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Research paper

Pushover Analysis of Symmetrical and Asymmetrical Buildings With and Without Heavy Loads

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Abstract

This Study compares the Structural behavior of buildings constructed on plain ground and on hilly slopes, Firstly by considering normal loads and thereafter by considering heavy loads. The building constructed on plane ground behaves distinctively different from buildings constructed on hilly slopes. Behavior of buildings on plain is simple and symmetrical whereas the buildings on hilly slopes are asymmetrical and irregular in nature. Similarly commercial buildings with normal loading behaves differently in comparison to special buildings with heavy loading. Three different types of Symmetrical and Asymmetrical Analytical Models are generated using "ETABS", and are studied under the effect of normal and heavy loads separately by performing Pushover analysis.

Keywords: *Symmetric Buildings; Asymmetric Buildings; Non Linear Pushover Analysis; Heavy Loads; Data Center*.

1. Introduction

Due to rapid Urbanization and Digitization loads of Data is produced, Processed and stored for future usage. Earlier companies used to outsource the Data storage to specialize firms but nowadays most of them prefer to have in-house Data storage facility. Buildings which accommodates complete Data and I.T. systems and technically facilitates the working and arrangement of complete computers, telecommunications and storage systems along with their necessary components and back up equipments are called as Data Center Buildings. Structurally these buildings have to support heavy loads.

This Study compares the Structural behavior of buildings constructed on plain ground and on hilly slopes, Firstly by considering normal loads (effects on normal commercial buildings) and thereafter by considering heavy loads (effects on the special buildings such as Data center buildings). The building constructed on plane ground is distinctively different from buildings constructed on hilly slopes. Behavior of buildings on plain is simple and symmetrical whereas the buildings on hilly slopes are asymmetrical and irregular in nature. Similarly commercial buildings with normal loading behaves differently in comparison to special buildings with heavy loading. Three different types of Symmetrical and Asymmetrical Analytical Models are generated using "ETABS", and are studied under the effect of normal and heavy loads separately by performing non linear static analysis (Pushover Method).

2. Methods

To study the Structural response under seismic loading, three types of 3-D analytical models for Symmetrical and Asymmetrical buildings are generated. Each of these Symmetrical and Asymmetrical building models are loaded with normal loads and Heavy loads separately. Pushover analysis is performed for all the models and Structural response such as displacement at Performance point, Ductility ratio, Response reduction factor and Damage Index is tabulated. To simulate the Plain ground, Symmetrical building models are generated by keeping the height of columns at ground storey as constant. Whereas, to simulate the effect of hilly slopes, Asymmetrical building models are generated by varying the height of ground storey columns between 3m to 13.8m. Plan layout is kept same throughout all the models.

2.1. Types of Analytical Models.

Model-1: Bare frame without infill walls.
Model-2: Brick Infills are modelled with both mass and stiffness in upper stories, whereas ground storey is without any infill wall.

Model-3: Brick Infills are modelled with both mass and stiffness in upper floors. In ground storey, walls are considered in all the periphery bays in longitudinal direction and in transverse direction it is considered only in the end bays along periphery.Brick wall thickness considered is 230mm.

3. Results

3.1. Structural Response

Pushover analysis is performed in order to examine the hinge status and study the deformation of symmetric and Asymmetric building models along transverse and longitudinal directions under the action of normal and heavy loads. Results are tabulated in Tables 1 to 6.

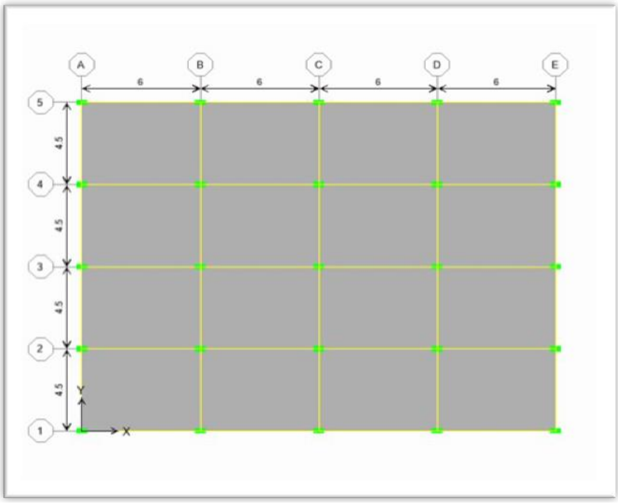

Fig. 1: Symmetrical (Plan: Model-1)

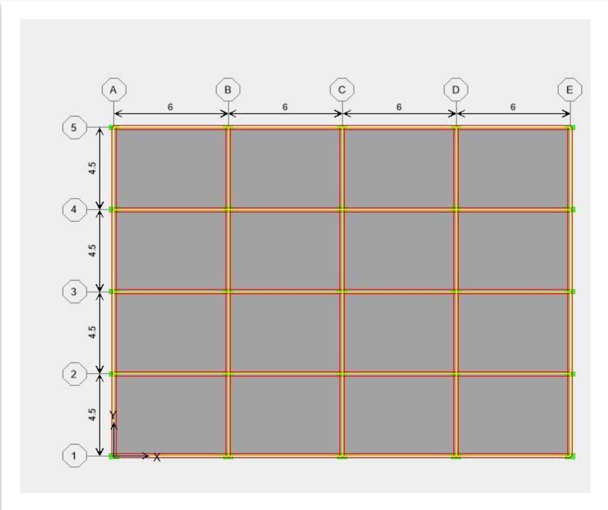

Fig. 2: Symmetrical (Plan: Model-2)

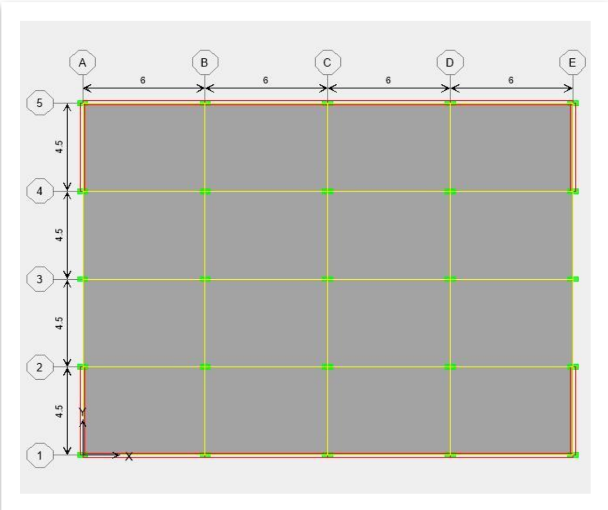

Fig. 3: Symmetrical (Plan: Model-3)

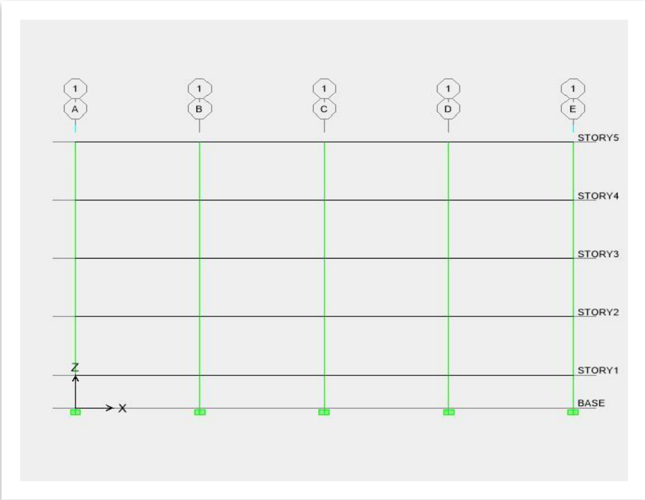

Fig. 4: Symmetrical (Elevation: Model -1)

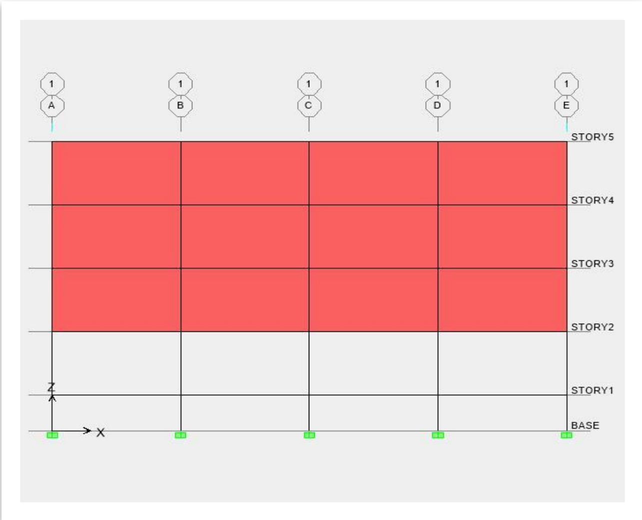

Fig. 5: Symmetrical (Elevation: Model-2)

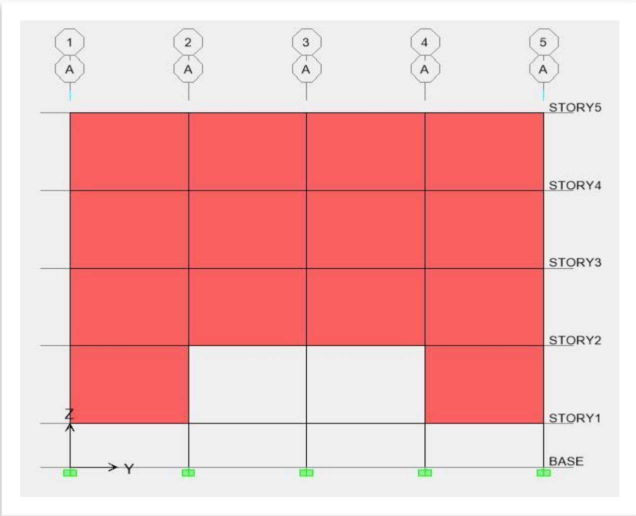

Fig. 6: Symmetrical (Elevation: Model-3)

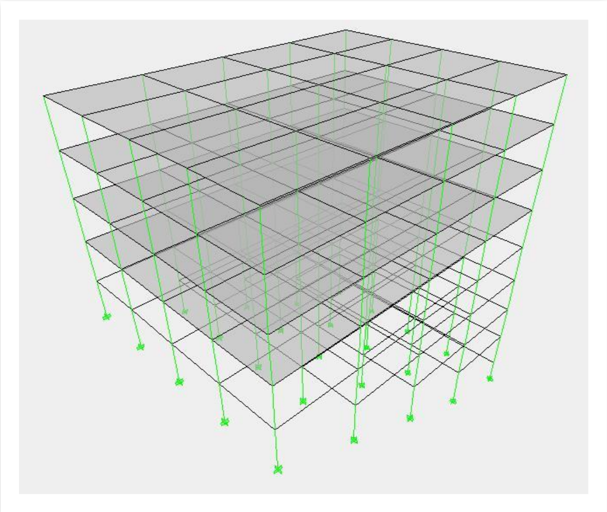

Fig. 7: Asymmetrical (3D View Model-1)

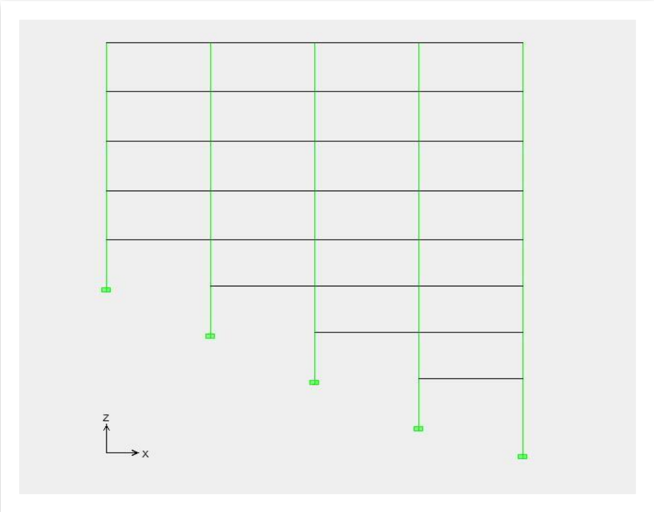

Fig. 10: Asymmetrical (Elevation: Model -1)

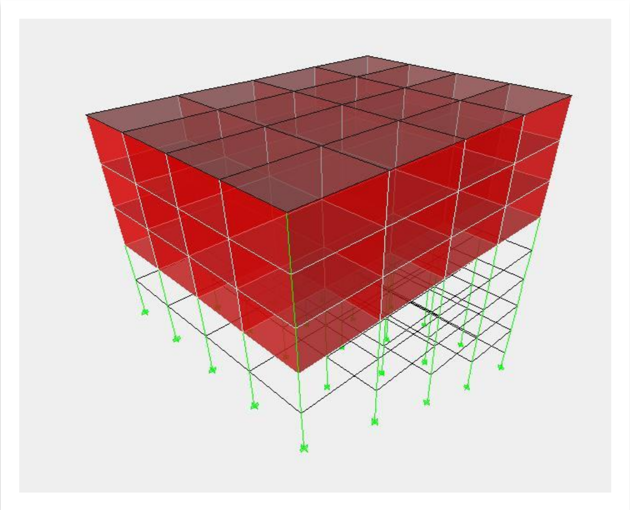

Fig. 8: Asymmetrical (3D View Model-2)

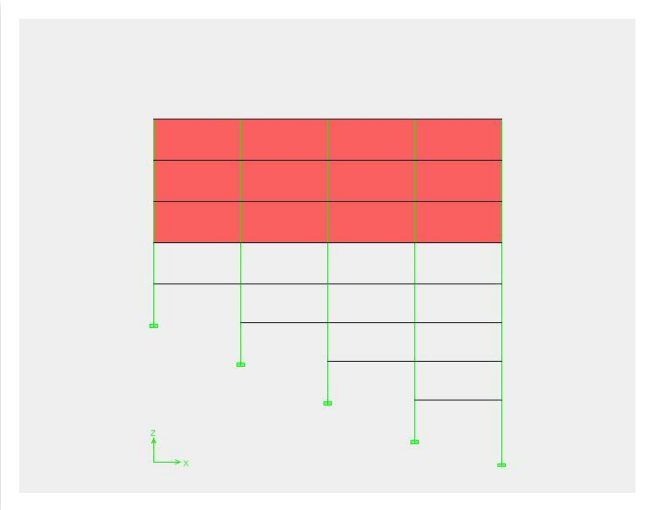

Fig. 11: Asymmetrical (Elevation: Model -2)

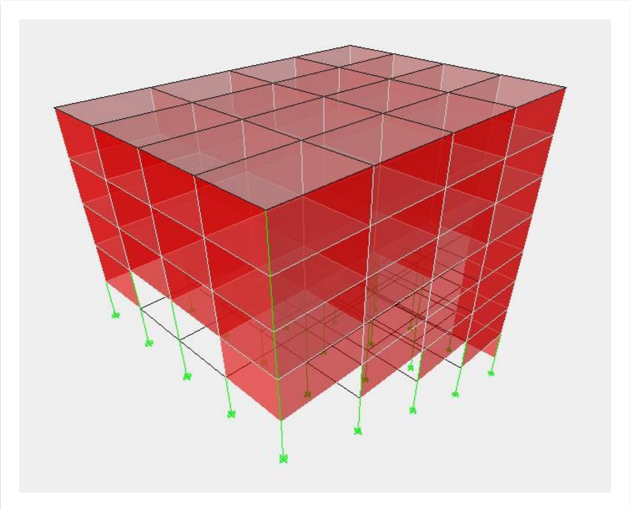

Fig. 9: Asymmetrical (3D View Model-3)

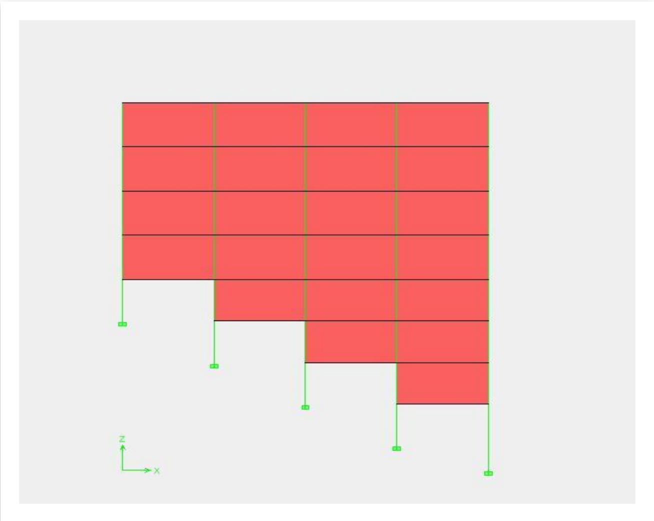

Fig. 12: Asymmetrical (Elevation: Model -3)

3.1.1. Symmetrical buildings

Table 1: Structural Response of Symmetrical building Model-1 along transverse and Longitudinal direction.

Model-1: Displacements At Performance Point				
Storey no	Pushover Method (Normal Loads)		Pushover Method (Heavy Loads)	
	Push-X	Push-Y	Push-X	Push-Y
5	77.559	73.130	77.830	178.537
4	72.630	69.147	73.375	168.403
3	57.817	55.857	58.881	137.735
2	31.505	30.740	32.424	84.719
1	5.599	5.500	5.809	25.132
0	0.000	0.000	0.000	0.000
Hinge Status	IO-LS	IO-LS	IO-LS	IO-LS

Table 2: Structural Response of Symmetrical building Model-2 along transverse and Longitudinal direction.

Model-2: Displacements At Performance Point				
Storey no	Pushover Method (Normal Loads)		Pushover Method (Heavy Loads)	
	Push-X	Push-Y	Push-X	Push-Y
5	29.601	31.072	29.779	31.196
4	29.497	30.825	29.695	30.991
3	29.377	30.555	29.594	30.760
2	29.150	30.178	29.387	30.422
1	10.041	10.442	10.071	10.477
0	0.000	0.000	0.000	0.000
Hinge Status	C-D	C-D	C-D	C-D

Table 3: Structural Response of Symmetrical building Model-3 along transverse and Longitudinal direction.

Model-3: Displacements At Performance Point				
Storey no	Pushover Method (Normal Loads)		Pushover Method (Heavy Loads)	
	Push-X	Push-Y	Push-X	Push-Y
5	23.978	27.686	23.951	17.246
4	23.645	26.992	23.604	16.896
3	23.230	26.210	23.173	16.454
2	22.757	24.989	22.677	15.698
1	21.841	22.413	21.668	14.032
0	0.000	0.000	0.000	0.000
Hinge Status	LS-CP	C-D	C-D	C-D

Following are the salient features to be noted in relation to Structural response of **Symmetrical building Models.**

Model-1: Hinge status remains within IO-LS range.
Model-2: Hinge status remains within C-D range.
Model-3: Hinge status remains within LS-CP & C-D range.

3.1.2 Asymmetrical buildings

Table 4: Structural Response of Asymmetrical building Model-1 along transverse and Longitudinal direction.

Model-1: Displacements At Performance Point				
Storey no	Pushover Method (Normal Loads)		Pushover Method (Heavy Loads)	
	Push-X	Push-Y	Push-X	Push-Y
5	72.988	58.782	97.820	66.205
4	70.110	56.432	94.391	64.024
3	62.112	51.252	93.106	58.910
2	46.986	39.529	61.378	48.115
1	29.046	17.384	35.906	35.887
0	0.000	0.000	0.000	0.000
Hinge Status	LS-CP	LS-CP	LS-CP	LS-CP

Table 5: Structural Response of Asymmetrical building Model-2 along transverse and Longitudinal direction

Model-2: Displacements At Performance Point				
Storey no	Pushover Method (Normal Loads)		Pushover Method (Heavy Loads)	
	Push-X	Push-Y	Push-X	Push-Y
5	56.317	58.340	65.421	59.102
4	56.457	57.849	65.609	58.639
3	56.430	57.218	65.616	58.029
2	56.342	56.343	65.548	57.165
1	42.910	48.004	51.145	48.680
0	0.000	0.000	0.000	0.000
Hinge Status	LS-CP	C-D	D-E	C-D

Table 6: Structural Response of Asymmetrical building Model-3 along transverse and Longitudinal direction.

Model-3: Displacements At Performance Point				
Storey no	Pushover Method (Normal Loads)		Pushover Method (Heavy Loads)	
	Push-X	Push-Y	Push-X	Push-Y
5	21.598	39.180	21.668	39.677
4	21.637	38.503	21.737	39.008
3	21.453	37.641	21.574	38.142
2	21.186	36.653	21.324	37.145
1	20.086	30.788	20.225	31.099
0	0.000	0.000	0.000	0.000
Hinge Status	LS-CP	C-D	C-D	C-D

Following are the salient features to be noted in relation to Structural response of **Asymmetrical building Models.**

Model-1: Hinge status remains within IO-LS range.
Model-2: Hinge status remains within LS-CP, C-D & D-E range.
Model-3: Hinge status remains within LS-CP & C-D range.

3.2. Ductility Ratio and Response Reduction Factor

The property by which structure undergoes deformation without damage or failure is called as ductility of the structure. Ductility enables structures to withstand severe earthquakes. By invoking the property of ductility into the structures, its ability to resist the earthquake increases. Ductility ratio and response reduction factor for symmetric and asymmetric building models for normal and heavy loading along transverse and longitudinal direction is tabulated in Table 7 to 10

Reduction factor "R " often referred to in an indirect manner through non-dimensional parameters, which are coefficient in terms of either the ductility or displacement. For intermediate-period system, $R=\sqrt{2\mu-1}$

3.2.1 Symmetrical buildings

Table 7: Ductility Ratio and Response Reduction Factor of Symmetrical building along transverse direction for Normal (NL) and Heavy Loads (HL)

PUSHX	Symmetric Buildings					
	Model-1		Model-2		Model-3	
	NL	HL	NL	HL	NL	HL
Yield displacement U_{yield} (mm)	12.008	8.136	6.781	6.721	3.740	3.793
Ultimate displacement $U_{ultimate}$ (mm)	201.24	183.5	83.928	83.90	28.545	24.23
Ductility Ratio (m)	16.76	22.56	12.38	12.49	7.63	6.39
R	5.70	6.64	4.87	4.90	3.78	3.43

Table 8: Ductility Ratio and Response Reduction Factor of Symmetrical models along Longitudinal direction for Normal (NL) and Heavy Loads (HL)

PUSH Y	Symmetric Buildings					
	Model-1		Model-2		Model-3	
	NL	HL	NL	HL	NL	HL
Yield displacement U_{yield} (mm)	12.68	11.12	6.402	6.358	3.993	6.358
Ultimate displace-ment $U_{ultimate}$ (mm)	187.1	183.8	83.42	83.58	27.68	33.09
Ductility Ratio (□)	14.76	16.53	13.03	13.15	6.93	5.21
R	5.34	5.66	5.01	5.03	3.59	3.07

Referring to Table 7 & 8 above, it clearly indicates that the Symmetrical building Models when subjected to Normal and Heavy loads, its ductility ratio and Response Reduction Factor reduces as the stiffness increases both in transverse and longitudinal directions. From bare frame Model-1 to infill Model-2 and Model-3 the stiffness of the Model increases due to presence of infill walls.

3.2.2 Asymmetrical buildings

Table 9: Ductility Ratio and Response Reduction Factor of Asymmetrical building along transverse direction for Normal (NL) and Heavy Loads (HL)

PUSHX	Asymmetric Buildings					
	Model-1		Model-2		Model-3	
	NL	HL	NL	HL	NL	HL
Yield dis-placement U_{yield} (mm)	12.47	11.98	6.947	6.765	7.488	7.299
Ultimate displacement $U_{ultimate}$ (mm)	207.0	203.86	80.983	81.509	49.997	50.268
Ductility Ratio (m)	16.60	17.01	11.66	12.05	6.68	6.89
R	5.67	5.75	4.72	4.81	3.51	3.57

Table 10: Ductility Ratio and Response Reduction Factor of Asymmetrical building along Longitudinal direction for Normal (NL) and Heavy Loads (HL)

PUSH Y	Asymmetric Buildings					
	Model-1		Model-2		Model-3	
	NL	HL	NL	HL	NL	HL
Yield dis-placement U_{yield} (mm)	13.58	17.7	12.3	12.292	11.460	11.650
Ultimate dis-placement $U_{ultimate}$ (mm)	183.6	193.3	115.9	116.4	58.464	59.384
Ductility Ratio (□)	13.52	10.89	9.37	9.47	5.10	5.10
R	5.10	4.56	4.21	4.24	3.03	3.03

Referring to Table 9 & 10 above, it clearly indicates that the Asymmetrical building Models when subjected to Normal and Heavy loads, its ductility ratio and Response Reduction Factor reduces as the stiffness increases both in transverse and longitudinal directions. From bare frame Model-1 to infill Model-2 and Model-3 the stiffness of the Model increases due to presence of infill walls.

4. Conclusion

1. Bare Frame structures (Model-1), Ductility ratio is maximum. For frames with infill (Model-2&3). Ductility ratio reduces when the effect of infill is considered, It can be concluded that Bare frame structures will give enough warning before collapse.
2. Response reduction factor is highest for Bare Frame (Model-1) and least for frames with infill (Model-2&3). Bare frame models has the resistance capability even after occurrence of first yielding. Hence the practice of ignoring the infill during the analysis and design process will be detrimental to the structure.
3. Ignoring the effect of infill wall brings the performance level of the structure within the safe limits of "Collapse prevention" and when the effect of infill is considered in the same model, performance level goes down drastically to "D" level. Hence consideration of infill effect should be a mandatory practice.
4. Displacement at First hinge formation is more for Asymmetrical buildings compare to the Symmetrical building models.
5. Presence of infill have overall effect on the structural response of buildings when subjected to seismic forces. Displacement and drifts reduces considerably for building models with infill.

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