International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 22 (2017) pp. 12008-12015

Seismic Performance of Symmetrical and Asymmetrical Buildings with Heavy Loads

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Abstract

In this study the focus is the seismic design of buildings with heavy loadings such as Data center Buildings which are compared with the normal buildings with normal loads. Buildings may be symmetric or asymmetric in plan or elevation which depends on the stiffness and mass distribution in each storey. Hilly regions of India fall under the high seismic zones. Behavior of the building differs in hilly terrain from the other buildings on plains. The different floor of buildings on hilly areas steps towards the hill backwards and simultaneously may have setbacks also. Due to complex configuration, these buildings are highly asymmetric and irregular. Building with heavy loads and constructed in hilly areas are more vulnerable to attract higher seismic forces.

In this study, 3D Analytical models of symmetric and asymmetric buildings are generated for hilly terrain and plains with normal and heavy loadings, which are analyzed using non linear structural analysis tool "ETABS 9.2.0". The effect of sloping ground on columns which have varying height are studied, the plan layout considered is same for hilly terrain and plains for both normal and heavy loads. To study the effects of infill's, seismic analysis is done using linear dynamic (response spectrum method) as well as nonlinear static procedure (pushover) has been performed.

Keywords: Non-Linear analysis, response spectrum method, pushover method, data center, heavy loads, symmetric buildings, Asymmetric buildings.

INTRODUCTION

Due to rapid urbanization and space crunch there is increase in R.C. framed buildings construction on hilly areas. Buildings which are constructed in hilly areas with sloping ground are highly irregular and asymmetrical in nature. Buildings constructed on sloping grounds attracts severe torsion when subjected to lateral forces due to earthquake. Usually buildings constructed on sloping grounds are supported by columns of varying heights, Since the stiffness of short columns is more, it attracts more forces thus short columns are susceptible to undergo more damage due to earthquake.

Loading on buildings can vary from normal commercial loads to heavy loads for special buildings used for specific purpose, such as Data centre buildings. Digitization and Globalization leads to production and storage of huge data. Compare to earlier ways of outsourcing the data storage to specialize companies, nowadays most of the organizations prefer to have their own setup for data storage. The buildings which houses complete computer, telecommunications and storage systems along with its components are called Data centre buildings. Structurally Data centre buildings have to support heavy loads imposed on it due to equipments of I.T., Telecommunications and storage systems.

In this Study, Separate 3D analytical models are generated for symmetrical buildings on plain areas and asymmetrical buildings on hilly terrains, with normal commercial loading (4Kn/m2) and heavy loading of Data centre (8.4Kn/m2). To study the seismic effects of infills on symmetrical and asymmetrical models with and without heavy loading, seismic analysis is performed using linear dynamic (Response spectrum method) and non linear static methods (Pushover analysis). Plan layout of all the analytical models are kept same for symmetrical buildings on plain grounds and asymmetrical buildings on sloping grounds.

METHODS

Three different types of 3D analytical models are generated for symmetrical and asymmetrical buildings, first with normal commercial loadings and then with heavy loads of data centre buildings. Symmetrical models of buildings on plain ground is generated with equal height of columns on ground storey. Asymmetrical models of buildings on sloping hilly terrain is generated with the height of ground storey columns varying from 3m to 13.8m

Model-1: Building model is considered as bare frame without walls.

Model-2: Building model considered have no walls in ground storey. In upper stories full brick masonry walls of 230 mm thickness is considered. Generated model includes both the mass and stiffness of infill wall.

Model-3: Building model considered have full brick masonry wall of 230mm in upper floors. In ground storey, walls are considered in all the bays along the periphery of building in longitudinal direction, whereas in transverse direction it is considered only in the end bays along periphery. Generated model includes both the mass and stiffness of infill wall.

Table 1: Design Parameters

Load	Intensity
Dead Loads Masonry Concrete	 20.0kN/m3 25.0kN/m3
Live Loads (Normal Commercial building) Live Load (Data Centre buildings) Roof Load Floor Finishes	$4.0kN/m^2$ $8.4kN/m^2$ $2.0kN/m^2$ $2.0kN/m^2$
Importance Factor	1
Response reduction factor	5.0

Member Properties used for modeling of structural elements are tabulated in Table-2.

Table 2: Member Properties

Member	Dimension mm
Columns	250x500
Beams	250x600
Slab	120
Wall	230

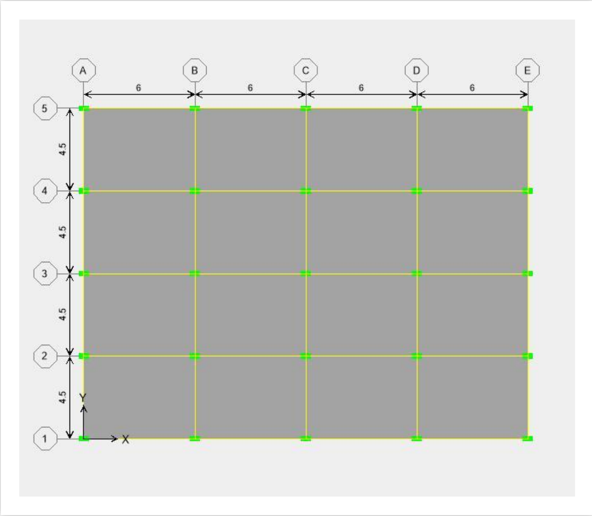

Figure 1: Plan Model 1(Symmetrical)

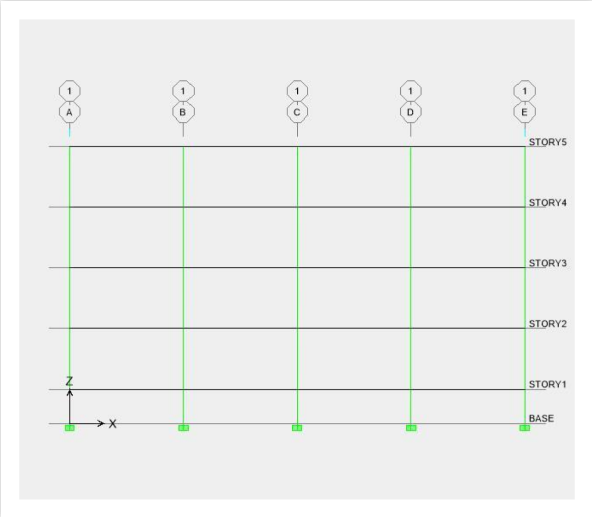

Figure 2: Elevation Model 1(Symmetrical)

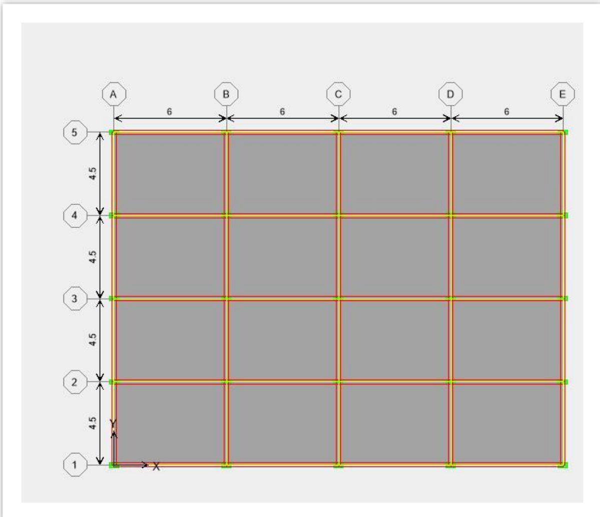

Figure 3: Plan Model 2(Symmetrical)

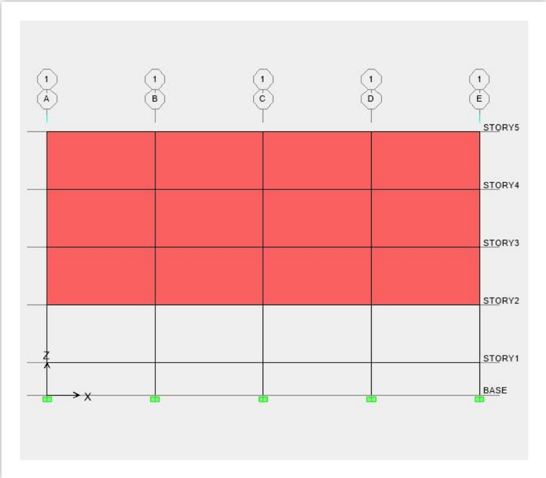

Figure 4: Elevation Model 2(Symmetrical)

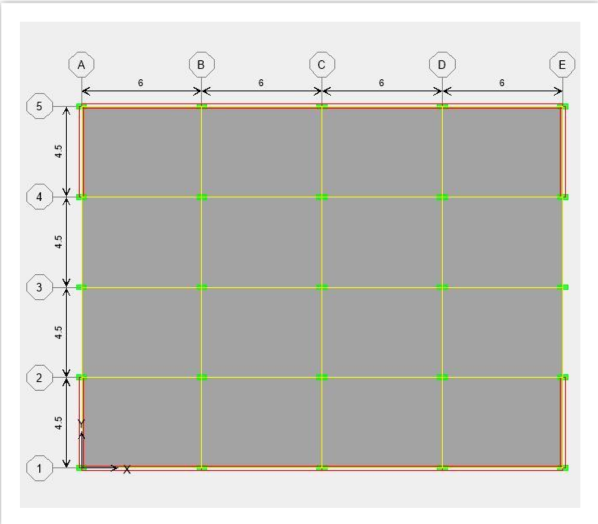

Figure 5: Plan Model 3(Symmetrical)

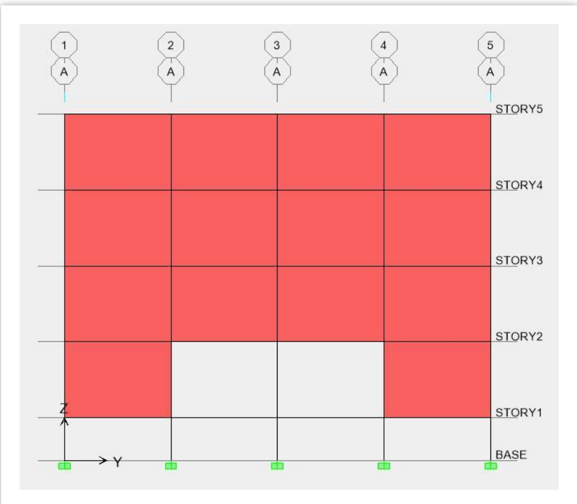

Figure 6: Elevation Model 3(Symmetrical)

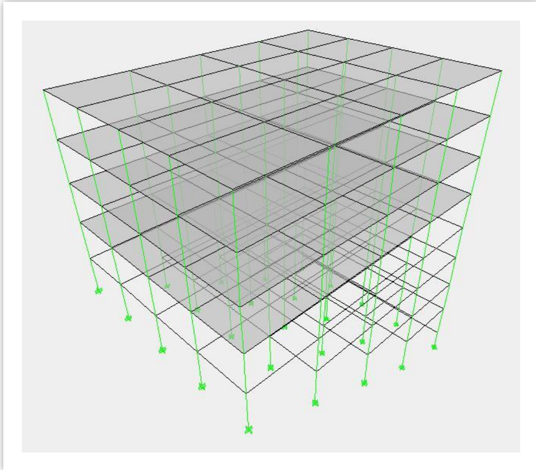

Figure 7: 3D View Model 1(Asymmetrical)

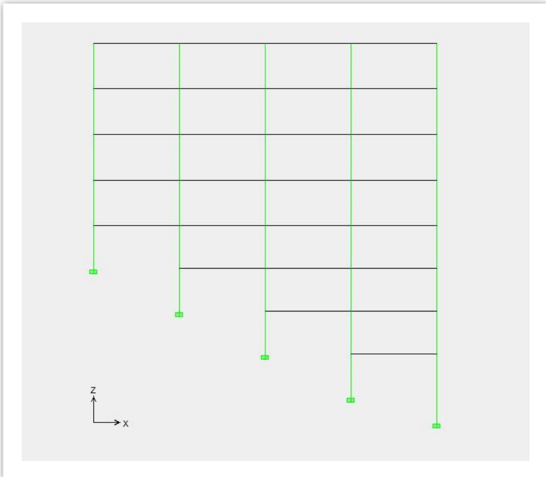

Figure 8: Elevation Model 1(Asymmetrical)

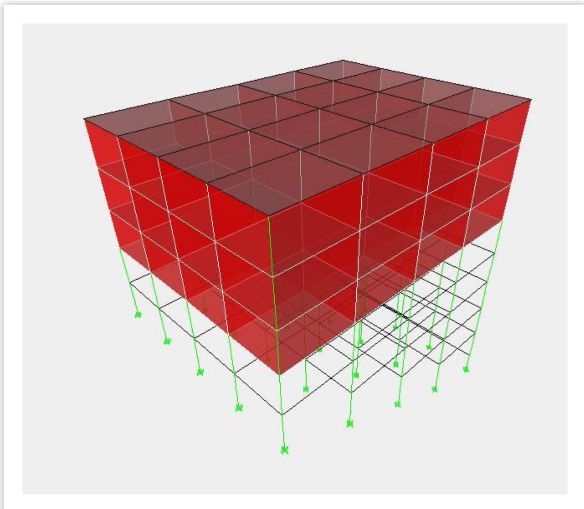

Figure 9: 3D View Model 2(Asymmetrical)

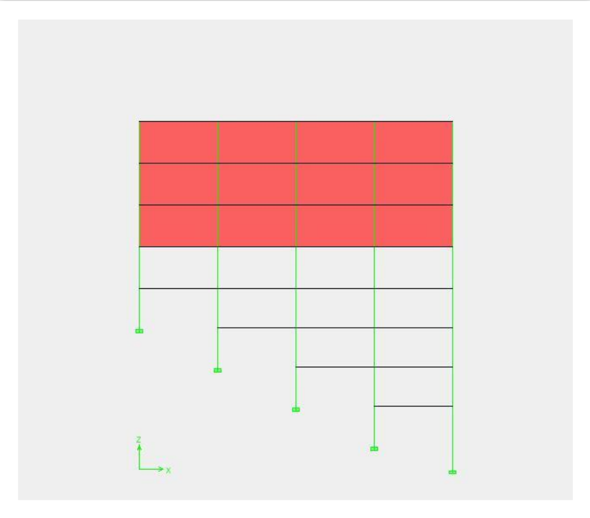

Figure 10: Elevation Model 2(Asymmetrical)

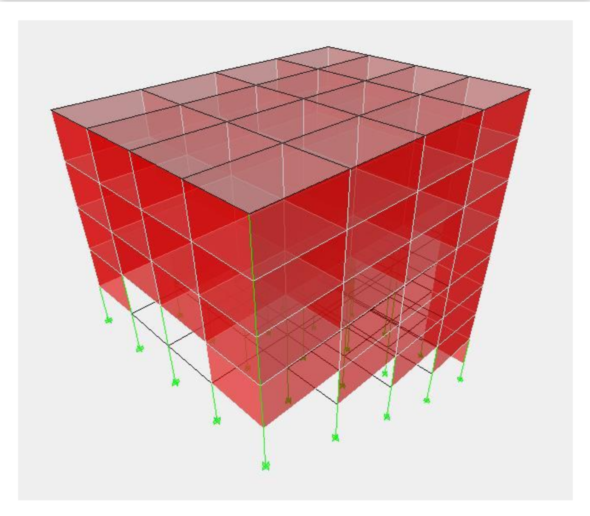

Figure 11: 3D View Model 3(Asymmetrical)

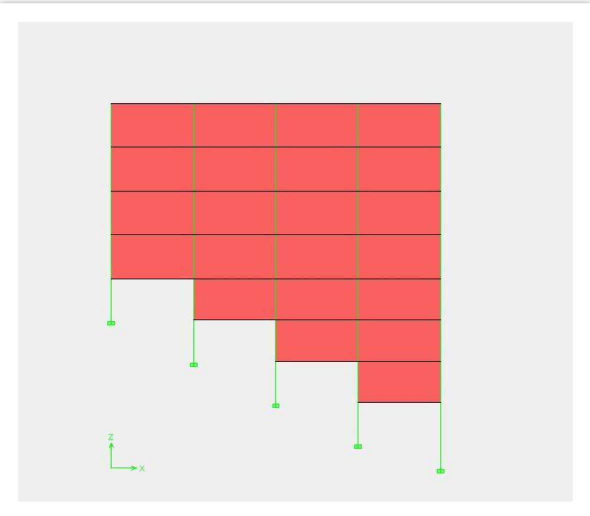

Figure 12: Elevation Model 3(Asymmetrical)

RESULTS

Lateral displacement results of Symmetric and Asymmetric building models with normal commercial loading and with heavy loadings are compared for response spectrum method and Pushover analysis.

Displacement for X & Y direction for Response Spectrum Method (Spec-X & Spec-Y) and for Pushover method of analysis (Push-X & Push-Y) are shown in Table 3 for symmetrical as well as asymmetrical building Model-1 with Normal commercial loading.

Table 3. Displacements: X & Y for Symmetrical and Asymmetrical Buildings for Model-1 under Normal commercial Loading.

MODEL-1 NORMAL LOADS (COMMERCIAL BUILDINGS)								
STOREY no	**Symmetric**				**Asymmetric**			
	Response Spectrum Method		Pushover Method		Response Spectrum Method		Pushover Method	
	Spe-X	Spe-Y	Pus-X	Pus-Y	Spe-X	Spe-Y	Pus-X	Pus-Y
5	5.25	7.61	7.32	23.7	6.40	7.40	8.48	24.9
4	4.60	6.73	6.54	21.5	5.90	6.84	8.03	23.4
3	3.46	5.13	5.12	17.1	4.99	5.83	7.06	20.3
2	1.94	2.96	3.00	10.3	3.75	4.45	5.48	15.8
1	0.35	0.49	0.55	1.75	2.29	1.98	3.43	7.08
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Displacement for X & Y direction for Response Spectrum Method (Spec-X & Spec-Y) and for Pushover method of analysis (Push-X & Push-Y) are shown in Table 4 for symmetrical as well as asymmetrical building Model-1 with Heavy loading.

Table 4: Displacements: X & Y for Symmetrical and Asymmetrical Buildings for Model-1 under Heavy Loading.

MODEL-1 HEAVY LOADS (DATA CENTRE BUILDINGS)								
STOREY no	**Symmetric**				**Asymmetric**			
	Response Spectrum Method		Pushover Method		Response Spectrum Method		Pushover Method	
	Spe-X	Spe-Y	Pus-X	Pus-Y	Spe-X	Spe-Y	Pus-X	Pus-Y
5	5.99	8.74	1.98	17.3	6.76	7.78	2.84	24.2
4	5.41	7.99	1.84	16.1	6.30	7.30	2.84	22.9
3	4.16	6.23	1.41	13.0	5.38	6.28	2.61	20.1
2	2.37	3.66	0.75	8.00	4.06	4.81	2.08	15.7
1	0.43	0.61	0.16	1.36	2.48	2.14	1.30	7.0
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Displacement for X & Y direction for Response Spectrum Method (Spec-X & Spec-Y) and for Pushover method of analysis (Push-X & Push-Y) are shown in Table 5 for symmetrical as well as asymmetrical building Model-2 with Normal commercial loading.

Table 5: Displacements: X & Y for Symmetrical and Asymmetrical Buildings for Model-2 under Normal commercial Loading.

MODEL-2 NORMAL LOADS (COMMERCIAL BUILDINGS)								
STOREY no	Symmetric				Asymmetric			
	Response Spectrum Method		Pushover Method		Response Spectrum Method		Pushover Method	
	Spe-X	Spe-Y	Pus-X	Pus-Y	Spe-X	Spe-Y	Pus-X	Pus-Y
5	3.49	5.60	6.70	12.9	5.52	6.34	5.88	15.7
4	3.46	5.57	6.70	12.9	5.47	6.29	6.23	15.6
3	3.44	5.54	6.69	12.8	5.41	6.24	6.63	15.5
2	3.40	5.51	6.67	12.8	5.32	6.18	6.91	15.3
1	0.80	1.00	1.56	2.29	3.60	2.86	4.91	7.13
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Displacement for X & Y direction for Response Spectrum Method (Spec-X & Spec-Y) and for Pushover method of analysis (Push-X & Push-Y) are shown in Table 6 for symmetrical as well as asymmetrical building Model-2 with Heavy loading.

Table 6: Displacements: X & Y for Symmetrical and Asymmetrical Buildings for Model-2 under Heavy Loading.

MODEL-2 HEAVY LOADS (DATA CENTRE BUILDINGS)								
STOREY no	Symmetric				Asymmetric			
	Response Spectrum Method		Pushover Method		Response Spectrum Method		Pushover Method	
	Spe-X	Spe-Y	Pus-X	Pus-Y	Spe-X	Spe-Y	Pus-X	Pus-Y
5	3.88	6.22	6.78	12.9	5.76	6.61	5.59	23.3
4	3.86	6.20	6.67	12.9	5.71	6.57	5.98	23.2
3	3.83	6.17	6.57	12.8	5.65	6.52	6.41	23.1
2	3.79	6.13	6.42	12.7	5.55	6.45	6.73	22.9
1	0.89	1.12	1.53	2.27	3.76	2.99	4.80	18.4
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Displacement for X & Y direction for Response Spectrum Method (Spec-X & Spec-Y) and for Pushover method of analysis (Push-X & Push-Y) are shown in Table 7 for symmetrical as well as asymmetrical building Model-3 with Normal commercial loading.

Table 7: Displacements: X & Y for Symmetrical and Asymmetrical Buildings for Model-3 under Normal commercial Loading.

MODEL-3 NORMAL LOADS (COMMERCIAL BUILDINGS)								
STOREY no	Symmetric				Asymmetric			
	Response Spectrum Method		Pushover Method		Response Spectrum Method		Pushover Method	
	Spe-X	Spe-Y	Pus-X	Pus-Y	Spe-X	Spe-Y	Pus-X	Pus-Y
5	1.04	3.21	4.82	7.29	4.08	6.73	6.69	20.9
4	1.02	3.18	4.68	7.27	4.01	6.67	6.83	20.6
3	1.00	3.15	4.53	7.22	3.92	6.59	6.99	20.4
2	0.97	3.08	4.34	7.14	3.81	6.47	7.07	19.9
1	0.90	2.97	4.00	6.90	3.64	6.17	6.97	19.0
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Displacement for X & Y direction for Response Spectrum Method (Spec-X & Spec-Y) and for Pushover method of analysis (Push-X & Push-Y) are shown in Table 8 for symmetrical as well as asymmetrical building Model-3 with Heavy loading.

Table 8: Displacements: X & Y for Symmetrical and Asymmetrical Buildings for Model-3 under Heavy Loading.

MODEL-3 HEAVY LOADS (DATA CENTRE BUILDINGS)								
STOREY no	Symmetric				Asymmetric			
	Response Spectrum Method		Pushover Method		Response Spectrum Method		Pushover Method	
	Spe-X	Spe-Y	Pus-X	Pus-Y	Spe-X	Spe-Y	Pus-X	Pus-Y
5	1.26	3.60	4.47	7.05	4.24	7.08	6.43	20.4
4	1.24	3.57	4.32	6.93	4.17	7.01	6.59	20.2
3	1.21	3.53	4.17	6.82	4.09	6.92	6.78	19.9
2	1.17	3.46	3.98	6.61	3.97	6.80	6.88	19.5
1	1.10	3.33	3.64	6.33	3.79	6.49	6.81	18.6
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 13. Shows the comparison of displacements values in mm for Model-1, **symmetrical buildings** subjected to Normal loading and Heavy Loading in both X & Y direction.

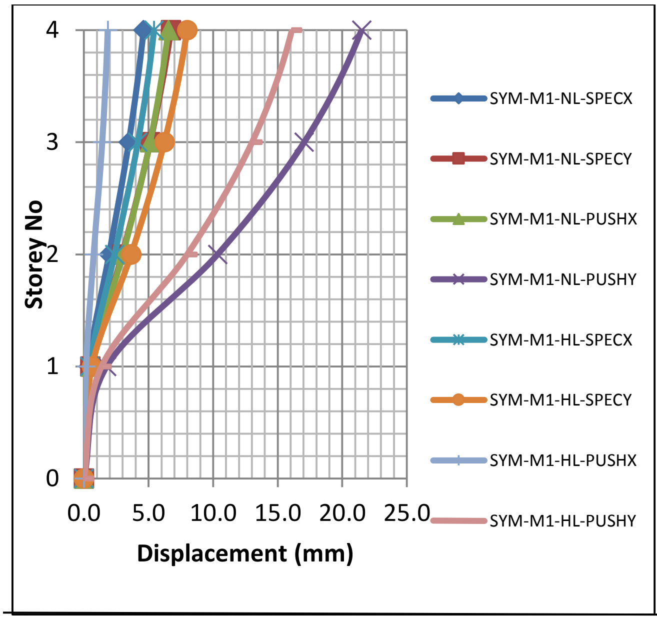

Figure 13: Displacement: X & Y direction for Model-1 symmetrical buildings.

Figure 14. Shows the comparison of displacements values in mm for Model-1 **Asymmetrical buildings** subjected to Normal loading and Heavy Loading in both X & Y direction.

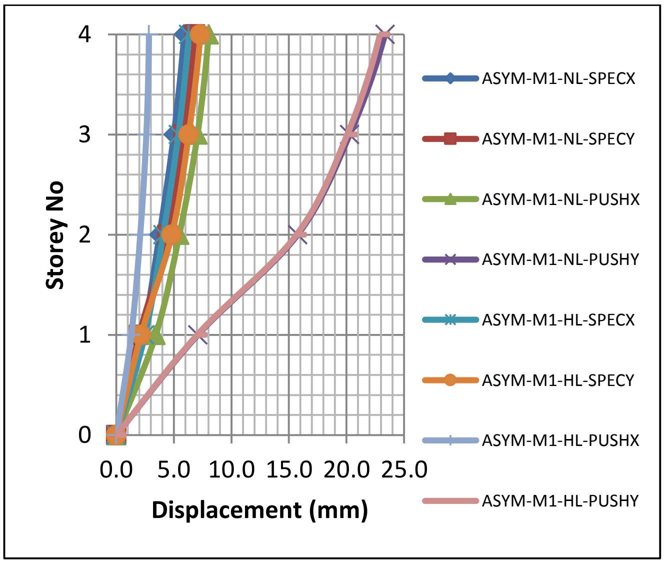

Figure 14: Displacement: X & Y direction for Model-1 Asymmetrical buildings.

Figure 15. Shows the comparison of displacements values in mm for Model-2, **Symmetrical buildings** subjected to Normal loading and Heavy Loading in both X & Y direction.

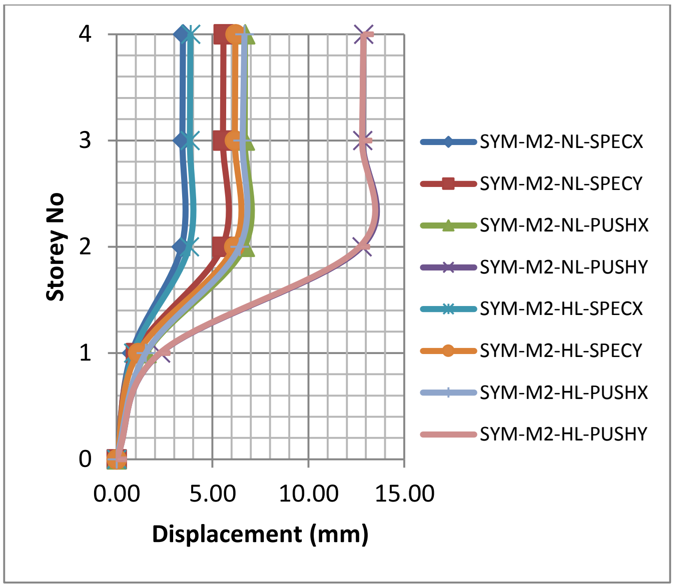

Figure 15.: Displacement: X & Y direction for Model-2 symmetrical buildings.

Figure 16. Shows the comparison of displacements values in mm for Model-2, **Asymmetrical buildings** subjected to Normal loading and Heavy Loading in both X & Y direction.

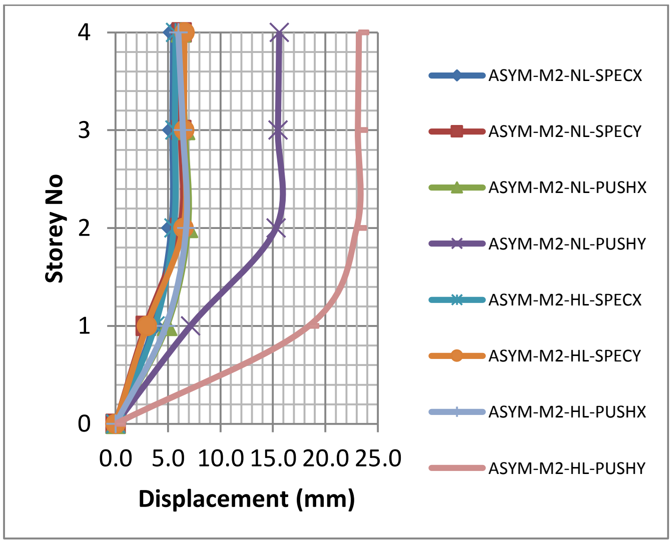

Figure 16: Displacement: X & Y direction for Model-2 Asymmetrical buildings.

Figure 17. Shows the comparison of displacements values in mm for Model-3, **Symmetrical buildings** subjected to Normal loading and Heavy Loading in both X & Y direction.

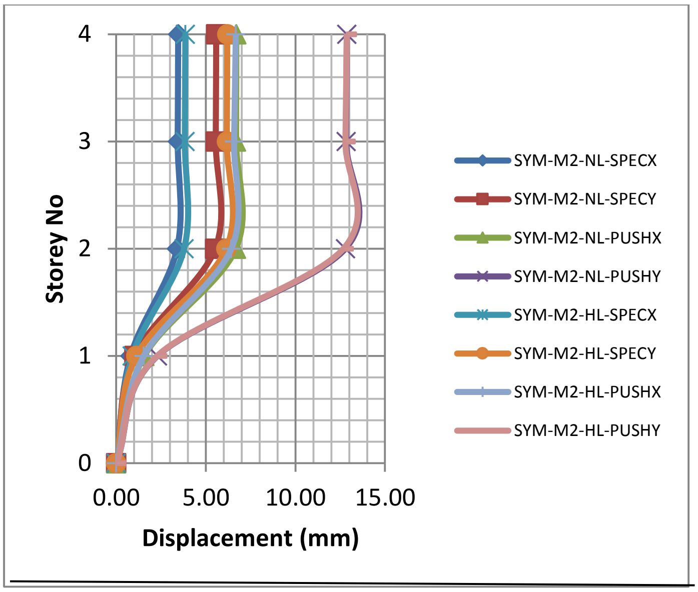

Figure 17: Displacement: X & Y direction for Model-3 symmetrical buildings.

Figure 18. Shows the comparison of displacements values in mm for Model-3, **Asymmetrical buildings** subjected to Normal loading and Heavy Loading in both X & Y direction.

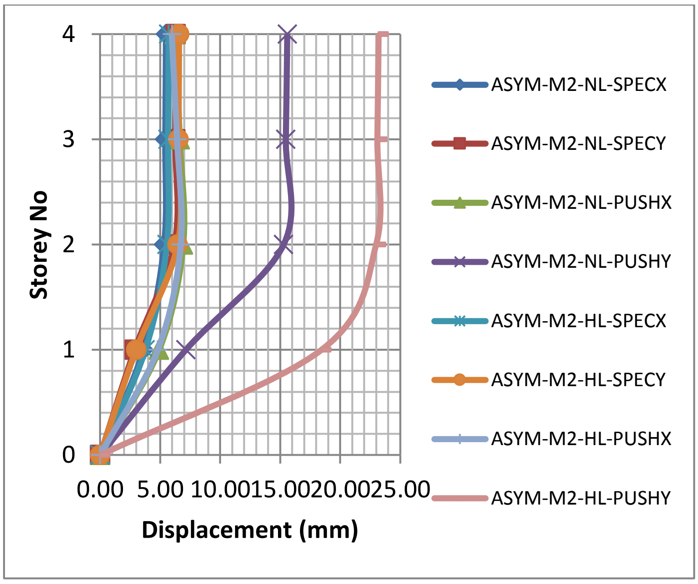

Figure 18: Displacement: X & Y direction for Model-3 Asymmetrical buildings.

CONCLUSION

1) Buildings constructed on hilly sloping terrain are very irregular in configuration and behaves differently than those built on plains.
2) Lateral displacements due to earthquake in Asymmetric buildings is more compare to the symmetrical buildings, as asymmetrical buildings are irregular in nature and are susceptible to the high torsion. Asymmetrical buildings of Model-1, Model-2 & Model-3 have more displacements compare to their respective symmetrical models.
3) Frames of buildings constructed on sloping grounds of hilly region are subjected to more displacements as the column heights in ground storey varies, as buildings step backs.
4) Displacements in buildings with heavy loading of data centre are higher compare to the buildings with normal loading for response spectrum method.
5) Presence of infills have overall effect on the behavior of buildings when subjected to the seismic forces. Displacements are considerably reduced in Model-3 because the effect of infill walls is considered.

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