

# Effect of Infill Walls on RC Framed Structure

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**ABSTRACT:** Brick masonry walls are used as infills in reinforced concrete frames (RC). The masonry infill walls are treated as a non-structural element and are usually neglected in structural analysis and seismic design calculations. The mass of the infill walls is considered while performing analysis, however, its structural properties like strength and stiffness is generally ignored. The structures located in seismic prone areas are more vulnerable to damages as they have to resist the lateral force/seismic forces in addition to gravity. The past experience of several researchers has shown that the brick masonry infill significantly contributed to the seismic performance of the building. However for the sake of convenience, most of the time, brick masonry infills are treated as non structural members. Therefore, this consideration may result in an inaccurate prediction of the strength, lateral stiffness and ductility of RC framed buildings. Therefore the present investigation was considered to study the effect of brick masonry infill wall on the performance of the framed structure. For this purpose in present study a building of G+5 storey is considered for analysis, building is located in seismic zone IV resting on medium soil. In totality five number of models were analysed which include Bare frame, complete infill frame and open ground soft storey these models were analysed using software ETABS 2015. The infill walls are modelled with 0% and 10% opening at the centre of the wall. The building is analysed with both static (Equivalent static lateral force method) and dynamic (Response spectrum analysis) method. Different parameters for the building such as displacement, storey drift, lateral forces on floors and storey drift are studied and comparisons are made for both ESLM (Equivalent Static Lateral force Method) and RSA (Response spectrum analysis). As the area of opening increases the strength and stiffness of RC infilled frame decreases. It was observed that performance of infill frames is better than those of bare frames when subjected to seismic forces. On comparison between ESLM and RSA, the Response spectrum analysis shows lesser values of displacement and drift than those obtained from Equivalent static lateral force method (ESLM).

**KEYWORDS:** Equivalent static lateral force method (ESLM), Response spectrum analysis (RSA), storey drift, storey displacement, fundamental time period, base shear.

## I. INTRODUCTION

Brick infill walls are provided between the structural members namely column and beams to create an enclosure. Brick infill walls add to dead load of the structure. These types of composite structures created by combination of moment resisting RC plane frame with brick infill wall panel are called as "Infilled Frame".

Brick masonry infill remains in contact with RC frame structures under very low lateral loads and hence there is composite action between RC frame and brick masonry infill. Therefore, the stiffness of structural system becomes larger than bare RC frame structure. With increasing lateral loads, the brick masonry infill begins to crack at the interface between RC frame and brick masonry infill. The separation between RC frame and brick infill walls is more pronounced in tension zone. On the other hand, on the compression zone, the brick masonry forms a diagonal strut action as shown in Fig 1.

In order to study the effect of infill walls, infill modelling was studied under the following types.

1. Bare Frame
2. Complete Infilled Frame
3. Infilled Frame with opening
4. Partial Infilled Frame.

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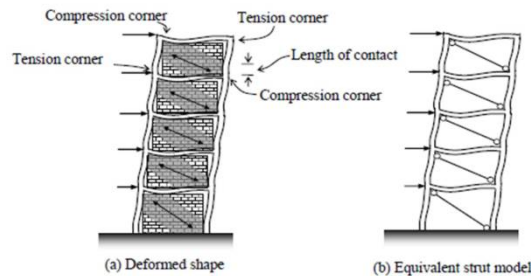


Fig 1. Behaviour of infill (C.V.R Murty <sup>[4]</sup>)

## II. RELATED WORK.

A number of experimental tests have been carried by numerous researchers to investigate the effect of masonry infill on seismic performance of infilled frame structures. Several numerical methods have also been developed to evaluate the strength and stiffness of masonry infill. The results show that the masonry infill has a significant effect on strength and stiffness. The width of the equivalent diagonal strut ( $w$ ) can be found out by using a number of expressions given by different researchers.

**Holmes (1961)** states that the width of equivalent strut to be one-third of the diagonal length of infill, which resulted in the infill strength being independent of frame stiffness

In 1961 Holmes,

$$w = d_{inf}/3 \dots \dots \dots (1)$$

Where  $d_{inf}$  is the diagonal length of infill

**Mainstone (1971)** gave equivalent diagonal strut concept by performing tests on model frames with brick infills. His approach estimates the infill contribution both to the stiffness of the frame and to its ultimate strength.

$$w = 0.16d_{inf} (\lambda h H_{inf})^{-0.3} \dots \dots \dots (2)$$

**Mainstone and Weeks (1974)** also based on experimental and analytical data, proposed an empirical equation for the calculation of the equivalent strut width:

$$w = 0.175d_{inf} (\lambda h H_{inf})^{-0.4} \dots \dots \dots (3)$$

**Liauw and Kwan (1984)** proposed the following equations based on experimental and analytical data

$$w = (0.95H \cos \theta) / \sqrt{\lambda_h} H_{inf} \dots \dots \dots (4)$$

**Paulay and Prestley (1992)** pointed out that a high value of  $w$  will result in a stiffer structure, and therefore potentially higher seismic response. They suggested a conservative value useful for design proposal, given by:

$$w = 0.25d_{inf} \dots \dots \dots (5)$$

**FEMA (1998)** proposed that the equivalent strut is represented by the actual infill thickness that is in contact with the frame ( $t_{inf}$ ) and the diagonal length ( $d_{inf}$ ) and an equivalent width,  $W$ , is given by:

$$w = 0.175(\lambda_1 h c o l)^{-0.4} r_{inf} \dots \dots \dots (6)$$

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## III.OBJECTIVES OF THE STUDY

The objectives include the following:

1. To find the response of G+5 storey masonry infill RC frame using both ESLM and RSA and compute the following parameters of the above said Models namely
  - i) Maximum storey displacement
  - ii) Fundamental time period
  - iii) Storey drift
  - iv) Base shear
 Numerical Modelling and analysis are carried out using ETABS 2015.
2. To compare performance of masonry infill RC frames provided with some percentage of openings with bare frame to arrive at the effectiveness of infill in RC frame

## IV.BUILDING DATA FOR ANALYSIS

The following Table 1 shows the details of G+5 building considered for analysis.

**Table 1. G+5 building details**

<b>A. Storey Details</b>	Number of stories = G+5		Depth of Slab = 150 mm
	Storey height = 3.5 m for all storeys.		Infill Wall thickness = 230 mm
<b>B. Plan Dimension</b>	No of bays in x-direction= 5		Unit weight of RCC = 25 kN/m <sup>3</sup>
	No of bays in y-direction= 4	<b>E. LOAD CONSIDERATIONS</b>	
	Distance between bays in x& y direction = 4m	<i>Live load</i>	2.5 kN/m <sup>2</sup> for other floors (as per IS 875 part 2)
			1.5 kN/m <sup>2</sup> for terrace
<b>C. Materials used</b>	$f_m$ = Compressive Strength of Brick Infill = 5 MPa	<i>Floor Finish</i>	1kN/m <sup>2</sup> for all floors
	$E_m$ = Modulus of Elasticity of infill	Water proofing	1.5 kN/m <sup>2</sup> on terrace
	$E_m = 550f_m$ kN/m <sup>2</sup>	<b>F. Seismic Zone</b>	IV
	$E_c$ =Modulus of Elasticity of Concrete = $5000\sqrt{f_{ck}}$ MPa	<b>G. Response Reduction Factor</b>	SMRF = 5
<b>D. SECTION PROPERTIES</b>	Size of Column = 500*500 mm	<b>H. Damping in Structure</b>	5%
	Size of Beam = 230*450 mm	<b>I. Soil type</b>	Medium

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## IV. PARAMETRIC STUDIES

A 3D RC infill frames with G+5 storey building is considered for Static and dynamic analysis. In totality 5 Models as detailed below are considered for comparison.

**Table 2. Models description**

Model type	Model name	Model Description
Bare frame	Bare	RC frame without masonry infill.
Complete (Full) infill	FI 0%	RC frame with brick infill at all stories with 0% opening in infill walls.
Complete (Full) Infill	FI 10%	RC frame with brick infill at all stories with 10% opening in infill walls
Open ground storey	OGS 0%	RC frame with no brick infill at ground storey and brick infill with 0% opening at all other storeys.
Open ground storey	OGS 10%	RC frame with no brick infill at ground storey and brick infill with 10% opening at all other storeys

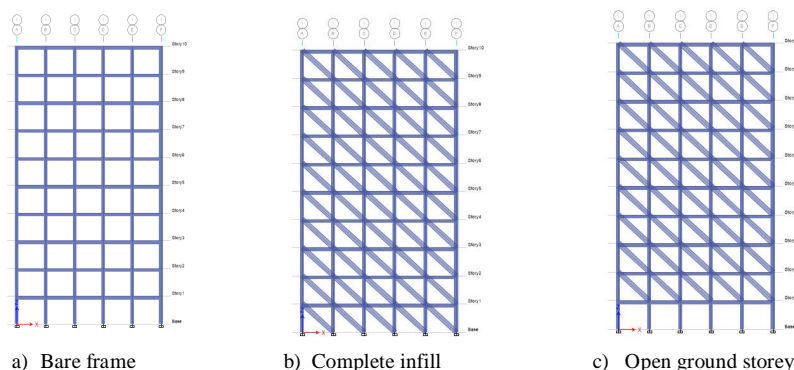


Fig 3. Elevation view of different type of infill models

Fig 3 shows the elevation view for different type of infill provision used in the present study. Masonry infill walls are modelled as equivalent diagonal strut in order to study its effect on strength and stiffness of RC framed structure.

## V. CALCULATION OF STRUT WIDTH

The calculation of strut width was carried out according to FEMA which is as detailed below:

The elastic in-plane stiffness of a solid unreinforced masonry infill panel prior to cracking shall be represented with an equivalent diagonal compression strut of width "a" is given by Equation 1. The equivalent strut shall have the same thickness and modulus of elasticity as the infill panel it represents.

$$a = 0.175(\lambda_1 h_{col}) - 0.4 r_{inf} \dots \dots \dots (7)$$

$$\lambda_1 = \left[ \frac{E_{me} t_{inf} \sin 2\theta}{4 E_{fe} I_{col} h_{inf}} \right]^{\frac{1}{4}}$$

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$h_{col}$  = Column height between centre lines of beams, in inches.  
 $h_{inf}$  = Height of infill panel, in inches.  
 $E_{fe}$  = Expected modulus of elasticity of frame material, psi  
 $E_{me}$  = Expected modulus of elasticity of infill material, psi  
 $I_{col}$  = Moment of inertia of column, in inches<sup>4</sup>  
 $L_{inf}$  = Length of infill panel, in inches.  
 $r_{inf}$  = Diagonal length of infill panel, in inches.  
 $t_{inf}$  = Thickness of infill panel and equivalent strut, in inches.  
 $\theta$  = Angle whose tangent is the infill height-to length aspect ratio, in radians  
 $\lambda_1$  = Coefficient used to determine equivalent width of infill strut

**Table 3. Calculated strut width by FEMA.**

0% Opening	10% opening
1050 mm	520 mm

Table 3 shows the strut width calculated for 0% and 10% opening in infill wall by FEMA 356. Strut width in X and Y-direction is same as the distance between bays in X and Y-direction is same.

## VI. RESULTS AND DISCUSSION

In the present study, Storey drift, storey displacement, base shear and fundamental time period are the major parameters that are studied and compared. FEMA method is used for calculating the strut width. All the models are modelled and analysed by ETABS 2015. Following are the effect of infill wall on different parameters

### 1. Effect of infill walls on maximum storey displacement

Storey displacement is referred to the lateral displacement of the storey with respect to ground. The maximum storey displacement for different models such as bare frame, complete (full) infilled frame, open ground storey with 0% and 10% opening were obtained by Equivalent static method and Response spectrum method for G+5 storey building.

**Table 4. Maximum storey displacement (mm) for different models**

Method of analysis	Equivalent static method				Response spectrum method			
Direction	X-direction		Y-direction		X-direction		Y-direction	
Openings in infill walls	0%	10%	0%	10%	0%	10%	0%	10%
Bare frame	58		56.3		43.3		40.4	
Complete (full) infill frame (FI)	18.7	26.2	20.6	28	14.6	20.4	16.1	22.2
Open ground storey (OGS)	20.7	28.1	22.4	29.5	16.2	22	17.4	22.6

From Table 4 it can be observed that with due to the introduction of infill walls the maximum storey displacement is decreased due to increase in stiffness of the infilled frame. Similarly from Table 4 it can be observed that when the opening is introduced in infill wall the maximum storey displacement decreases due to decrease in stiffness.

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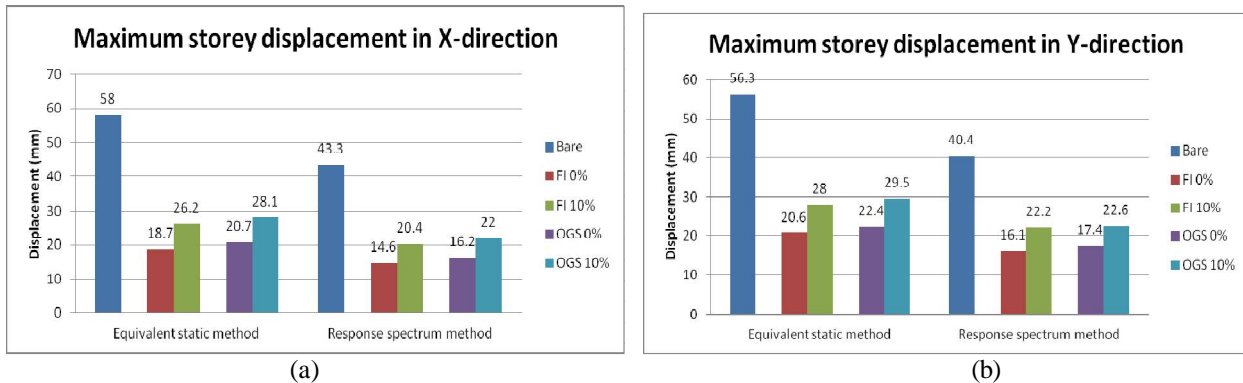


Fig. 4. Maximum storey displacement (a) Maximum storey displacement in X-direction for various models (b) Maximum storey displacement in Y-direction for various models.

From above Fig 4 it can be observed that when the infill walls are introduced the maximum storey displacement of building gets reduced. Brick infill possesses lateral stiffness due to which the stiffness of infilled frame is more than that of the RC bare frame. It can be observed that due to the introduction of infill wall the maximum storey displacement reduces upto 70% - 80%. Complete (full) infill has minimum storey displacement as compared to other models as it possesses more stiffness as compared to other models considered. On comparing the results of ESLM and RSA it is observed that RSA yields lesser value of maximum storey displacement as compared to that of ESLM. When the percentage of opening in infill wall is increased the stiffness of infilled frames gets reduced due to which maximum storey displacement of structure increases as shown in Fig 4. The reduction of in maximum storey displacement due to infill walls is more in X-direction as compared to that of Y-direction since the number of bays in X-direction is more due to which number of infill walls in a storey is more in X-direction than Y-direction.

## 2. Effect of infill walls on fundamental time period.

It is the first (longest) modal time period of vibration. The fundamental time period for different models such as bare frame, complete (full) infilled frame, open ground storey with 0% and 10% opening were obtained for G+5 storey building and which are tabulated below.

Table 5. Fundamental time period for G+5 building.

Opening in infills	0%	10%
Bare frame	0.94	
Complete(full) infill frame (FI)	0.58	0.66
Open ground storey (OGS)	0.67	0.72

From Table 5 it can be observed that fundamental time period of structure decreases due to increase in stiffness of RC bare frame by brick infill. Fundamental time period of open ground storey is more as compared to complete (full) infill as the stiffness of open ground storey is less due to the absence of infill walls at ground storey. With increase in percentage of opening in infill the fundamental time period increases due to decreases in stiffness of the infilled frame.

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## 3. Effect of infill walls on storey drift

Storey drift is defined as the difference in lateral deflection between two adjacent stories. The base shear for different models such as bare frame, complete (full) infilled frame, open ground storey with 0% and 10% opening were obtained for G+5 storey building and which are tabulated below.

**Table 6. Storey drift (mm) by Equivalent static method**

Storey	X-direction					Y-direction				
	Bare	FI		OGS		Bare	FI		OGS	
		0%	10%	0%	10%		0%	10%	0%	10%
6	0.648	0.222	0.295	0.221	0.292	0.701	0.278	0.353	0.276	0.352
5	1.073	0.36	0.479	0.357	0.476	1.152	0.441	0.565	0.437	0.565
4	1.381	0.451	0.605	0.448	0.603	1.478	0.549	0.71	0.545	0.71
3	1.547	0.497	0.672	0.492	0.673	1.653	0.603	0.787	0.597	0.789
2	1.538	0.513	0.692	0.57	0.748	1.639	0.617	0.804	0.679	0.862
1	0.978	0.404	0.512	0.817	0.785	1.035	0.472	0.58	0.876	0.843

From Table 6 it can be observed that as the brick infill wall are introduced the storey drift of structure decreases in both X and Y-direction. Storey drift at ground floor is larger for OGS as compared to other models due to absence of infill walls at ground floor. Storey drift increases due to the introduction of opening in infill walls.

**Table 7. Storey drift (mm) by Response spectrum method.**

Storey	X-direction					Y-direction				
	Bare	FI		OGS		Bare	FI		OGS	
		0%	10%	0%	10%		0%	10%	0%	10%
6	0.451	0.147	0.197	0.135	0.188	0.473	0.189	0.237	0.174	0.228
5	0.772	0.254	0.342	0.235	0.328	0.801	0.315	0.401	0.293	0.388
4	1.050	0.347	0.467	0.325	0.452	1.083	0.422	0.542	0.398	0.527
3	1.257	0.416	0.563	0.394	0.55	1.292	0.501	0.649	0.478	0.637
2	1.334	0.461	0.621	0.505	0.664	1.366	0.55	0.709	0.594	0.739
1	0.885	0.379	0.477	0.751	0.721	0.899	0.437	0.53	0.737	0.746

On comparing the results from Table 6 and Table 7 it can be observed that ESLM yields larger value of storey drift as compared to that of RSA.



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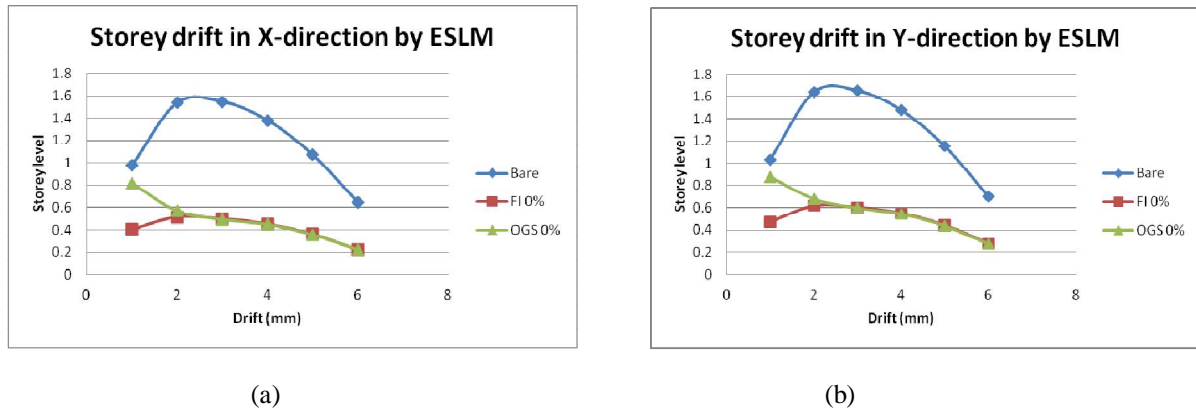


Fig. 5. (a) storey drift for models with no opening in X-direction by ESLM (b) storey drift for models with no opening in Y-direction by ESLM

From Fig 5(a) & 6(b) it can be observed that due to introduction of brick infill walls the storey drift of structure reduces upto 75% due to increase in stiffness of RC bare frame. Similarly it can be observed that in open ground storey the storey drift at ground floor increases as compared to complete (infill) frame due to formation of soft storey at ground floor.

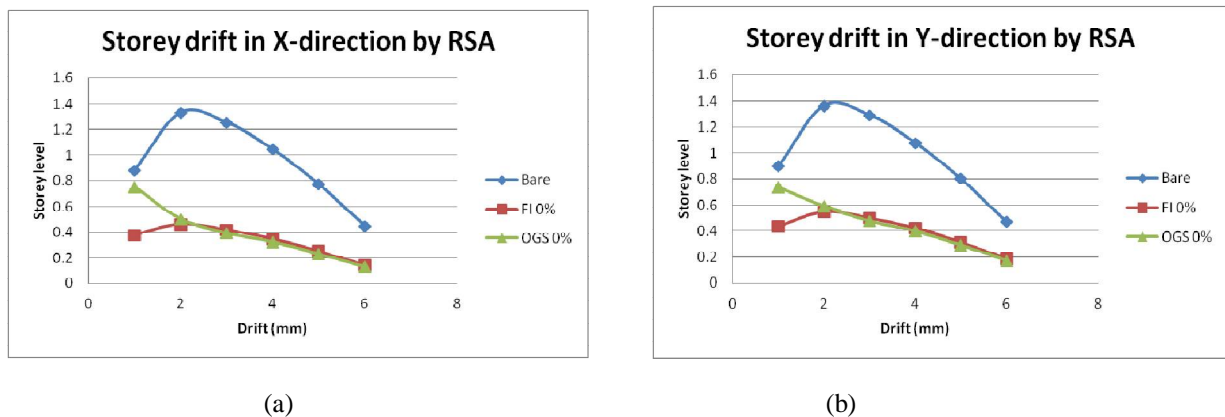


Fig 6. (a) storey drift for models with no opening in X-direction by RSA (g) storey drift for models with no opening in Y-direction by RSA

From Fig 6(a) & 6(b) it can be observed that the value of storey drift by RSA is lesser as compared to that of ESLM in both X and Y-direction. Brick infill provides strength and stiffness to RC frame structure which results in better performance of structure during earthquakes. Results from RSA and ESLM both show that due to the absence of infill wall at ground floor the storey drift increases significantly which is the main reason for failure of structure. Therefore, Indian code 1893:2002 (part 1) clause 7.10.3(a) states: "The columns and beams of the soft-storey are to be designed for the multiplication factor of 2.5 times the storey shears and moments calculated under seismic loads of bare frame".



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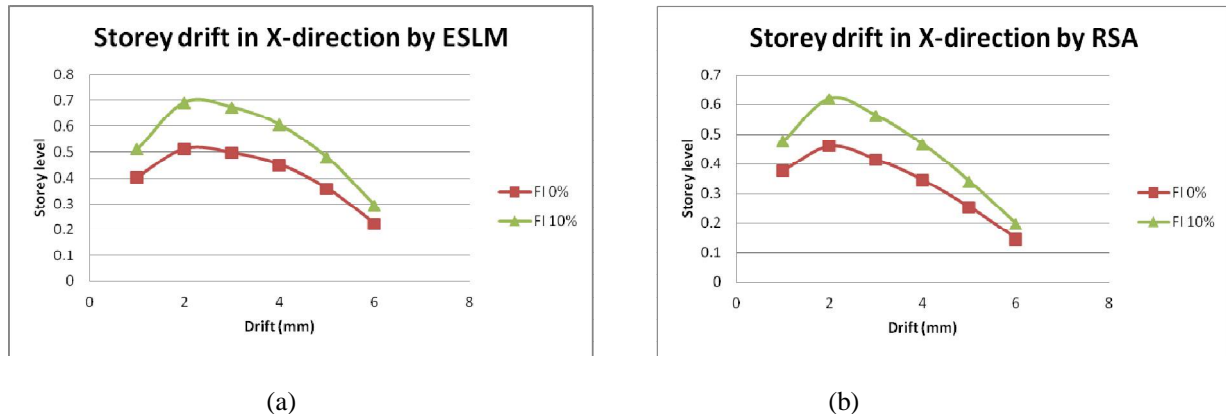


Fig 7. (a) storey drift for complete (full) infill model with 0% and 10% opening in X-direction by ESLM (b) storey drift for complete (full) infill model with 0% and 10% opening in X-direction by RSA

From Fig 7(a) & 7(b) it can be observed that due to introduction of opening in infill wall the storey drift for complete (full) infill increases as the stiffness of infilled frame gets reduced. Peak storey drift is obtained at 2 storey in both RSA and ESLM.

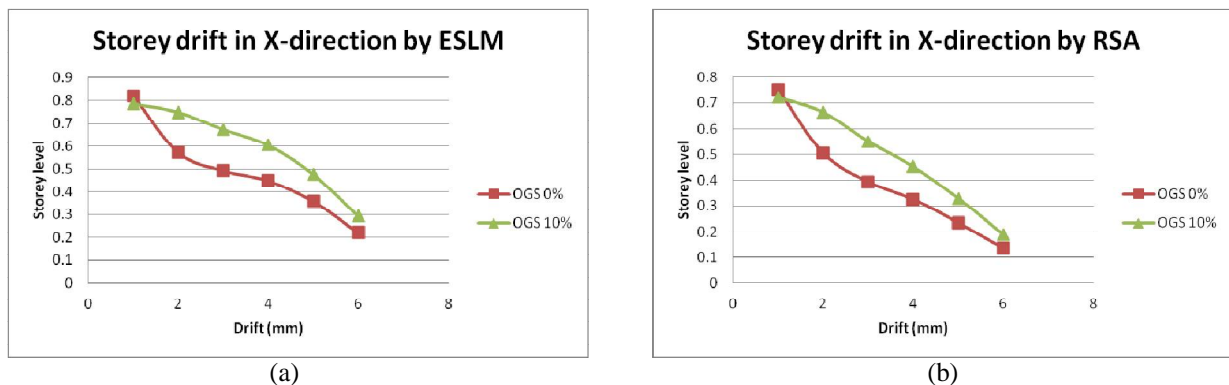


Fig 8.(a) storey drift for open ground storey model with 0% and 10% opening in X-direction by ESLM (b) storey drift for open ground storey model with 0% and 10% opening in X-direction by RSA

From Fig 8(a) & 8(b) it can be observed that due to introduction of opening in infill wall the storey drift for complete (full) infill increases as the stiffness of infilled frame gets reduced. Due to absence of infill wall at ground storey there is formation of soft storey at ground floor which results in increases in storey drift. Storey drift at top storey is reduced when opening is provided because as the opening is increased the behaviour of open ground storey tends towards the behaviour of bare frame.

## 4. Effect of infill walls on storey drift

The base shear for different models such as bare frame, complete (full) infilled frame, open ground storey with 0% and 10% opening were obtained for G+5 storey building and which are tabulated below.

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**Table 8. Base shear (kN) for G+5 building**

	X-direction		Y-direction	
Opening in infill	0%	10%	0%	10%
Bare frame	757.6		748.1	
Full infill frame	1370.6	1125.1	1279.8	1046.6
Open first storey	1233.4	1047.6	1155.1	989.8

From Table 8 it can be observed that base shear for infilled frame is more as compared to that of RC bare frame as the increase in stiffness of infilled frame. Base shear decreases when the opening is introduced in infill wall.

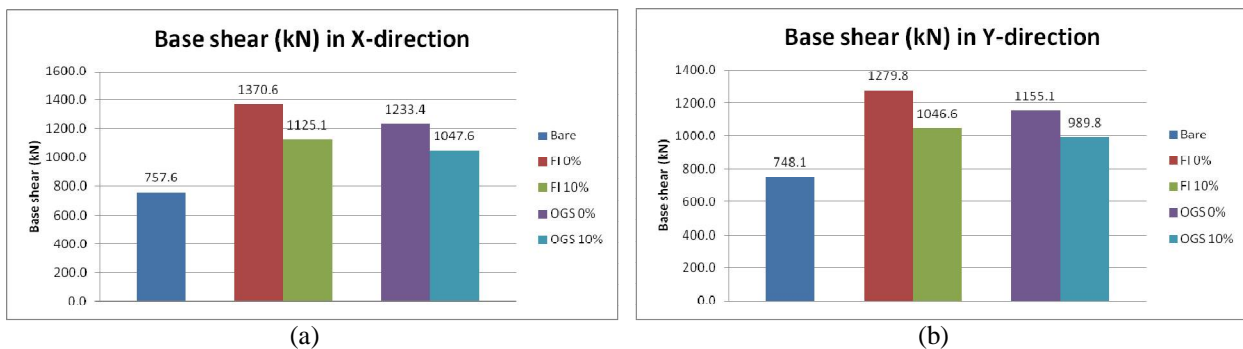


Fig. 6. Base shear (a) Base shear in X-direction for various models (b) Base shear in Y-direction for various models

From Fig 7 it can be observed that due to the introduction of infill walls the base shear of structure increases due to increase in stiffness of RC bare frame. Base shear for complete (full) infill is more as compared to that of bare frame and open ground storey as the stiffness of complete (full) infill is more as compared to other models considered. When the opening in infill wall is introduced the value of base shear decreases due to decrease in stiffness of infilled frame.

## VII. CONCLUSION

1. Displacement decreases up to 70% to 80% due to increase in strength and stiffness of the structure by infill walls for the investigated models.
2. As the percentage of opening in infill walls is increased the strength and stiffness of the infilled frame decrease due to which storey drift, storey displacement and fundamental time period of the structure increases.
3. Storey drifts are widely affected due to infill walls, i.e storey drift decreases up to 75% due to infill walls.
4. The storey drift of open ground soft storey is very large as compared to other due to absence of infill walls in the storey.
5. RSA results in lesser value for all the parameters as compared to ESLM.
6. The base shear of the structure increases due to the introduction of infill walls. When the effect of infill wall is ignored this leads to the underestimation of base shear acting on a structure during earthquake.

## REFERENCES

1. Asteris, P.G., "Lateral Stiffness of Brick Masonry Infilled Plane Frames" Journal of Structural Engineering, Vol. 129, pp 1071-1079, 2003.
2. BIS, IS 1893 (Part 1): (2002): Criteria for Earthquake Resistant Design of Structures Part-1 General Provisions and Buildings, Bureau of Indian Standards, Fifth revision.
3. BIS, IS 456:2000, Plain and reinforced concrete code of practice Bureau of Indian Standards, Fourth revision.
4. BIS, IS 1893 (part1): 2002 proposed draft provision and commentary.

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

5. FEMA 306, Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings: Basic Procedures Manual, *Federal Emergency Management Agency*, 1998.
6. FEMA 356, Pre-standard and Commentary for the Seismic Rehabilitation of the Buildings, Federal Emergency Management Agency & American Society of Civil Engineers, November 2000.
7. Holmes, M., "Steel Frames with Brickwork and Concrete Infilling", *Proceedings of the Institution of Civil Engineers*, Vol. 19, pp. 473-478, 1961.
8. Kodur, V.K.R., Erki, M.A., and Quenneville, J.H.P., "Seismic analysis of infilled frames", *Journal of Structural Engineering* Vol.25 pp 95-102, 1998.
9. Kose, M.N., "Parameters affecting the fundamental period of RC buildings with infill walls", *Engineering Structures*, Vol. 31, pp 93-102, 2009.
10. Liauw, T.C., and Kwan, K.H., "Nonlinear Behaviour of Non-Integral Infilled Frames", *Computers & Structures*, Vol. 18, pp. 551-560, 1984.
11. Mainstone, R.J., "On the Stiffness and strength of infilled frames", *Proceeding of the Institution of Civil Engineers*, Supplement IV, pp. 57-90, 1971.
12. Mainstone, R.J., "Supplementary Notes On The Stiffness And Strength Of Infilled Frames", *Current Paper CP 13/74*, Building Research Station, Garston, Watford, U.K, 1974.
13. Mahidi, T.B., "Seismic response of Asymmetrical Infilled concrete frames", *Procedia Engineering*, Vol. 54, pp 341-352, 2013.
14. Murthy, C.V.R, Jain, S.K., and Arlekar, J.N., "Seismic Response of Frame Buildings with Soft First Storeys", *Proceedings of the CBRI Golden Jubilee Conference on Natural Hazards in Urban Habitat*, New Delhi, 1997.
15. Paulay, T., and Priestley, M., "Seismic Design of Reinforced Concrete and Masonry Buildings". New York: John Wiley & Sons, 1992.