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EFFECT OF INFILL WALL ON SEISMIC PERFORMANCE OF RC BUILDING WITH OPEN GROUND STOREY

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Abstract — *Earthquake is an unavoidable natural disaster which causes large damage to the property and the lives. Most earthquake-related deaths are caused by the collapse of structures. Day by day demands of high rise structures increases with the increase in population. However, to fulfill the need of parking spaces ground story of building is utilized which makes building more vulnerable under lateral loads. Past earthquakes shows that the most of the damages in open ground storey are occurred in the ground storey columns and is called 'soft-storey collapses', 'storey-mechanism' or column mechanism'. These are due to the sudden lowering stiffness or strength in the open ground storey as compare to other infill stories. To prevent the soft storey failure IS 1893:2002 recommends a multiplication factor of 2.5. But, the multiplication factor proposed by IS 1893:2002 and selected international codes are not consistent. Therefore, it calls an assessment of multiplication factors by static nonlinear analysis considering infill stiffness and strength. In present paper static nonlinear analysis of infilled walled building with open ground storey is discussed for more realistic seismic analysis. For the study purpose G+5, G+7 and G+9 storey infilled wall buildings with different infill percentage has been considered. The modeling and static nonlinear analysis of building is carried out using ETABS software. The base shear multiplication factor obtained for various buildings are compared with the standard base shear multiplication factor available in IS1893-2002.*

Keywords- *Infill walled building, Soft-storey collapse, Base shear Multiplication factor, ETABS.*

I. INTRODUCTION

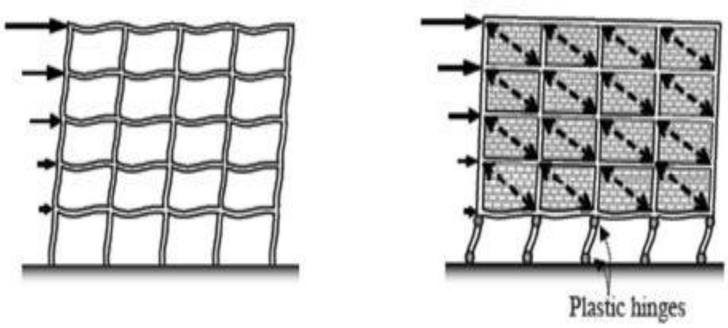
Earthquakes are one of the most devastating of all natural hazards and are considered to be the most powerful natural disasters which are unavoidable. The hazards associated to earthquakes are referred to as seismic hazards. Most earthquake-related deaths are caused by the collapse of structures. Day by day need of space became very important in urban areas due to increase in population especially in developing countries like India. However, to fulfill the need of parking spaces ground story of building is utilized which makes building more vulnerable under lateral loads. These types of buildings having no infilled walls in ground storey, but in-filled in all upper stories, are called Open Ground Storey (OGS) buildings. The majority of apartments or building constructed are falls in this category.

Estimation of seismic response on structures is an important aspect for earthquake resistant design of structures. Various important structures and buildings are designed as per guidelines specified in IS 1893 (Part I): 2002. IS code 1893:2002 allows to analyse open ground storey RC framed building without considering infill stiffness but with a multiplication factor of 2.5 to compensate stiffness discontinuity generated due to open ground storey. But, the multiplication factor proposed by IS 1893:2002 and selected international codes are not consistent. Therefore, it calls an assessment of multiplication factors by static nonlinear analysis considering infill stiffness and strength.

In present paper static nonlinear analysis of open ground store RC framed building has been carried using ETABS software. ETABS is widely used software for three dimensional structural analysis of buildings. The response of Open ground storey building is depends on height of building as well as infill wall stiffness. So, both the variable varying height of building and infill wall stiffness has been considered.

II. OPEN GROUND STOREY (OGS) BUILDINGS

The Open Ground storey becomes an essential part to cater the need of parking. Generally, building constructed with infill walls in upper story and ground storey has no infill walls are called open ground storey (OGS) buildings. Typical open ground storey building Infill walls in the upper storeys increases the stiffness of the building. Due to increase in the stiffness of upper storey, the base shear demand on the building increases in the open ground storey building. Both the frames and infill walls take the increased base shear in all upper storey of the building. However, infill walls are not present at ground story the increased base shear is resist entirely by the columns of the open ground storey building. The increased shear forces in the ground storey columns may increase in the bending moments, displacement and larger drifts at the first floor level. The large lateral deflections will results in the larger bending moments due to the P-Δ effect. Top and bottom ends of the open ground storey columns developed plastic hinges as shown in Figure 1.



Bare frame **Typical infilled frame**

Figure 1. Behavior of bare frame and OGS building

Past earthquakes shows that the most of the damages in open ground storey are occurred in the ground storey columns. These are due to the sudden lowering stiffness or strength in the open ground storey as compared to a typical infilled frame building. During Bhuj Earthquake -2002 so many complete OGS frame building collapse has been reported due to soft-storey mechanism in the ground storey due to the absence of infill walls. While upper stories experiences a lesser damage and move almost like a rigid body. So, during earthquake an Inverted pendulum type of effect is generated in which upper infill stories moves like a pendulum. These buildings are vulnerable due to the sudden lowering of stiffness or strength (vertical irregularity) in the ground storey as compared to a typical Infilled frame building.

III. INFILL WALL MODELLING

It's very important to develop a computational model on which linear static, non-linear static, dynamic analysis is performed. Accurate modelling of non linear properties of various structural elements is very important in non-linear analysis.

Infill walls are two-dimensional elements that can be model with plate element for analysis of Infilled wall buildings. But, two dimensional nonlinear plate element modeling does not understood well. Therefore, for nonlinear analysis of the buildings, the infill wall is modeled as a line element (one-dimensional) i.e. equivalent diagonal strut element which is most common method of modeling an infill walls.
There are different approaches to model infill were as equivalent struts. There are four approaches to model the equivalent strut found in literature and are listed below:

- Elastic Analysis Approach
- Ultimate Load Approach
- Approach Based on Plastic Analysis
- Approach Based on Finite Element Analysis

From the literature, it is clear that Elastic analysis approach is most common and widely used for nonlinear analysis of infill walls. The study of the complicated behavior of masonry infill by polyakov (1956) suggested that the infill and frame disparate excluding at two compression corners. He established the idea of equivalent diagonal strut and proposed that transformation of stresses from the frame to infill occurs only in the compression zone of the infill.
After that Holmes introduced infill wall modeling as an equivalent diagonal (strut) compression member. Equivalent diagonal strut thickness is recommended as the thickness of the infill wall itself, and One-third of the diagonal of the infill panel is used as equivalent strut width is recommended. However, researchers later found that this model overestimates the actual stiffness of Infilled frames and give upper bound values. Researchers have given different model for masonry infill panels which are listed in Table 1.

But the widely used approach for modelling for masonry infill panels was proposed by Mainstone in 1971 where the cross sectional area of strut was calculated by considering the sectional properties of the adjoining columns. In the present study, the approach given by Mainstone is used for modeling of infill panel as a Diagonal strut element.

Table 1. Equations for infill strut width by various researcher

Researchers	Strut width (w)	Remark
Holmes	$0.333d_m$	d_m *is the lenght of diagonal*
Mainstone	$0.175\,D\,(\lambda_h H)^{-0.4}$	$\lambda_h H = H\left[\frac{E_m t \sin 2\theta}{4E_c I_c h_m}\right]$
Liuw and Kwan	$\frac{0.95\,h_m t \cos\theta}{\sqrt{\lambda h_m}}$	$\lambda_h = \left[\frac{E_m t \sin 2\theta}{4E_c I_c h_m}\right]^{\frac{1}{4}}$
Pauly and priestley	$0.25\,d_m$	d_m *is the lenght of diagonal*
Hendry	$0.5[\alpha_h + \alpha_L]^{\frac{1}{2}}$	$\alpha_h = \frac{\pi}{2}\left[\frac{E_c I_c h_m}{E_m t \sin 2\theta}\right]^{\frac{1}{4}}$, $\alpha_L = [\frac{E_c I_c L}{2E_m t \sin 2\theta}]^{\frac{1}{4}}$

3.1 Opening consideration

In the buildings opening are provided for access area and ventilation for air, light. Opening size of infill wall leads to decrease in stiffness of infill wall and hence affects seismic performance of building. To consider the effect of Opening, stiffness of infill wall has been reduced for calculation of width of strut. The reduction of stiffness of infill wall with respect to opening percentage is carried out as per Figure 2. The considered graph is obtained from experimental and analytical study carried out by Panagiotis et al.

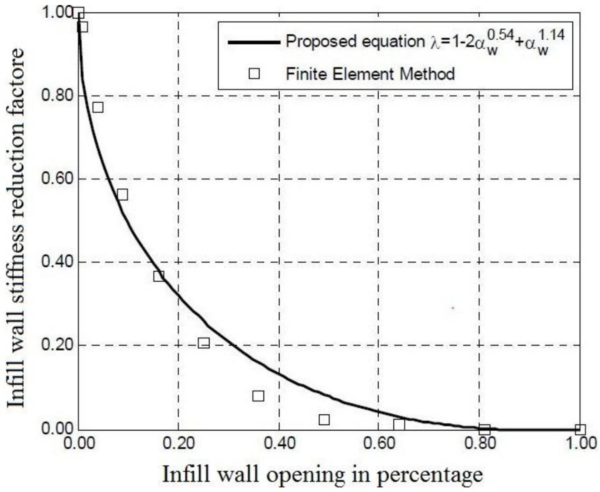


Figure 2. Stiffness reduction factors for infills

In this paper, 0% opening, 10% opening and 20% opening has been considered. According to opening percentage Infill wall stiffness reduces to 1, 0.55 and 0.35 respectively for 0% opening, 10% opening and 20% opening.

IV. BASE SHEAR MAGNIFICATION FACTOR

The OGS buildings can be considering as extreme soft-storey type of buildings in most of the practical situations, and shall be design considering special provisions to increase the lateral stiffness or strength of the soft/open storey. Here we are ignoring the infill strength and stiffness of infill walls. The various code recommendations is to magnify the bending moments and shear forces of bare frame for the columns in the soft/open storey by Magnification factor (MF). IS code 1893:2002 allows to analyse open ground storey RC framed building with a multiplication factor of 2.5 to compensate stiffness discontinuity generated due to open ground storey for all type of buildings. However this MF value does not account for number of storeys, number of bays, type and number of infill walls present, etc and hence it is independent of all of the above factors. Even the multiplication factor proposed by IS 1893:2002 and selected international codes are not consistent. Therefore, it calls an assessment of multiplication factors by static nonlinear analysis considering infill stiffness and strength

V. BUILDING CONFIGURATION

For understanding effect of building height and Infill opening on response of open ground storey building as shown in Figure.3 is considered.

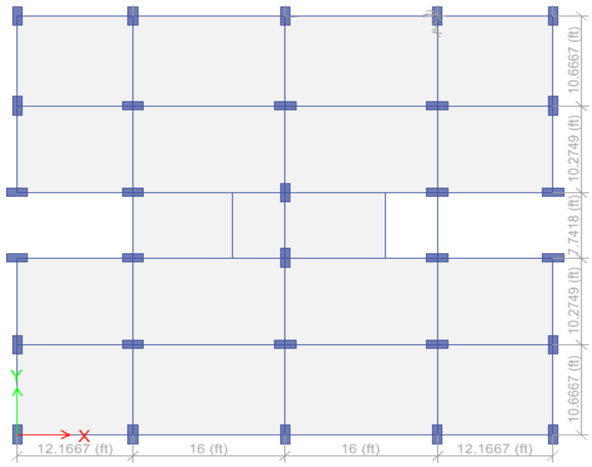


Figure 3. Plan of multistory building.

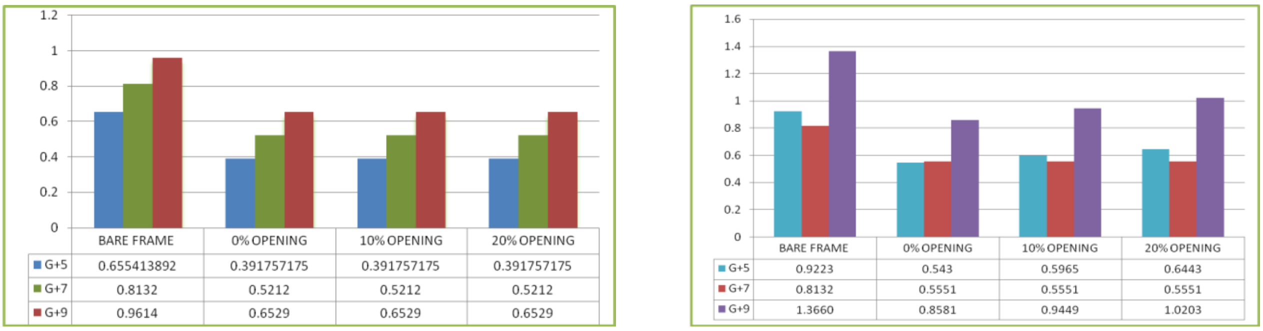
Story height of building is considered as 3m. Further three different storey buildings are taken into consideration i.e. G+5, G+7 and G+9. The dimension of various structural elements is given in Table 2.

Table 2. Building Parameters considered for Analysis

Building Parameters		Seismic Parameter	
Storey	G+5, G+7,G+9	Seismic Zone	IV
Storey Height	3m	Importance Factor	1
Geometrical property			
Size of Beam	230x500mm	External Wall	230mm
Slab thickness	128mm	Internal wall	120mm
Material property		Loading	
Concrete Grade (MPa)	25	LL	2KN/m^2
Steel Grade (MPa)	Fe415		

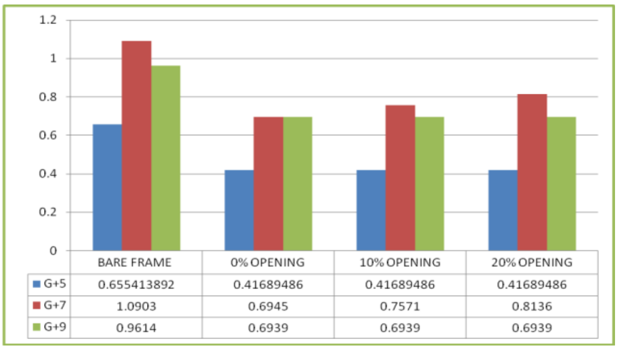
VI. MODAL ANALYSIS

The Modal analysis of the multi storey infilled wall frame buildings is carried out using ETABS software. The time period of all the buildings are obtained using dynamic analysis and are compared with that of empirical formula given in IS1893-2002. The same is shown in Figure 4 and 5.



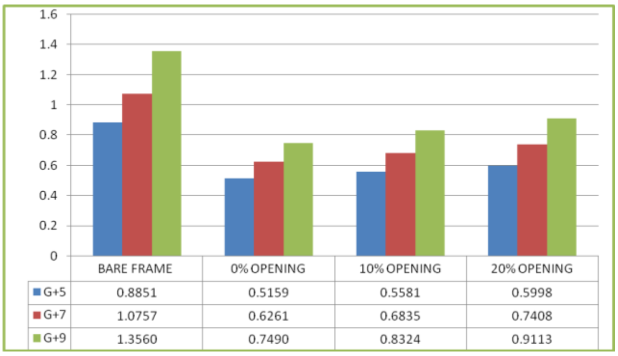
(a) Static Time Period in X Direction ***(b) Static Time Period in Y Direction***

Figure 4. Static time period (in Second) of different height building



	BARE FRAME	0% OPENING	10% OPENING	20% OPENING
G+5	0.655413892	0.41689486	0.41689486	0.41689486
G+7	1.0903	0.6945	0.7571	0.8136
G+9	0.9614	0.6939	0.6939	0.6939

(a) Dynamic Time Period in X Direction



	BARE FRAME	0% OPENING	10% OPENING	20% OPENING
G+5	0.8851	0.5159	0.5581	0.5998
G+7	1.0757	0.6261	0.6835	0.7408
G+9	1.3560	0.7490	0.8324	0.9113

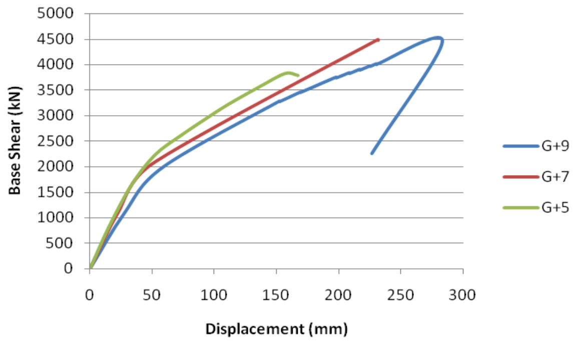
(b) Dynamic Time Period in Y Direction

Figure 5. Dynamic time period (in Second) of different height building

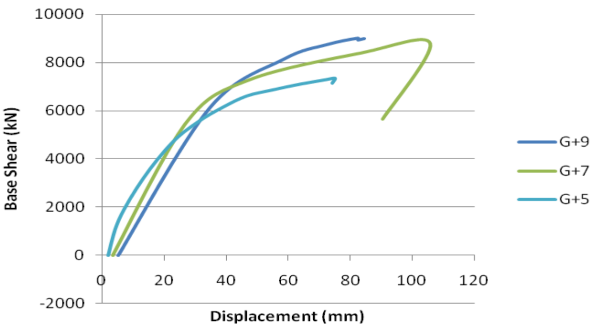
VII. STATIC NONLINEAR ANALYSIS

Pushover analysis is a static, nonlinear procedure to analysis any building where the building is loaded incrementally with a certain definite predefined pattern (i.e., inverted triangular or uniform). Local nonlinear effects are modelled and the structure is pushed until a collapse mechanism is developed in the same building. With increase in the magnitude of loads, weak links and failure modes of the building are observed. Important part for the nonlinear pushover analysis is the hinge properties definition and assignment for nonlinear behavior of structure. Nonlinear hinge is assign to beams, columns and struts atthe probable location of hinge formations in structural members. In case of beams governing forces are Shear force and Bending Moments, so default Moment (M3) hinges and Shear (V2) hinges are added at relative distance zero and one, while Moment (M3) hinges are also assigned at centre of beams . The columns are assigning with default Axial Moment Interaction (PMM) hinges at both top and bottom ends of column. Shear (V) hinges are also assigned to the column ends. The diagonal struts were provided with user defined Axial Hinges (P) property. Diagonal strut is such that it takes only axial compressive load under lateral loading

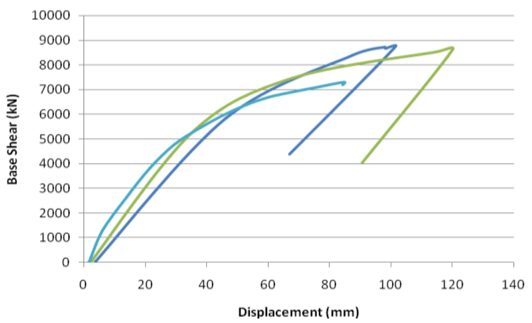
Pushover analysis is carried using ETABS and results obtained in form of Pushover curve is shown in Figure 6 for different infill percentage in X direction and Figure 7 represents pushover curve in y direction for different infill percentages .



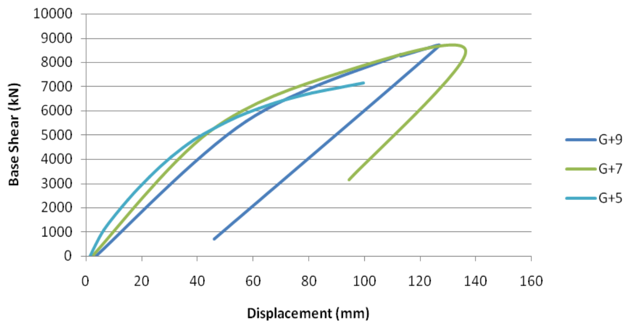
(a) Pushover curve for Bare Frame



(b) Pushover curve for 0% opening

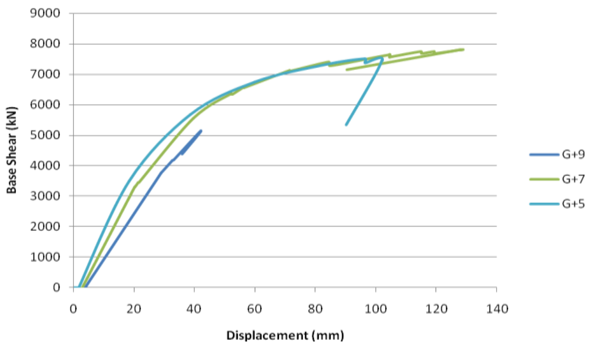


(c) Pushover curve for 10%opening

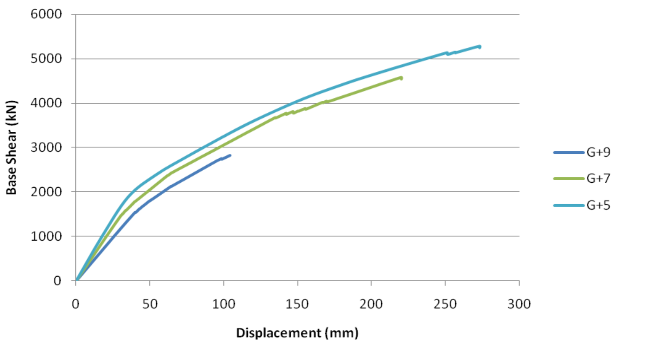


(d) Pushover curve for 20% opening

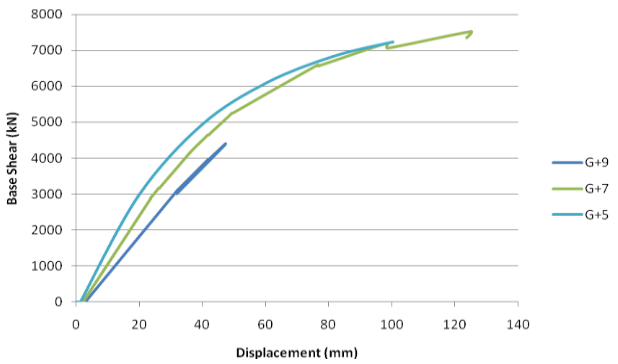
Figure 6. Pushover curve for different height building in X Direction



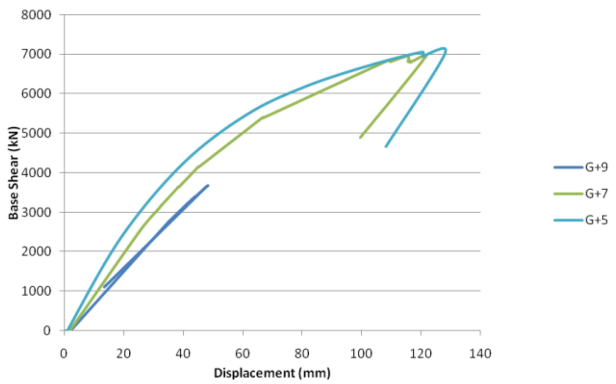
(a) Pushover curve for Bare Frame



(b) Pushover curve for 0% opening



(c) Pushover curve for 10%opening



(d) Pushover curve for 20% opening

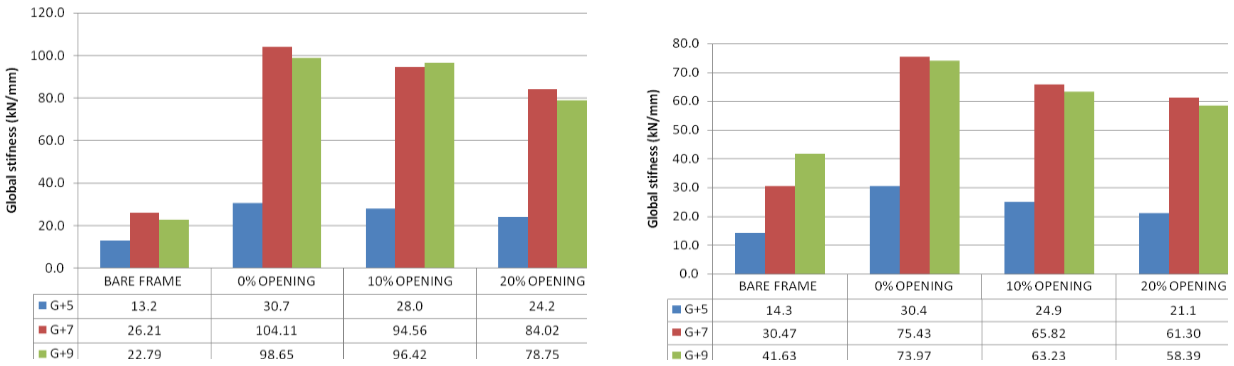
Figure 7. Pushover curve for different height building in Y Direction

From Pushover curve it is found that both of the maximum base shear and roof displacement capacity for without-infill case is higher than that of with-infill case. This is true for both X- and Y- direction push. Also, it is clear from these figures that building modeled without infill stiffness has more ductility compared to the building modeled with infill stiffness. Performance point is basically the intersection of capacity curve and demand curve of the building which are tabulated in Table 3.

Table 3. Performance Point for Different Building

	G+5 MODEL				G+7 MODEL				G+9 MODEEL			
	X -Direction		**Y - Direction**		**X -Direction**		**Y - Direction**		**X -Direction**		**Y - Direction**	
	Base Shear (kN)	Disp (mm)	Base Shear (kN)	Disp (mm)	Base Shear (kN)	Disp (mm)	Base Shear (kN)	Disp (mm)	Base Shear (kN)	Disp (mm)	Base Shear (kN)	Disp (mm)
Bare frame	1120.89	85.03	1161.75	81.40	1241.5	108.4	3089.3	101.40	2997.3	131.5	6779.5	162.84
0% opening	1886.91	61.55	1892.04	62.22	8287.4	79.60	4711.5	76.00	9005.3	81.75	5413	162.84
10% opening	1844.29	65.96	1720.00	69.08	7792.8	82.41	7038.9	93.32	8323.8	86.33	5412.9	163.85
20% opening	1715.93	70.87	1593.29	75.58	7401.3	88.09	6477.6	98.41	7323.8	93	5071.8	147.96

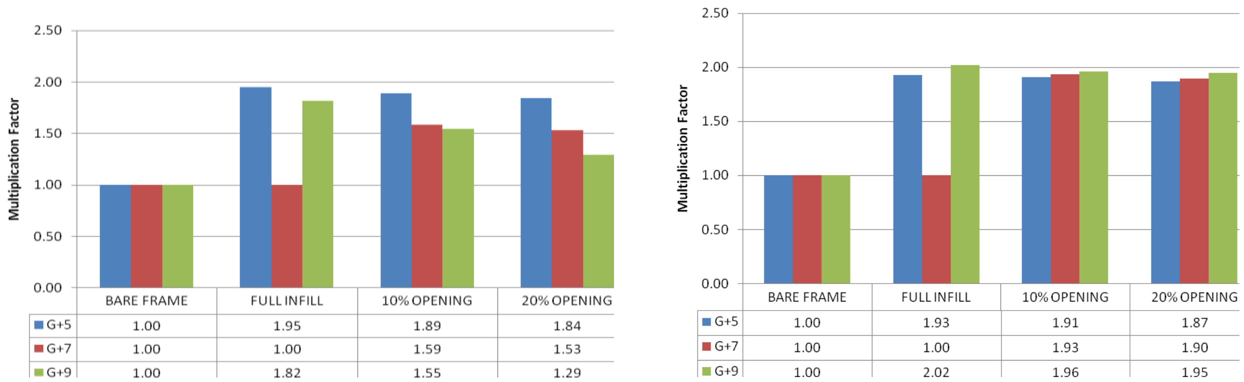
Global stiffness of building is defined as the ratio of base force to displacement at the performance point is found out by the nonlinear pushover analysis. Figure 8 represents Global stiffness of buildings. As the opening percentage increases in the infill panels, the base shear reduces and lower base shear obtained in bare frame. Global stiffness indicate that's bare frame has lower stiffness than infill



(a) Global stiffness in X-Direction ***(b) Global stiffness in Y-Direction***

Figure 8. Global Stiffness for different height building

Multiplication factor is defined as ratio of parametric results of bare frame to other models by static nonlinear analysis. The Multiplication factors obtained from pushover analysis are shown in Figure 9.



(a) Base shear Multiplication in x-Direction ***(b) Base shear Multiplication in Y-Direction***

Figure 9. Global Stiffness for different height building

VIII. CONCLUSIONS

From the above study following conclusions can be made

- It is concluded that the Dynamic analysis gives higher time period as compare to static analysis. Higher time period observed in bare frame cases and as the opening percentage increases time period increases that is due to reduction in stiffness.
- It is found that both of the maximum base shear and roof displacement capacity for without-infill case is higher than that of with-infill case. This is true for both X- and Y- direction push.
- The building modeled without infill stiffness has more ductility compared to the building modeled with infill stiffness.
- The global stiffness is reducing with increase in percentage opening in infill.
- The presence of infill wall can affect the seismic behavior of frame structure to large extent, and the infill wall increases the strength and stiffness of the structure.
- Base shear Multiplication factor obtained from pushover analysis are lesser than the prescribed in IS: 1893. So, for medium rise building's the multiplication factor given in code is on safer side.

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