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Seismic Evaluation of RC Building with Various Infill Thickness at Different Positions

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Abstract - *The recent trend of building construction in urban and semi-urban area, like several other countries around the world, is reinforced concrete frames. The vertical space created by reinforced concrete (RC) beams and columns are usually filled in by walls referred to as masonry infill wall or panels. The walls are usually of burnt clay bricks in cement mortar. One of the main reasons in using masonry infill is economy and ease of construction, because it uses locally available material and labour skill. Moreover, it has a good sound and heat insulation and waterproofing properties, resulting in greater comfort for the occupants. The infill walls are sometimes rearranged to suit the changing functional needs of occupants. The changes are carried out without considering their adverse effects on the overall structural behaviour. The conventional finite element modelling of RC structures without considering the effect of infill in the analytical model renders the structures more flexible than they actually are. For this reason building codes imposes an upper limit to the natural period of a structure by way of empirical relations. Since infills are not considered in conventional modelling in seismic design, their contributions to the lateral stiffness and strength may invalidate the analysis and proportioning of structural members for seismic resistance on the basis of its results. This study aims to investigate the effect of brick masonry infill wall on a reinforced concrete moment resisting frame conventionally analyses and designed as a bare frame. In this study, high rise buildings of 15m x 15 m plan areas with various infill thickness under different earthquake zones are considered so as to evaluate the efficient building frame with proper infill thickness. These are achieved by comparing the result with different parameter like moment, shear force, peak displacement and drift.*

KEY WORDS: *Infill wall, seismic force, RCC framed structure, storey drift, moments, forces, etc.*

1.INTRODUCTION

Behaviour of masonry infill is difficult to predict because of significant variations in material properties and failure modes that are brittle in nature. If not judiciously placed, during seismic excitation, the infills also have some adverse effects. One of the major ill effects is the soft story effect. This is due to absence of infill wall in a particular storey. The absence of infill in some portion of a building plan will induce torsional moment. Also, the partially infilled wall, if not properly placed may induce short column effect thus creating localized stress concentration. This is mainly due to lack of generally accepted seismic design methodology in the National Building Codes that incorporates structural effects of infill. In fact very few codes in the world currently provide specifications for the same. Hence, there is a clear need to develop a robust design methodology for seismic design of masonry infill reinforced concrete structures. The open ground storey framed building behaves differently as compared to a bare framed building or a fully infilled framed building under lateral load. A bare frame is much less stiffer than a fully infilled frame; it resists the applied lateral load through frame action and shows well-distributed plastic hinges at failure. When this frame is fully infilled, truss action is introduced thus changing the lateral load transfer mechanism. A fully infilled frame shows lesser inter-storey drift, although it attracts higher base shear (due to increased stiffness). Inclusion of stiffness and strength of infill walls in the open ground storey building frames decreases the fundamental time period compared to a bare frame and consequently increases the base shear demand and the design forces in the ground storey beams and columns. This increased design forces in the ground storey beams and columns of the open ground storey buildings are not captured in the conventional bare frame analysis. An appropriate way to analyse the open ground storey buildings is to model the strength and stiffness of infill walls. Unfortunately, no guidelines are given in IS 1893: 2002 (Part-1) for modelling the infill walls. As an alternative a bare frame analysis is generally used that ignores the strength and stiffness of the infill walls. Masonry infill walls are widely used as partitions all over the world. Evidences are that continuous infill masonry walls can reduce the vulnerability of the reinforced concrete structure. Often masonry walls are not considered in the design process because they are supposed to act as non-structural members or elements. Separately the infill walls are stiff and brittle but the frame is relatively flexible and ductile. The composite action of beam-column and infill walls provides additional strength and stiffness. Different types of analytical models based on the physical understanding of the overall behaviour of an infill panels were developed over the years to simulate the behaviour of infilled frames. The infilled frame consists of a steel or reinforced concrete column and girder frame with infill of brickwork or concrete block work. They are usually provided as exterior walls, partitions, and walls around stair, elevator and service shafts and hence treated as non structural elements. Some of the prominent research in this area are as follows:

Stafford Smith (1966) reported that the weak frame cannot transmit the forces to the compressive diagonal of infill and therefore it suffers local crushing at the ends of compressive diagonal. The strong frame can transmit high forces to the compressed diagonal which set infill to initiate cracking from the central region and propagates towards the compressed diagonal ends. **Fardis (1996)** investigated the seismic response of an infilled frame which had weak frames with strong infill material. It was found that the strong infill which was considered as non structural is responsible for earthquake resistance of weak reinforced concrete frames. However, since the behaviour of infill is unpredictable, with the likelihood of failing in brittle manner, it was recommended to treat infill as non structural component by isolating it from frames. On the contrary, since infill is extensively used, it would be cost effective if positive effects of infill is utilised. **Al-Chaar (1998)** performed studies on the behaviour of reinforced concrete frames with masonry infill. The test was conducted on two half scale specimens in which one of the frames was stronger than the other. The stronger frame specimen showed diagonal tension cracking while the weak frame failed because of diagonal cracking as well as hinging of the column at lower end. Both the frames were reported to have shown the ductile behaviour but the extent of ductility is not specific. However, he concluded that the infill wall improves the strength, stiffness and energy absorption capacity of the plane structures which are useful for structures in seismic regions. **Asokan (2006)** studied how the presence of masonry infill walls in the frames of a building changes the lateral stiffness and strength of the structure. This research proposed a plastic hinge model for infill wall to be used in nonlinear performance based analysis of a building and concludes that the ultimate load (UL) approach along with the proposed hinge property provides a better estimate of the inelastic drift of the building. **Doudoumis (2006)** studied the importance of contact condition between the infill and frame members on a single storey finite element model. He reported that the interface condition, friction coefficient, size of mesh, relative stiffness of beam to column, relative size of infill wall have significant influence o the response of infilled frame, while the effect of orthotropy of infill material was reported to be insignificant. That means that the infill can be treated as homogeneous material. **Kaushik (2006)** conducted a comparative study of the seismic codes especially on the design of infilled framed structures. The study revealed that the most of the modern seismic codes lack the important information required for the design of such buildings. Moreover, the relevant clauses of codes are not consistent and vary from country to country. Such variations were attributed to the absence of adequate research information on important structural parameters as determination of natural period of vibration of infilled structures, soft storey phenomenon associated with the presence of infill, exclusion of strength and stiffness of infill and considerations of openings. **Hashmi and Madan (2008)** conducted non-linear time history and pushover analysis of OGS buildings. The study concludes that the MF prescribed by IS 1893(2002) for such buildings is adequate for preventing collapse. Menonet. al. (2008) concluded that the MF increases with the height of the building, primarily due to the higher shift in the time period. **Sattar and Abbie (2010)** reported that the pushover analysis showed an increase in initial stiffness, strength, and energy dissipation of the infilled frame, compared to the bare frame, despite the wall's brittle failure modes. Likewise, dynamic analysis results indicated that fully-infilled frame has the lowest collapse risk and the bare frames were found to be the most vulnerable to earthquake-induced collapse. The better collapse performance of fully-infilled frames was associated with the larger strength and energy dissipation of the system, associated with the added walls.

2. METHODOLOGY

In this study seismic evaluation of a mid rise building have been carried out considering different positions and infills. It is observed that infill locations have significant influence on force and displacement resultants of the building frame. Modelling of the building frames have been carried out using STAAD.Pro software. The plan and elevation are shown in Fig 1 and 2. Models of the structure are -

(a) Bare frame (Fig.3)
(b) Infill at centre (Fig.4)
(c) Infill at corner (Fig.5)
(d) Infill at transverse (Fig.6)
(e) Infill at outer (Fig.7)

Table 1: Details of Structure

Type of structure	Residential building (G+11)
Thickness of Infill wall	200mm, 250 mm & 300 mm
Height of each storey	3m
Depth of foundation	3m
Bay width in longitudinal direction	3m
Bay width in transverse direction	3m
Size of beams	250 mm X 450 mm
Size of columns	450 mm X 450 mm
Thickness of slab	150mm
Thickness of walls	200 mm, 250 mm and 300 mm
Seismic zone	II, III and IV
Soil condition	Medium (type II)
Response reduction factor	5
Importance factor	1
Density of brick masonry	20 kN/m^3

2.1 Geometry

For the study 3 different models of a 12 storey building of 200 mm, 250 mm and 300 mm thick infill are considered. The building is kept symmetric in both orthogonal directions in plan to avoid torsional response under lateral force. The column is kept square and size of the column is kept same throughout the height of the structure to keep the discussion focused only on the storey effect without distracted by the issues like orientation of column.

2.2 Modelling

The building is considered to be located in seismic zone II, III, IV and intended for residential use. The building is founded on medium strength soil through isolated footing under the columns. Response reduction factor for the special moment resisting frame is taken as 5.0 (assuming ductile detailing). The floor finish on the floors is taken to be 1.0 kN/m^2. The live load on floor is taken as 3.0 kN/m^2 and that on the roof to be 1.5 kN/m^2. In seismic weight calculations, 25 % of the floor live loads are considered in the analysis. Details of the structure are given in Table 1

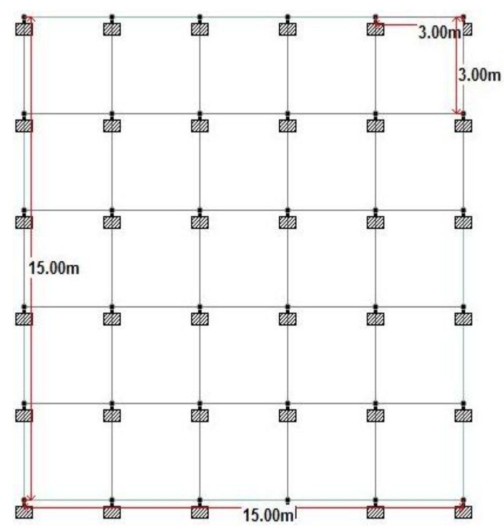

Fig. 1: Plan of the 12 storey building

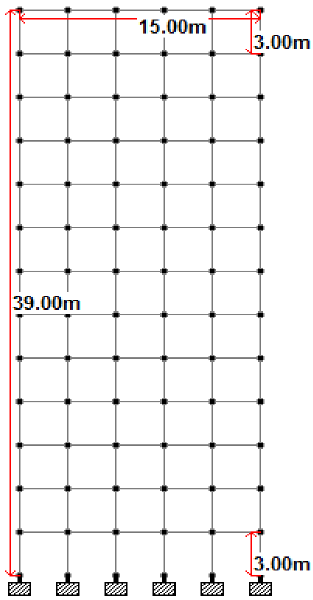

Fig. 2: Elevation of 12 storey building

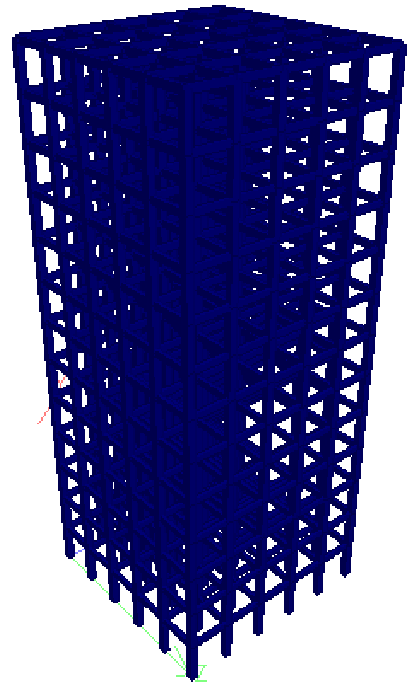

Fig. 3: Isometric

view of structure (Bare Frame)

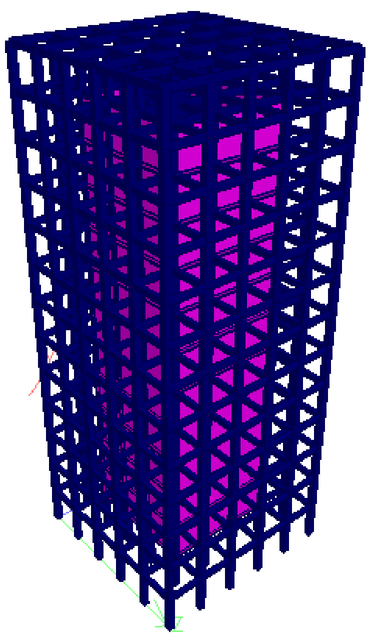

Fig. 4: Structure with Infill at centre

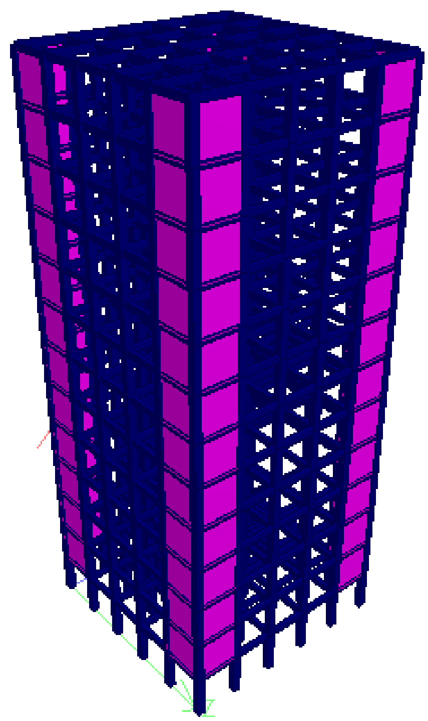

Fig. 5: Structure with Infill at corner

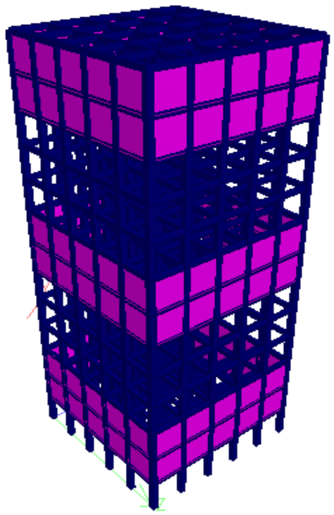

Fig. 6: Structure with Infill at transverse

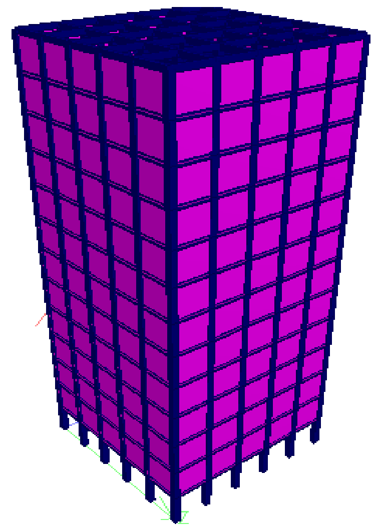

Fig. 7: Structure with Infill at outer

3. RESULTS & DISCUSSION

After analysing the structure with the help of STAAD.Pro software, results for displacements, moments, axial force and drift are given in Table 2 to 6. Results are discussed below.

Table 2: Max displacement (mm)

MODELS	TYPES	ZONE-II	ZONE-III	ZONE-IV
	BARE FRAME	64.88	103.75	155.57
200 mm THICK INFILL WALL	INFILL AT CENTRE	11.70	18.71	28.05
	INFILL AT CORNER	27.25	43.56	65.30
	INFILL AT TRANSVERSE	31.27	50.00	74.97
	INFILL AT OUTER	12.36	19.72	29.53
250 mm THICK INFILL WALL	INFILL AT CENTRE	11.68	18.68	28.00
	INFILL AT CORNER	27.78	44.40	66.57
	INFILL AT TRANSVERSE	32.61	52.14	78.19
	INFILL AT OUTER	12.22	19.50	29.19
300 mm THICK INFILL WALL	INFILL AT CENTRE	11.74	18.77	28.14
	INFILL AT CORNER	28.35	45.32	67.95
	INFILL AT TRANSVERSE	33.88	54.18	81.25
	INFILL AT OUTER	12.05	19.22	28.78

1. Displacements

Maximum displacement are given in Table 2 and shown in Fig. 8

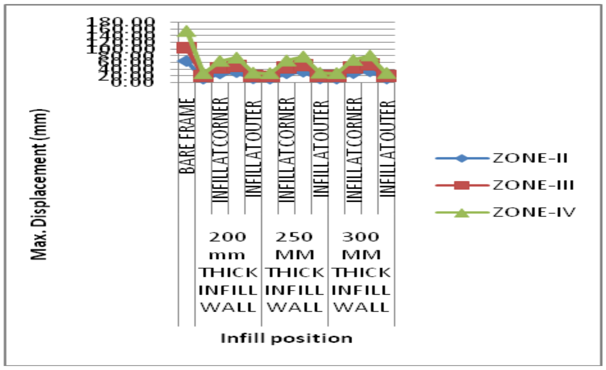

Fig. 8: Max displacement (mm) in structure

It can be observed that displacement is maximum for bare frame and minimum for infill at centre and at outer. Infill at corner and at transverse is not much effective.

2. Column Forces

Maximum axial force are given in Table 3 and shown in Fig. 9

Table 3: Max axial force (kN) in column members of structures

MODELS	TYPES	ZONE-II	ZONE-III	ZONE-IV
	BARE FRAME	3228.72	3228.72	3542.44
200 mm THICK INFILL WALL	INFILL AT CENTRE	3304.04	3670.51	4159.15
	INFILL AT CORNER	2822.45	3279.33	3888.49
	INFILL AT TRANSVERSE	2116.57	2345.71	2654.53
	INFILL AT OUTER	2790.64	3059.78	3424.31
250 mm THICK INFILL WALL	INFILL AT CENTRE	3660.15	4062.52	4599.01
	INFILL AT CORNER	3106.97	3593.25	4241.62
	INFILL AT TRANSVERSE	2311.70	2557.56	2886.79
	INFILL AT OUTER	3154.01	3449.18	3842.75
300 mm THICK INFILL WALL	INFILL AT CENTRE	4007.21	4443.58	5025.41
	INFILL AT CORNER	3385.95	3901.12	4588.01
	INFILL AT TRANSVERSE	2055.29	2767.27	3116.58
	INFILL AT OUTER	3514.50	3835.40	4263.26

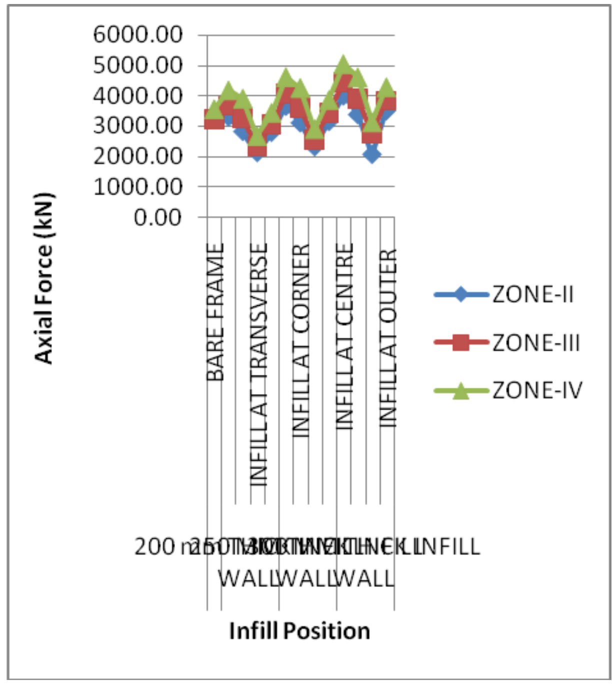

Fig. 9: Max axial force (kN) in column members

It can be observed that axial force is maximum for centre and minimum for infill at transverse. Infill at corner and at outer is not much effective.

3. Beam Forces

3.1 Bending moment

Maximum bending moment are given in Table 4 and shown in Fig. 10

Table 4: Max bending moment (kNm) in beam members

MODELS	TYPES	ZONE-II	ZONE-III	ZONE-IV
	BARE FRAME	145.72	208.03	292.00
200 mm THICK INFILL WALL	INFILL AT CENTRE	73.87	97.40	132.84
	INFILL AT CORNER	82.13	119.90	170.37
	INFILL AT TRANSVERSE	107.55	165.03	241.68
	INFILL AT OUTER	82.80	82.80	87.76
250 mm THICK INFILL WALL	INFILL AT CENTRE	81.80	107.57	141.92
	INFILL AT CORNER	83.99	122.85	175.15
	INFILL AT TRANSVERSE	113.15	174.06	255.28
	INFILL AT OUTER	83.61	83.61	97.85
300 mm THICK INFILL WALL	INFILL AT CENTRE	89.53	117.47	154.72
	INFILL AT CORNER	85.50	125.50	179.65
	INFILL AT TRANSVERSE	118.93	182.52	268.03
	INFILL AT OUTER	83.39	83.68	107.51

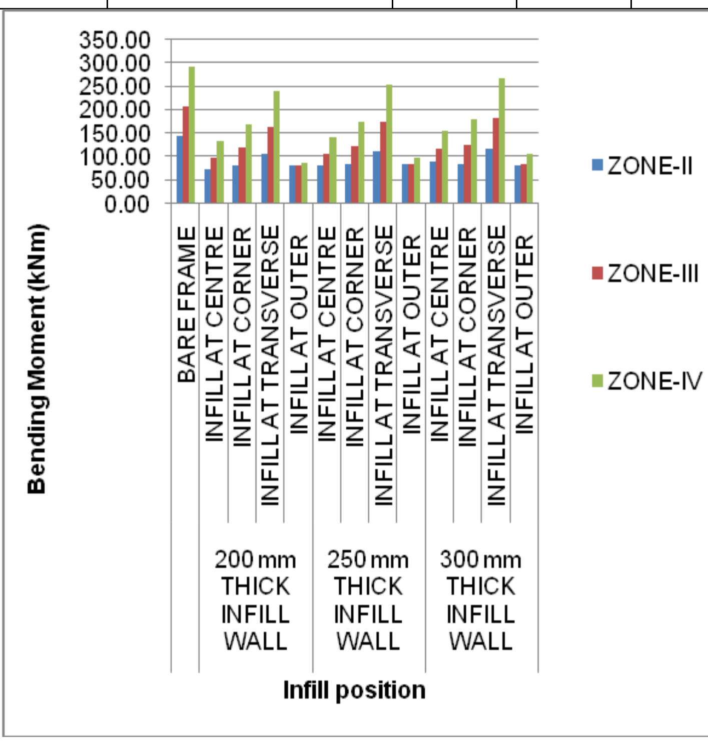

Fig. 10: Max bending moment (kN) in beam members

It can be observed that axial force is maximum for bare frame and minimum for infill at outer. Infill at corner and at transverse is not much effective.

3.2 Shear force

Maximum shear force are given in Table 5 and shown in Fig. 11

Table 5: Max Shear force (kN) in beam members

MODELS	TYPES	ZONE-II	ZONE-III	ZONE-IV
	BARE FRAME	127.20	166.88	220.36
200 mm THICK INFILL WALL	INFILL AT CENTRE	72.37	79.27	99.99
	INFILL AT CORNER	64.04	84.71	116.45
	INFILL AT TRANSVERSE	78.56	115.92	165.74
	INFILL AT OUTER	79.39	73.39	79.65
250 mm THICK INFILL WALL	INFILL AT CENTRE	78.08	86.67	109.54
	INFILL AT CORNER	64.70	86.39	119.20
	INFILL AT TRANSVERSE	82.24	121.74	174.41
	INFILL AT OUTER	73.59	75.39	84.66
300 mm THICK INFILL WALL	INFILL AT CENTRE	83.51	93.81	118.76
	INFILL AT CORNER	65.28	87.88	121.78
	INFILL AT TRANSVERSE	85.64	127.13	182.46
	INFILL AT OUTER	73.87	80.53	89.40

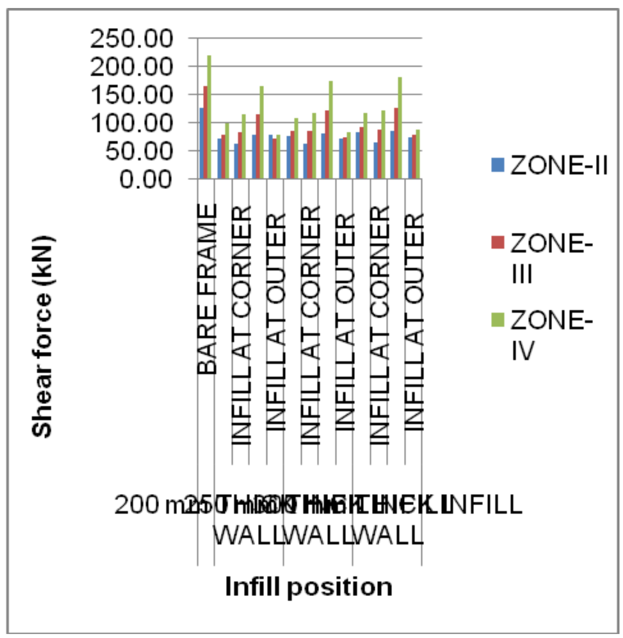

Fig. 11: Max shear force (kN) in beam members

It can be observed that shear force is maximum for bare frame and minimum for infill at centre and at outer. Infill at corner and at transverse is not much effective.

4. Storey Drift

To understand the effect of seismic force which generate storey drift on RCC framed structure, we take the seismic zone IV for representing the pattern of results instead of tabulating all the results collected during the analysis process. Storey drift are given in Table 6 and shown in Fig. 12,13 and 14

Table 6: Max Storey drift (mm) in members of structures

Floors	Bare frame	200 mm THICK INFILL WALL				250 MM THICK INFILL WALL				300 MM THICK INFILL WALL			
		Infill at centre	Infill at corner	Infill at transverse	Infill at outer	Infill at centre	Infill at corner	Infill at transverse	Infill at outer	Infill at centre	Infill at corner	Infill at transverse	Infill at outer
Bottom	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Base	5.95	2.95	3.07	3.09	3.25	3.13	3.20	3.27	3.54	3.30	3.34	3.43	3.82
GF	9.43	1.73	3.00	2.43	1.58	1.77	3.10	2.47	1.67	1.82	3.19	2.50	1.75
1st Floor	10.05	1.34	3.22	2.75	1.31	1.34	3.29	2.80	1.32	1.35	3.37	2.84	1.33
2nd Floor	10.18	1.19	3.41	5.60	1.15	1.18	3.47	5.92	1.13	1.18	3.54	6.22	1.11
3rd Floor	10.13	1.15	3.57	6.52	1.07	1.13	3.63	6.91	1.03	1.13	3.69	7.31	0.991
4th Floor	9.94	1.16	3.68	5.65	1.03	1.14	3.74	5.97	0.99	1.13	3.81	6.28	0.94
5th Floor	9.57	1.18	3.74	3.03	1.03	1.16	3.80	3.10	0.97	1.15	3.87	3.15	0.92
6th Floor	9.01	1.20	3.73	2.87	1.02	1.18	3.80	2.94	0.97	1.17	3.87	2.99	0.92
7th Floor	8.23	1.21	3.65	4.63	1.02	1.19	3.72	4.88	0.97	1.18	3.80	5.11	0.92
8th Floor	7.22	1.21	3.49	4.84	0.99	1.19	3.57	5.13	0.95	1.18	3.65	5.42	0.90
9th Floor	5.95	1.20	3.24	3.82	0.94	1.18	3.32	4.03	0.90	1.18	3.41	4.25	0.87
10th Floor	4.43	1.19	2.88	1.88	0.85	1.19	2.96	1.92	0.82	1.19	3.05	1.95	0.80
11th Floor	2.86	1.32	2.37	1.33	0.75	1.33	2.45	1.38	0.75	1.34	2.53	1.42	0.76

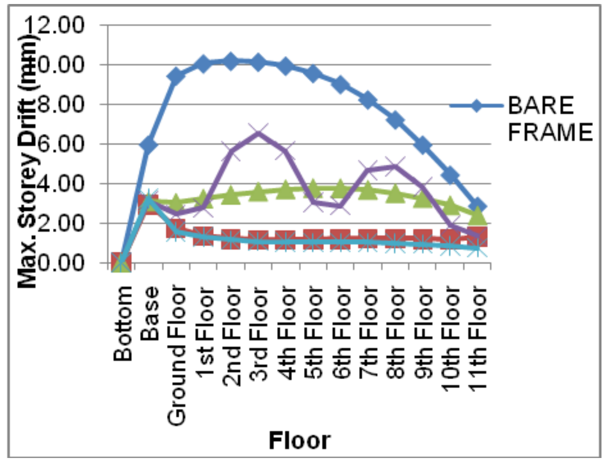

Fig. 12: Max Storey drift (mm) in members of structures with infill wall of 200 mm

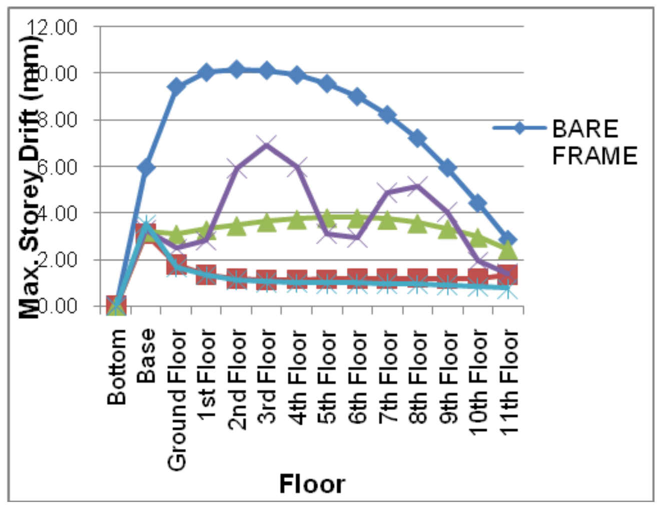

Fig. 13: Max Storey drift (mm) in members of structures with infill wall of 250 mm

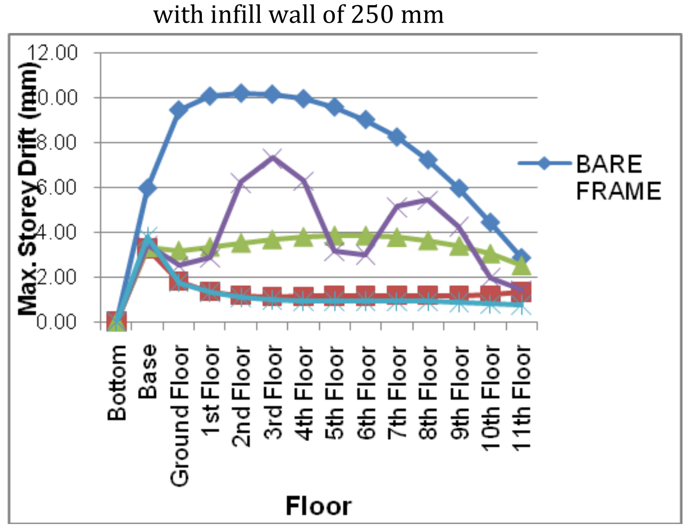

Fig. 14: Max Storey drift (mm) in members of structures with infill wall of 300 mm

It can be observed that storey drift is maximum for bare frame and minimum for infill at centre and at outer. Infill at corner and at transverse is not much effective.

CONCLUSION

In this study, seismic evaluation of RC buildings with various infill thickness at different positions have been carried out using STAAD.Pro software. It is observed that bare frame is the most critical producing large deflection and forces. Out of 4 types of infills, infill at centre and at outer are most effective. Proper positioning of infill is very important for safe design of buildings. It is observed that even smaller thickness of infill at correct position will yield lower response than larger thickness at incorrect position. Proper design of infill is crucial for the durability of the RC structures.

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