SEISMIC ASSESSMENT OF RC STRUCTURES WITH INFILL MASONRY PANELS IN NEPAL - SENSITIVITY ANALYSIS

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ABSTRACT

Reinforced concrete (RC) buildings in Nepal are constructed as RC frames with masonry infill panels. These structures exhibit a highly non-linear inelastic behaviour resulting from the interaction between the masonry infill panels and the surrounding frames. In this context, the paper presents an extensive case study of existing RC-framed buildings in a high seismic risk area in Nepal. A sensitivity analysis of the structures with masonry infill is performed. For this, the influence of different material properties is studied, namely diagonal compressive stress, modulus of elasticity and tensile stress of masonry infill panels. Result shows the influence on the structural behaviour particularly by variation of the diagonal compressive strength of infill masonry panels.

Keywords   RC buildings; Seismic assessment; Masonry infill panel; Sensitivity analysis

1 INTRODUCTION

Reinforced concrete (RC) frame structures with masonry infill are extensively used in Nepal (JICA, 2002). Brick masonry is the most common infill material in Nepal because of its abundance, low cost, good sound and heat insulation properties, and the availability of labour skilled in this construction technique. Masonry panels are usually built up after the frames and floor structures have been constructed. There is a lack of structural design standards for masonry infill walls since they are normally treated as non-structural components. However, they will interact with the surrounding frame in the event of an earthquake.

RC structures are normally designed and analysed as a bare frame without considering the contribution of the infill material to strength and stiffness. However, during earthquakes, infill walls modify the response of the structure which is different from that predicted for bare frame structures. Significant experimental and analytical research is reported in the literatures, which show the beneficial as well as ill effects of infill walls (Crisafulli, 1997, Smyrou et al., 2011). Much of this research has concluded that infill walls increase the global strength, stiffness, damping and energy dissipation capacity of the structures. Infill decreases the inter-storey drift and hence the total deflection of the structure (Varum, 2003, Rodrigues et al., 2008, Rodrigues et al., 2010). The pushover curve of an infill frame can be quite different from that of the corresponding bare frame (Silva, 2013). The presence of infill panels normally involves the modification of the typical elastic-perfectly plastic

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response into a curve characterized by higher peak strength, followed by a step descent enclosed within a short displacement range (Pillai, 2003, Fajfar et al., 2005).

In this context, the paper presents an extensive case study regarding the analysis of existing RC framed buildings in a highly seismically active region – Nepal (see Fig. 1). A sensitivity analysis of reinforced concrete buildings with masonry infill is performed. Non-linear analyses are performed on structural models of each of the buildings in order to evaluate the influence of parametric variation on the seismic response of structures. For this, five low rise buildings with different structural configurations and details are selected for analysis. The study is mainly concentrated to study the effect on variation of diagonal compressive stress, modulus of elasticity and tensile stress of masonry infill walls on non-linear behaviour of the structures.
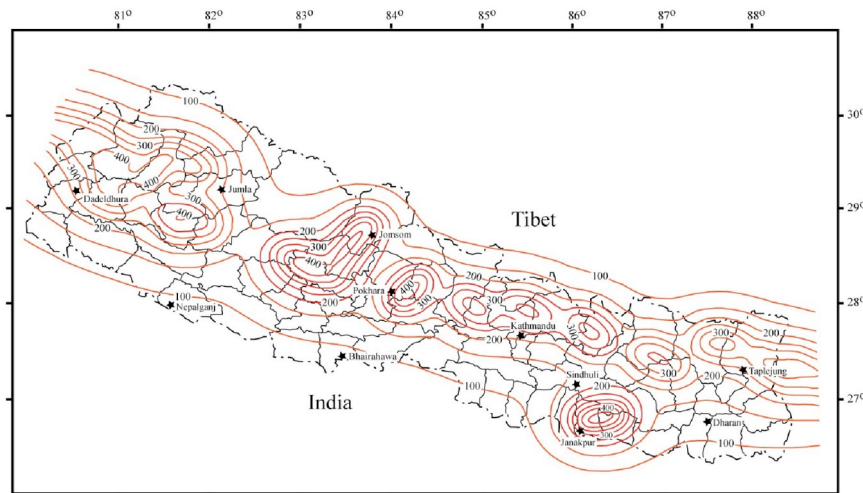

Figure 1. Seismic hazard map of Nepal (after Pandey et al., 2002). Bedrock peak ground horizontal acceleration is calculated for 500-year return period. Contour interval is 100 gals.

2 DESCRIPTION OF THE STUDIED BUILDING STRUCTURE

In this study, five existing RC moment-resisting frame structures with masonry infill walls are selected for analysis. All these building configurations are typical of seismically active regions, where the vast majority of dwellings are RC buildings with similar structural characteristics (Chaulagain et al., 2013). Two of the buildings studied are representative of non-engineered construction, namely: (a) NRCB1 and (b) NRCB2. A second type of buildings is engineered RC-MRF constructions, denoted as: (c) NRCB3 and (d) NRCB4. The remaining building is a well designed structure, denoted as NRCB5. Non-engineered buildings (mostly owner built construction) are those constructed without technical advice. These buildings are usually built informally without following specific engineering guidelines. On the other hand, engineered buildings are built with some input from engineers for earthquakes. Some of the newly constructed RC buildings in Nepal are likely to be of this type. The well designed structure is constructed based on the standard seismic code, considering seismic design with ductile detailing appropriate for a building located in the seismic zone V and medium soil type.

All the aforementioned structures are typical three-storey residential buildings constructed in different locations in Kathmandu valley. The arrangement of brick walls is as shown in figures 2–6. The grade of concrete used is M20 and the steel is Fe415. For concrete, the modulus of elasticity is taken as that recommended by IS 456, that is, $5700\sqrt{fck}$ MPa, where fck is 28-days characteristic cube strength. The Poisson's ratio and unit weights for the concrete are taken as 0.2 and 25 kN/m3 respectively. For brick masonry infill walls, the modulus of elasticity (Em) and Poisson's ratio (μ) are taken as 2300 N/mm2 and 0.15 respectively. The diagonal compressive stress (fm) and tensile stress of brick masonry wall is taken as 2.3 N/mm2 and 0.575 N/mm2 respectively. The masses of brick walls are distributed to all beams at floor levels. The external and internal brick walls are taken to be 230 mm and 115 mm thick respectively. The floor finish on floors and the weathering course on the roof

are taken as 1.0 kN/m2 and 2.25 kN/m2, respectively. The live load on floors and that on the roof are taken as 2.0 kN/m2 and 0.75 kN/m2, respectively.
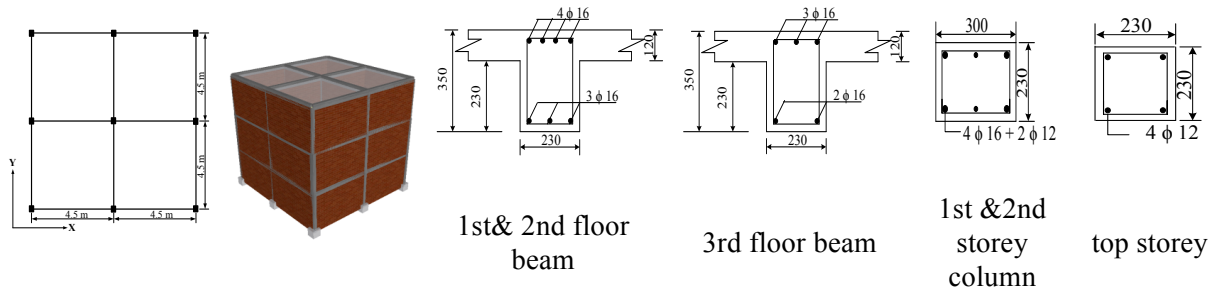

1st& 2nd floor beam   3rd floor beam   1st &2nd storey column   top storey

Figure 2. Plan, tridimensional model and cross-sectional detailing of building model NRCB1

1st& 2nd floor beam   3rd floor beam   interior columns   corner/façade columns   top storey columns
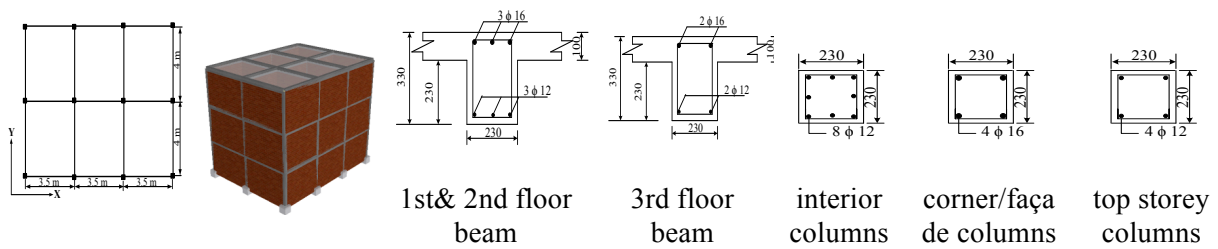
Figure 3. Plan, tridimensional model and cross-sectional detailing of building model NRCB2
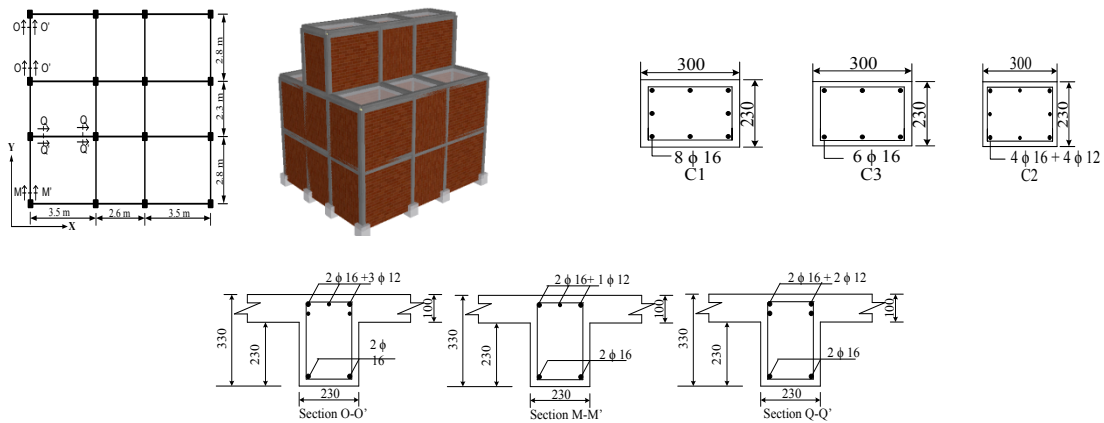

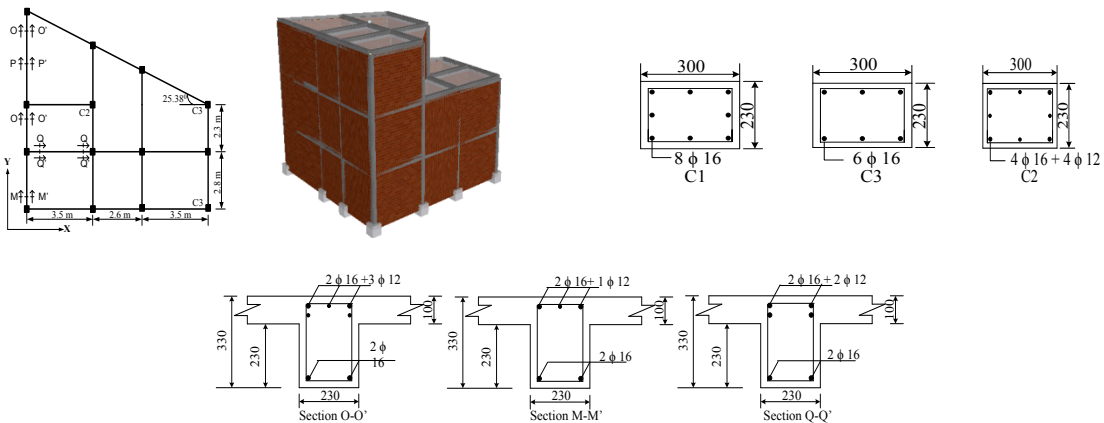Figure 4. Plan, tridimensional model and RC cross-sectional detailing of building model NRCB3

Figure 5. Plan, tridimensional model and RC cross-sectional detailing of building models NRCB4

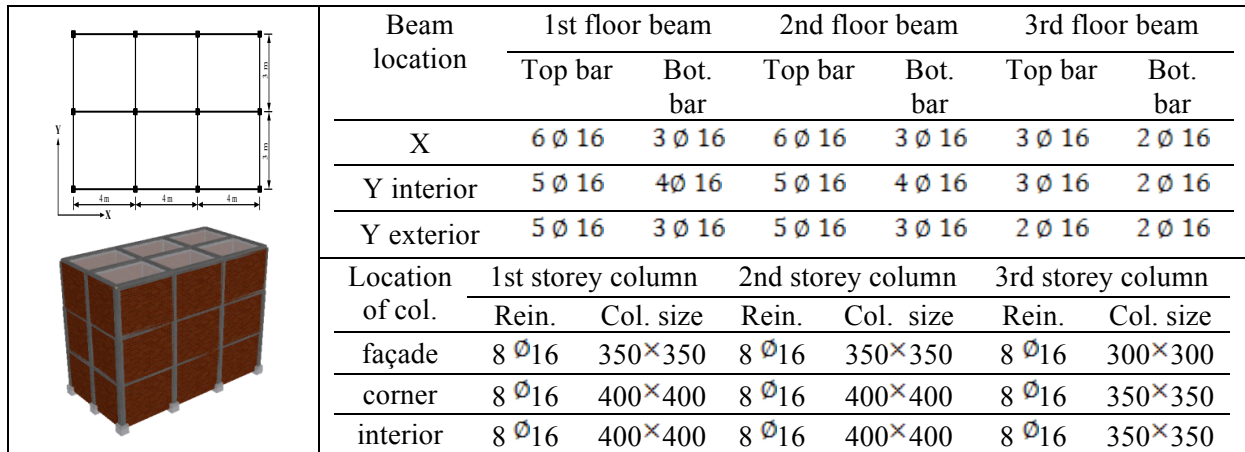| Beam location	1st floor beam		2nd floor beam		3rd floor beam	
	Top bar	Bot. bar	Top bar	Bot. bar	Top bar	Bot. bar
X	6 Ø 16	3 Ø 16	6 Ø 16	3 Ø 16	3 Ø 16	2 Ø 16
Y interior	5 Ø 16	4 Ø 16	5 Ø 16	4 Ø 16	3 Ø 16	2 Ø 16
Y exterior	5 Ø 16	3 Ø 16	5 Ø 16	3 Ø 16	2 Ø 16	2 Ø 16
Location of col.	1st storey column		2nd storey column		3rd storey column	
	Rein.	Col. size	Rein.	Col. size	Rein.	Col. size
façade	8 Ø16	350×350	8 Ø16	350×350	8 Ø16	300×300
corner	8 Ø16	400×400	8 Ø16	400×400	8 Ø16	350×350
interior	8 Ø16	400×400	8 Ø16	400×400	8 Ø16	350×350

Figure 6. Plan, tridimensional model and detailing of NRCB5 structure

Note: All dimensions are in mm unless stated otherwise
    : Beam size of NRCB5 structure is 230 mm x 325 mm.
    : All the interior, interior, façade and corner columns of building models NRCB3 and NRCB4 are C1, C2 and C3 respectively unless stated otherwise.

3 NUMERICAL MODELS

In order to assess the seismic capacity of the five case study buildings presented, numerical simulations have been performed through adaptive pushover and non-linear dynamic analysis. This provides the most accurate method for evaluating the inelastic seismic response of RC structures. The model adopted in the analyses performed in this study is presented in figures 2–6. Due to lack of real-time historical data in Nepal, the generated earthquake a record of maximum peak ground acceleration of 0.513 g has been used (Parajuli, 2009). We have made the assumption that this represents similar behaviour to the ground motion in Nepal. For adaptive pushover analysis, user-defined response spectrum provided in IS 1893-2002 (2002) is used. These data have similar PGA values to those of past earthquakes in Nepal (Chaulagain et al., 2013). The procedure for modelling the bare frame and infill of the building structures is described in the following sections.

3.1 Modelling of RC structural elements

The computer program SeismoStruct (2006) is used, adopting a lumped plasticity model. Numerical analysis is based on modelling the bare frame buildings with three-dimensional models. In the analyses performed in this paper, half of the larger dimension of the cross-section was considered as the plastic hinge length with fibre discretization at the section level. The consideration of non-linear material behaviour in the prediction of the RC columns' response requires accurate modelling of the uniaxial material stress-strain cyclic response.

The concrete model is based on the Madas uniaxial model, which follows the constitutive law proposed by Mander et al (1988). The cyclic rules included in the model for the confined and unconfined concrete were proposed by Martinez-Rueda (1997) and Elnashai (1993). The confinement effects provided by the transverse reinforcement were considered through the rules proposed by Mander et al. (1988), whereby constant confining pressure is assumed throughout the entire stress-strain range, traduced by the increase in the peak value of the compression strength and the stiffness of the unloading branch.

The uniaxial model proposed by Menegotto and Pinto (1973), coupled with the isotropic hardening rules proposed by Filippou et al. (1983), was adopted for the representation of steel reinforcement in these analyses. This steel model does not represent the yielding plateau characteristic of the mild steel virgin curve. The model takes into account the Bauschinger effect, which is relevant for the representation of the degradation of stiffness of the columns under cyclic loading.

3.2 Modelling the infill panels

Masonry infill panel is a composite constructional material of brick units and mortar joints. Due to the unique characteristics of individual materials, its material and geometrical properties can vary to a large extent in the practical application. Nowadays, two finite element modelling techniques: (1) micro-models (plane finite element) and (2) macro-models (equivalent strut models) are adopted for numerical analysis of infill panels. The first group of models is based on continuum theory, providing relatively accurate computational representations of both material and geometrical aspects of masonry infill panels, but they are computationally extensive and difficult to apply for the numerical analysis of large scale structures. On the contrary, macro models use the equivalent diagonal struts which are capable of describing the most common failure modes of masonry infill panels, which are of the most practical importance and of the greatest interest for engineers. The obvious advantage in terms of computational simplicity and efficiency thus makes the macro-models preferable for analyzing the global responses of masonry infilled frames with adequate precision.

As shown in figure 7, the infill panel is represented by six strut members in the equivalent strut model. Each diagonal direction features two parallel struts to carry axial loads across two opposite diagonal corners and a third one to carry the shear from the top to the bottom of the panel. This latter strut only acts across the diagonal that is under compression; hence its activation depends on the deformation of the panel. The axial load struts use the masonry strut hysteresis model, while the shear strut uses a dedicated bilinear hysteresis rule. The hysteresis rules of two strut models are shown in figure 8 (Crisafulli, 1997; Smyrou et al., 2011). Also, as can be observed in figure 7, four internal nodes are employed to account for the actual points of contact between the frame and the infill panel (i.e. to account for the width and height of the columns and beams, respectively), whilst four dummy nodes are introduced with the objective of accounting for the contact length between the frame and the infill panel. All the internal forces are transformed to the exterior four nodes, where the element is connected to the frame. The geometrical and mechanical properties of strut members can be determined in terms of the geometrical parameters and material properties of the masonry infill panel.

In this study, the Seismsoft computer program is used for modelling the infill panels of the structures. It is based on a finite element package capable of predicting the large displacement behaviour of frames under static or dynamic loading, considering both geometric non-linearities and material inelasticity. For the numerical analysis of masonry panels, the finite element program of an advanced double-strut nonlinear cyclic model is used. The double-strut model is satisfactorily precise and less complicated than the single- and triple-strut models, and able to represent more accurately the local effect between infill and frame (Crisafulli, 1997). The idealization of an infill panel is based on the assumption that there is no bond between frame and infill. The brick masonry infill is modelled as a diagonal strut member whose thickness is the same as that of the masonry and whose length is equal to the diagonal length between compression corners of the frame. The effective width of the diagonal strut depends on various factors including; contact length, aspect ratio of the infill, and the relative stiffness of frame and the infill. Various researchers had proposed different strut widths, however in the present study the effective width as suggested by Holmes, Pauley and Priestley, and FEMA 273 was considered initially. Subsequently, Pauley and Priestley's suggested effective width closer to the experimental value was used in this study.

In the models, the strut areas for the infill with small window, large window and door are estimated as 70%, 60% and 50% respectively of the equivalent strut area as initially calculated before considering the presence of infill (Smyrou et al., 2011); these percentages are comparable with those proposed by Pinho and Elnashai (2000).
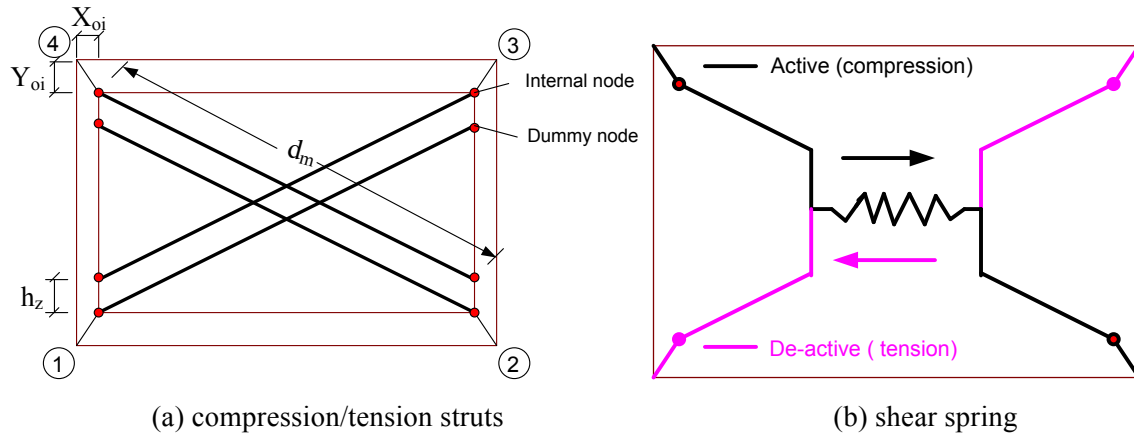
(a) compression/tension struts   (b) shear spring

Figure 7. Equivalent strut model for infill panel (Crisafulli, 1997)

(a) compression/ tension struts   (b) shear spring
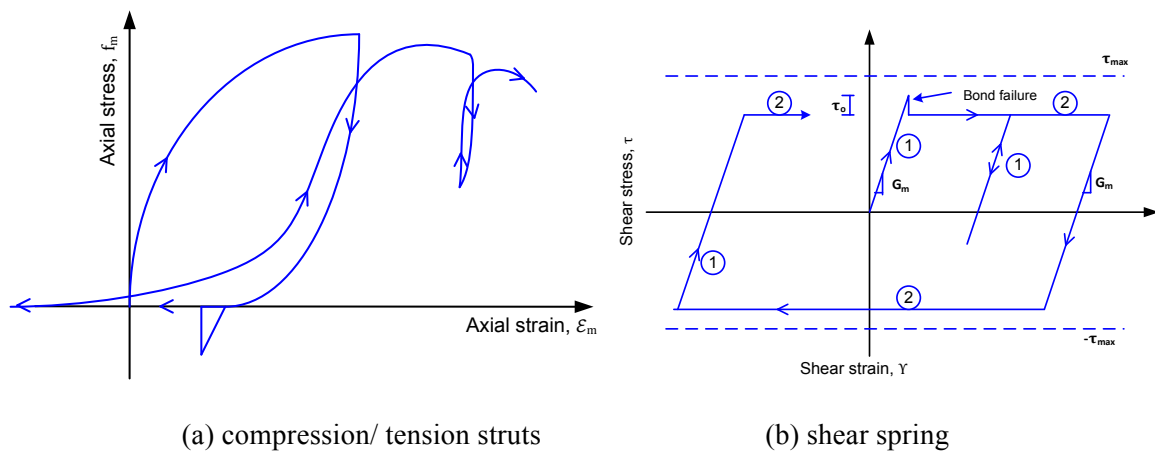
Figure 8. Hysteretic rules for compression/tension struts and shear spring (Crisafulli, 1997)

4 INFLUENCES OF MATERIAL PROPERTIES ON BUILDING RESPONSE

Reinforced concrete structures with masonry infill panels are designed to provide lateral resistance in highly seismically active environments like Nepal. Most of the cases studied here were based on owner built construction. Even in well designed structures, structural engineers have largely ignored the influence of masonry panels when selecting the structural configuration, assuming that these brick masonry panels are brittle elements compared with the frame. The design practices of neglecting the infill leads to inaccuracy in predicting the lateral strength, stiffness and ductility of the structure. There is a lack of sufficient test results on the material properties of masonry infillin Nepal. However, the varied material properties also indicate the large variation in results (Pradhan, 2012). Thus, in this study, the effect of variation of material properties on the response of masonry infill is discussed. For this the diagonal compressive strength, modulus of elasticity and tensile stress of the brick masonry is selected. It is due to the fact that these material properties are important parameters in the analytical analysis of the masonry infill structure (Seismosoft, 2006). The variation of the studied parameters is taken 25% and 50% respectively for diagonal compressive stress, modulus of elasticity and tensile strength of brick masonry. The parameters are selected based on Pradhan (2010), Ambrisi (2011) and Pradhan (2012).

4.1 Sensitivity analysis

In this section, the effect of parametric variation on the response of the structure is discussed. The influence in variation of material properties of masonry, namely diagonal compressive strength (fm),

young's modulus of elasticity (Em), and tensile strength (ft), was studied. The results from the variation of each parameter can be expressed in terms of maximum roof displacement; maximum IS drift and maximum base shear.

The results of the parametric analysis indicate that the variation of diagonal compressive stress on the structure is clearly apparent in all building models. The maximum IS drift is decreased by 34% and 64% when the diagonal compressive stress of masonry is increased by 25% and 50% respectively. For the same ratio of increment of fm value, the maximum displacement is decreased by 28% and 53% respectively. However, the maximum inter-storey drift value is increased to 180%, for 25% reduction of diagonal compressive stress of masonry (fm) panel. In short, the reduction of diagonal compressive stress of the brick masonry wall plays an important role especially for increase in inter-storey drift in non-engineered building structures. If the reduction of fm value is continued up to 50%, it elongates IS drift, resulting in numerical instabilities in the structures. Besides, the variation in base shear is limited to 40% for all building models. The Young's modulus is also an important parameter in Nepalese buildings. It introduces differences to some extent in all building models, though tensile stress does not have so much effect when compared with other parameters. As indicated in figure 9, it can be concluded that the performance of structure is dominated by the diagonal compressive strength of the masonry infill panel. There is very minor fluctuation in structural response due to the variation of Young's modulus and the tensile stress of the masonry panel.
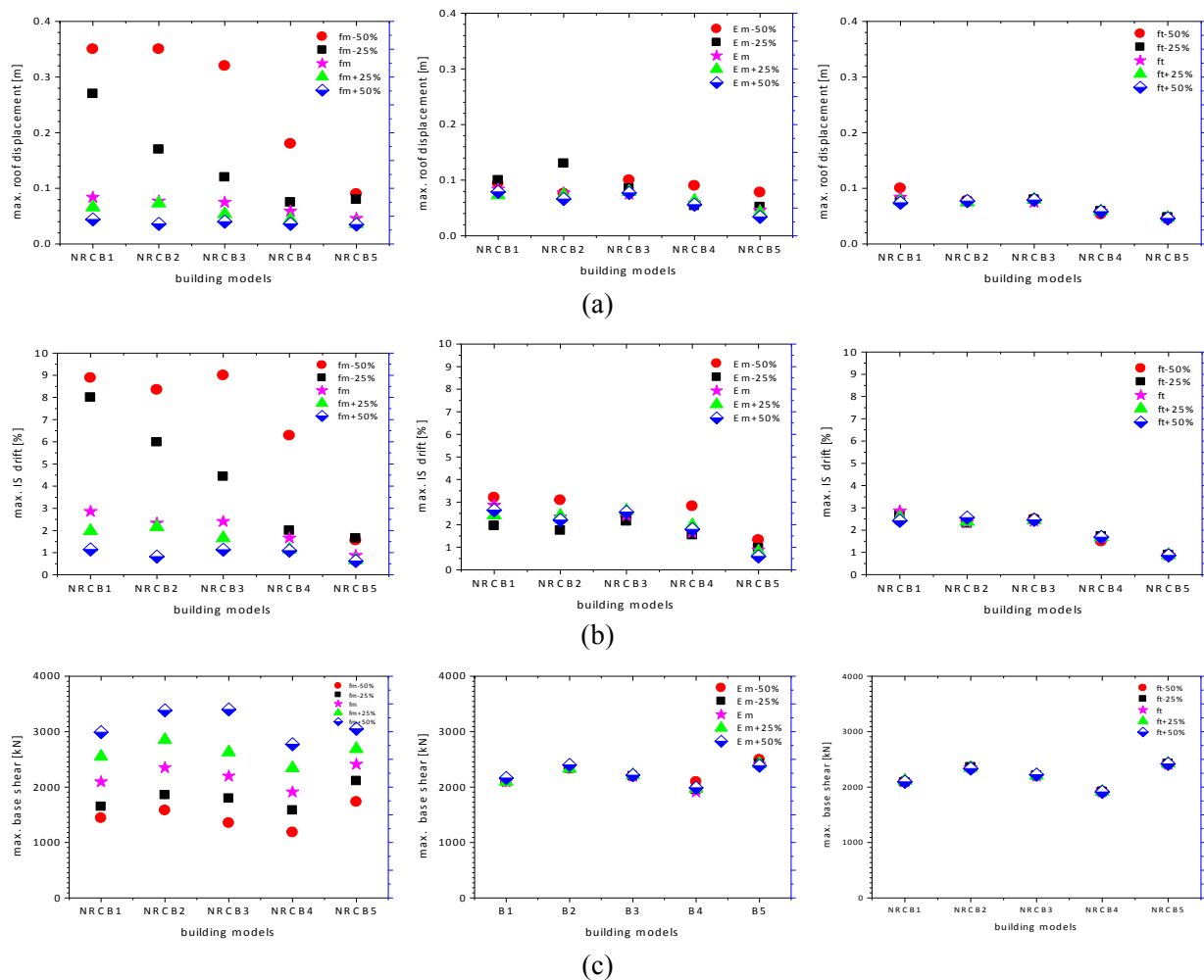

Figure 9. Effect in variation of diagonal compressive stress (fm), Young's modulus (Em) and tensile stress (ft) of masonry infill on (a) max. roof displacement, (b) max. IS drift and (c) max. base shear respectively

4.2 Effect on reduction of diagonal compressive strength on global response of structure

In this section, the influence of material properties on building response is presented. The selection of material properties and building model is based on the parametric study described in aforementioned section (see section 4.1 for details). Based on that analysis, the reduction of diagonal compressive strength of a masonry panel plays an important role in infilled masonry structures. Therefore, the non-linear dynamic analysis is conducted for the normal level (2.3 N/mm2), decreased by 25% (1.725 N/mm2) and decreased by 50% (1.15 N/mm2), of diagonal compressive stress of a masonry panel with increasing peak ground acceleration records. Figure 10 represents the influence of material properties on the response of non-engineered (NRCB2) (see figure 10.a) and engineered (NRCB3) (see figure 10.b) building models. In both of these building models, initially a masonry infill panel significantly improves the response of buildings by reducing the inter-storey drift. However, the maximum IS drift value increased greatly at lower values of diagonal compressive strength of masonry. Initially at lower ground motion, structures of both the normal and reduced material properties have similar behaviours up to 0.25 g PGA value. The behaviours of the structures are modified with increasing ground motion values. This shows that the reduction of diagonal compressive stress of materials gives favourable results to a certain extent. At a higher magnitude of ground motion, however, it has adverse effect. Similarly, the material properties give the best result to a certain level (in our case, the initial material properties). If we use values lower than its limiting value, that gives adverse results for the structures.

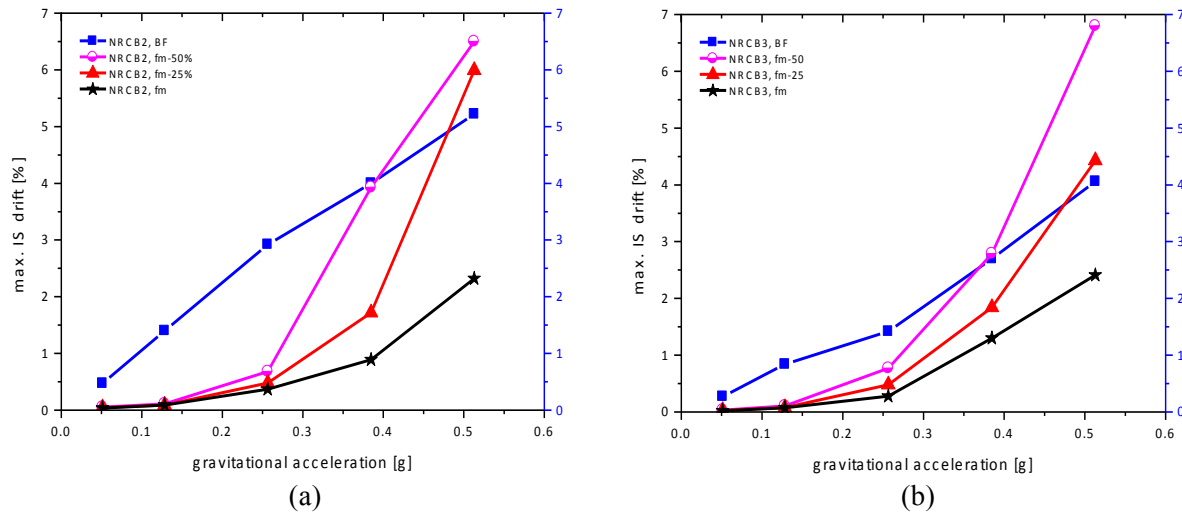(a)   (b)

Figure 10. Effect of reduction of diagonal compressive strength of masonry infill on seismic vulnerability of structures for (a) NRCB2, and (b) NRCB3

5 CONCLUSIONS

Masonry infill panels have a complex behaviour due to their unique material properties and to the interaction with the surrounding frame. Therefore, the response of such structures is highly complex and depends on many factors from material properties to workmanship. In these circumstances, this paper presents an extensive case study regarding the analysis of existing RC framed buildings in a high seismic risk area in Nepal. The obtained results can be summarized as:

- Parametric analysis based on variation in material properties of compressive strength, modulus of elasticity and tensile strength of masonry infill indicates that the diagonal compressive stress of masonry has a significant influence on the performance of structures as compared with other parameters.

- The reduction of diagonal compressive stress of materials has favourable results within certain level of ground motion (PGA values). However, if the stress is further reduced, it has the adverse effect in higher magnitude of earthquakes (PGA values). The selection of diagonal

compressive stress qualities of the masonry infill panels plays a very important role in the response of a structure. Thus, structures are designed/constructed considering such a important issues in the structures.

Acknowledgements

REFERENCES

Carvalho EC, Coelho E, Campos Costa A. Preparation of the full-scale tests on reinforced concrete frames - Characteristics of the test specimens, materials and testing conditions. ICONS report, Innovative Seismic Design   Concepts for New and Existing Structures, European TMR Network - LNEC, Lisbon; 1999.

Chaulagain H, Rodrigues H, Jara J, Spacone E, and Varum H. Seismic Response of Current RC Buildings in Nepal: A Comparative Analysis of Different Design/ Construction. Engineering Structures 49; 284–294, 2013.

Crisafulli FJ (1997) Seismic behavior of reinforced concrete structures with masonry infills, PhD thesis, University of Canterbury, New Zealand

D'Ambrisi A, Stefano, M.de, Tanganelli1, M. and Viti, S. Influence of the Variability of Concrete Mechanical Properties on the Seismic Response of Existing RC framed Structures. 6th European Workshop on the seismic behaviour of Irregular and Complex Structures , 2011

Elnashai AS, Elghazouli AY. Performance of composite steel/concrete members under earthquake loading, Part I: Analytical model. Earthquake Engineering and Structural Dynamics, Vol. 22, pp. 315-345;1993.

Filippou FC, Popov EP, Bertero VV. Effects of bond deterioration on hysteretic behaviour of reinforced concrete joints. Report EERC 83-19, Earthquake Engineering Research Center, University of California, Berkeley; 1983.

IS 1893 (Part1):2002. Indian Standard Criteria for Earthquake Resistant Design of Structures. *Bureau of Indian Standards*, Fifth Revision, 2002.

Mander JB, Priestley MJN, Park R. Theoretical stress-strain model for confined concrete. Journal of Structural Engineering, Vol. 114, No. 8, 1804-1826; 1988.

Martinez-Rueda JE. Energy Dissipation Devices for Seismic Upgrading of RC Structures. PhD Thesis, Imperial College, University of London, London, UK; 1997.

Menegotto M, Pinto PE. Method of analysis for cyclically loaded R.C. plane frames including changes in geometry and non-elastic behaviour of elements under combined normal force and bending. Symposium on the Resistance and Ultimate Deformability of Structures Acted on by Well Defined Repeated Loads, International Association for Bridge and Structural Engineering, Zurich, Switzerland, pp. 15-22; 1973.

Pradhan P. Equivalent strut width for partial infilled frames. Journal of Civil Engineering Research, , 2(5): 42-48 DOI: 10.5923/j.jce.20120205.03 ,2012.

Prachan P, Murty CVR, Hoiseth K, Aryal M. Nonlinear simulation of stress-strain curve of infill materials using PLP fit model. Journal of the Institute of Engineering, Vol. 7, No. 1, pp. 1-12, 2010

Pandey MR, Chitrakara GR, Kafle B, Sapkota SN, Rajaure S, Gautam UP. Seismic hazard map of Nepal. National Seismological Centre, Kathmandu Nepal, 2002.

Pillai EBP. Influence of brick infill on multistory multibay RC frames. PhD thesis, Department of Civil Engineering, Coimbatore institute of Technology, Combatore, 2003.

Pinho R and Elnashai AS. Dynamic collapse testing of a full-scale four storey RC frame. ISET Journal of Earthquake Engineering, Special Issue on Experimental Techniques, Vol. 37, No. 4, pp. 143-164, 2000

SeismoSoft. A Computer Program for Static and Dynamic Nonlinear Analysis of Framed Structure [online], available from   URL: http//www.seismosoft.com; 2006.

Rodrigues H, Varum H, Costa A. Simplified Macro-Model for Infill Masonry Panels, Journal of   Earthquake Engineering, , 14:3, 390-416, DOI:10.1080/13632460903086044, 2010.

Rodrigues H, Varum H, Costa A. A non-linear masonry infill macor-model to represent the global behaviour of buildings under cyclic loading. Int J Mech Mater Des ,4:123–135 DOI 10.1007/s10999-008-9070-6, 2008.

Silva V, Crowley H, Varum H, Pinho R (2014) "Seismic Hazard and Risk Assessment of Portugal", Second European Conference on Earthquake Engineering and Seismology, Istanbul Aug. 25-29

Smyrou E, Blandon C, Antoniou S, Pinho R, Crisafulli F. Implementation and verification of a masonry panel model for nonlinear dynamic analysis of infilled RC frames. Bull Earthquake Eng 9(6):1519–34, 2011.

Varum, H. Seismic Assessment, Strengthening and Repair of Existing Buildings. PhD Thesis, Department of Civil Engineering, University of Aveiro (2003).