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Performance Evaluation of RC Frame with Brick Infill under Dynamic Loading

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Abstract- Brick walls have significant in plane stiffness contributing to the RC frame against lateral load. The structural effect of brick infill is generally not considered in the design of structural components RC framed buildings. This study focuses the effect of brick masonry infill wall on a 3D reinforced concrete moment resisting frame conventionally designed as a bare frame, using software package ETABS. This paper aimed at findings out the seismic response of symmetric RC frame with and without masonry infill having different infill configurations under dynamic loading. Equivalent diagonal strut method is used to find out the width of strut. Parameters considered in the context of model study are infill wall thickness and elastic modulus of infill. Seismic performance is assessed by performing linear direct integration time history analysis as per IS 1893-2002. Results shows with an increase in number of struts, variation is observed in the structural responses such as time period, maximum storey displacement, beam moment and column axial force.

Index Terms-Equivalent strut width, time history analysis, masonry infill.

1. GENERAL

In developing countries like India, RC moment resisting frame buildings are the most preferred type due to rapid progressive construction and relatively low cost. Good aesthetic appearance and better functional behavior under earthquake loading makes it the ultimate choice. It has always been a human wish to create taller and taller structures. There is an increasing demand for high-rise buildings in developing metro cities. Column and girder framing of reinforced concrete, or sometimes steel, is in-filled by panel of brickwork, block work, cast in place or pre-cast concrete. Masonry infill panels are used as exterior masonry walls and/or interior partitions, between the frame members and they are classified as non-structural elements. Furthermore, brick masonry has good characteristics like acoustic insulation, thermal and fire resistance. As the part of the building, masonry infill panels play a very important role on the seismic performance of the building RC structure.

Polyakov (1967) conducted one of the first analytical study based on elastic theory. Multiple strut models are proposed by Schmidt (1969). The main advantage of these models is the ability to represent the actions in the frame more accurately. Stafford Smith (1967) pointed out that contact length can be used as a reference parameter to evaluate stiffness of the in-filled frame. Holmes (1991) proposed that equivalent diagonal strut should have a width same as one third of length of infill. This work was followed by many other researchers. Different types of analytical models were developed and studied by

Kulkarni and Mulghand (2001). Samolia (2012) carried out linear analysis of a masonry infill concrete frame with a single story single bay by modeling masonry infills using five different techniques. The results were compared so as to arrive at a rational modeling scheme for masonry infilled concrete frame.

2. EQUIVALENT DIAGONAL STRUT METHOD

For modeling infill, basically macro modeling and micro modeling approaches are used. Macro-models are the ones in which the masonry infill is replaced by an equivalent diagonal strut system as shown in fig. 1. Many researchers used the equivalent diagonal strut concept to model infill frames. The elementary parameter which affects the strength and stiffness of these struts is their equivalent width which depends on the relative infill-frame stiffness.

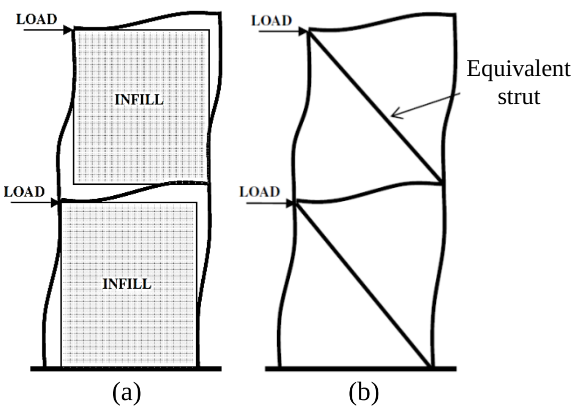


Fig. 1. (a) Laterally loaded infilled frame
(b) Equivalent diagonal strut frame

3. DETERMINATION OF EQUIVALENT STRUT WIDTH

Equivalent diagonal strut method is applicable to existing masonry infill and new panel added to an existing frame. Strut has the same properties as the infill panel it represents. Various expressions proposed by researchers/codes for equivalent strut width are given in the table 1.Based on validation, FEMA-356, Moghaddam and Dowlingand Euro code expressions are selected for single strut, double strut and three strut models respectively for the study.

Table 1. Expressions for equivalent strut width

Researchers/Code	Equivalent Strut Width (W)
Holmes	$W = d_z/3$
Mainstone	$W = 0.175(\lambda_h)^{0.4}$ $\lambda_h = H[E_m t \sin 2\theta / 4E_c I_c H_m)]$
Hendry	$W = 0.5[\alpha_h + \alpha_L]^{½}$ $\alpha_h = [E_c I_c H_m / 2E_m \sin 2\theta]^{¼}$ $\alpha_L = [E_b I_b L / 2E_m \sin 2\theta]^{¼}$
Liaw & Kwan	$W = [0.95 H_m Cos\ \theta / \sqrt{\lambda_h}]$
Pauley&Priestly	$W = 0.25\ d_z$
Moghadom &Dowling (1988)	$W = d_z/6$
Smith & Carter	$W = \pi/2\ \lambda_h$
Eurocode 8	$W = 0.15\ d_z$
FEMA 356	$W = 0.175[\lambda_h\ H]^{-0.4} H_m$
Durrani and Luo (1994)	$W = d_z\ [\ \gamma \sin 2\theta]\ ¼$ $\gamma = [0.32 \sqrt{} \sin 2\theta (H^4 E_i t / m E_c I_c b)^{-0.1}]$ $m = 6[1+[6\alpha \tan(E_b I_b H / E_c I_c L)/\pi]]$
Cavaleria &Papia (2003)	$W = d[c/z[1/(\lambda^*)^{\beta}]]$ $\lambda^* = (E_d\ th' / E_f\ A_c)\ [h'^2/l'^2 + A_c l'/4A_b h']$ $c = 0.249 - 0.0116\upsilon + 0.567\upsilon^2$ $\beta = 0.146 + 0.0073\upsilon + 0.126\upsilon^2$
P100/1-2006	$W = d_z\ /10$
MSJC (2007)	$W = 0.3/\ \lambda h \cos\theta$

Where,
d_z= Diagonal length
H= Height of frame
H_m= Height of masonry infill
E_m= Elastic modulus of infill
α_h= Ratio of column contact length to height ofcolumn.
α_L = Ratio of beam contact length to span of thebeam.

4. DESCRIPTION OF THE MODELS

The theoretical approach given by equivalent diagonal strut model is applied to buildings having 5, 10, 15, 20 stories. All the buildings have a symmetrical layout with typical story height of 3.2m and basement height 1.5m. Building plan chosen for the study is shown in fig. 2. The bay length along both directions is taken as 5m. Column sizes are 0.4m x 0.4m, 0.46m x 0.46m, 0.51m x 0.51m, 0.53m x 0.53m for 5, 10, 15 and 20 storied buildings respectively. Beams are 0.3m x 0.5m in size. Thickness of floor slab, roof slab and infill masonry wall are 150mm, 120mm and 200mm respectively for all the models. Young's modulus for infill panels are taken as 2300 N/mm^2. Strut dimensions are determined according to the methods described in table 1. Figure 3 shows elevation of 10 storeyed building frame modeled as bare frame (BF), bare frame with single strut (BFSS), bare frame with double strut(BFDS) and bare frame with triple strut (BFTS).

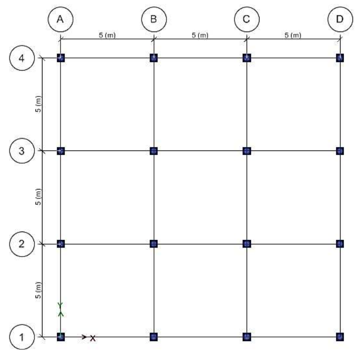


Fig. 2. Building plan modeled in ETABS

5. ANALYSIS METHOD

This study is mainly concerned with seismic performance; therefore vertical load analysis is not carried out. The models are subjected to earthquake load only. There are different ways to carry out the earthquake load analysis of a design model. Time history analysis or response spectrum analysis can be performed. Time-history analysis is a step-by-step analysis of the dynamic response of a structure to a specified loading that may vary with time. Figure 4shows the ground motion data for three earthquakes - Bhuj, Northridge and Kobe that are chosen for linear direct integration time history analysis.

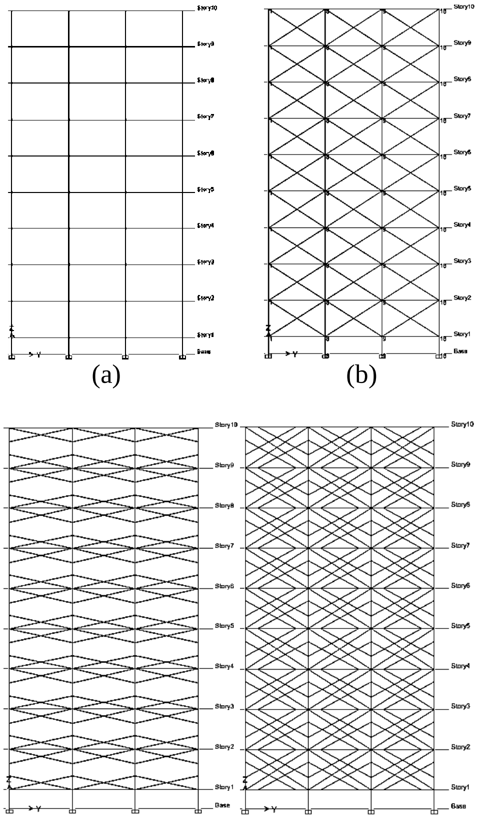


Fig. 3. Elevation of building frame (a) bare frame (b) bare frame with single strut (c) bare frame with double strut (d) bare frame with triple strut

reality as the infill walls would definitely interact with the enclosing frame especially under seismic forces.

6.1. *Effect of strut models*

A comparative study, based on the models proposed was carried out to assess a suitable model for masonry infills in RC frames. The effect of infill on the member forces in beams and columns were studied. This is one of the most important parameter in the design of any building structure. Its observed that with an increase in number of struts, variation is observed in the structural responses such as time period, maximum storey displacement, maximum beam moment, and maximum column axial force.

6.1.1. *Time period*

Modal analyses were carried out to obtain the time period for bare frame and infilled frame models. The sources of mass were from the dead load of infill walls and the frame elements. The dead load from the infill walls were applied as the uniformly distributed load along the beams. The equivalent diagonal strut's mass is not included but its stiffness was included in the analysis since the models were studied under the in-plane loads. Variation of fundamental period with no. of storey is shown in fig. 6. Fig. 7 shows variation of time period with respect to mode for 10 storied building. Similar trend was also observed for 5, 15 and 20 storeyed models. It is observed that BFSS and BFTS model shows similar trend, while BFDS model is different from the other two. The time period

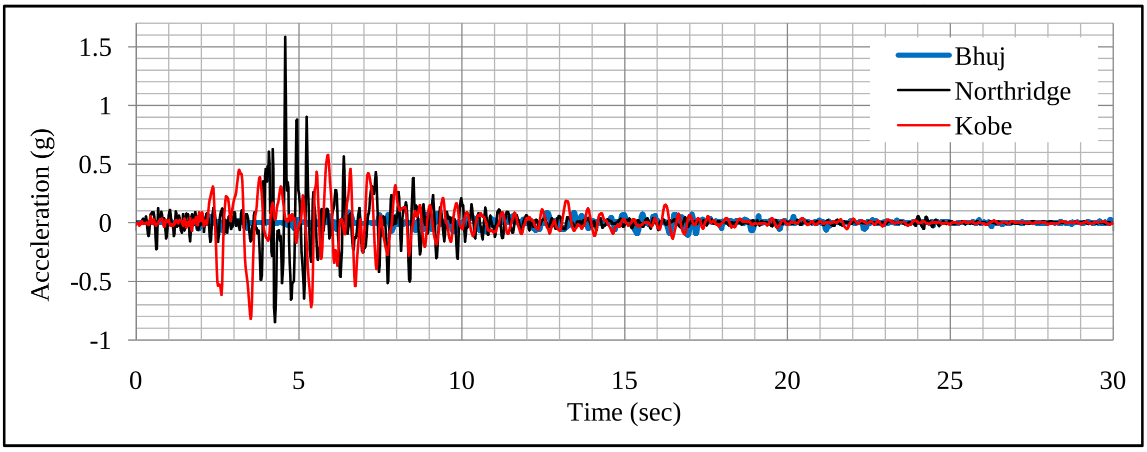


Fig. 4. Ground motion data of Bhuj, Northridge and Kobe earthquake

6. RESULTS AND DISCUSSION

Study on effect of masonry infill walls on behaviour of reinforce concrete frame buildings under seismic force was studied using different equivalent strut models. The infill walls were usually considered as non-structural elements and were not included in the analysis and design. However, the fact is far from

obtained using empirical equation in IS 1893:2002 is higher compared to BFSS and BFTS models

6.1.2. *Maximum storey displacement*

Maximum storey displacement for different strut models is shown in figure 7. The graph shows that under all earthquake BFSS and BFTS with5, 10 stories have less maximum story displacement compared to BF and BFDS models. Here it is observed that both BFSS and BFTS show reasonable value of storey displacements.

6.1.3. *Maximum column axial force*

Column axial forces are observed to be maximum in bottom stories. In fig. 8 it shows that that is a drastic increase in maximum column axial force due to the presence of infill under Kobe and Northridge earthquakes. It is also observed that for all the models

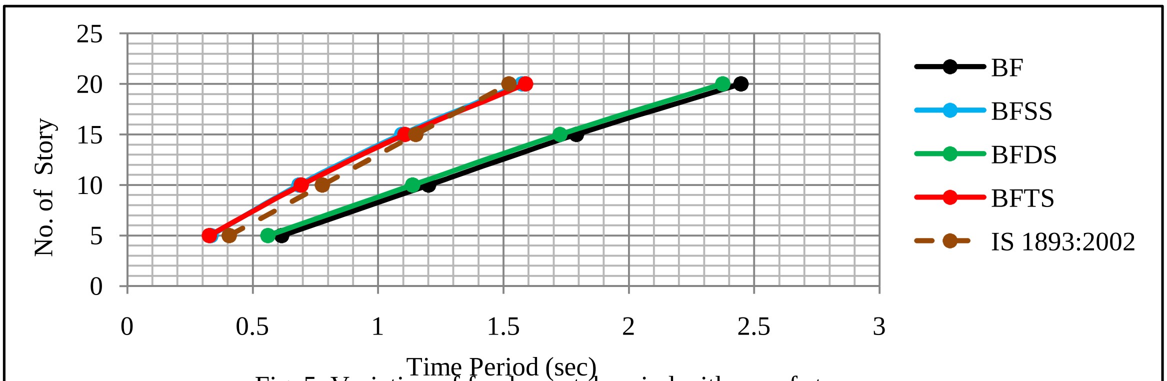


Fig. 5. Variation of fundamental period with no. of story

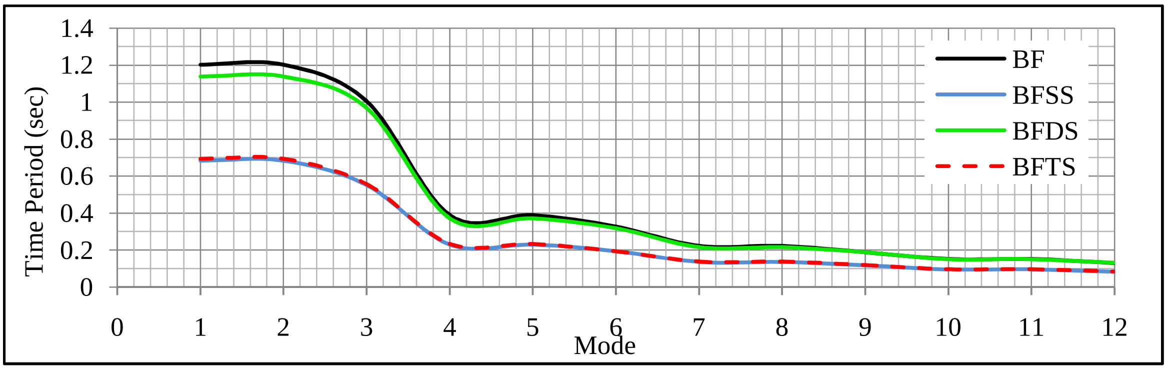


Fig. 6.Variation of time period with mode

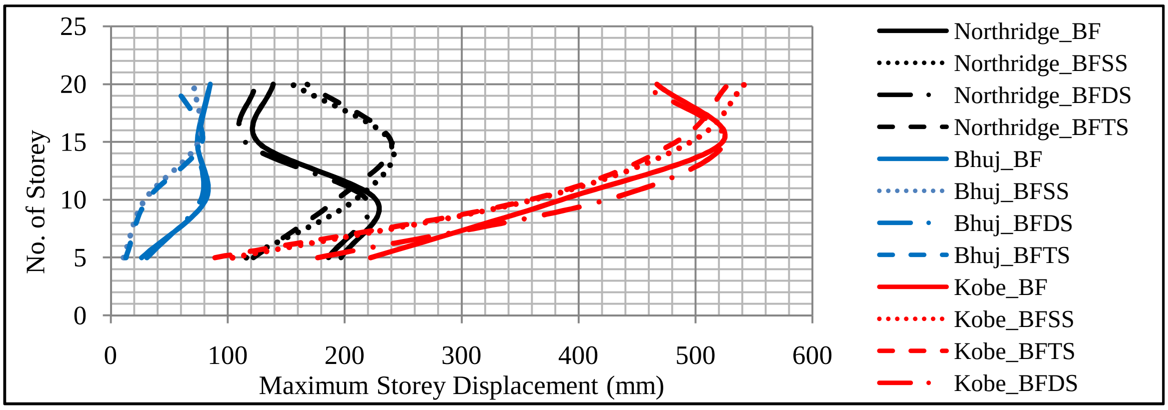
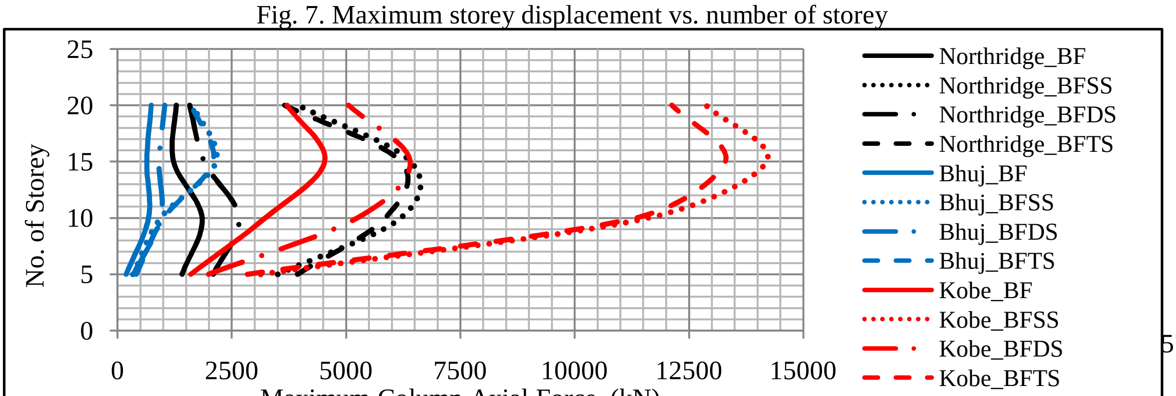


Fig. 7. Maximum storey displacement vs. number of storey



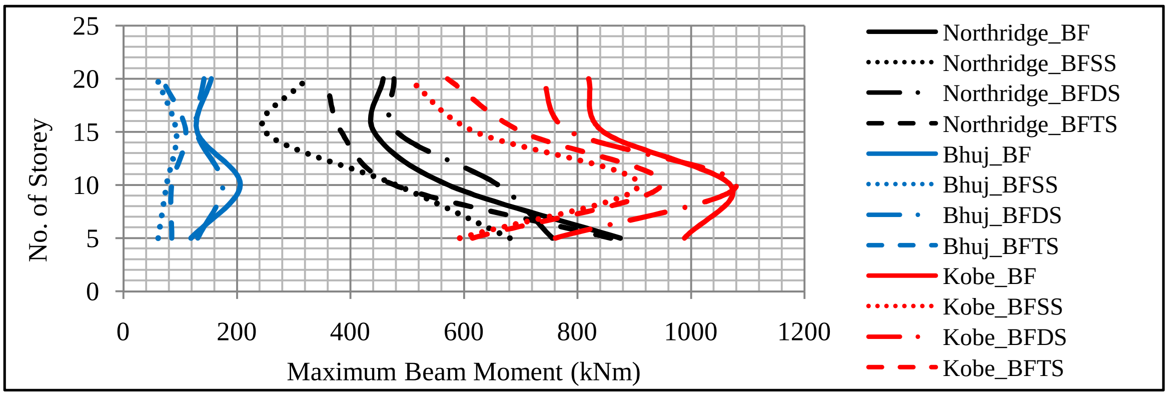


Fig. 9. Maximum beam moment vs. number of storey

due to presence of infill, 15 storied building has maximum column axial force. This increase in axial load will result in the failure of columns. This may also result in yielding of columns prior to yielding of beams. The change in behaviour was due to change in load transfer mechanism of the building models from frame action to truss action, due to presence of masonry infill walls.

6.1.3. *Maximum beam moment*

Variation of maximum beam moment due to presence of infill is shown in fig. 9. It is observed the maximum beam moment reduces due to presence of infill walls. It is seen that beam moment is maximum for 10 storied buildings for Bhuj and Kobe earthquakes. For Northridge earthquake it is maximum for 5 storied building.

6.2. *Effect of infill thickness*

To study the effect of infill wall thickness on building models, 100mm, 200mm and 300mm thickness were adopted. Structural response is examined in terms of story displacement and story shear. When the thickness of the infill wall was increased, the stiffness and strength of the building models increased.

6.2.2. *Storey Displacement*

Plot of story displacement with height of building is shown in fig. 10.It is observed that for all models under all the three earthquakes, storey displacement decreases with increase in thickness. As the thickness increases buildings becomes stiffer and attract more forces there by reducing storey displacement.

6.2.2. *Story Shear*

Story shear experienced for three different infill thickness are sketched in fig. 11. Results show that storey shear increases with increase in infill wall thickness. For all the models, shear is found to be maximum at bottom storey. Base shear is found to be maximum for building with 300mm infill thickness under Kobe earthquake.

6.3. *Effect of elastic modulus of infill*

To study the effect of elastic modulus of infill wall, three types of infills are considered namely – weak infill, intermediate infill and strong infill, which has a Young's modulus of 2300 MPa, 3800 MPa and 4200 MPa respectively. The values of Young's modulus are taken from previous literature (Hemant B. K., *et al*, 2007). The effect of infill on inter-story drift and column axial load were studied.

6.3.1 *Inter-story Drift*

The drift value has a particular importance of serviceability requirement. In general, the effect of infill panel is to reduce the seismic demand of a building structure both in terms of lateral displacement as well as inter story drift. As expected, the infill has a better response during earthquake excitation. It is observed that is a considerable reduction in inter-storey due to presence of strong infill walls. In fig. 12, it shows that inter-storey drift is maximum for lower stories for all the models.

6.3.2.*Column axial load*

Figure 13 represents variation of column axial load with respect to building height. It is observed that there is not much effect on column axial load, when building models are subjected to Bhuj and Kobe earthquakes. But for Northridge earthquake, there is a drastic increase in column axial load due to the presence of strong infill.

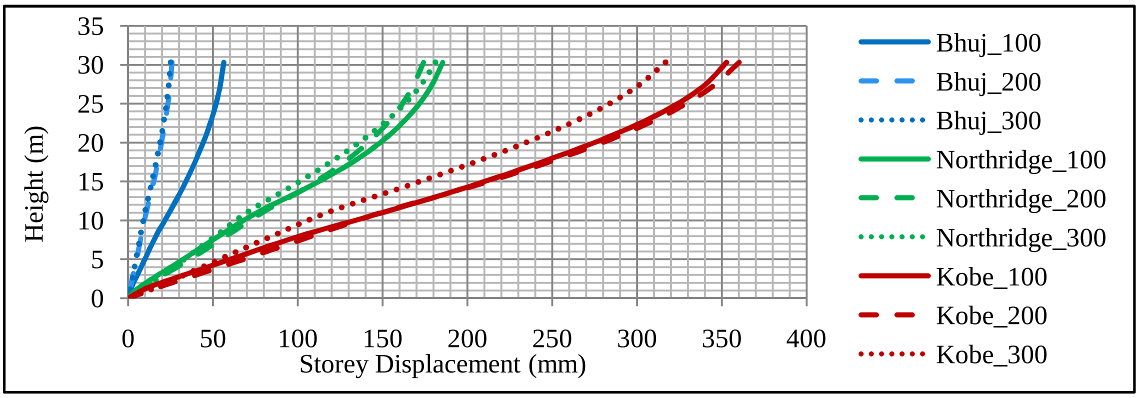


Fig. 10. Variation of storey displacement with building height

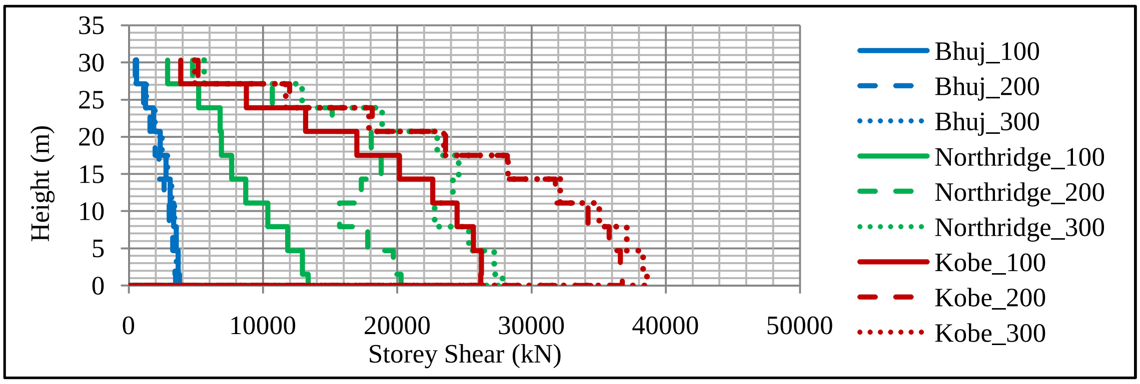


Fig. 11. Variation of storey shear with building height

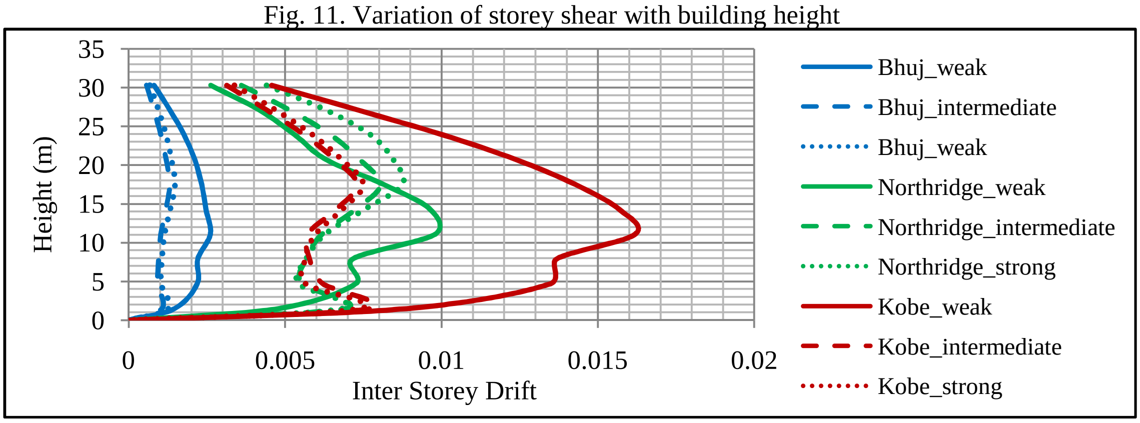
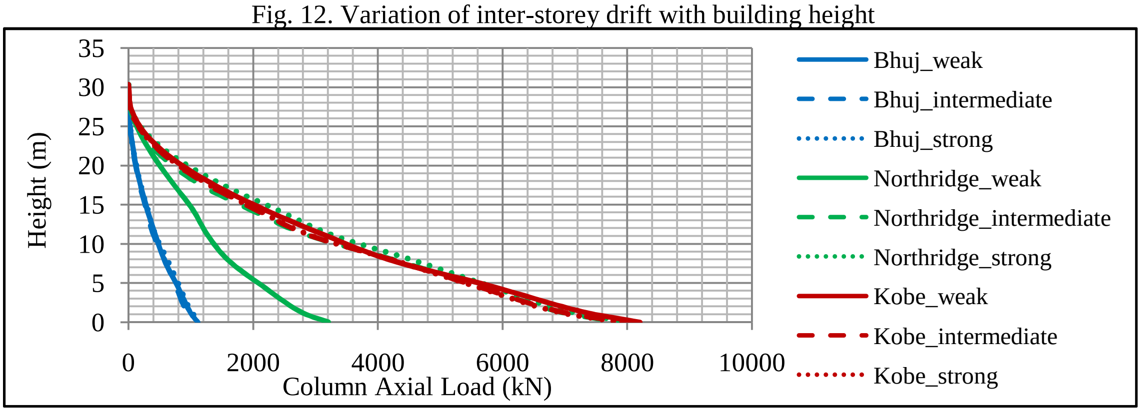


Fig. 12. Variation of inter-storey drift with building height



7. SUMMARY AND CONCLUSION

A study on effect of masonry infill walls on behaviour of reinforced concrete frame buildings under seismic force was studied using different infill models. The infill walls were usually considered as non-structural elements and were not included in the analysis and design. However, the fact is far from reality as the infill walls would definitely interact with the enclosing frame especially under seismic forces. The effect of masonry infills on seismic behaviour of RC frame buildings with different heights was studied by linear time history analysis. The infill walls were modeled as compressive equivalent diagonal strut using single, double and triple strut model. The parametric study on thickness of infill, fundamental period and elastic modulus of infill walls were also done.

The results obtained shows that calculation of earthquake forces by treating RC frames as bare frames without regards to masonry infill leads to under estimation of base shear and column axial force. The results from the different models on fundamental periods shows that masonry infill walls had significant effect (decreases the time period) on the dynamic characteristics like fundamental period of the buildings. The fundamental periods were dependent on the area of infill walls. The results of analysis demonstrated that masonry infill walls highly increased the stiffness and strength of a structure.

The other parametric study that was done was infill wall thickness. The results indicated that the structural responses were affected with infill thickness. The increased in infill thickness decreased the fundamental period and roof displacement. With the increase in thickness, story shear and column axial load increases.

Young's modulus is found to be very significant in seismic analysis. Single strut model is better to be used in analysis regarding the general behavior of infill frames. Three strut model is the appropriate approach for determining the local effects of frame infill interaction. Strong infill panel gives better seismic performance i.e. strength and stiffness is higher compared to weak and intermediate infills.

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