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Modelling and Analysis of Infilled Frame Structures Under Seismic Loads

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Abstract: In-filled frame structures are commonly used in buildings, even in those located in seismically active regions. Precent codes unfortunately, do not have adequate guidance for treating the modelling, analysis and design of in-filled frame structures. This paper addresses this need and first develops an appropriate technique for modelling the infill-frame interface and then uses it to study the seismic response of in-filled frame structures. Finite element time history analyses under different seismic records have been carried out and the influence of infill strength, openings and soft-storey phenomenon are investigated. Results in terms of tip deflection, fundamental period, inter-storey drift ratio and stresses are presented and they will be useful in the seismic design of in-filled frame structures.

INTRODUCTION

Treating infill as a non-structural component is a common practice in the seismic analysis and design of low rise buildings in developing countries such as Bhutan. The contribution of the infill to the lateral strength and stiffness of a structure is disregarded in the current seismic codes used in these countries. These codes do not have adequate guidance due to insufficient research information on the complex seismic response of infill frame structures and due to the wide variation of opening sizes and material properties of the infill. Though, some seismic codes imply the presence of infill, it is normally considered through empirical equations. Despite large amount of research performed in this field both experimentally and numerically in the last few decades, present seismic codes such as (IS1893 2002) [1] provide limited guidance which may not be adequate for the varying properties of infill. Kaushik (2006) [2] made comparative study among the different seismic codes and found inconsistency in the consideration of infill and reported that most codes do not consider infill due to its brittle nature of failure and lack of adequate information.

The validity of different macro-models consisting of 4-node shear panels, 4-node plane stress element and the higher order 8-node plane stress element were studied (Doudoumis and Mitsopoulou 1995) [3] and reported inaccuracy in results of macro models. Singh, Paul *et al.* (1998) [4] had developed a method to predict the formation of plastic hinges and cracks in the infill panels under static and dynamic loads by using 3-noded frame element, 8-noded isoparametric element and 6 noded interface element for frame member, infill panel and the interface element respectively. The study has shown good agreement with the experimental results, especially in terms of failure load and the strut width. Doudoumis (2007) [5] studied the importance of contact condition between the infill and frame members on a single storey Finite element model. It was reported that the interface condition, friction coefficient, size of the mesh, relative stiffness of beam to column, relative size of infill wall have significant influence on the response of infilled frame, while the effect of orthotropy of infill material was insignificant. When the mesh density was made finer the stress pattern within the infill also improved, with maximum values of stresses at the compressive corners. The existence of friction coefficient at the interface was reported to increase the lateral stiffness of the system. However, friction coefficient is dependent on the quality of material and the workmanship CEB 1996 [6] which is difficult to define accurately, hence codes do not provide any guidance.

Moghaddam and Dowling (1987) [7] reported the high initial stiffness and low deformation capacity of infill. Merabi (1994) [8] reported significant improvement of lateral stiffness, strength and energy dissipation capability of infilled structures from the analytical and experimental studies. On account of high initial stiffness, the change in structural behaviour from frame action to truss action was studied (Murty and Jain 2000) [9]. Consequently, structural member forces in the beams and columns of an infilled structure are reduced.

Fardis (1996) [10] investigated the seismic response of an infilled frame which had weak frames with strong infill material and reported the strong infill is responsible for earthquake resistance of weak reinforced concrete frames. Negro and Colombo (1997) [11] investigated the effects of irregularity induced by non-structural masonry wall on a full scale four storey RC structure under pseudo-dynamic loads and observed changes in the behaviour of frame due to infill. The irregular distribution of infill has been reported to impose unacceptably high ductility demand on the frame buildings. Al-Chaar (1998) [12] performed studies on the behaviour of infilled RC frames. The frames were reported to have shown the ductile behaviour but the extent of ductility is not specified. However, the author concluded that the infill wall improves the strength, stiffness and energy absorption capacity of the plane structures which will be useful for seismic structures. Dolsek and Fajfar (2008) [13] carried out push-over analysis on a four storey structure and reported total change in distribution of damages within the structure. How-

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ever, the presence of infill did not cause the shear failure of columns, which is contrary to literature (Pauley & Priestley 1992) [14]. Amanat (2006) [15] reported that the amount of infill has significant influence on the fundamental period of the structure; however recommended pursuing further study in this field. Kose MM (2008) [16] conducted a study on the parameters affecting the natural period of the infilled frames. The Equivalent diagonal strut was used as the infill panels and opening was considered by varying the width of struts proposed in separate study (Asteris 2003) [17]. The height of the structure and the amount of shear wall were reported to be the main influencing parameters. A soft-storey issues associated with infilled structures was studied (Santhi, Knight *et al*. 2005) [18] on a single bay three storey RC frame which had no opening in infill panels. The natural frequency of the soft structure was decreased by 30% while the shear demand was increased by 2.5 times of the bare frame. The bare frame structures behaved in flexure mode while the soft structure behaved in shear mode. However, the author has not considered the opening as the presence of it may reduce shear force.

Most of the past research has considered simple single storey systems or diagonal strut models for the infill, ignoring openings which are normally present. The possibility of the infill having a wide range of properties has also been treated. It is thus evident that there is inadequate research information on the seismic response of realistic RC frame structures with infill and consequently inadequate design guidance. This paper treats this research gap using finite element (FE) time history analyses.

INTERFACE ELEMENT

At present there is no (code) guidance on modelling the interface between the frame and infill. An appropriate interface or gap element is developed in this paper. The study on the effective stiffness of the gap element was carried out on a single storey single bay infilled frame as shown in Fig. (**1**). The size of the column section was 375 x 375 mm square and the beam section was 500 mm deep and 420 mm wide and the infill was 200 mm thick. The interface between the frame element and the infill wall was simulated using the gap elements.

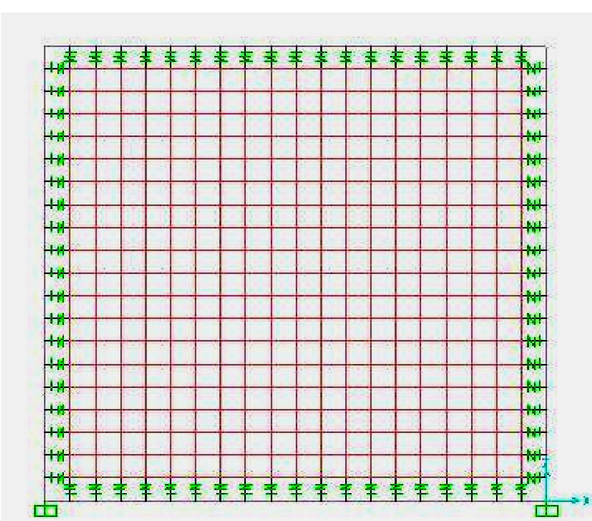


Fig. (1). Frame, infill and the gap elements.

The stiffness of gap element was developed by a trial and error procedure so that the present results compared well previous research results (Doudoumis & Mitsopoulou 1995) and thus validated the computer model as shown in Fig. (**2**). The trends in the variation of roof displacement is similar under different interface conditions. Since the friction coefficient between the frame and infill wall is uncertain, the current model is simulated to obtain the stiffness equivalent to the average friction coefficient of 0.5 ($u = 0.5$). The advantage of using gap element over contact element is its simplicity in modeling and ability to transfer the forces directly to the infill wall from the exterior frame members. However, separation and sliding cannot be considered using the gap element, but these are not important in for the type of analysis treated herein.

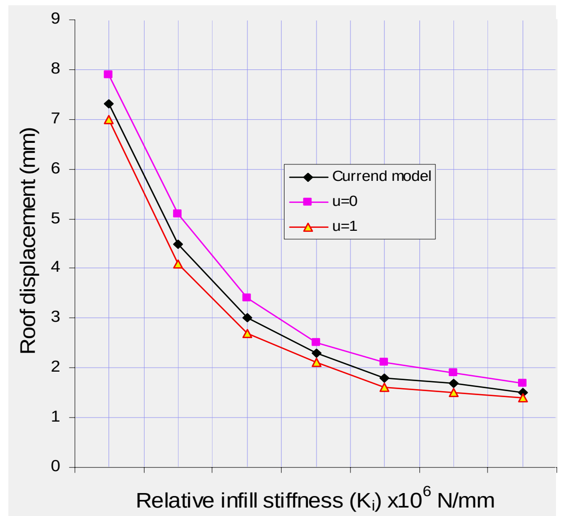


Fig. (2). Roof displacement Vs relative stiffness of an infill wall.

By comparing the results from the present model with those from the reference, an equation for an effective gap stiffness was developed as;

$$K_g = 0.0378\, K_i + 347$$

$$K_i = E_i t$$

Where; K_g = stiffness of gap element in N/mm; K_i = stiffness of the infill panel; E_i = Young's modulus of elasticity of infill material and t = thickness of the infill panel. Fig. (**3**) shows the variation of the Gap stiffness with infill strength and the line of best fit, obtained from the validation analysis. The stiffness property of the gap element is used for modelling the interface element between the frame and the wall in the other structures treated in this paper for the parametric studies.

The height of structural models was varied from three to ten storeys. All of them were designed with and without seismic codes and their member properties are shown in Table **1** & **2**. The Young's modulus of elasticity and Poisson's ratio of concrete was assumed to be 24000 MPa and 0.2. The models which represent non seismic structures were designed to resist gravity loads using the existing code [19] while the aseismic models were designed to meet the requirements of present seismic code [1].

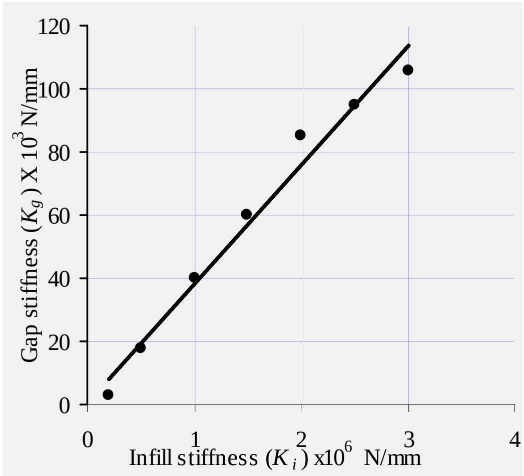


Fig. (3). Variation of gap stiffness with infill strength.

The gap element was used to connect the frame member and the infill wall. The structural member sizes were kept uniform throughout the height of the structure to make structure simple. Uniformly distributed dead and live loads of 21 KN/m and 10KN/m were applied to the beams (assuming that there is 5m width of tributary slab). The sources of mass during dynamic analyses were from the structural elements, viz, columns, beams and the infill. Time history analyses were carried out under three different earthquakes, all scaled initially to a constant peak ground acceleration (PGA) of 0.2g. Though there are two different materials such as concrete and infill, it was assumed to follow the classical damping matrix with a coefficient of 0.05% for both mass and the stiffness.

Table 1. Member Sizes for Models without Seismic Design

Models	Column Size (mm)	Beam Size (mm)
Three storey	300 x 300	300 x 250
Five storey	350x350	300 x 250
Seven storey	400x400	400 x 300
Ten storey	450x450	400 x 300

Table 2. Member Sizes for Models with Seismic Design

Models	Column Size (mm)	Beam Size (mm)
Three storey	350x 350	300x250
Five storey	400x400	300x250
Seven storey	450x450	400x300
Ten storey	500x5050	400x300

RESULTS

Effect of Infill

The influence of the Young's modulus of infill martial was studied on a ten storey model designed without any seismic provisions. The damping was assumed to be 5%. Since there is no appropriate guidance on the infill material, it is randomly selected depending on the availability and cost of the material. Thus, the use of solid concrete blocks, burnt clay bricks, stone and adobe blocks were common in the past. Consequently, some of the buildings in Bhutan have suffered from cracks in the infill walls during moderate seismic action, while the others survived. Thus, the effect of infill material was studied under a credible earthquake of 0.2g which gave the minimum strength requirement of the infill material.

The effect of E_i is significant on the fundamental period, roof displacement and inter-storey drift ratios as shown in Figs. (**4-6**). All these responses decrease as the E_i increase, indicating that the Young's modulus of material, which is empirically related to material strength, increases the stiffness of the model, as expected. However, the increase in fundamental period and roof displacement is significant only in the lower range of E_i(< 2500 MPa).

On the average, the fundamental period was found to decrease by an average of 6.7% for every 2500 MPa increase in E_i. *Su*ch variation in structural response cannot be captured in general engineering practices and thus it is important to include it in the standards.

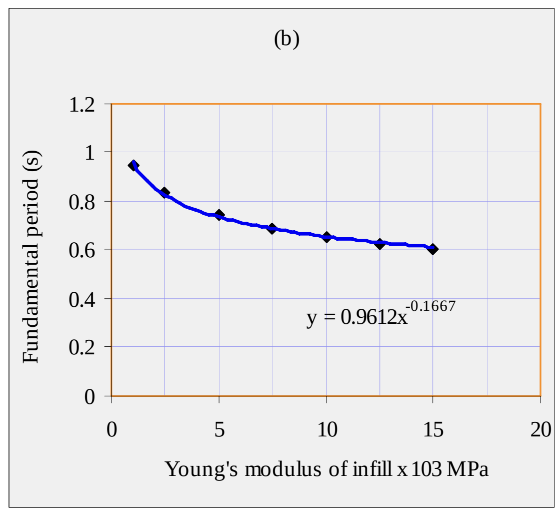


Fig. (4). Variation of fundamental period with E_i.

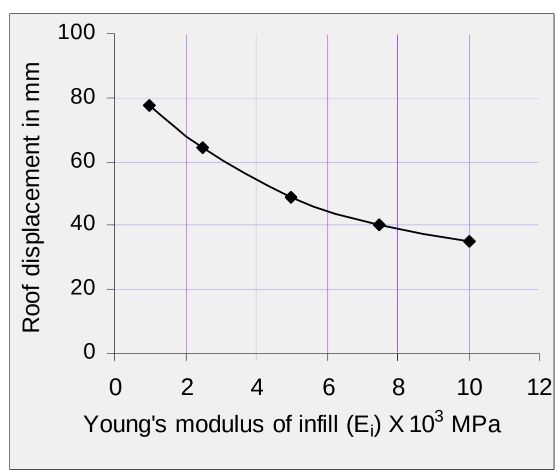


Fig. (5). Variation of roof displacement with E_i.

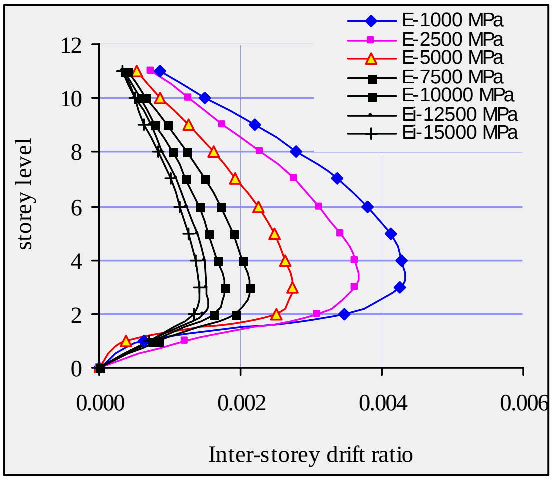


Fig. (6). Variation of inter-storey drift ratios with E_i.

The stresses, in the infill wall, however, were found to increase with the increase in Young's modulus of elasticity due to the increase in stiffness of the system, attracting more forces to the infill. The increase in stresses is very small after crossing the E_i value of 7500 MPa as shown in Fig. (**7**).

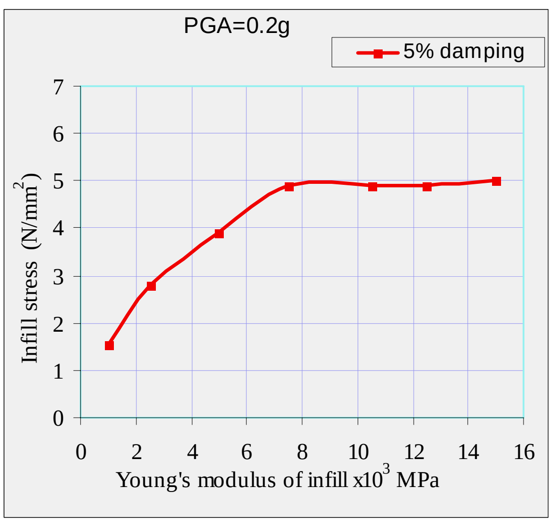


Fig. (7). Variation of infill stresses with E_i.

This could be the upper limit of the Young's modulus of infill material which should be used for buildings under serviceable earthquake. The lower limit of E_i value under the same earthquake was found to be 2000 MPa for a ten storey structure as below this value the compressive strength of material exceeded its limit.

Effect of Opening Size

While the consideration of the fully infilled frame is not realistic for real structures, ignoring the openings during modelling and analysis of the infilled frame construction would not give true results. The Equivalent diagonal strut method is quite vague as openings are assumed to be present on either the upper or lower side of the strut, when in reality most of the openings are present at the mid level of the floor height, typical of buildings in Bhutan. The infill wall enhances the lateral stiffness of the framed structures, however, the presence of openings within the infill wall would reduce the lateral stiffness. Since the opening is a common feature of the building, consideration of the opening should be given and its effect on the seismic resistance of the model is important.

Fig. (**8**) shows the variation of the fundamental period with the percentage opening. The fundamental period increases as the opening size increases, as expected, due to reduction in stiffness of the model. Such variation of periods cannot be considered using the Code values. The fundamental period of the fully infilled model was 54.87% higher than that of the bare frame model. There is no clear relationship between the opening size and the fundamental period, but the opening size does have an influence on the fundamental period of the structure.

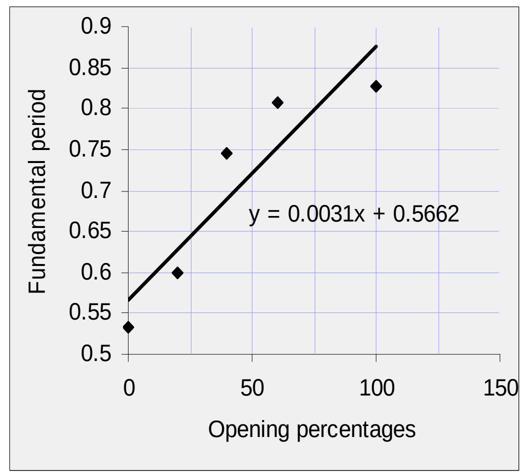


Fig. (8). Variation of fundamental period with opening size.

The roof displacement, inter-storey drift ratios and the infill stresses increase with the increase in opening size as the frame becomes more flexible. The lateral stiffness decreases by an average value of 38.98% for every 20% increase in opening size and there is a corresponding decrease in the inter-storey drift ratios (Fig. **9**) and the roof displacements.

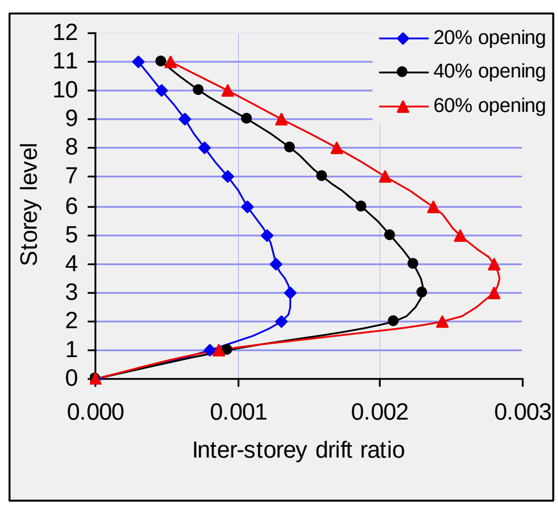
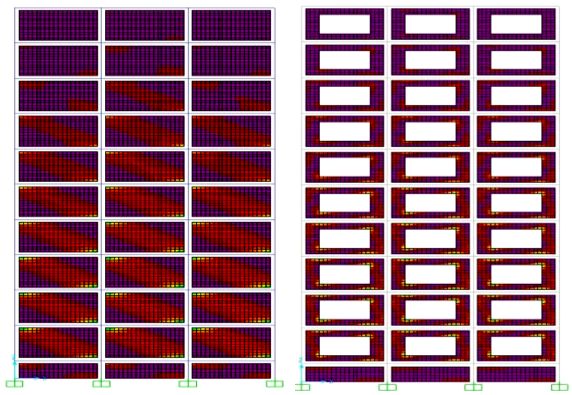


Fig. (9). Variation of inter-storey drift ratios with opening percentage.

The maximum infill stress which was found to increase by 23.57% and its variation is given in Table **3**. The maximum stresses were observed at the corners of the openings unlike in fully in-filled model where maximum stresses are observed at the compressive ends, as shown in Fig. (**10**). This indicates that the material strength of the infill should be increased as the opening size increases, if damage of the infill is to be prevented under a design earthquake.



10(a) 10(b)

Fig. (10). Maximum stresses within the infill walls (**a**) Fully infilled wall and (**b**) Infill with 40% opening.

Table 3. Varaition of Infill Stress with Opening %

Opening %	20	40	60
Infill stress (N/mm^2)	2.8	3.92	4.2

The moments in frames increase as the opening size increases, while the shear force decreases for both beams and columns. The increase in moment could be due to increase in flexibility, while the decrease in shear force is due to a decrease in the mass of the structure with the larger opening size. The column and the beam moments were increased by an average of 36.591% and 33.88% for every 20% increase in opening size, while the shear forces in the columns and beams were generally reduced. Overall the opening size of the infill opening affects the important response parameters of the structure and its consideration during modelling and analysis is important.

Effect of Infill Thickness

The effect of thickness was studied on a ten storey model which had the opening size of 40% (typical). The analyses were performed using a peak ground acceleration of the 0.2g Kobe earthquake on a model with an infill thickness of 125 mm and was re-analysed for the same load but had the infill thickness of 250 mm. Generally infill walls of different thicknesses are used for internal and peripheral partitions, however some clients opt for thin wall with the aim to reduce the mass of the structure. Thus, it was felt necessary to study the effect of thickness under earthquake loads as the present code does not consider the influence of infill thickness.

The effect of thickness on the fundamental period of vibration is insignificant. From this study, the difference in fundamental period between the models was 1.4%. The fundamental period only slightly increases as the infill wall thickness increases, since the increase in thickness only increases the mass of the structure rather than its stiffness. Both the roof displacement and the inter-storey drift ratio increase with the increase in thickness and the percentage of increase in roof displacement and inter-storey drift ratio were 4.69% and 4.45% respectively. Thus, it is evident that there is no improvement in the lateral stiffness of the infill wall by increasing its thickness, for the cases treated herein.

Since the influence of infill thickness on the global responses, particularly the natural periods, roof displacement and the inter-storey drift ratios, were not significant; the stresses in the infill walls were not affected by varying the thickness. The maximum principal stress in the infill walls was found to be 4.2 N/mm^2 for all models.

Effect of Peak Ground Acceleration (Pga)

The seismic resistance of all models, which are shown in Fig. (**11**), was studied by varying the peak ground acceleration of the earthquake and the performance of the structure was measured in terms of the inter-storey drift ratio and the onset of cracking in the infill panels. The infill was assumed to crack once the stress in the infill exceeded the ultimate compressive stress of the infill material. The Young's modulus of elasticity and the thickness of the infill walls were assumed as 5000 MPa and 250 mm respectively (as specific material properties of infill are not available).

The results showed that the inter-storey drift ratio of most of the models from three storeys to ten storeys, did not exceed the inter-storey drift ratio limit given in IS 1893(2002) [1], even when the PGA was increased to 0.4g. An exception was the ten storey model, which exceeded the drift ratio limit after 0.3g PGA. This shows that the structures constructed without seismic provisions can meet the drift requirements of the current code if the appropriate infill walls are considered. Thus, the presence of infill walls significantly reduces the inter-storey ratios of the models under seismic load. However, the current results could overestimate the actual capacity of real buildings as the Young's modulus of elasticity of the infill was considered to be 5000 MPA. It also shows that the infill helps to reduce the inter-storey drift ratios, consequently reducing the structural member forces, which indicates that the infilled buildings have an additional strength to survive earthquake forces even if they are not designed to resist them.

The stresses in the infill wall increase with increase in PGA, as shown in Fig. (**12**). However, all models performed well up to 0.4g PGA of ground acceleration, except the ten storey model whose maximum infill stress exceeded the maximum compressive stress of the material (6.66 N/mm^2). It is evident that the structure requires an E_i value of 7500 MPa if infill is to remain un-cracked at 0.4g PGA. It was also found that the strength requirement of infill material varied with the height of the structure under a same PGA, as shown in Fig. (**13**). Low-rise structure will require lower infill strength than high-rise structures for the same perform-

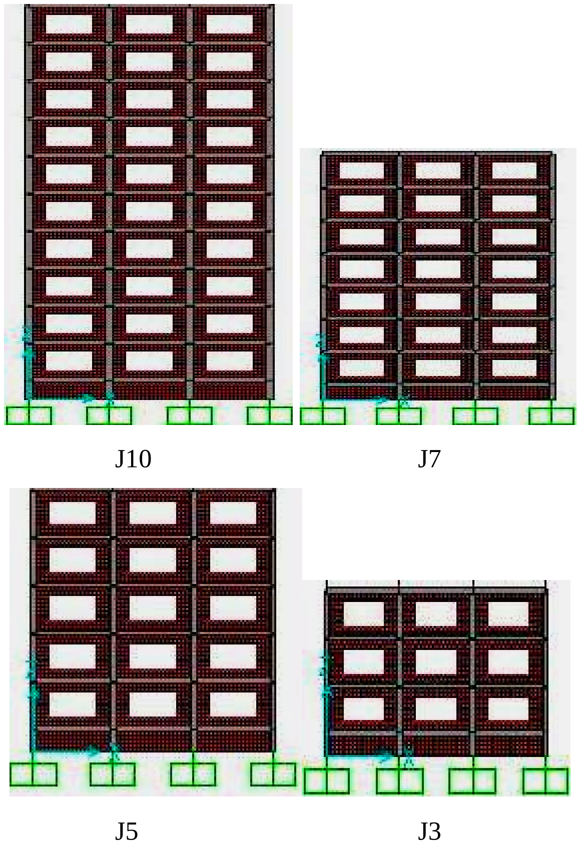


Fig. (11). Models of building structures.

ance level. Such variation in material strength requirement should be addressed in the seismic guidance.

Similar results were obtained for the models designed to conform to the seismic requirements of the IS1893 (2002) [10]. Both the inter-storey drift ratios and the infill stresses increased with the increase in PGA. This indicates that there is not much influence on the storey drift and the infill stress from the structural member sizes. It means that there is a significant stiffness contribution from the infill to overall structural behaviour.

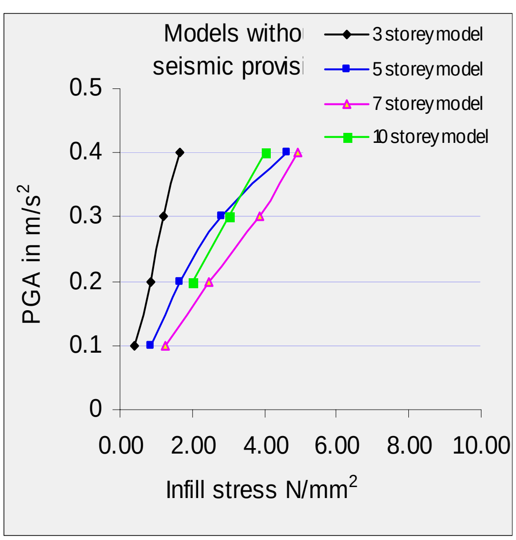


Fig. (12). Variation of stresses in the infill wall with PGA.

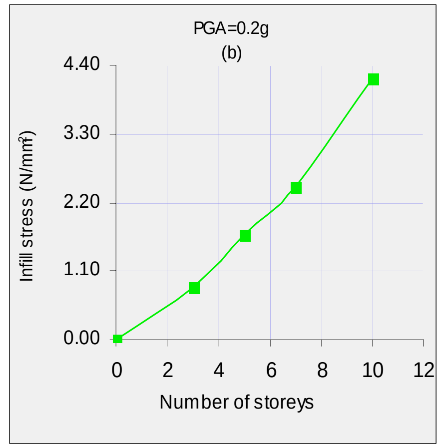


Fig. (13). Variation of minimum strength of infill material with height of the structure under a Serviceable earthquake.

The above results show that the buildings which were constructed before and after introduction of seismic Codes performed similar if the infill walls are considered. However, the strength of the infill material E_i should be greater 5000 MPa. If the $E_{i,}$ values are low, structures will not be able to resist higher ground acceleration as the lateral stiffness will be low.

Effect Of Concrete (E_c)

Over the last few decades, there have been changes in the specification of concrete material for building construction in Bhutan. Moreover, many buildings were constructed using the old codes which had inferior material specification than the modern codes. Thus, there is a need to study the effect of concrete strength as the results will be useful in the assessment of old buildings under dynamic loads. The range of the concrete strength (E_c) that was considered to study the variation of structural responses was 15 to 40 MPa.

The global structural responses such as fundamental period, roof displacement, inter-storey drift ratio and the infill stresses, all decrease with the increase in E_c value, as expected. This is due to the increase in stiffness of the model as E_c increases. It was found that the fundamental period increases by 7.8% for every 5000 MPa increase of E_c, indicat-

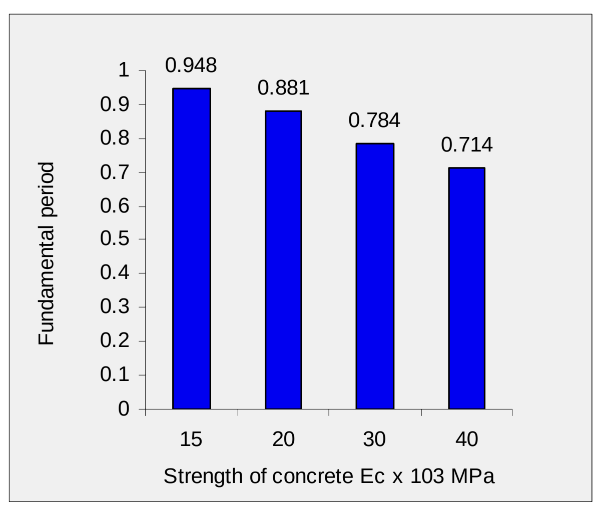


Fig. (14). Concrete strength VS. Fundamental period.

ing that old buildings which have used low strength concrete could have a longer period of vibration, as shown in Fig. (**14**). This must be considered to avoid possible resonance with seismic motions with similar dominant periods. Such variation of the period is not considered in the Empirical formulae available in the code.

The effect of E_c on the roof displacement is significant only for lower values of E_c. For example, roof displacements were 36.6 mm, 30.6 mm and 30.8 mm for models with E_c of 20 GPa, 30 GPa and 40 GPa respectively. However, the effect of E_c on the inter-storey drift ratio is not significant. The average decrease in inter-storey drift ratio for every 5 GPa increase of E_c was just 4.77%, as shown in Fig. (**15**). However, there is not much variation in the infill stress with the concrete strength. For instance, the maximum infill stress was 1.68 N/mm^2 for the model which had an E_c of 15 GPa, while the maximum stress in the other model which had an E_c of 40 GPa was 1.33 N/mm^2. In summary, the concrete strength is significant only in terms of its effect on the fundamental periods. However, it does not have significant effect on the roof displacement, inter-storey drift ratios or the infill stress, provided resonance is averted.

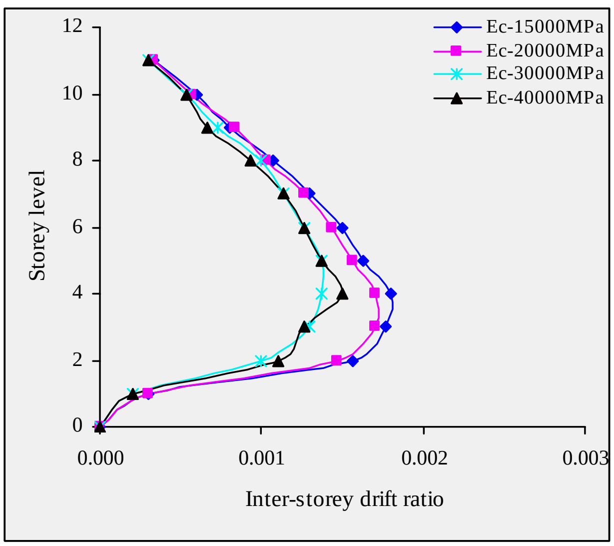


Fig. (15). Inter-storey drift ratios with E_c.

Soft Storey Phenomenon

The presence of Arcade at the bottom storey of the building structure may induce soft-storey phenomenon during dynamic earthquake loads. Such problems are currently treated by assigning magnification factor which may or may be true to the buildings which have Arcades.

This study addressed this problem by treating two models, S and S1 in which S has a uniform infill throughout the structure while S1 does not have infill at bottom storey (Fig. **16**). The infill walls were assumed to have 40% opening percentage at the centre of the infill wall. The increase in inter-storey drift ratios (Fig. **17**) was significant and correspondingly the moments and shear forces in the beams and columns were observed to increase. However, the magnification factor increases with increase in the amount of the infill in upper storeys as well as the height of the building.

Fig. (16). S-normal model and S1-model with Arcade.

The low rise model (three storeys) showed small increase in member forces while the medium rise model (ten-storey) showed significant increase in magnification factor. However, the magnification factors obtained from this research are relatively less than the values given in the current code (IS1893 2002) [1].

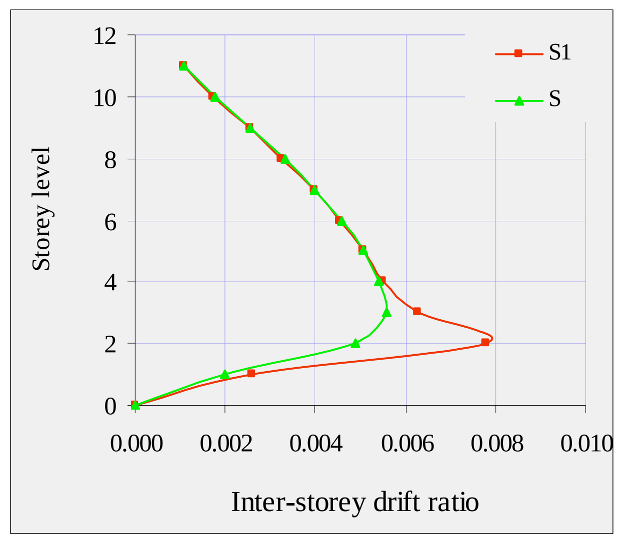


Fig. (17). Inter-storey drift ratios.

Since the buildings do have openings, this research recommends the magnification factor of structural member forces to be as shown in Table **4**. Even though the magnification factor for low rise structure could be smaller than these values, it should be acceptable to use for structure lower than ten storeys as it will be conservative and safe.

DISCUSSION AND CONCLUSION

At present there is no adequate information on the modelling, analysis and design of in-filled frame structures to

Table 4. Magnification Factors

Member Forces	Magnification Factor
Column moment	1.76
Beam moment	1.45
Column shear	1.1
Beam shear	1.1
Inter-storey drift ratio	1.7

seismic loads. This paper developed an appropriate technique for modelling the interface between infill and frame and used it to study the seismic response of in-filled frame structures and investigated the influence of important parameters. The research information will be useful in the design of such structures. The main findings of the paper are listed below;

- The strength of infill in terms of its Young's Modulus (*Ei*) has a significant influence on the global performance of the structure. The structural responses such as roof displacements, inter-storey drift ratios and the stresses in the infill wall decrease with increase in (*Ei*) values due to increase in stiffness of the model. It is therefore important to choose the right material for infill, know its properties and consider these in the analysis and design.
- The minimum compressive strength of infill material required to maintain the structure in an un-cracked condition under a credible earthquake (with 0.2g PGA) varies with the height of the building. It has been shown that under exposure to similar seismic hazards, medium rise buildings require higher strength infill material (compared to low rise building).
- The opening size of the infill has a significant influence on the fundamental period, inter-storey drift ratios, infill stresses and the structural member forces. Generally they increase as the opening size increases, indicating that the decrease in stiffness is more significant than the decrease in mass.
- Under a particular level of PGA (0.2g), the increase in infill stress is not very significant beyond infill strength of Ei = 7500 MPa. This value could be considered to be the maximum limit of the Young's modulus of infill material if the infill walls are used for retrofitting old buildings.
- The performances of buildings constructed with and without seismic provisions are almost similar if the infill has a minimum value of 5000 MPa for its Young's Modulus (*Ei*). This is because the structural capacity is greatly influenced by the type of infill walls and the values of their Young's Modulus.

REFERENCES

[1] IS1893, "Indian seismic code, Part 1, Criteria for Earthquake Resistant Design of Structures, General Provisions and Buildings", 2002.

[2] H. B. Kaushik, D. C. Rai, M. Eeri and S. K. Jain, "Code approaches to seismic design of masonry-infilled reinforced concrete frames: a state-of-the-art review", *Earthquake Spectra,* vol. 22, pp. 961-983, November 2006.

[3] I. N. Doudoumis and E. N. Mitsopoulou, "The deficiency of the macromodels with fixed support interface conditions in the analytical modelling of infill panels", In: *Proceedings of the fifth Conference on European seismic design practice,* 1995, pp. 427-433.

[4] H. Singh, D. K. Paul and V. V. Sastry, "Inelastic dynamic response of reinforced concrete infilled frames", *Computers & Structures*, vol. 69, pp. 685-693, November 1998.

[5] I. N. Doudoumis, "Finite technique modelling and investigation of the behaviour of elastic infilled frames under monotonic loading", *Engineering Structures,* vol. 29, pp. 1004-1024, September 2006.

[6] CEB (Comite Euro-international du Beton), *"Frames Under Earthquake Loading: State of the Art Report"*, Thomas Telford; heron Quy, London, 1996.

[7] H. A. Moghaddam and P. J. Dowling, *"The State-of-the -Art in Infilled Frames"*, Imperial College of Science and Technology Department of Civil Engineering, London, 1987.

[8] A. B. Mehrabi, "*Behavior of Masonry Infilled Reinforced Concrete Frames Subjected to Lateral Loadings*", Ph.D. thesis, University of Colorado, Colorado, United States, 1994.

[9] C. V. R. Murty and S. K. Jain, "Beneficial influence of masonry infills on seismic performance of RC buildings", In: *Proceedings of 12th World Conference on Earthquake Engineering*, New Zealand, 2000.

[10] M. N. Fardis, "*Experimental and Numerical Investigation on the seismic Response of R.C Infilled frames and Recommendations for Code Provisions*", European Consortium of Earthquake Shaking Tables and Prenormative Research in Support of Eurocode 8, no. 6, November 1996.

[11] P. Negro and A. Colombo, "Irregularities induced by nonstructural masonry panels in framed buildings", *Engineering Structures*, vol. 19, pp. 576-585, 1997.

[12] G. K. Al-Chaar, "*Nonductile Behavior of Reinforced Concrete Frames with Masonry Infill Panels Subjected to in-plane Loading*", Ph.D. thesis, University of Illinois, Chicago, United States, 1998.

[13] M. Dolsek and P. Fajfar, "The effect of masonry infills on the seismic response of a four-storey reinforced concrete frame -- a deterministic assessment", *Engineering Structures*, vol. 30, pp. 1991-2001, February 2008.

[14] T. Pauley and M. N. J. Priestley, "*Seismic Design of Reinforced Concrete and Masonry Buildings*", John Wiley & Sons, 1992.

[15] K. M. Amanad and H. Kramul, "A rationale for determining the natural period of RC building frames having infill", *Engineering Structures,* vol. 28, pp. 495-502, March 2006.

[16] M. M. Kose, "Parameters affecting the fundamental period of RC buildings with infill walls", *Engineering Structures,* vol. 31, pp. 93-102, 2008.

[17] P. Asteris, "Lateral stiffness of brick masonry infilled plane frames", *Structural Engineering,* vol. 129, pp. 1071-1080, 2003.

[18] M. H. Santhi, G. M. S. Knight and K. Muthumani , "Evaluation of seismic response of soft-storey infilled frames", *Computers and Concrete,* vol. 2, pp. 423-437, December 2005.

[19] IS456:1978,*"Indian Standard Code of Practice for General Structural Use of Plain and Reinforced Concrete"*, 2000.

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