Seismic Response of RC Framed Structures Having Plan and Vertical Irregularities with and Without Masonry Infill Action

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Abstract - *The disquisition work is involved with the comparison of the seismic evaluation of RC buildings connected with and without masonry infill action along with plan and vertical irregularities. The method of analysis was carried out in terms of equivalent static, response spectrum and pushover analysis according to IS 1893:2002(part1) code. The comparison of equivalent static, response spectrum and pushover methods by using finite element software package ETABS version 9.7.4 is used to perform the modeling and analysis of 9-storey building by considering the seismic zone V as per IS 1893:2002(part 1) code. For Gravity load and for 0.9, 1.2 and 1.5 seismic load combination IS 456:2000 and IS 1893:2002 (part 1) codes are referred. Results of these analyses are discussed in terms of the base shear, lateral displacement, storey drift and performance point. From these results it is concluded that lateral displacement and storey drift will be more in bare frame compare with the infill frames, whereas the base shear will be less in bare frame compare with the infill frames. Also it is observed that lateral displacement and storey drift will be more for irregular buildings when compared to regular buildings.*

***Key Words:* Base shear, Lateral displacement, Storey drift and performance point.**

1. INTRODUCTION

It is the responsibility of structural engineers to ensure the built environment can withstand extreme dynamic actions, such as wind, traffic or earthquake. Structural engineers must understand how the built environment will respond to such dynamic actions. . An immediate effect of earthquakes is numerous fatalities due to structural collapse and falling debris, while in the long-term thousands of individuals are left homeless due to collapsed or unsafe buildings and the resulting slow process of rebuilding. The structural engineering community has the ability to influence the direct consequences of these events by better understanding the seismic response of building structures and aiming to constantly improve their seismic design. A structure has to be designed to resist the lateral actions applied to it by the earthquake ground motion. In order to achieve this, a lateral load resisting system is needed to resist these lateral forces. Typical methods of achieving moderate increased lateral stiffness are moment resisting frames, shear walls, infilled frame. The moment resisting frame resists the lateral actions through framing action of rigid connections at the joints. Infilled frame shear wall systems can be masonry but are typically constructed in reinforced concrete and resist lateral actions through in-plane resistance of the shear wall.

To perform well in an earthquake, a building should possess four main attributes, namely simple and regular configuration, and adequate lateral strength, stiffness and ductility. Buildings having simple regular geometry and uniform distribution of mass and stiffness in plan as well as in elevation, suffer much less damage than buildings with irregular configurations.

1.1 IRREGULARITY OF STRUCTURES

Irregularities in building structures refer to the non-uniform response of a structure due to non-uniform distribution of structural properties. There are two types of structural irregularity; vertical (also termed in-elevation) and plan (also termed plan asymmetry). Vertical irregularity typically refers to the uneven distribution of mass along the height of a multi-storey structure or geometrical set-backs changing the floor plan between adjacent floors. During a seismic event, the result can be a soft storey mechanism. Plan irregularity typically refers to the uneven distribution of stiffness or strength in the plan of a structure resulting in a torsional response of the structure when subjected to a seismic excitation. Structures with plan irregularity quite often suffer severe damage in earthquake events because the response of the structure is not only translational, but also torsional.

1.2 OBJECTIVES OF STUDY

a) To study the effect of re-entrant corners where both projection of the structure beyond the re-entrant corner

are greater than 1.5 percent of its plan dimension in the given direction which comes under plan irregularity on behavior of bare and infilled frames.
b) To study the effect of vertical geometric irregularity where the horizontal dimensions of the lateral force resisting system in any storey is more than 150 percent of that in its adjacent storeys on behavior of bare and infilled frames.
c) To study the performance level of the structure.

2. METHODLOGY

There are different methods of analysis, which provide different degree of accuracy. The analysis process can be categorized on the basis of three factors: the type of externally applied loads, the behavior of structure / structural materials, and the type of structural model selected. Based on the type of externally applied load and behavior of structure the seismic methods of analysis considered for the study are Linear Static Analysis, Linear Dynamic Analysis and Non-Linear Static Analysis.

2.1 Linear Static Analysis

Linear static analysis can be performed by equivalent static lateral force method. This method can be applied for regular structure with limited height i.e. for low and medium height buildings.

2.2 Linear Dynamic Analysis

Linear dynamic analysis can be performed in two ways either by Mode Superposition Method (Response Spectrum Method) or Elastic Time History Method. This analysis will produce the effect of higher modes of vibration and the actual distribution of forces in the elastic range in a better way. This analysis represents an improvement over Linear Static Analysis. The significant difference between linear static and linear dynamic analysis is the level of force and their distribution along the height of the structure.

2.3 Non-linear Static Analysis

This is an improvement over the linear static or dynamic analysis in the sense that it allows the inelastic behavior of the structure. This method assumes a set of static incremental lateral load over the height of structure, which neglects the variation of loading, influence of higher modes and the effect of resonance. This method, under the name of push over analysis has acquired a great deal of popularity in spite of the above deficiencies. It provides reasonable estimation of global deformation capacity, especially for structures, which primarily respond according to the first mode. Performance point is the point where capacity spectrum intersects the appropriate demand spectrum (capacity equals demand). To have desired performance, every structure has to be designed for this level of forces. Desired performance with different damping ratios have been shown in Fig.1.

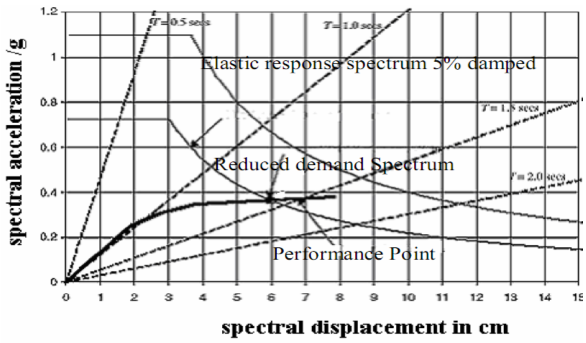

Fig-1 Determination of performance point

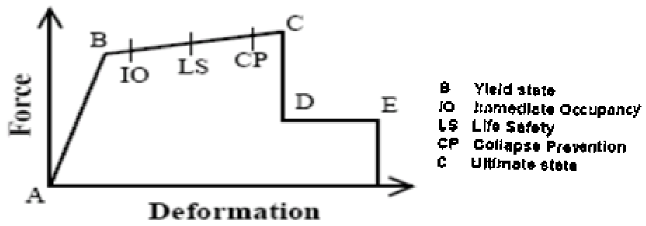

Figure-2 Hinge property

3. ANALYTICAL MODELLING

The plan layout, elevation and 3D view of the reinforced concrete moment resisting frame building of nine storeyed building for different models. In this study, the plan layout is deliberately kept similar for all the buildings for the study. The each storey height is kept 3.5 m for all the different buildings models. The building is considered to be located in the seismic zone-V and intended for office use. In the seismic weight calculations only 50% of the floor live load is considered.

Model 1: Regular bare frame

Model 2: Regular infill frame

Model 3: Bare frame with plan irregularities

Model 4: Infill frame with plan irregularities

Model 5: Bare frame with vertical geometric irregularities

Model 6: Infill frame with vertical geometric irregularities

Model 7: Bare frame with both plan and vertical geometric irregularities

Model 8: Infill frame with both plan and vertical geometric irregularities

The plan, elevation and 3D view all models considered are in following figures

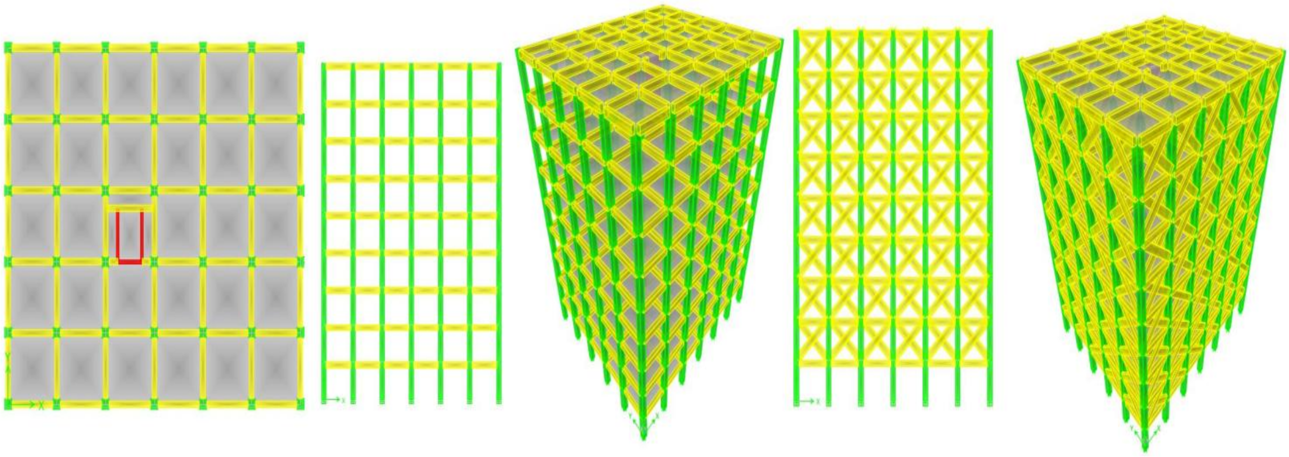

Fig 3: Plan, Elevation and 3D view of bare and infill frame for model-1 and model-2 respectively.

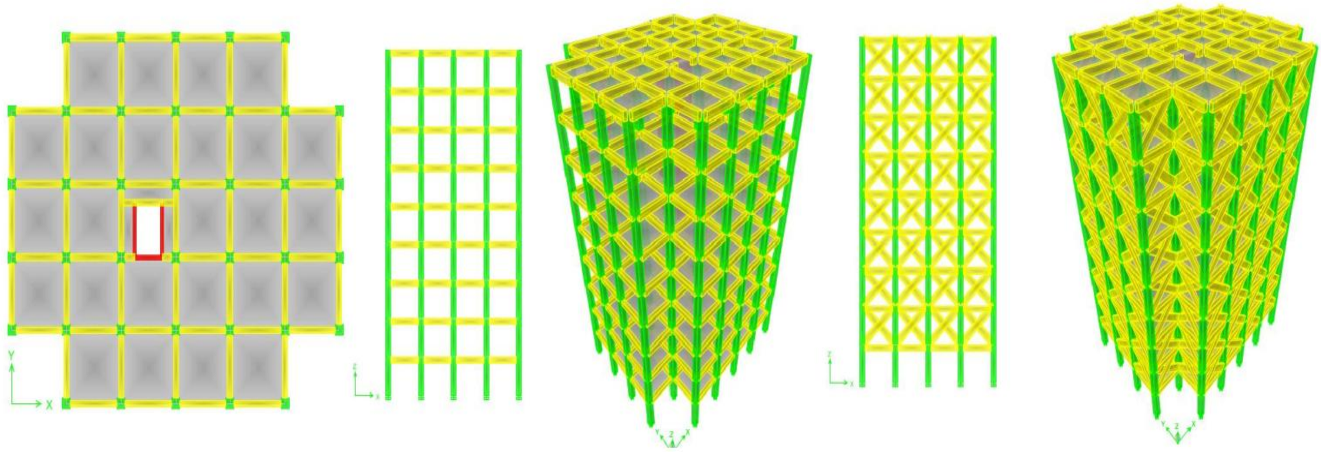

Fig 4: Plan, Elevation and 3D view of bare and infill frame for model-3 and model-4 respectively.

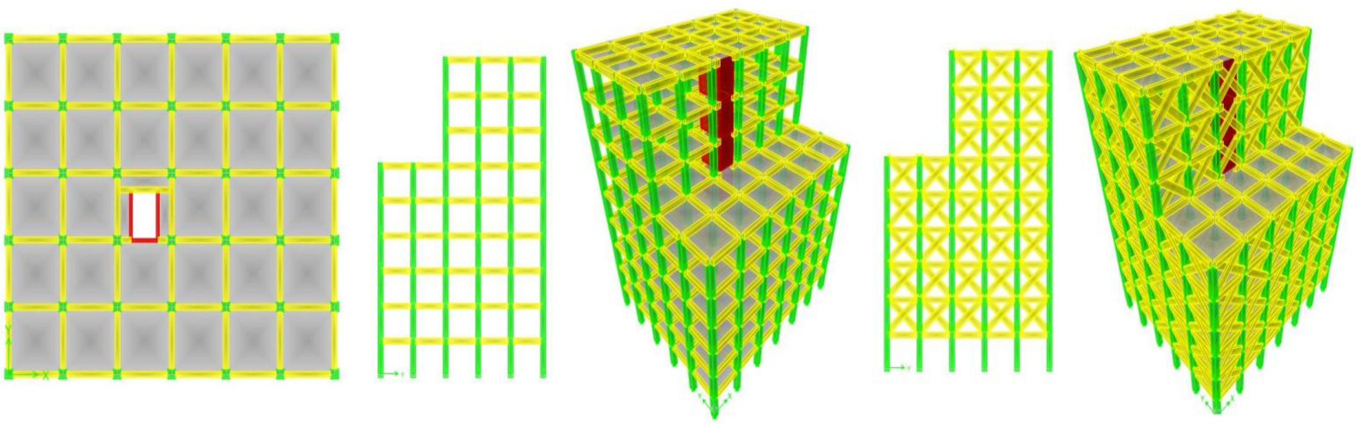

Fig 5: Plan, Elevation and 3D view of bare and infill frame for model-5 and model-6 respectively.

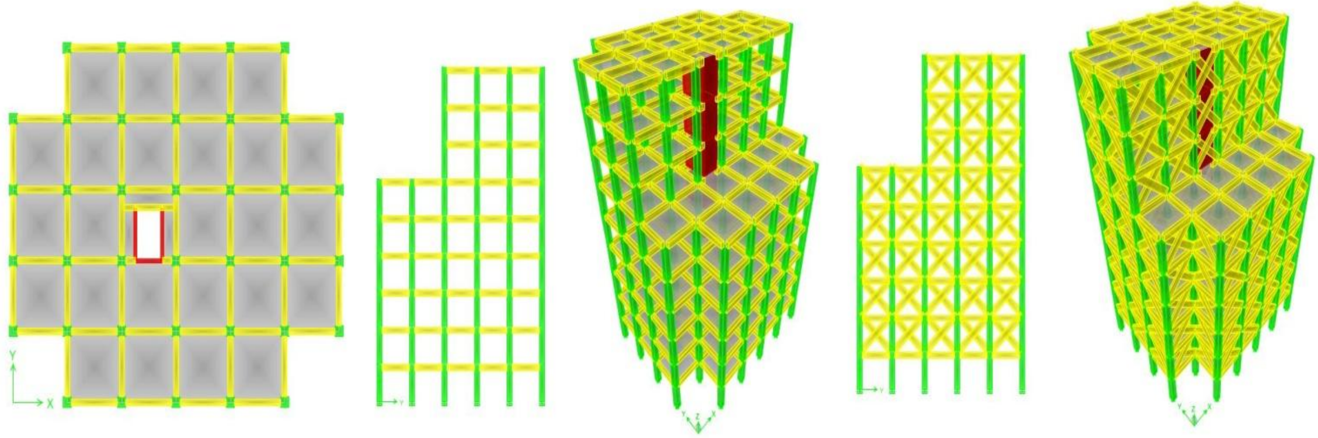

Fig 6: Plan, Elevation and 3D view of bare and infill frame for model-7 and model-8 respectively.

3.1DESIGN DATA FOR ALL THE BUILDINGS:

i) Material Properties:

Young's modulus of (M25) Concrete, $E_c = 25 \times 10^6$ KN/m^2

Density of Reinforced Concrete = 25 KN/m^3

Young's modulus of Steel, $E_s = 2 \times 10^5$ KN/m^2

Density of Steel = Fe500

Modulus of elasticity of brick masonry = 1.8x10^6 KN/m^2

Density of brick masonry = 19.2 KN/m^3

Poisson's ratio for Concrete = 0.2

Poisson's ratio for Masonry = 0.198

ii) Details of Building:

Type of Structure = Ordinary Moment Resisting Frame (OMRF)

No. of floors in all models = 9

Type of Building = Office Building

Storey Height = 3.5m

Seismic Zone = V

iii) Member properties:

Thickness of Slab = 0.125m

Column size for all model buildings = (0.6m x 0.6m)

Beam dimensions for all model buildings = (0.375mx0.6m)

Thickness of wall = 0.230m

iv) Loads Considered in all models:

Floor finishes = 1.5 KN/m^2

Live load on floors = 4 KN/m^2

Wall load of 230mm thick = 15.54 KN/m

Parapet wall of 1m high = 4.65 KN/m

v) Seismic Forces:

Zone factor (V) = 0.36

Importance Factor (I) = 1.5

Response Reduction Factor (R) = 5

Type of Soil = II (For medium soil types)

Earthquake Live load on Slab as per clause 7.3.1 and 7.3.2 of IS 1893 (Part-I) - 2002 is calculated as:

Roof (clause 7.3.2) = 0

Floor (clause 7.3.1) = 0.5x4=2 KN/m2

Fundamental Natural period for bare frame,

$$T_a = 0.075 * h^{0.75},$$

(h=Height of the building in meters)= 0.997 Sec

Fundamental Natural period for infill frame $T_a = \dfrac{0.09*h}{\sqrt{d}}$,

(h=Height of the building in m and d= Base dimension of the building at the plinth level, in m, along the considered direction of the lateral force)

In x-direction = 0.579 Sec

In y-direction = 0.634 Sec

vi) Size of diagonal strut:

These provisions were based on the early work (FEMA 273, 1997), of Mainstone and Weeks (1970) and Mainstone (1971).The thickness of strut '*w*' is given by,

$$w = 0.175d\,(\lambda_h h_{col})^{-0.4}$$

Where, λ_h = coefficient used to determine equivalent width of infill strut, given by

$$\lambda_h = \sqrt[4]{\frac{E_m t \sin 2\theta}{4 E_c I_c h}}$$

h_{col} = Column height between center lines of beams, mm.
h = Height of infill panel, in.
E_c = Expected modulus of elasticity of column, N/mm2
E_m = Expected modulus of elasticity of infill, N/mm2
I_c = Moment of inertia of column, in.mm4
d = Diagonal length of infill panel, mm.
t = Thickness of infill panel and equivalent strut, mm.
θ = Angle whose tangent is the Infill Height – to length, radius

Table 1 Size of diagonal strut

Column size in mm	I_c(in m^4)	h(in m)	d(in m)	θ (in degrees)	λ_h	w (in m)	A =wXt	Size of diagonal strut in mm
600 X 600	0.0108	3.5	5.315	41.18	0.5739	0.704	0.162	704mmX230mm

4. Results and discussions

The following parameters of the results obtained from analysis are considered for the study.

The results obtained in terms of natural time period, base shear, lateral displacement and storey drift for different building models considered for different types of analysis carried out namely equivalent static analysis, response spectrum analysis and pushover analysis are presented. An effort has made to study the behavior of regular and irregular RC framed buildings with and without infill action.

4.1 Base shear

On analysis of all Models as Bare frame and Infilled frame, the base shears obtained is tabulated in Table 2.

Table 2 Comparison of Base shear (KN) in Bare frame and Infilled frame

Type of Frame	Base Shear(KN)	
	x-direction	y-direction
Model 1	6555.41	6555.41
Model 2	9140.77	8347.8
Model 3	5800.82	5800.82
Model 4	8078.47	7377.65
Model 5	5822.53	5822.53
Model 6	7973.26	7281.58
Model 7	5181.85	5181.85
Model 8	7094.52	6479.07

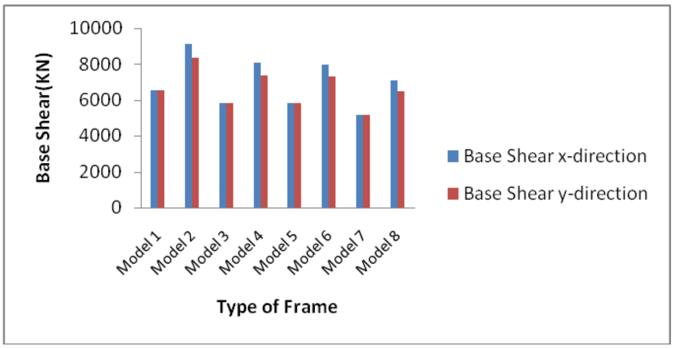

Fig 7 Comparison of Base shear in Bare frame and Infilled frame for different Models

4.2 LATERAL DISPLACEMENT

The maximum lateral displacements at each floor level for Equivalent Static, Response Spectrum and Pushover Analysis are presented in Table 3 to 6. The percentage of variation of displacement between bare frame and infill frame is also shown at each level in the respective table.

Table 3 Comparison of Maximum displacement (mm) for regular bare (Model 1) and infill frames (Model 2)

Storey	Equivalent static method		Variation in %	Response Spectra method		Variation in %	Pushover method		Variation in %
	Model-1	Model-2		Model-1	Model-2		Model-1	Model-2	
9	62.4515	35.1451	44	62.4515	35.1451	44	115.0241	69.3217	40
8	58.8868	33.3157	43	59.0694	33.3157	44	109.9664	66.9387	39
7	53.9362	30.6186	43	54.8125	31.2138	43	102.6253	62.9492	39
6	47.399	27.2095	43	49.0579	28.4442	42	93.1599	56.9303	39
5	39.6623	23.2915	41	41.9232	25.045	40	81.9929	48.4002	41
4	31.1352	19.0524	39	33.6098	21.1102	37	69.6463	37.6117	46
3	22.2196	14.6601	34	24.6452	16.748	32	56.6295	25.684	55
2	13.3401	10.2715	23	15.2603	12.0954	21	43.5203	14.1441	67
1	5.142	5.6798	-10	6.0282	6.8716	-14	27.935	5.2272	81

Table 4 Comparison of Maximum displacement (mm) for regular bare (Model 3) and infill frames (Model 4)

Storey	Equivalent static method		Variation in %	Response Spectra method		Variation in %	Pushover method		Variation in %
	Model-3	Model-4		Model-3	Model-4		Model-3	Model-4	
9	61.8267	35.1203	43	63.485	35.6417	44	413.9587	35.2991	91
8	58.2792	33.2419	43	60.1623	34.2387	43	377.2061	33.4165	91
7	53.3458	30.5075	43	55.8294	32.0954	43	332.3507	30.6754	91
6	46.8522	27.0706	42	49.9741	29.2264	42	280.0945	27.2285	90
5	39.1802	23.1332	41	42.7191	25.7116	40	222.5879	23.2774	90
4	30.7346	18.8837	39	34.268	21.6491	37	163.2316	19.0104	88
3	21.9125	14.4907	34	25.1836	17.1507	32	106.256	14.5965	86
2	13.1342	10.1118	23	15.587	12.3565	21	56.3731	13.037	77
1	5.0448	5.5477	-10	6.1384	6.9753	-14	18.6829	10.9682	41

Table 5 Comparison of Maximum displacement (mm) for regular bare (Model 5) and infill frames (Model 6)

Storey	Equivalent static method		Variation in %	Response Spectra method		Variation in %	Pushover method		Variation in %
	Model-5	Model-6		Model-5	Model-6		Model-5	Model-6	
9	66.8679	36.9789	45	66.8679	38.0844	43	439.6889	157.8534	64
8	63.5731	35.0751	45	63.5731	36.7078	42	399.3114	147.3613	63
7	58.2216	32.2056	45	58.2216	34.4869	41	351.0869	133.1453	62
6	51.1343	28.586	44	51.9185	31.4917	39	296.2898	116.4378	61
5	42.9319	24.6119	43	45.1031	28.0376	38	237.2317	100.8858	57
4	33.8317	20.2678	40	36.8696	23.9159	35	176.0813	83.9719	52
3	24.2579	15.7195	35	27.4304	19.2243	30	116.5252	66.0348	43
2	14.6423	11.1325	24	17.1412	14.1134	18	63.3033	47.8275	24
1	5.6688	6.247	-10	6.815	8.1878	-20	21.8579	32.7776	-50

Table 6 Comparison of Maximum displacement (mm) for regular bare (Model 7) and infill frames (Model 8)

Storey	Equivalent static method		Variation in %	Response Spectra method		Variation in %	Pushover method		Variation in %
	Model-7	Model-8		Model-7	Model-8		Model-7	Model-8	
9	66.5867	36.9869	44	66.5867	39.2523	41	350.6448	156.2493	55
8	63.3695	35.1255	45	63.3695	37.883	40	319.8178	150.1959	53
7	58.1063	32.3062	44	58.9274	35.6373	40	282.0813	141.0357	50
6	51.0941	28.7291	44	53.2356	32.5819	39	238.3749	129.1313	46
5	42.8717	24.7015	42	46.2764	28.9962	37	190.455	115.3371	39
4	33.7605	20.3054	40	37.8446	24.7132	35	140.5028	100.0903	29
3	24.1853	15.7119	35	28.1579	19.8377	30	91.8616	83.9091	9
2	14.5759	11.0864	24	17.5815	14.5239	17	48.8517	67.4694	-38
1	5.6226	6.1705	-10	6.9661	8.3591	-20	16.4317	46.8415	-185

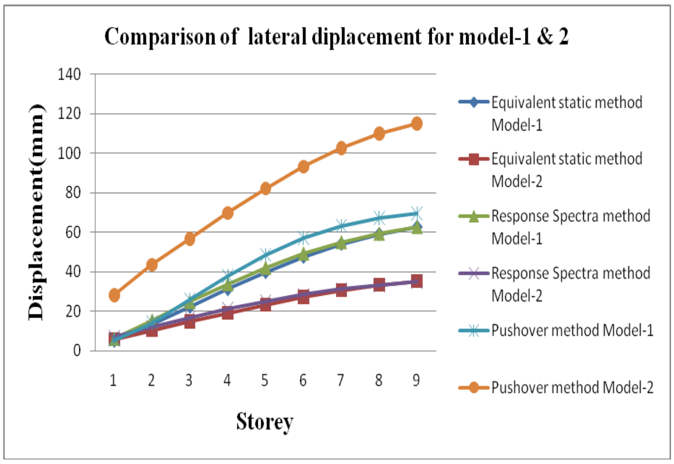

Fig 8 Comparison of lateral displacement in Bare and Infilled frames for model-1 and model-2

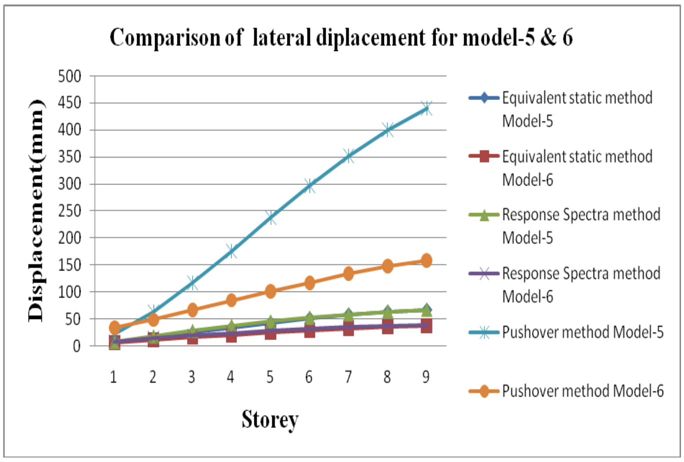

Fig 10 Comparison of lateral displacement in Bare and Infilled frames for model-5 and model-6

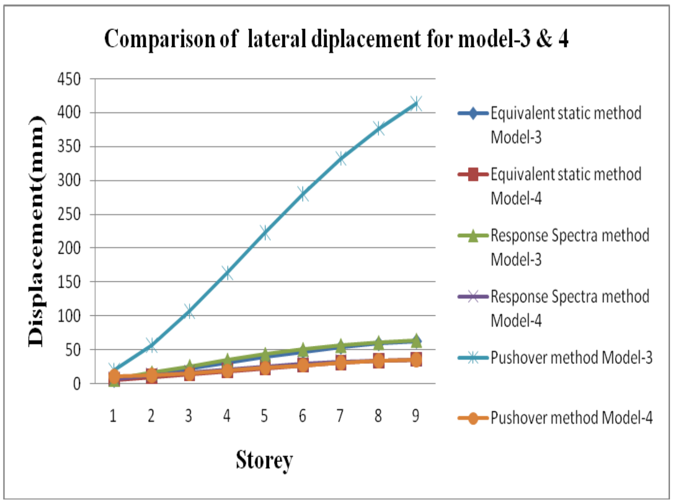

Fig 9 Comparison of lateral displacement in Bare and Infilled frames for model-3 and model-4

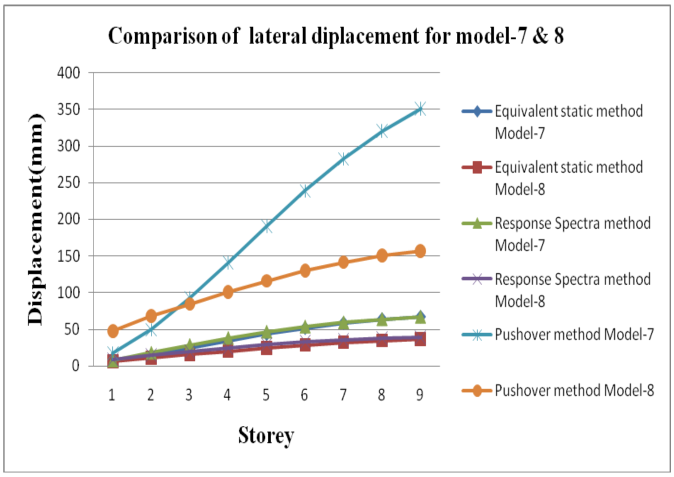

Fig 11 Comparison of lateral displacement in Bare and Infilled frames for model-7 and model-8

From the above tables and graphs it is observed that,

For Equivalent Static Method and Response Spectrum Method, infill frames have 1.8 times less displacement compared to bare frames for all regular and irregular buildings. But at storey-1 bare frame has 1.1 times more displacement when compared to infill frame.

For Pushover Method, model-2 has 1.66 times less displacement compared to model-1 i.e. for all regular buildings. Whereas for irregular buildings, i.e. model-4 has 11.7 times less displacement when compared to model-3, model-6 has 2.8 times less displacement when compared to model-5 and also model-8 has 2.24 times less displacement when compared to model-7.

4.3 STOREY DRIFTS

The permissible inter storey drift is limited to 0.004 times the storey height, so that minimum damage would take place during earthquake and pose less psychological fear in the minds of people. The maximum storey drifts of different models are shown in Tables 7 to10.

Table 7 Comparison of Maximum storey drift (mm) for regular bare (Model 1) and infill frames (Model 2)

Storey	Equivalent static method		Variation in %	Response Spectra method		Variation in %	Pushover method		Variation in %
	Model-1	Model-2		Model-1	Model-2		Model-1	Model-2	
9	1.135	0.575	49	1.135	0.575	49	1.952	1.469	25
8	1.496	0.771	48	1.496	0.771	48	2.849	2.097	26
7	1.926	0.974	49	1.926	0.974	49	3.997	2.704	32
6	2.265	1.119	51	2.265	1.119	51	5.176	3.191	38
5	2.488	1.211	51	2.488	1.211	51	5.937	3.528	41
4	2.585	1.255	51	2.672	1.267	53	6.096	3.719	39
3	2.537	1.254	51	2.763	1.336	52	5.535	3.745	32
2	2.342	1.312	44	2.64	1.493	43	4.164	4.453	-7
1	1.469	1.623	-10	1.722	1.963	-14	1.892	7.981	-322

Table 8 Comparison of Maximum storey drift (mm) for regular bare (Model 3) and infill frames (Model 4)

Storey	Equivalent static method		Variation in %	Response Spectra method		Variation in %	Pushover method		Variation in %
	Model-3	Model-4		Model-3	Model-4		Model-3	Model-4	
9	1.163	0.599	48	1.163	0.599	48	11.05	1.616	85
8	1.496	0.787	47	1.496	0.787	47	12.828	2.105	84
7	1.916	0.982	49	1.916	0.982	49	14.948	2.685	82
6	2.246	1.125	50	2.246	1.125	50	16.451	3.159	81
5	2.461	1.214	51	2.526	1.214	52	16.979	3.482	79
4	2.552	1.255	51	2.72	1.316	52	16.3	3.661	78
3	2.508	1.251	50	2.813	1.385	51	14.274	3.679	74
2	2.311	1.304	44	2.701	1.538	43	10.775	4.351	60
1	1.441	1.585	-10	1.754	1.993	-14	5.338	7.913	-48

Table 9 Comparison of Maximum storey drift (mm) for regular bare (Model 5) and infill frames (Model 6)

Storey	Equivalent static method		Variation in %	Response Spectra method		Variation in %	Pushover method		Variation in %
	Model-5	Model-6		Model-5	Model-6		Model-5	Model-6	
9	1.439	0.779	46	1.439	0.779	46	12.526	3.205	74
8	1.695	0.947	44	1.695	0.947	44	14.389	4.062	72
7	2.025	1.077	47	2.025	1.077	47	16.472	4.774	71
6	2.344	1.135	52	2.344	1.135	52	17.824	4.495	75
5	2.6	1.241	52	2.6	1.241	52	18.526	4.845	74
4	2.735	1.3	52	2.735	1.35	51	18.125	5.125	72
3	2.747	1.311	52	2.952	1.465	50	16.32	5.209	68
2	2.564	1.396	46	2.952	1.695	43	12.883	5.722	56
1	1.62	1.785	-10	1.947	2.339	-20	6.902	12.999	-88

Table 10 Comparison of Maximum storey drift (mm) for regular bare (Model 7) and infill frames (Model 8)

Storey	Equivalent static method		Variation in %	Response Spectra method		Variation in %	Pushover method		Variation in %
	Model-7	Model-8		Model-7	Model-8		Model-7	Model-8	
9	1.454	0.801	45	1.454	0.801	45	10.178	1.911	81
8	1.681	0.958	43	1.681	0.958	43	11.862	2.648	78
7	2.003	1.084	46	2.003	1.084	46	13.943	3.401	76
6	2.349	1.151	51	2.349	1.151	51	15.423	3.941	74
5	2.603	1.256	52	2.603	1.256	52	16.209	4.356	73
4	2.736	1.312	52	2.801	1.403	50	15.951	4.623	71
3	2.746	1.322	52	3.034	1.523	50	14.364	4.697	67
2	2.558	1.405	45	3.035	1.763	42	11.201	5.894	47
1	1.606	1.763	-10	1.99	2.388	-20	5.902	13.383	-127

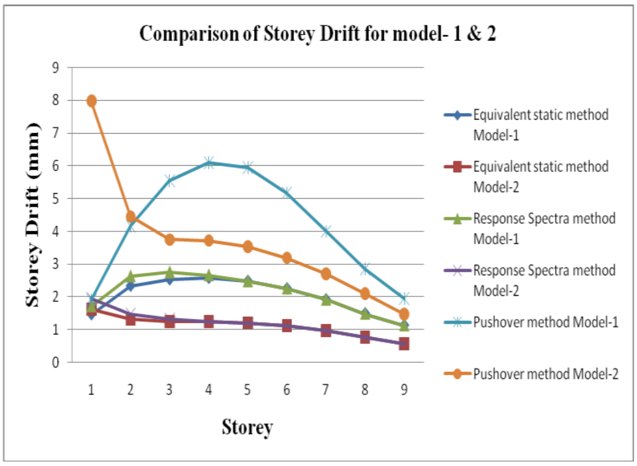

Fig 12 Comparison of storey drift in Bare and Infilled frames for model-1 and model-2

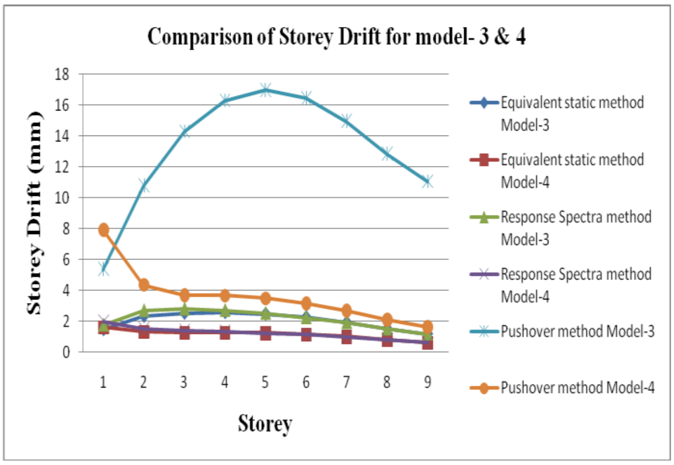

Fig 13 Comparison of storey drift in Bare and Infilled frames for model-3 and model-4

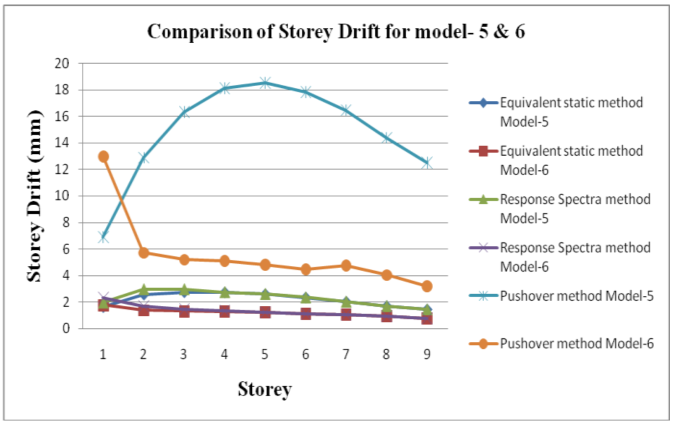

Fig 14 Comparison of storey drift in Bare and Infilled frames for model-5 and model-6

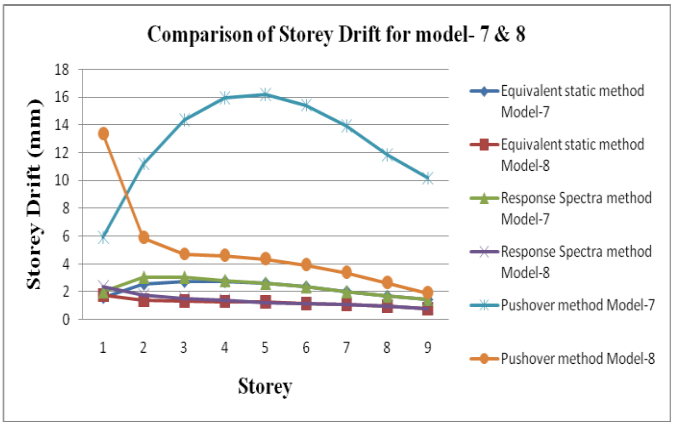

Fig 15 Comparison of storey drift in Bare and Infilled frames for model-7 and model-8

From the above tables it can be seen that, all storey drifts are within the permissible limit (0.004*h=14mm) except for irregular bare frames i.e. model-3, model-5 and model-7. In model-3, model-5 and model-7, the drifts are more than the permissible limit due to bare frame storeys; this is due to the less stiffness of the structure (because infill walls are not present in the storeys.

4.4 PERFORMANCE POINT

The performance point of the building models in longitudinal and transverse directions are shown in figure 15 to 22 as obtained from ETABS.

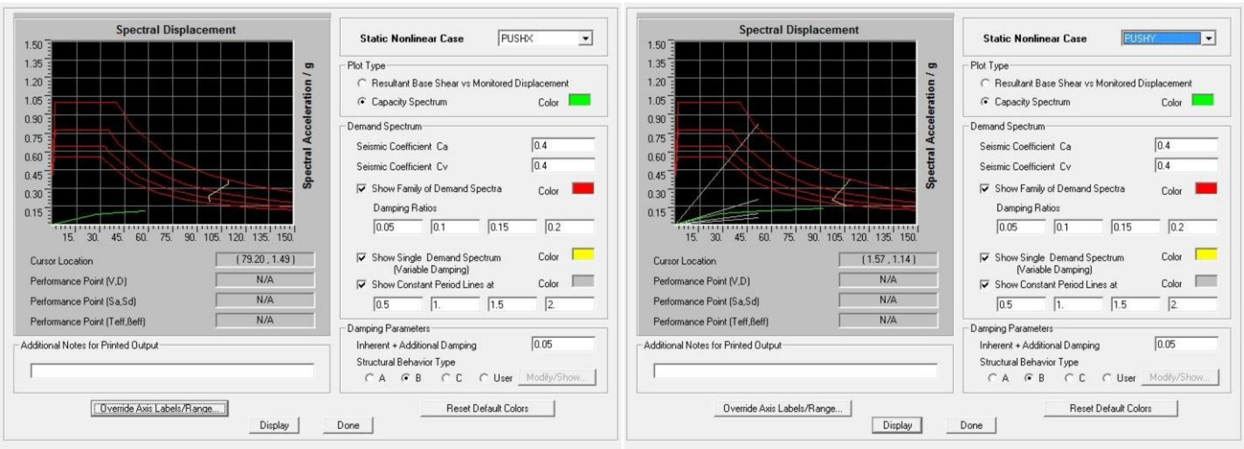

Fig 16 Performance point of model-1 along longitudinal and transverse directions

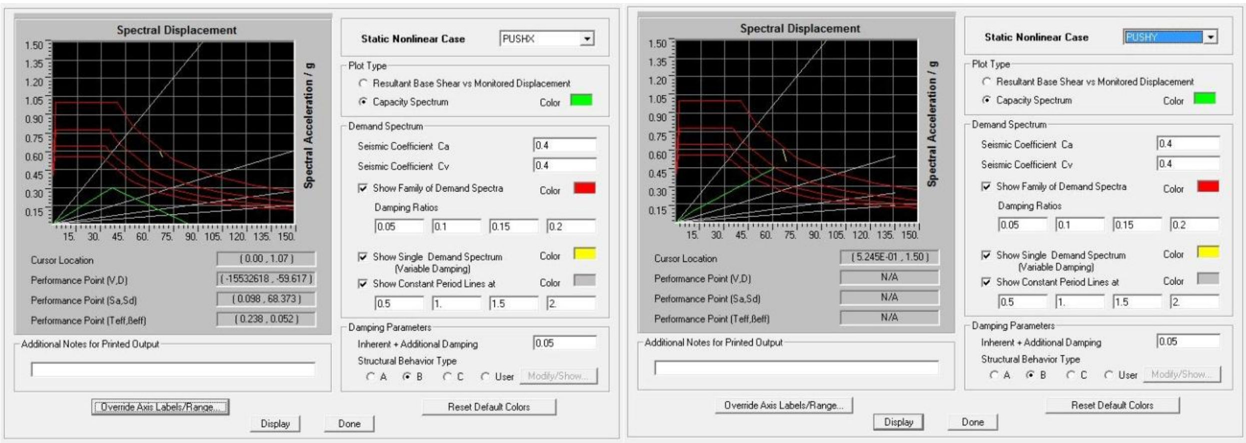

Fig 17 Performance point of model-2 along longitudinal and transverse directions

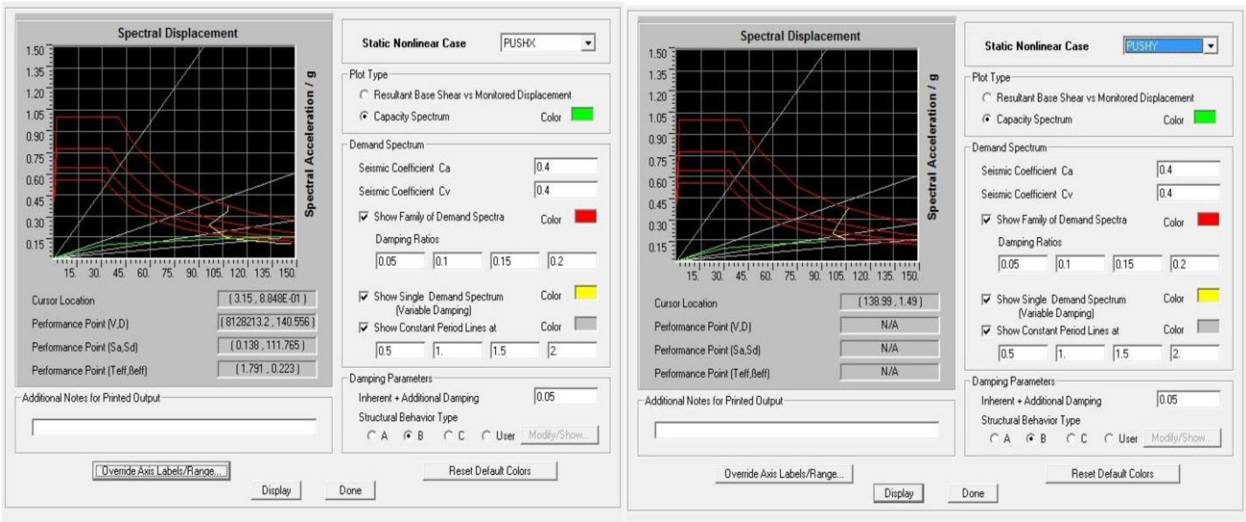

Fig 18 Performance point of model-3 along longitudinal and transverse directions

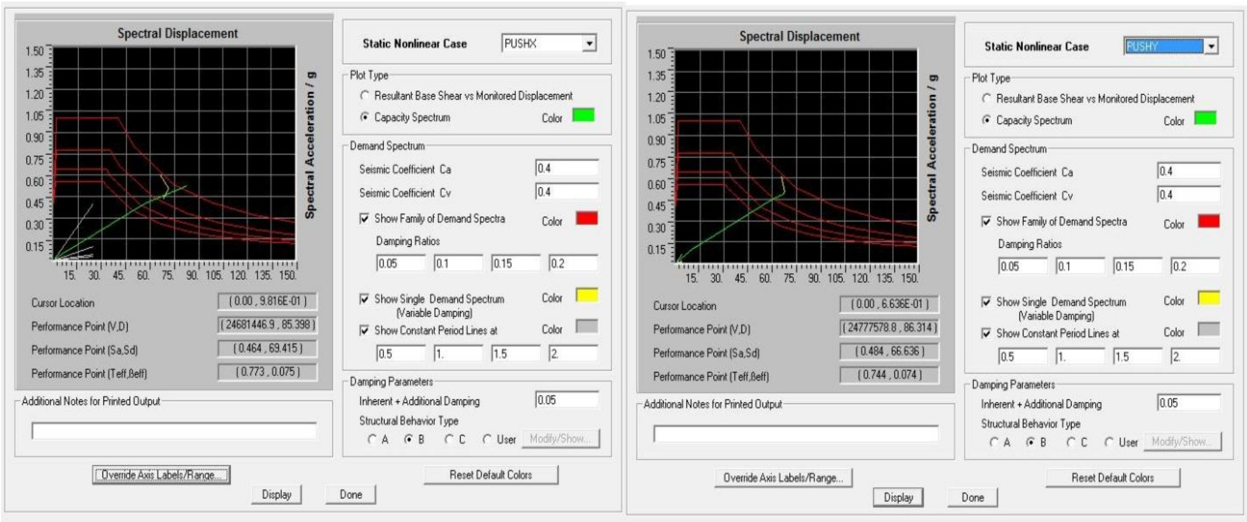

Fig 19 Performance point of model-4 along longitudinal and transverse directions

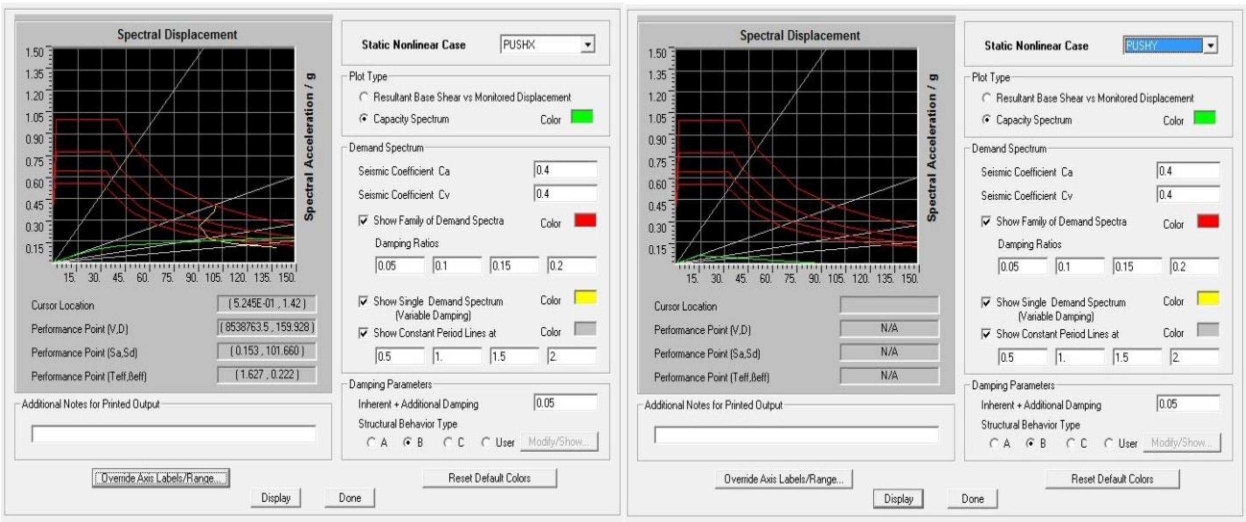

Fig 20 Performance point of model-5 along longitudinal and transverse directions

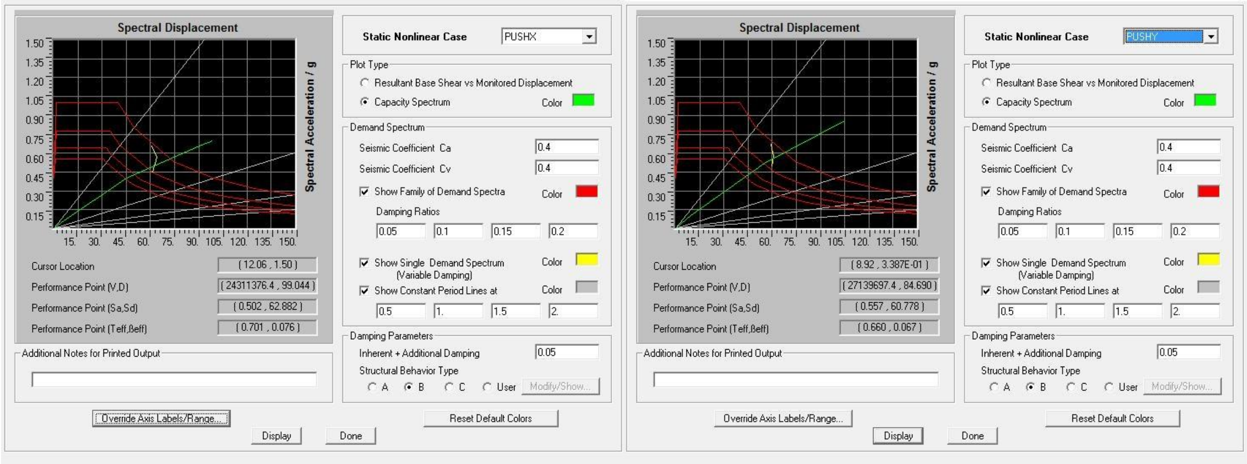

Fig 21 Performance point of model-6 along longitudinal and transverse directions

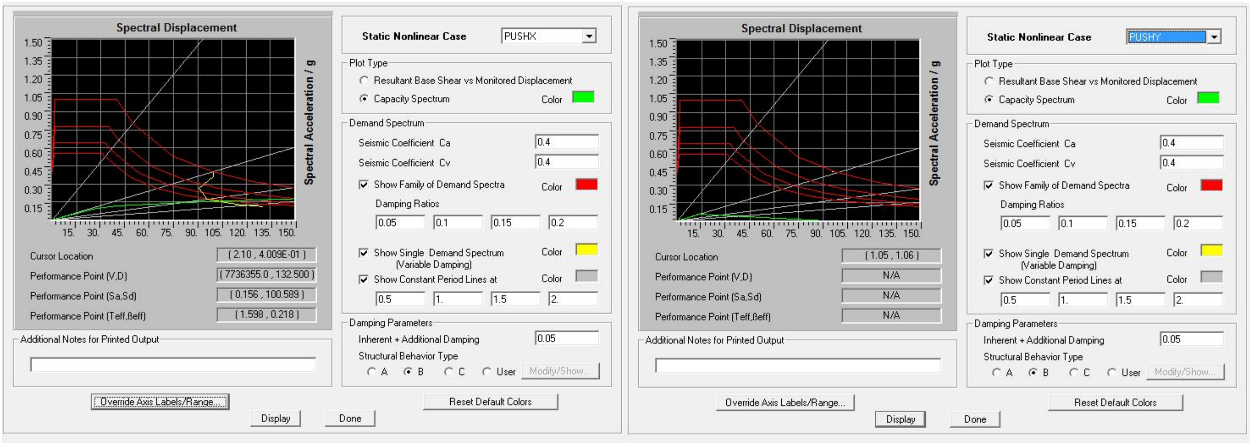

Fig 22 Performance point of model-7 along longitudinal and transverse directions

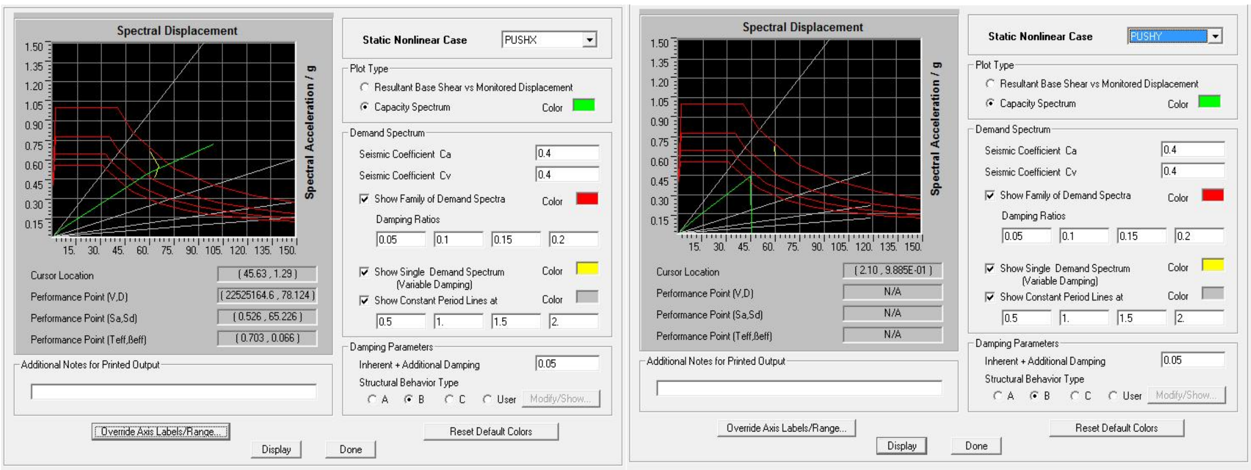

Fig 23 Performance point of model-8 along longitudinal and transverse directions

From above figures it can be seen that demand curve is increasing the capacity curve which shows the performance of the all models are good.

5. CONCLUSIONS

- It is essential to consider the effect of masonry infill for the seismic evaluation of movement resisting RC frames especially for the prediction of its ultimate state. Infills increase the lateral resistance and initial stiffness of the frames they appear to have a significant effect on the reduction of the global lateral displacement.
- Infills having no irregularity in elevation having beneficial effects on buildings. In infilled frames with irregularities, such as bare frame, damage was found to concentrate in the level where the discontinuity occurs.
- Due to infill action percentage increase in base shear increase as the irregularity increases showing that the irregular building needs to be designed for higher base shear than a regular building.
- Displacement at any storey level and maximum displacement reduce due to infill action because of the increase in lateral stiffness of frame. The percentage reduction in displacement due to infill action slightly increases at the level below i.e. at storey 1.
- The obtained storey drifts from analysis with partial load factor of 1.0 are within the permissible limits for both regular and irregular infill frames.
- The capacity curve is intersecting the demand curve of the infill structures which indicates that the performance level of the building is good. The capacity curve and demand curve are intersecting only for infill structures. The performance level of the infill structure is good and whereas the bare frame storey structure is poor.
- Plastic hinges formation for the building mechanisms have been obtained at different displacement levels. Plastic hinges formation started with beam ends and base columns of lower stories, then propagates to upper stories and continue with yielding of interior intermediate columns in the upper stories. The formation of first hinge is not early in models with infills and bare frame, but since yielding occurs at events B, IO, LS, the amount of damages in the buildings are limited. The behaviors of the building frames are adequate as indicate by the intersection of the demand and capacity curves and the distribution of hinges in the beam and the columns. The results obtained in terms of demand, capacity and plastic hinges shows the real behavior of the structures.

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