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RESEARCH ARTICLE

BEHAVIOR OF 3D RC FRAMES WITH VARYING PROPORTION OF OPENING IN MASONRY INFILLS SUBJECTED TO DYNAMIC LOADING

***Jayaramappa, N. and Arunkumar Sagar**

Department of Civil Engineering, UVCE, Bangalore University, Bangalore 560056, India

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ABSTRACT

Masonry Infills, which generally have high stiffness and strength, play a crucial role in reinforced concrete frame buildings during earthquakes but these are normally considered as non-structural elements and their stiffness contributions are generally ignored in practice, such an approach can lead to an unsafe design. The Masonry infill (MI) though constructed as secondary elements behaves as a constituent part of the structural system and determines the overall behaviour of the structure especially when it is subjected to seismic loads. The proportions of opening in MI play a major role in the seismic analysis of RC frames. In this seismic analysis, 3D RC frames by varying the number of store's, proportions of opening in MI and soft storey is considered. The MI is represented by equivalent diagonal strut and the proposed openings are considered with aspect ratio of the opening to that of the infill. Finite Element Analysis is adopted in modeling, equivalent static and response spectrum analyses are used. The results such as natural time period, mode shapes, base shear for static and dynamic loading, storey displacement and storey drift are presented.

1. INTRODUCTION

The composite structures formed by the combination of a moment resisting plane frame and infill walls are termed as "Infilled frames". Reinforced Concrete (RC) frames consist of horizontal elements (beams) and vertical elements (columns) connected by rigid joints. RC frames provide resistance to both gravity and lateral loads through bending in beams and columns. The infill masonry is seldom included in numerical analysis of structural system, because masonry panels are generally considered as structural elements of secondary importance, which introduce unwanted analytical complexities without having pronounced effect on the structural performance. However, the significant effects of the infilled masonry on the structural responses of frames have been realized by many researchers that it can affect the seismic behaviour of framed building to at large extend without the presence of non-structural masonry infills. These effects are generally positive: masonry infills can dramatically increase global stiffness and strength of the structure. On the other hand, potentially negative effects may occur such as tensional effects induced by in plan-irregularities, soft-storey effects induced irregularities in elevation and short-column effects due to openings.

****Corresponding author: Jayaramappa, N.***
Department of Civil Engineering, UVCE, Bangalore University, Bangalore 560056, India.

I frames, a structure combining the frame with the infill within the frame, has better lateral resistance potential and therefore, attracted the investigator's attention since the fifties of the present century. Brick masonry infill within such a frame type structures are normally treated as non-structural and all the lateral loads is considered to be a borne by the frame alone. It has been appreciated that the addition of walls and floors impart considerable extra strength to a frame building. Fig.1 shows the typical models of three story one bay infilled frame for the RC frame considered for the varying proportions MI in three different cases:

- Case A1: Fully infilled frame,
- Case A2: Infilled frame with a soft story ,
- Case A3: Bare frame.

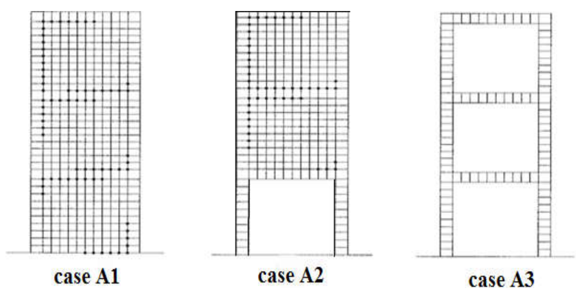


Fig. 1. Infill frames for three different cases of infill frame (P. G. Asteris, M.ASCE 2003)

2. Description of the models

The studies are carried out for 10, 15 and 20 storey and seismic zone III and V are considered for the analysis. Table 1 shows the models considered in the present work.

Table 1. Models considered for the analysis

No. of models	Details	Nomenclature
1	Fully infilled frame	100% MI
2	10% opening in MI	90% MI
3	20% opening in MI	80% MI
4	30% opening in MI	70% MI
5	40% opening in MI	60% MI
6	50% opening in MI	50% MI
7	Soft storey with fully infilled frame	100% MIS
8	Soft storey with 10% opening in MI	90% MIS
9	Soft storey with 20% opening in MI	80% MIS
10	Soft storey with 30% opening in MI	70% MIS
11	Soft storey with 40% opening in MI	60% MIS
12	Soft storey with 50% opening in MI	50% MIS
13	Bare frame	Bare frame

The main objectives of this research are:

- Analysis for the 3D RC frame with varying proportions of opening in MI due to seismic loading for infilled frame, soft storey and bare frame.
- To obtain the stiffness reduction factor 'λ' and width of equivalent diagonal strut for 10%, 20%, 30%, 40% and 50% opening in MI.
- To generate response spectra for seismic zone III and zone V.
- To perform finite element analysis involving modal, equivalent static and response spectra analyses.

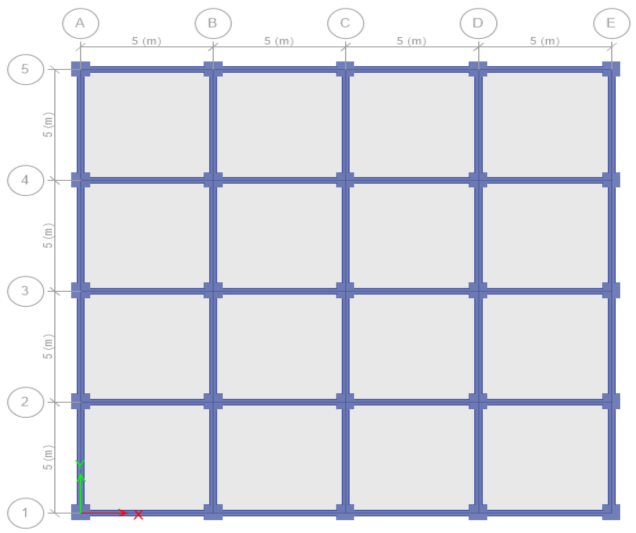
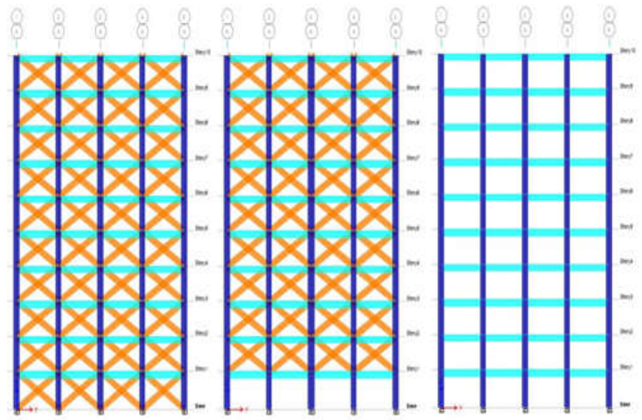


Fig. 2. Plan of 10, 15 and 20 storey building models

2.1 Calculation of width of diagonal strut

The presence of masonry infill affects on the distribution of lateral loads in RC framed structure because of the increase the stiffness. The study of interaction of infill with frames has been attempted by using rigorous analysis like finite element analysis or theory of elasticity. But due to uncertainty and complexity in defining the interface conditions between masonry infill and the RC frames, many approximate methods are being developed. One of the most common and popular approximations is, replacing the masonry infill by equivalent diagonal strut whose thickness is assumed to be equal to the thickness of the masonry infill. It provides a rational basis for lateral strength and stiffness of MI in RC frames as well as the MI diagonal cracking load. The elastic in-plane stiffness of a solid unreinforced masonry infill wall is represented with an equivalent diagonal compression strut of width W_{ef}.



(a) Fully infilled frame (b) Soft storey with fully infilled frame (c) Bare frame

Fig. 3. Elevations of models considered

The width is given by,

$$w=0.175[\lambda H]^{-0.4} x \sqrt{H^2+L^2}$$

Where,

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

H and L are the height and length of the RC frame, Ec and E_m are the elastic moduli of the column and of the MI frame, 't' is the thickness of the infill panel, 'θ' is the angle defining diagonal strut, 'I' is the moment of inertia of the column and 'H' is the height of the infill panel.

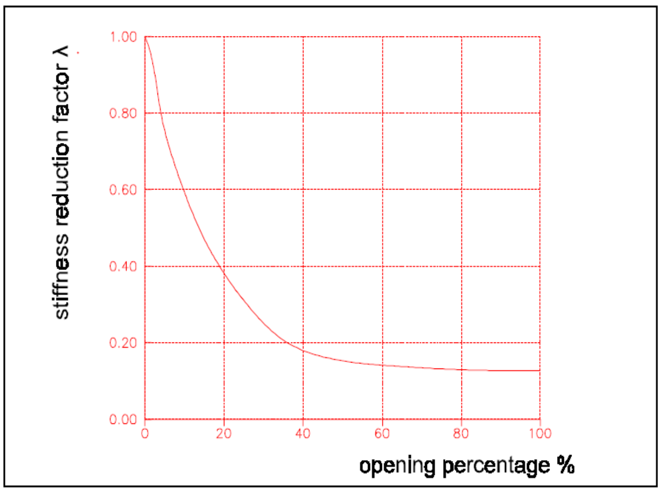


Fig. 4. Stiffness reduction factor 'λ' of the infilled frame in relation to the opening Percentage

3. Different proportions of opening

Width of strut for opening =
Stiffness reduction factor X width of equivalent diagonal strut

Table 2. Width of Equivalent diagonal strut

Opening percentage (%)	0% opening (fully infill)	10% opening	20% opening	30% opening	40% opening	50% opening
Stiffness Reduction Factor (λ)	1.00	0.59	0.38	0.26	0.18	0.15
Width of Equivalent Diagonal Strut (m)	0.631	0.372	0.240	0.164	0.114	0.095

These widths of equivalent diagonal strut shown in Table 2 are used for analysis of 3D RC frames with various aspect ratios of openings in MI. According to P G Asteris, *et al.* 2011, the increase in the opening percentage leads to a decrease in the frame's stiffness. Specially, for an opening percentage greater than the 50% the stiffness reduction factor tends to zero. Hence in this work up to 50% opening is considered.

3.1 Generation of response spectra as per is 1893 (Part 1): 2002

The design horizontal seismic coefficient A_h for a structure is determined by the following expression:

$$A_h = \frac{Z\,I\,Sa}{2\,R\,g}$$

Provided that for any structure with T ≤ 0.1 s, the value of $\boldsymbol{A_h}$ will not be taken less than Z/2 whatever be the value of I/R.
The design base shear V_B thus obtained shall be distributed along the height of the building as per the following expression:

$$Q_i = V_B \frac{W_i h_i^2}{\sum_{i=1}^{n} W_i h_i^2}$$

The final Base Shear obtained from response spectrum analysis for 10, 15 and 20 storey building models for zone III and V are listed in the Table 2 and Table 3 respectively.

Table 2. Base Shear from response spectrum analysis in zone III

No. of models	Models	BASE SHEAR (kN)		
		10 storey	15 storey	20 storey
1	100% MI	2122	2463	2193
2	90% MI	1904	2040	1923
3	80% MI	1768	1789	1794
4	70% MI	1683	1694	1707
5	60% MI	1625	1634	1627
6	50% MI	1579	1588	1591
7	100% MIS	2131	2427	2205
8	90% MIS	1876	2015	1909
9	80% MIS	1757	1772	1779
10	70% MIS	1666	1695	1692
11	60% MIS	1603	1623	1625
12	50% MIS	1568	1580	1577
13	Bare frame	848	944	1010

Table 3. Base Shear from response spectrum analysis in zone V

No. of models	Models	BASE SHEAR (kN)		
		10 storey	15 storey	20 storey
1	100% MI	4774	5542	4934
2	90% MI	4284	4590	4327
3	80% MI	4013	4026	4037
4	70% MI	3786	3812	3841
5	60% MI	3655	3676	3690
6	50% MI	3553	3573	3580
7	100% MIS	4794	5461	4961
8	90% MIS	4220	4533	4296
9	80% MIS	3952	3986	4002
10	70% MIS	3749	3814	3806
11	60% MIS	3606	3652	3657
12	50% MIS	3527	3555	3357
13	Bare frame	1909	2124	2273

4. RESULTS AND DISCUSSION

The proportions of opening in MI are varied with different percentages in this study. In FE analysis, modal, equivalent static and response spectra analyses are performed. The results tabulated are of natural time period, storey displacements and storey drifts

4.1 Fundamental time period and mode shapes

Fundamental time period calculated as per IS 1893(Part 1): 2002 and modal analysis results are tabulated in Table 4 and the graph showing time period versus models is given in Fig. 5. IS 1893 (Part 1): 2002 gives the formulae for calculating the natural time period with MI. i.e.

$T_a = 0.09h/\sqrt{d}$ - RC frame building with MI

Table 4. Fundamental time period for 10, 15 and 20 storey building models

Type of models	IS 1893 (Part 1) : 2002 (sec)			Modal analysis (sec)		
	10 storey	15 storey	20 storey	10 storey	15 storey	20 storey
100% MI	0.608	0.910	1.212	0.454	0.772	1.182
90% MI				0.518	0.849	1.258
80% MI				0.589	0.944	1.366
70% MI				0.662	1.046	1.490
60% MI				0.741	1.159	1.631
50% MI				0.782	1.220	1.707
100% MIS				0.555	0.861	1.258
90% MIS				0.595	0.919	1.320
80% MIS				0.650	1.001	1.418
70% MIS				0.712	1.093	1.533
60% MIS				0.781	1.198	1.667
50% MIS				0.818	1.255	1.740
Bare frame	0.966	1.307	1.621	1.358	2.103	2.876

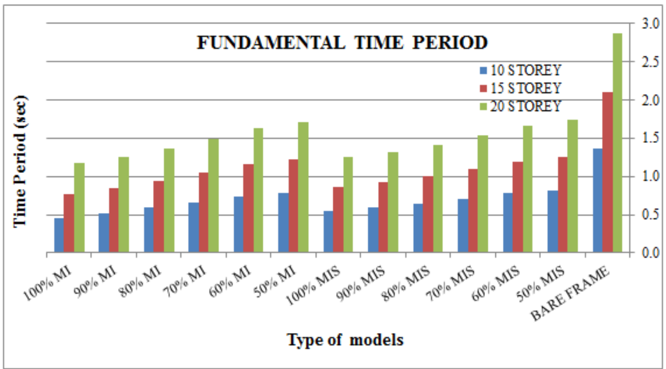


Fig. 5. Fundamental time period for 10, 15 and 20 storey building models

4.2 Storey displacement

The maximum storey displacements are tabulated in the Table 5 and Fig.6 shows the maximum storey displacement versus number of storey's in zone V for infill with soft storey and bare frame models.

Table 5. Maximum storey displacement in zone V

No. of models	Models	Maximum Storey Displacement (mm)		
		10 storey	15 storey	20 storey
1	100% MI	4.4	10.7	16.9
2	90% MI	5.7	11.6	18.2
3	80% MI	7.2	13.0	20.7
4	70% MI	8.9	15.4	23.7
5	60% MI	11.0	18.4	27.4
6	50% MI	12.0	19.9	29.1
7	100% MIS	5.7	11.7	17.9
8	90% MIS	6.6	12.4	18.9
9	80% MIS	8.0	13.6	21.2
10	70% MIS	9.6	16.1	24.1
11	60% MIS	11.5	18.9	27.7
12	50% MIS	12.5	20.4	27.9
13	Bare frame	20.6	35.2	52.3

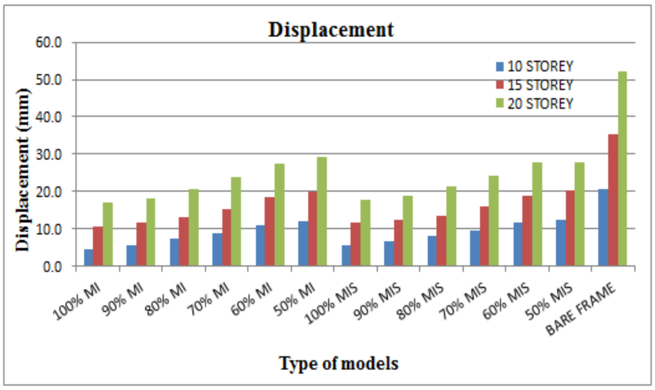


Fig. 6. Maximum displacement for 10, 15 and 20 storey building models in zone V

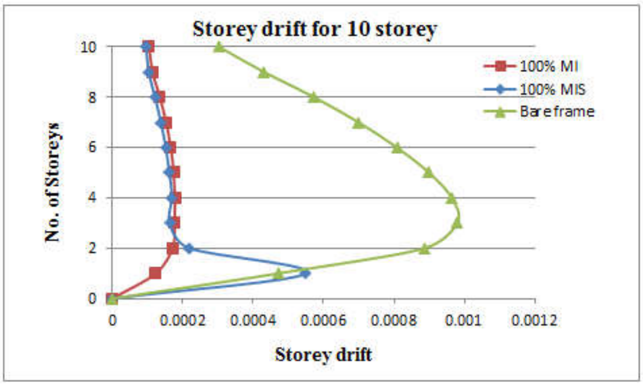


Fig. 7. Storey drift of 10 storey building for MI and Bare frame models in zone V

4.3 Storey drift

Storey drift is the displacement of one level relative to the other level above or below. Storey drift obtained from the response spectrum analysis for zone V are plot with respect to the number of storeys as per IS 1893(Part 1): 2002 is considered for infill frame, soft storey and bare frame models shown in Fig .7 to Fig. 8.

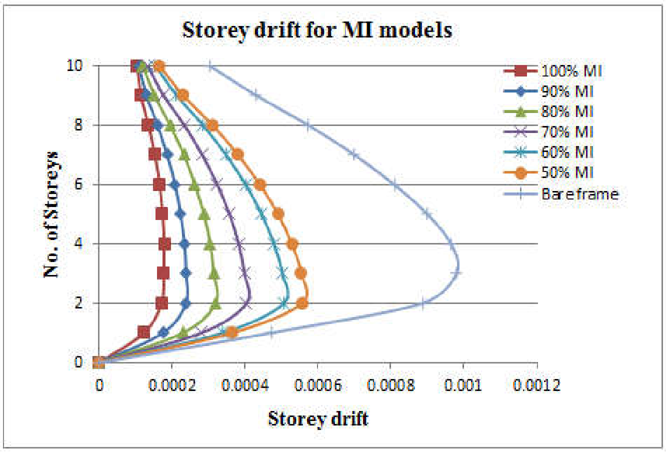


Fig. 8. Storey drift of 10 storey building for MIS and Bare frame models in zone V

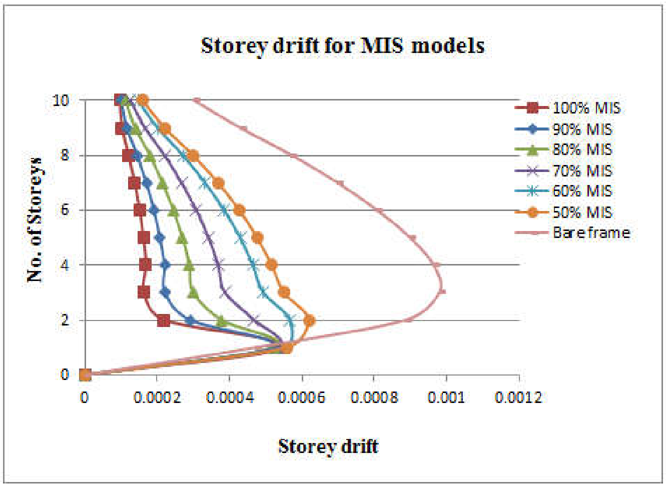


Fig. 9. Storey drift of 10 storey building for fully infilled frame, soft storey and bare frame models in zone V

Storey drifts obtained from the response spectrum analysis for 15 storey building in zone V are plotted with respect to the number of storeys considering infill frame, soft storey and bare frame models.

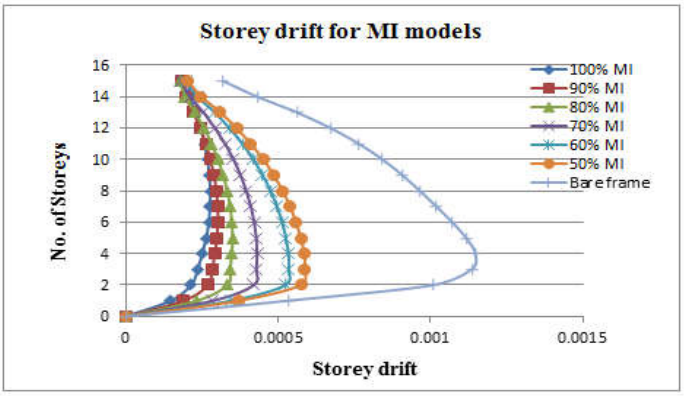


Fig. 10. Storey drift of 15 storey building for MI and Bare frame models in zone V

Storey drifts obtained from the response spectrum analysis for 20 storey building in zone V are plotted with respect to the number of storeys considering infill frame, soft storey and bare frame models.

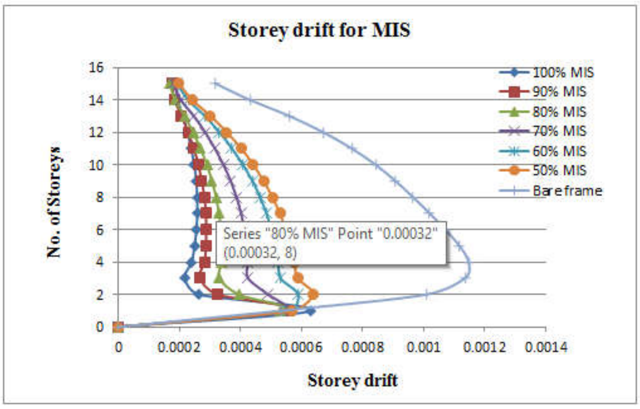


Fig. 11. Storey drift of 15 storey building for MIS and Bare frame models in zone V

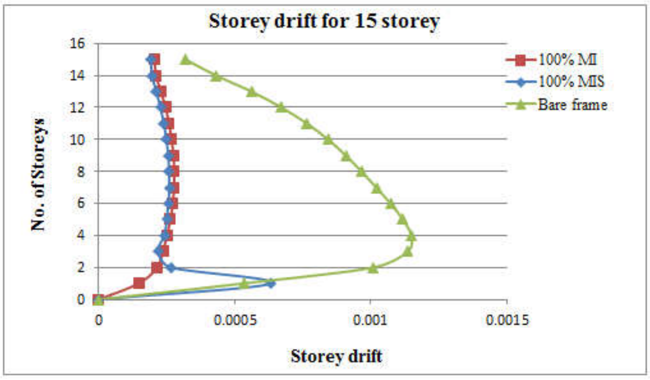


Fig. 12. Storey drift of 15 storey building for fully infilled frame, soft storey and bare frame models in zone V

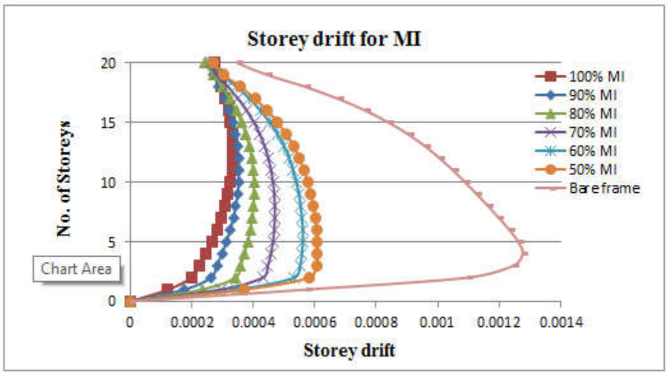


Fig.13. Storey drift of 20 storey building for MI and Bare frame models in zone V

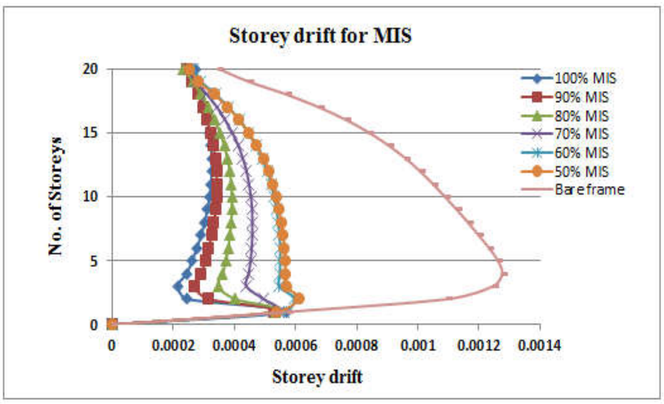


Fig. 14. Storey drift of 20 storey building for MIS and Bare frame models in zone V

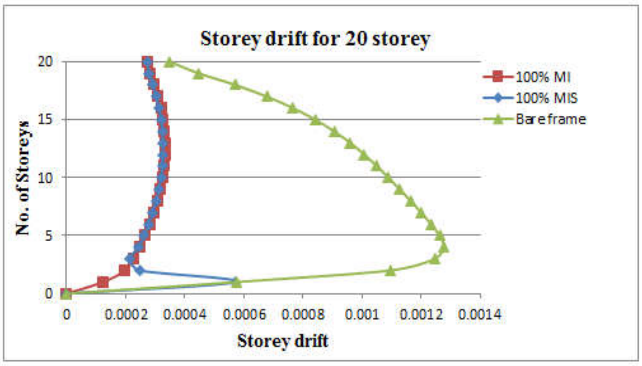


Fig.15. Storey drift of 20 storey building for fully infilled frame, soft storey and bare frame models in zone V

5. Conclusions

- Displacement increases as the height of the building increases.
- The displacement of bare frame is 3 to 5 times more than the fully infilled frame for 10 to 20 storey building models.
- The displacement of 50% MI is relatively 2 times more compare to 100% MI in all storeys.
- 100% MI have 25% less displacement compared to 100% MIS.
- The storey drift is maximum at 'height/2' for all models except soft storey conditions.
- In soft storey condition, the storey drift is maximum at the soft storey level itself.
- In case of 100% MIS, the storey drift at the soft storey level is 5 times more compare to 100% MI and 1.2 times more compare to bare frame.
- In case of 50% MIS, storey drift in soft storey level is 1.5 times more compare to 100% MI and 1.2 times more to bare frame.
- As the proportions of opening increases, the storey drift increases. i.e., 100% MI has 3 times less storey drift compare to 50% MI due to the influence of stiffness from MI.
- As the height increases in soft storey condition, the values of storey drift decreases by 1.9 times for 15 storeys and 3 times for 20 storeys.
- Storey drift for all the models are within the range of 0.004h as per IS 1893(Part 1): 2002.
- Soft storey buildings are considered as vertically irregular buildings as per IS 1893(Part 1): 2002 that requires seismic analysis considering strength and stiffness of the infill frames.
- MI plays a major role in seismic analysis of RC frames and hence the varying proportions of opening in MI have to be accounted doing seismic analysis.
- Storey drift has to be limited in the RC frames as it may cause failure of non-structural elements like cladding, partitions and pipe works.

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