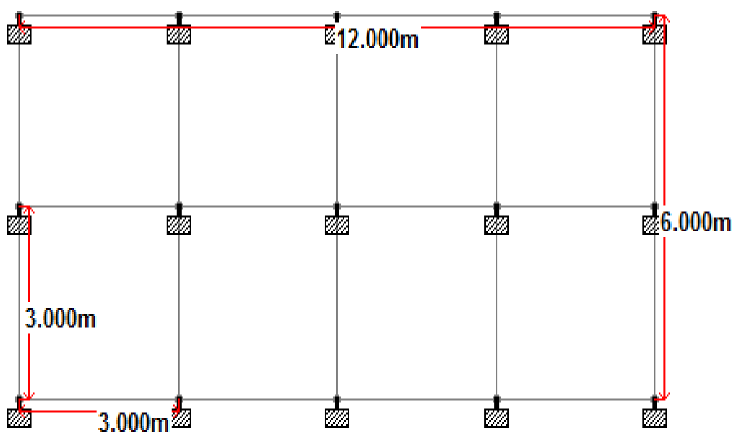

Figure 1. Plan of buildings frames for all cases of Groups (1, 2, 3)

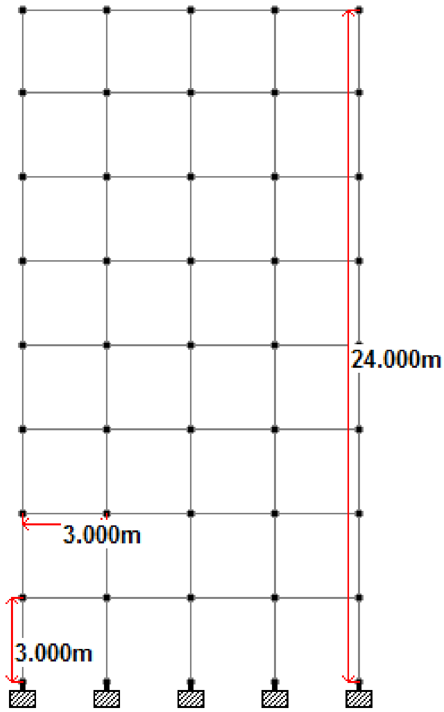

Figure 2. Normal Case (Group 1)

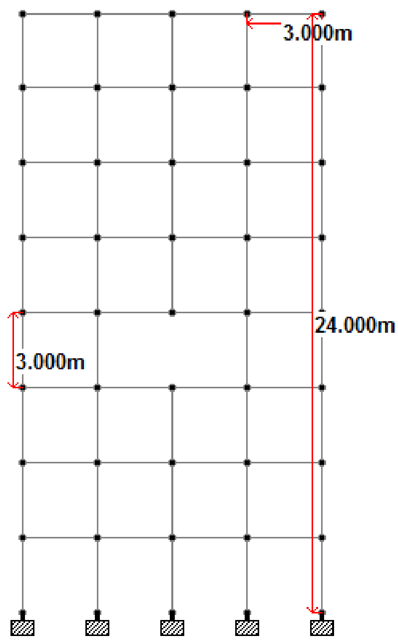

Figure 3. Floating Column at G+3 storey (Group 2)

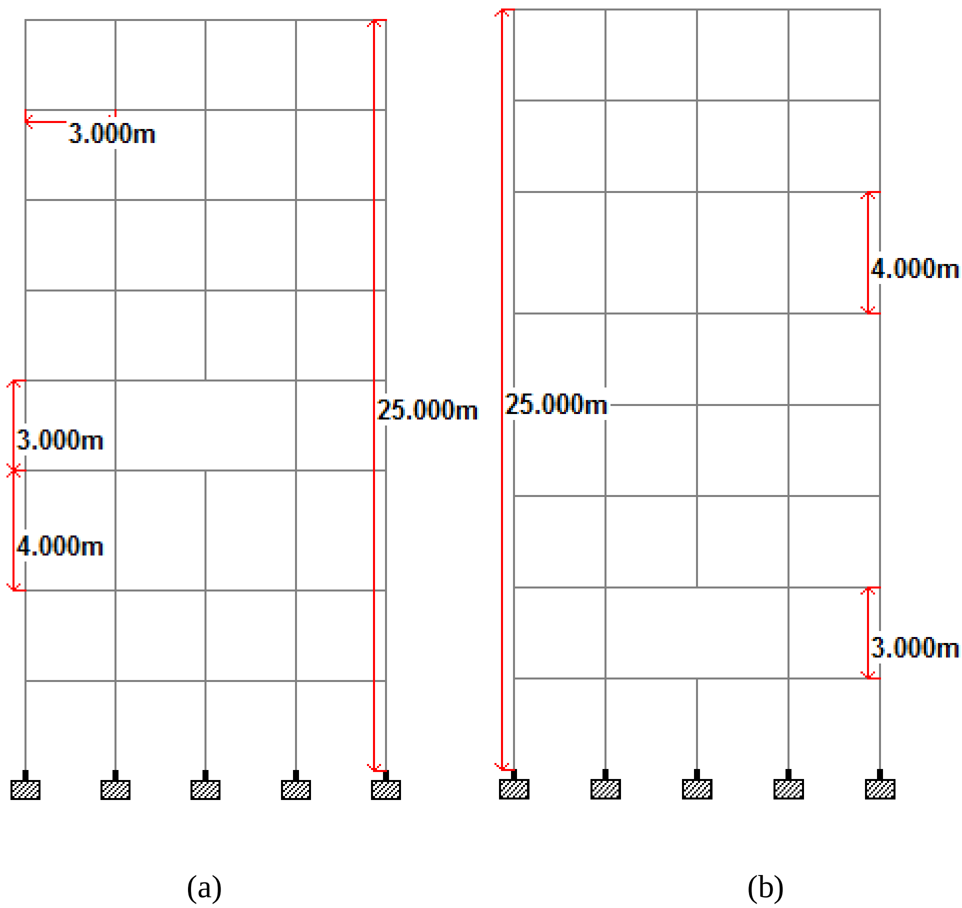

Figure 4. Floating columns at particular storey with soft storey being varied (Group 3) (a) CASE 27 (b) CASE 42

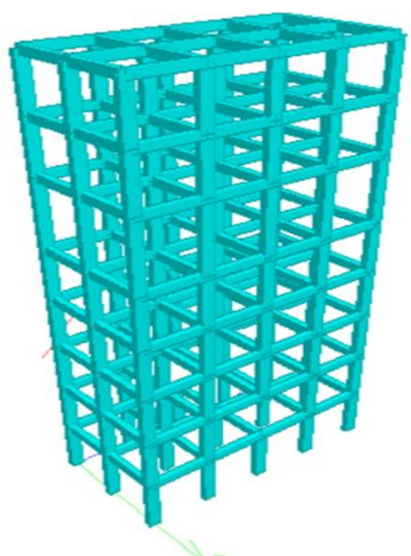

Figure 5. 3D Frame: CASE 14 (Group 3)

Table -1 Detail of load cases

Load Case No.	**Load Case details**
1	**Dead Load**
2	**Live Load**
3	**WL_x**
4	**WL_z**
5	**1.5 DL + 1.5 LL**
6	**1.5 DL + 1.5 WL_x**
7	**1.5 DL + 1.5 WL_z**
8	**1.2 DL + 1.2 LL +1.2 WL_x**
9	**1.2 DL + 1.2 LL +1.2 WL_z**

III. RESULT AND DISCUSSION

Results of structural analysis are discussed in following sections with respect to the groups mentioned above.

A. Group 1 –

Normal case, in which neither floating columns are present nor any soft storey is present. Height of building is 24 m. Axial force is the higher parameter in terms of quantity as given in Table 2 and shown in Fig. 6.

Table -2 Values of analysis parameters for Group 1

Max. Node disp. (Res.) (mm.)	Max. B.M. Mz (kNm)	Max. Axial Force Fx (kN)	Max. S.F. Fy (kN)
17.299	51.537	883.648	44.372

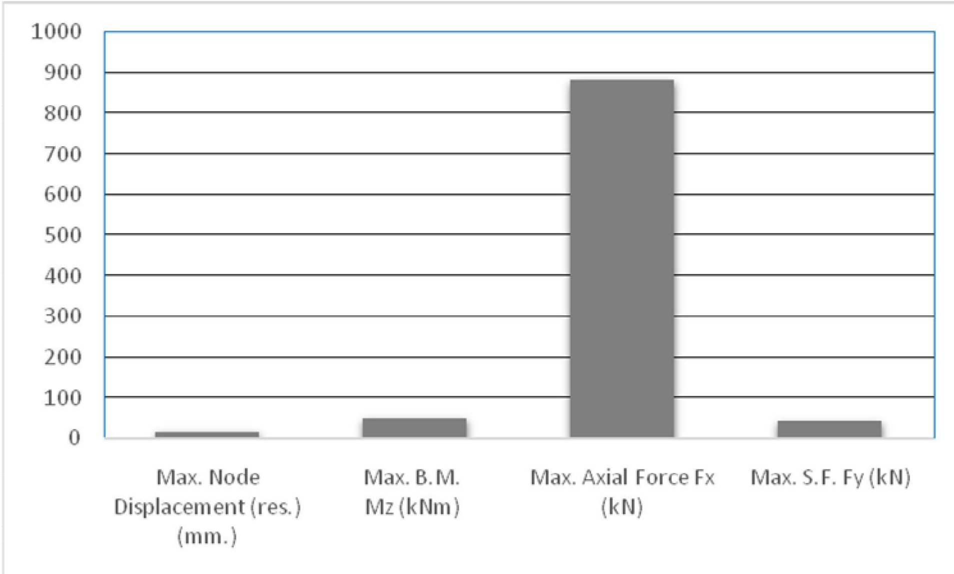

Figure 6. Various analysis parameters in Group 1

B. Group 2 –

Buildings in which, only a particular storey level has floating columns, without any soft-storey at any level. Height of buildings is 24 m. Maximum nodal displacement, maximum bending moment, maximum shear force and maximum axial force are found on ground storey when central floating columns are at ground storey level (Table 3 & Fig. 7).

Table -3 Values of analysis parameters for Group 2

Floating column at	Max. Node disp. (Res.) (mm.)	Max. B.M.: Mz (kNm)	Max. Axial Force: Fx (kN)	Max. S.F. : Fy (kN)
G	19.363	130.945	1192.881	108.099
G+1	19.125	54.291	112.327	62.307
G+2	18.956	47.416	103.829	57.816
G+3	18.724	41.432	96.377	53.958
G+4	18.383	36.191	90.899	50.627
G+5	17.985	35.210	87.784	47.606
G+6	17.694	35.111	86.029	44.683
G+7	17.429	35.112	85.400	30.325

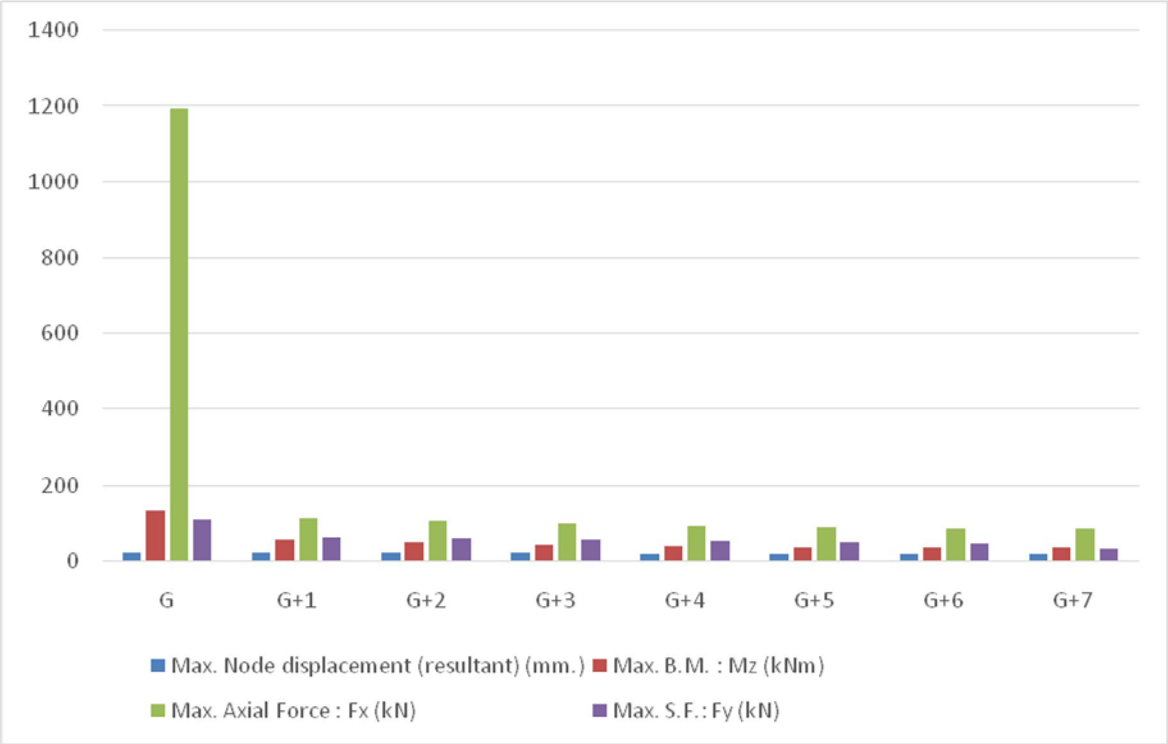

Figure 7. Values of analysis parameters in Group 2

C. Group 3 –

Buildings in which a particular storey has floating columns with soft storey being varied from ground storey to G+7. Height of buildings is 25 m.

Table -4 Values of analysis parameters for Group 3: CASE 1-8: when the floating columns are at ground (G) storey and soft storey being varied from G to G+7

Soft Storey at	Max. Node disp. (Res.) (mm.)	Max. B.M.: Mz (kNm)	Max. Axial Force: Fx (kN)	Max. S.F. : Fy (kN)
G	22.844	127.811	1179.706	106.459
G+1	20.559	60.112	697.324	55.255
G+2	22.483	82.236	695.789	69.182
G+3	22.449	81.440	697.94	68.646
G+4	23.365	81.02	699.166	68.351
G+5	22.899	80.764	699.858	68.173
G+6	22.331	80.613	700.205	68.067
G+7	21.882	80.610	700.840	68.066

In group 3: CASE 1-8, Max. Node displacement is obtained when soft storey is at G+4 (Table 4). Max. B.M., Max. S.F. and Max. Axial Force are highest for soft storey being at ground storey (Table 4 & Fig. 8).

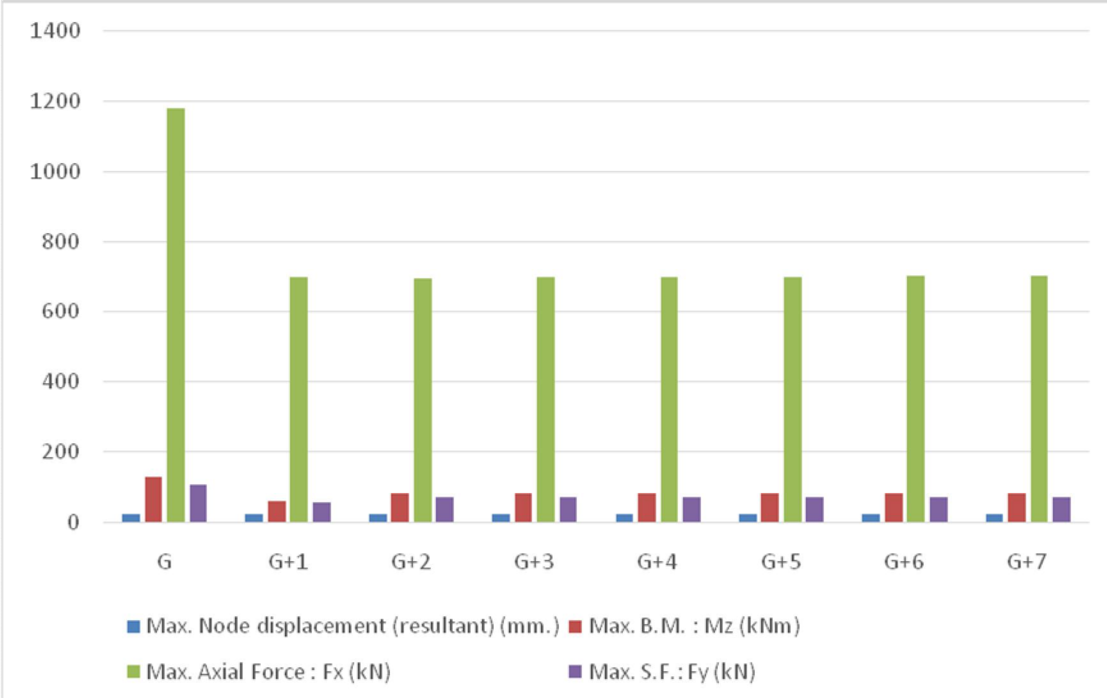

Figure 8. Values of analysis parameters in Group 3: Case 1-8

Table -5 Values of analysis parameters for Group 3: CASE 9-16: when the floating columns are at G+1 storey and soft storey being varied from G to G+7

Soft Storey at	Max. Node disp. (Res.) (mm.)	Max. B.M.: Mz (kNm)	Max. Axial Force: Fx (kN)	Max. S.F. : Fy (kN)
G	22.092	71.075	639.169	61.829
G+1	23.129	70.310	646.433	61.486
G+2	22.666	73.276	651.283	63.575
G+3	22.605	73.562	653.371	63.468
G+4	23.524	72.850	654.705	62.989
G+5	23.057	72.478	655.442	62.728
G+6	22.488	72.254	655.816	62.572
G+7	22.039	72.229	656.454	62.556

In cases belonging to Group 3: CASE 9-16, the max. nodal displacement is obtained when G+4 storey is made soft. Max. B.M. is obtained when soft storey is at G+3 storey level. Max. Axial force is at G+ 7 soft storey levels. Max. S.F. is at G+2 soft storey level (Table 5 & Fig. 9).

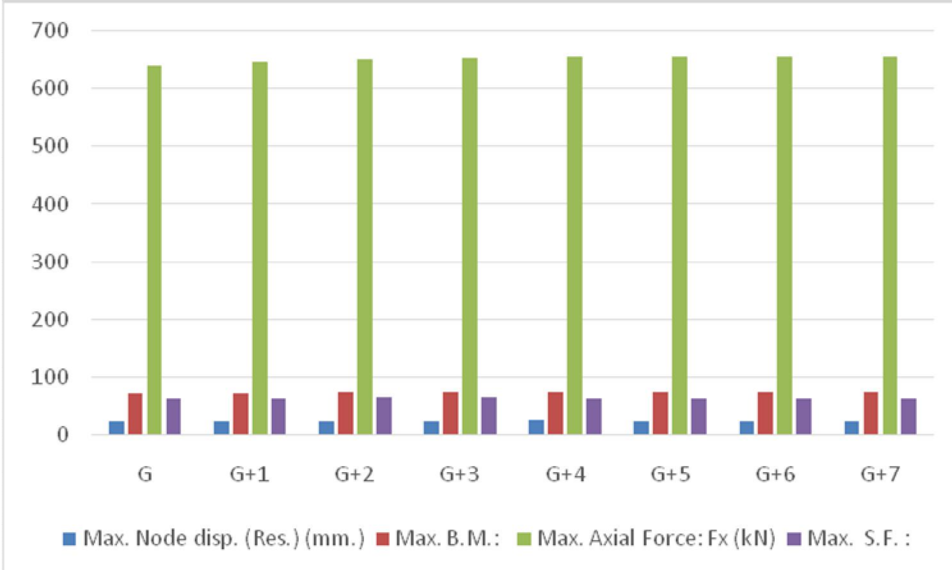

Figure 9. Values of analysis parameters in Group 3: CASE 9-16

Table -6 Values of analysis parameters for Group 3:CASE17-24: when the floating columns are at G+2 storey and soft storey being varied from G to G+7

Soft Storey at	Max. Node disp. (Res.) (mm.)	Max. B.M.: Mz (kNm)	Max. Axial Force: Fx (kN)	Max. S.F. : Fy (kN)
G	21.861	64.772	598.082	57.505
G+1	22.325	64.716	604.271	57.487
G+2	22.970	64.406	608.360	57.143
G+3	22.461	66.390	611.699	58.863
G+4	23.339	66.706	612.967	58.799
G+5	22.864	66.084	613.792	58.381
G+6	22.299	65.763	614.203	58.156
G+7	21.850	65.705	614.844	58.117

In cases of Group 3:CASE17-24: When soft storey is at G+4, Max. Node displacement is obtained. Max. B.M. is at G+4 soft storey level. Max. Axial Force is obtained at G+7 soft storey level. Max. S.F. is at G+3 soft storey level (Table 6 & Fig. 10).

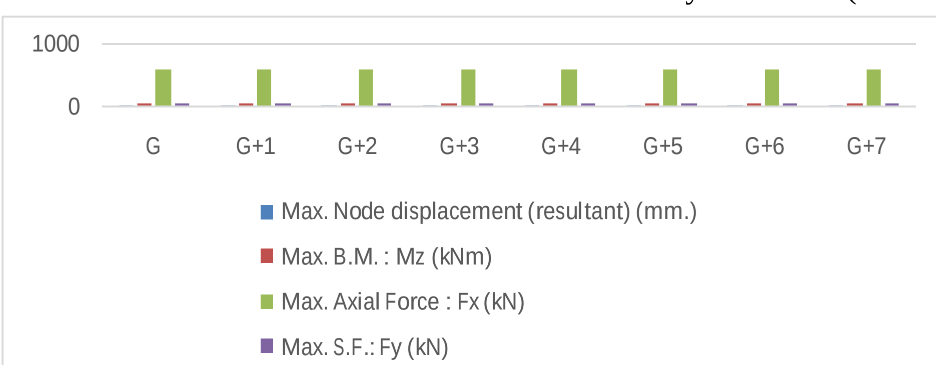

Figure 10. Values of analysis parameters in Group 3: CASE 17-24

Table -7 Values of analysis parameters for Group 3: CASE 25-32: Floating Columns are at G+3 storey and soft storey being varied from G to G+7

Soft Storey at	Max. Node disp. (Res.) (mm.)	Max. B.M.: Mz (kNm)	Max. Axial Force: Fx (kN)	Max. S.F. : Fy (kN)
G	21.850	65.705	614.844	58.117
G+1	21.608	53.319	564.618	53.730
G+2	22.050	59.356	569.919	53.755
G+3	22.095	59.779	573.230	53.719
G+4	22.711	60.075	575.847	53.397
G+5	22.607	61.135	578.861	54.761
G+6	23.103	61.761	578.117	54.788
G+7	22.037	60.457	579.335	54.402

In group 3:CASE 25-32:Max. Nodal displacement is obtained when soft storey is at G+6.The Max. B.M., Max. Axial force, Max. Shear Force are obtained when soft storey is at ground (Table 7 & Fig. 11).

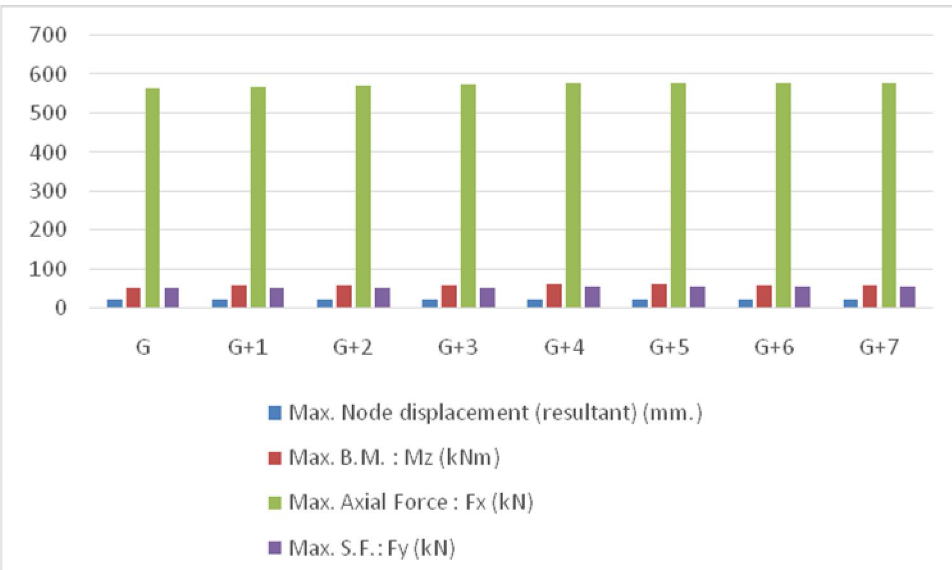

Figure 11. Values of analysis parameters in Group 3: CASE 25-32

Table -8 Values of analysis parameters for Group 3: CASE 33-40: when the floating columns are at G+4 storey and soft storey being varied from G to G+7.

Soft Storey at	Max. Node disp. (Res.) (mm.)	Max. B.M.: Mz (kNm)	Max. Axial Force: Fx (kN)	Max. S.F. : Fy (kN)
G	21.254	54.665	538.818	50.458
G+1	21.695	54.692	543.615	50.476
G+2	21.719	54.707	546.320	50.487
G+3	21.724	57.414	548.429	50.450
G+4	23.149	60.221	550.019	50.161
G+5	22.248	55.490	551.579	51.258
G+6	21.661	55.841	551.956	51.252

G+7	21.212	55.620	552.614	51.113

In Group 3:CASE 33-40, Max. Nodal displacement, Max. B.M. are obtained when soft storey is at G+4. Max. Axial Force is obtained when soft storey is at G+7, whereas Max. Shear Force is at G+5 storey level(Table 8 & Fig. 12).

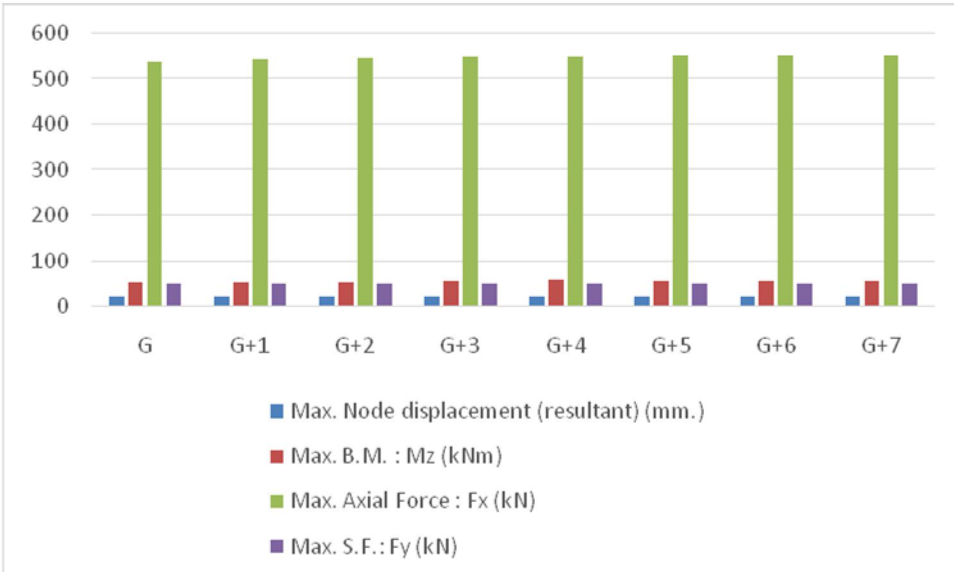

Figure 12. Values of analysis parameters in Group 3: CASE 33-40

Table -9 Values of analysis parameters for Group 3: CASE 41-48: When the floating columns are at G+5 storey and soft storey being varied from G to G+7.

Soft Storey at	Max. Node disp. (Res.) (mm.)	Max. B.M.: Mz(kNm)	Max. Axial Force: Fx(kN)	Max. S.F. : Fy(kN)
G	20.849	50.456	519.877	47.476
G+1	21.289	53.065	524.323	47.492
G+2	21.312	53.830	526.752	47.499
G+3	21.299	53.686	528.442	47.504
G+4	22.144	54.126	529.737	47.474
G+5	22.116	50.789	530.664	47.230
G+6	21.138	50.995	531.713	48.065
G+7	20.779	51.624	532.239	48.280

In group 3: CASE 41-48, Max. Nodal displacement, Max. B.M., Max. Axial Force, Max. S.F. are obtained when soft storey is at G+4, G+4, G+7 and G+ 7 respectively (Table 9 & Fig. 13).

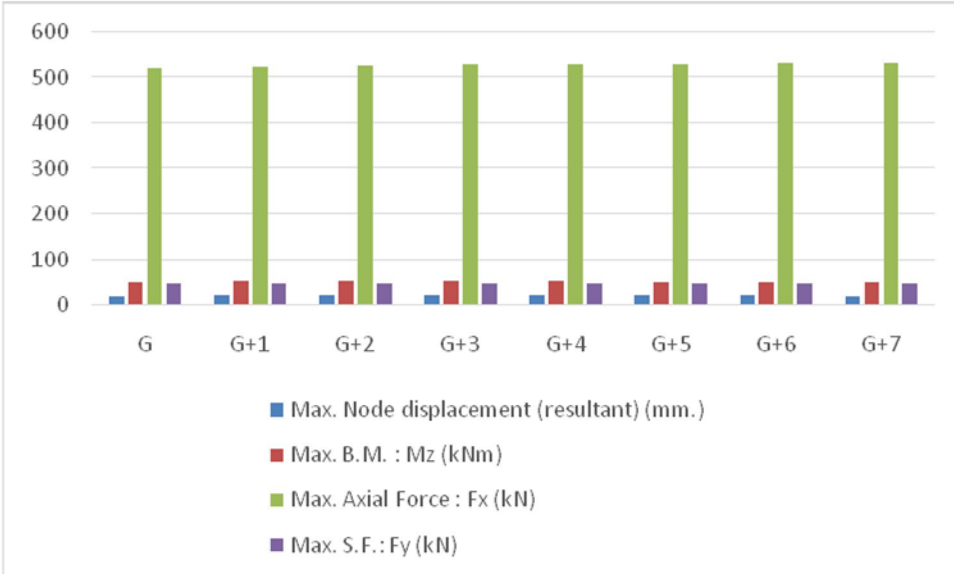

Figure 13. Values of analysis parameters in Group 3: CASE 41-48

Table -10 Values of analysis parameters for Group 3: CASE 49-56: when the floating columns are at G+6 storey and soft storey being varied from G to G+7

Soft Storey at	Max. Node disp. (Res.) (mm.)	Max. B.M.: Mz (kNm)	Max. Axial Force: Fx (kN)	Max. S.F. : Fy (kN)
G	20.549	52.401	585.029	50.565
G+1	20.990	53.175	510.583	44.594
G+2	21.012	54.364	512.836	44.601
G+3	20.998	54.110	514.376	44.604
G+4	21.802	54.405	515.375	44.607
G+5	21.347	51.423	516.165	44.587
G+6	21.102	51.175	516.616	44.431
G+7	20.460	51.179	517.676	45.493

In group 3: CASE 49-56, Max. Nodal displacement, Max. B.M. are obtained when soft storey is at G+4. , whereas Max. Axial Force, Max. S.F. are obtained at ground soft storey (Table 10 & Fig. 14).

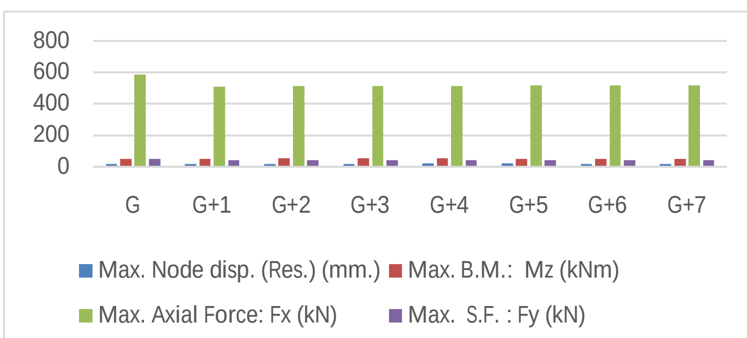

Figure 14. Values of analysis parameters in Group 3: CASE 49-56

Table -11Values of analysis parameters for Group 3: CASE 57-64: when the floating columns are at G+7 storey and soft storey being varied from G to G+7

Soft Storey at	Max. Node disp. (Res.) (mm.)	Max. B.M.: Mz (kNm)	Max. Axial Force: Fx (kN)	Max. S.F. : Fy (kN)
G	20.275	49.780	511.945	38.886
G+1	20.714	53.218	515.120	40.098
G+2	20.737	54.499	516.997	41.355
G+3	20.723	54.217	518.343	41.032
G+4	21.527	54.788	519.237	41.872
G+5	21.066	51.522	519.769	40.172
G+6	20.516	51.308	520.281	40.062
G+7	20.262	51.303	519.666	40.038

In group 3: CASE 57-64, Max. Nodal displacement, Max. B.M. are obtained when soft storey is at G+4. , whereas Max. Axial Force is obtained at G+6 soft storey level and Max. S.F. at G+4 (Table 11 & Fig. 15).

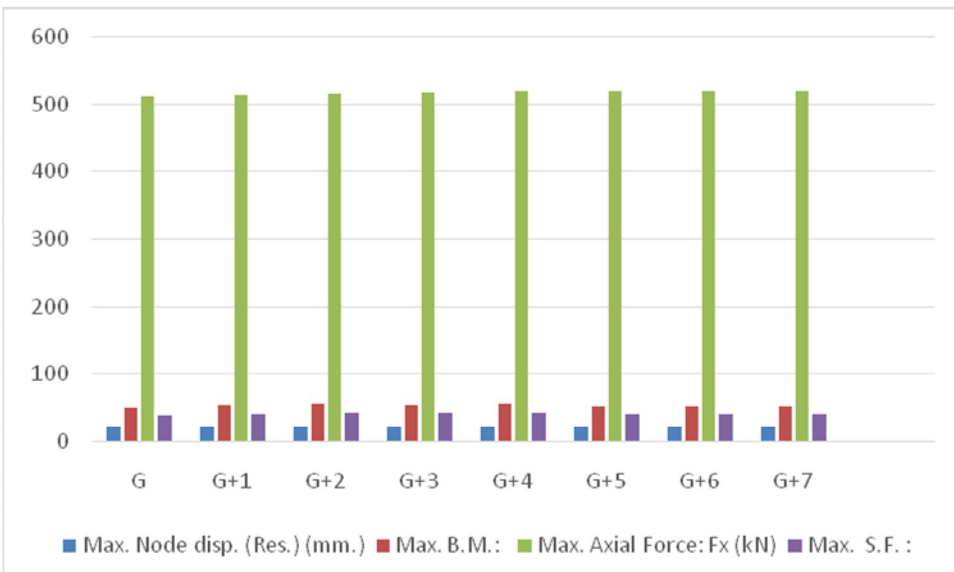

Figure 15. Values of analysis parameters in Group 3: CASE 57-64

D. Maximum Storey Drift –

Drift is significant in case of buildings subjected to wind loads. Hence the values listed in Table 12 are obtained for cases of a particular group, taken to be highest among all values but on a specific storey level. The same is shown in Fig. 16.

Table -12 Max. Storey Drift (mm.)

Storey	Group1	Group2	Group 3							
			CASE 1-8	CASE 9-16	CASE 17-24	CASE 25-32	CASE 33-40	CASE 41-48	CASE 49-56	CASE 57-64

G	0.436	0.529	1.049	0.853	0.846	0.847	0.846	0.846	0.846	0.846
G+1	0.693	0.821	0.940	1.490	1.250	1.241	1.241	1.240	1.240	1.240
G+2	0.739	0.874	1.297	1.316	1.562	1.315	1.305	1.303	1.303	1.302
G+3	0.728	0.864	1.283	1.285	1.303	1.552	1.302	1.292	1.290	1.290
G+4	0.647	0.768	1.195	1.196	1.195	1.216	1.445	1.211	1.202	1.202
G+5	0.502	0.592	0.923	0.924	0.925	0.925	0.943	1.113	0.936	0.931
G+6	0.342	0.347	0.621	0.623	0.623	0.625	0.625	0.638	0.748	0.636
G+7	0.177	0.260	0.386	0.387	0.389	0.389	0.389	0.388	0.395	0.476

In Group 1 and Group 2, Max. Storey Drift is at G+2 storey. In Group 3: CASE 1-8, 9-16, 17-24, 25-32, 33-40, 41-48 ,49-56 and 57-64, Max. Storey Drift is at G+2,G+1, G+2, G+3, G+4,G+2 and G+2 respectively.

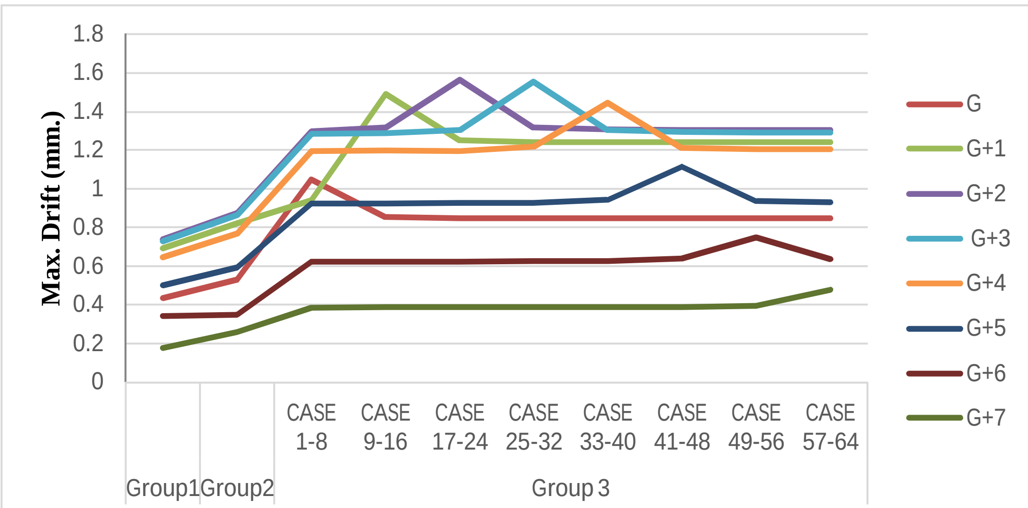

Figure 16. Values of Max. Drifts (mm.) for all groups

IV.CONCLUSION

Following notable conclusions can be drawn from the results given above:-

1. Under the defined loading conditions, maximum bending moment increases 2.54 times as soon as floating columns are introduced at ground storey level with reference to a normal building under same loads but without any floating columns.

2. The presence of floating columns at the top most storey increases the maximum nodal displacement resultant for a non-soft storey building.

3. There are marginal fluctuations in value of design wind pressure till height range of around 15 m.

4. There is general decrease in the value of maximum shear force among various cases, for e.g. values are higher in CASE 1-8 than in CASE 9-16 of Group 3.

5. The value of maximum axial force is less when both the central floating columns and soft storey are located at ground in Group3: CASE 1-8, as compared to Group 2, where only central floating columns are located at ground storey.
6. The maximum nodal displacement is obtained either in most of the cases belonging to G+4 storey level in Group 3.
7. The shifting of central floating columns to higher storey uptill G+6 levels results in shifting of maximum shear force to higher storeys in Group 3.
8. Wind loads can cause maximum storey drift if floating columns are at G+2 storey and soft storey is also G+2 storey level.
9. Higher values of drift are concentrated upto G+4 storey level under the effect of wind loads.

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