Jurnal
Teknologi

Full Paper

DRIFT DEMANDS OF LOW-DUCTILE MOMENT RESISTANCE FRAMES (MRF) UNDER FAR FIELD EARTHQUAKE EXCITATIONS

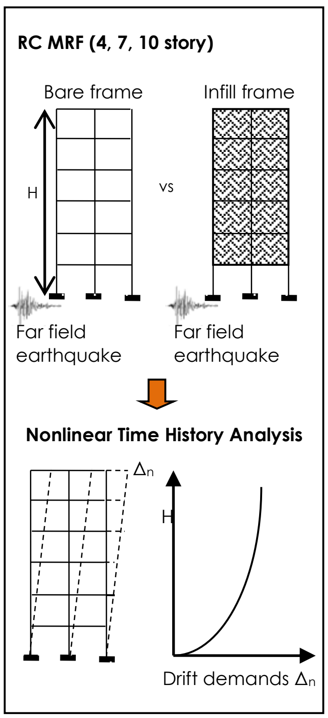
Mohammadreza Vafaei[a], Sophia C. Alih[b*], Qotrunnada Abdul Rahman[b]

[a]Forensic Engineering Center, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Malaysia
[b]Institute of Noise and Vibration, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Malaysia

Article history
Received
30 July 2015
Received in revised form
24 October 2015
Accepted
15 May 2016

*Corresponding author
sophiacalih@utm.my

Graphical abstract



Abstract

Most of current Malaysian's structures have not been designed with consideration of seismic excitation effect. Tremors that have been recorded locally due to active local faults and earthquake events in neighboring countries have raised the question about the level of safety of these structures. The effects of seismic excitation on the stability and fragility of the structures are now being concerned by most researchers and engineers in order to mitigate structural damage and societal losses. This study focuses on the seismic performance of Reinforced Concrete (RC) Moment Resistance Frames (MRF) in Malaysia which has been only designed to resist gravity and wind loads effects. An ordinary building layout with different number of stories (four, seven, and 10 stories) is selected in a way that can represent the potential of soft-story phenomenon in RC buildings in Malaysia. Such structures have limited lateral load capacity to withstand against strong ground motion. Nonlinear time history analysis is used to analyze the structures using seven different ground motions scaled to 0.05g, 0.1g and 0.15g to suit Malaysian condition. The outcomes of this study illustrate the vulnerability of the typical RC, MRF structures in Malaysia to soft-story phenomenon and clarify on the necessity of seismic retrofit for such structures.

Keywords: Reinforced concrete, seismic vulnerability, masonry infills, soft-story building, gravity load design, non- linear dynamic analysis

Abstrak

Majoriti daripada bangunan di Malaysia tidak direkabentuk bagi menahan beban gempabumi. Tahap keselamatan bangunan di negara ini diragui berikutan beberapa siri gegaran yang berlaku akibat daripada garis sasar aktif gempa di Malaysia dan negara jiran. Kesan gempabumi terhadap kestabilan struktur menjadi persoalan dan isu kajian bagi mengurangkan kerosakan struktur. Kajian ini memberi perhatian kepada kelakuan struktur konkrit bertetulang bagi kerangka rintangan momen di Malaysia, yang hanya mengambil kira beban graviti dan beban angin dalam rekabentuk. Rekabentuk bangunan lazim di Malaysia dengan ketinggian yang berbeza (empat, tujuh, dan sepuluh tingkat) telah dipilih bagi mewakili fenomena tingkat lembut yang biasa berlaku di Malaysia. Analysis dinamik tak linear digunakan untuk menganalisa struktur dengan menggunakan tujuh rekod gempa bumi yang diskalakan kepada 0.05g, 0.1g, dan 0.15g bersesuaian dengan tahap gempabumi Malaysia. Keputusan kajian ini memberikan gambaran terhadap tahap sensitiviti bangunan di Malaysia dan keperluan menjalankan kerja-kerja pengukuhan struktur.

Kata kunci: Konkrit tetulang, sensitiviti gempa, dinding bata, fenomena tingkat lembut, rekabentuk beban graviti, analysis dinamik tak linear

© 2016 Penerbit UTM Press. All rights reserved

1.0 INTRODUCTION

Frame reinforced concrete (RC) structures are popular structural system and have been constructed increasingly all over the world [1, 2]. In earthquake prone Mediterranean countries including Italy, this type of structure represent more than 50% of the total buildings. Many of these structures were built before the advent of seismic codes or with the utilization of old and inadequate anti-seismic design criteria [3]. During past earthquakes (Southern Italy 1980, USA 1994, Japan 1995, Turkey 1999, Greece 1999, Taiwan 2001) RC buildings (in particular Moment Resistant Frame, MRF) often displayed unsatisfactory seismic behavior, especially when their design included only vertical loads and ductile detailing was not explicitly provided [4]. Such gravity load designed frames have a limited lateral load resistance and are susceptible to column-sidesway or soft-story mechanisms when subjected to earthquakes [5]. Thus, the evaluation of seismic vulnerability of this low-ductile MRF has a key role in the determination and reduction of earthquake impact.

Figure 1 illustrates the soft story mechanism due to the opening on ground floor of the building which caused significant difference in stiffness between the ground floor and adjacent upper floors. When earthquake happen, total deformation of the building will be concentrated on the ground floor instead of being distributed along the height. Thus, the ground floor will suffer major damages which may lead to structural collapse. This type of failure has been observed in several earthquake events.

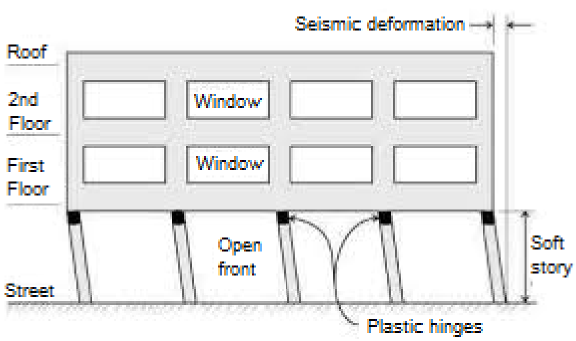


Fig. 1 Soft story mechanism in building

Over the past several years, researchers have continuously studied the seismic performance and fragility of RC MRF which has been designed for gravity load (or gravity plus wind load). A study has been conducted by Perrone *et al*., [6] to evaluate seismic behavior of frames designed to bear only gravity load using a simulated design procedure based on code provisions and design practices in force in Italy between 1950s and 1970s. The considered frames have height varying between 7 and 34 meters. A parametric study has been performed to take into account the typical mechanical properties of masonry available in Italy. A pushover analysis has been carried out to evaluate the capacity curves and collapse mechanisms of infilled frames. The performed analysis allowed to analyzing the influence of infill properties on the ductility of existing RC frames. The results emphasized the importance of infill and their significant influences on the global seismic behavior of RC frames.

Masi and Vona [7] evaluated seismic capacity of some structural models which represented real RC existing buildings designed to gravity loads only using non-linear dynamic analysis, NLDA. The study was aimed to identify the influence of some structural parameters on the non-linear seismic behavior of gravity load designed RC buildings. Specifically, the role of construction age, dimensions in plan and elevation, presence and position of infill walls and concrete strength were evaluated through NLDA. Ductility demands and inter-story drift were analyzed to determine seismic response of the structure. The study concluded that infill distribution and height played the most influential role in building performance among the parameters adopted to classify the structural types. Other research by [8] also found that infill distribution, soft-story phenomenon, and material properties were parameters that strongly influenced the seismic response of structures.

The effect of masonry infills in the seismic response of gravity load designed RC frame buildings, typically of older construction design practice, have been further discussed in a study conducted by Magenes and Pampanin [5]. The interaction between un-reinforced masonry infills and RC frame systems was investigated through pushover and nonlinear time-history analyses on 2-D frame systems. Six story frame system was used to determine the effects of infills distribution and mechanical properties on the damage distribution. The study confirmed the inherent weakness of this system. Sudden reduction of story stiffness due to the damage of the infills could lead to the formation of a soft story mechanism, which, due to the interaction with joint damage, could occur not necessarily at the first floor level and independently of the regular or irregular distribution of the infills along the elevation.

Dolsek and Fajfar [1] has also studied the effects of masonry infill on the seismic response of a four-story RC frame using simplified seismic performance assessment method (N2 method). The method is based on pushover analysis and the inelastic spectrum approach. Comparison was made between the behavior of bare frame and infill frame (with and without opening). The results of the analyses indicated that the infills could completely change the distribution of damage throughout the structures. The infills could have a beneficial effect on the structural response, provided that they were placed regularly throughout the structure, and that they did not cause shear failures of columns.

Studies on seismic behavior of RC frame designed for gravity load has also been conducted for structures subjected to far-field earthquake excitation. Celik and Ellingwood [9] published their assessment work on structures performance of RC frame in the Central and Eastern United State (CEUS) based on far field excitation from Mid-America Ground motion; New Madrid seismic zone (NMSZ). A set of RC structure from one of concentrated population area closed to NMSZ was selected as representative of real existing RC local buildings which were designed by considering gravity load only. Seismic fragility assessment of the structural models were then checked under several different far field ground motion force values from different seismic source of modeling. From the study, it was observed the fragility of the structures highly depended on the selection of the ground motions especially in case of flexible structure. Seismic fragilities were derived for low-rise, mid-rise, and high-rise RC frame that suite to RC frame inventory in CEUS by using the stimulation-based reliability analysis to meet the recent guideline on life safety and structural protection control due to earthquake hazard.

Polese *et al.*, [10] conducted almost similar procedure to that of Celik and Ellingwood [9] on presenting a vulnerability analysis for a case study of the Arenella district in Naples (Southern Italy). The model of structures represented the MRF structures and was designed by considering gravity load only. Seismic fragilities were derived in terms of elastic spectral displacement that suite to gravity load designed MRF RC structure in Naples, Italy by using push-over analysis.

Previous researches have demonstrated the importance and significant effect of masonry infill to the seismic behavior of RC frames especially those designed to resist gravity load only and has low ductility. Such structural type system is common in most countries as well as Malaysia. The vulnerability of this structural type has been studied rigorously in the countries with high seismicity. Even though Malaysia is considered as low-seismic region, tremors that have been recorded locally due to local active fault lines and earthquake events in neighboring countries have triggered the question on the level of safety of buildings that has been designed based on gravity and wind load only. Surrounded by the major tectonic plates; Australia plate, Eurasian plate and Philippine Sea plate [11] far field earthquake effect to buildings in Malaysia is therefore being concerned. The vulnerability of this type of structures under far field earthquake excitation has not yet being determined.

This study focuses on the seismic performance of non-ductile RC MRF designed for gravity and wind loads in Malaysia considering infill panel effects subjected to far field earthquake excitations. An ordinary structural building layout is selected in a way that represents soft-story phenomenon. The effect of infill panels together with number of stories on the ductility and lateral stiffness of this type of buildings were determined to investigate the vulnerability of this type of structures.

2.0 PROCEDURE OF ANALYSES

Figure 2 shows the procedure of analyses conducted in this study. The procedure started with selection of an ordinary residential building layout to represent Malaysia's MRF RC building. The selection of the structural layout and its characteristics is discussed in the following section. Based on the structural layout, finite element models were designed for gravity and wind loads by using ETABs software [12]. Two types of frames are studied herein; bare frame and infill frame which represent frame without and with consideration of stiffness of infill panels, respectively. It should be mentioned that for the latter, infill panel distribution is not considered at the ground level in order to represent soft-story phenomenon; a common type of construction in Malaysia. In other published works, such as the one conducted by Masi, 2003 [3], this type of frame is refer to as pilotis frame. In this study, however, it will be referred to as infill panel frame (INF) for better differentiation with bare frame.

Next, nonlinear time history analyses were performed, considering far field earthquake excitations. Seven sets of ground motion records are selected based on past earthquakes data and scaled to suit Malaysian seismicity level. Seismic response parameters including inter-story drift demand is used to evaluate the seismic vulnerability of the studied models. The behavior of bare frame was first analyzed to evaluate the influence of infill panels.

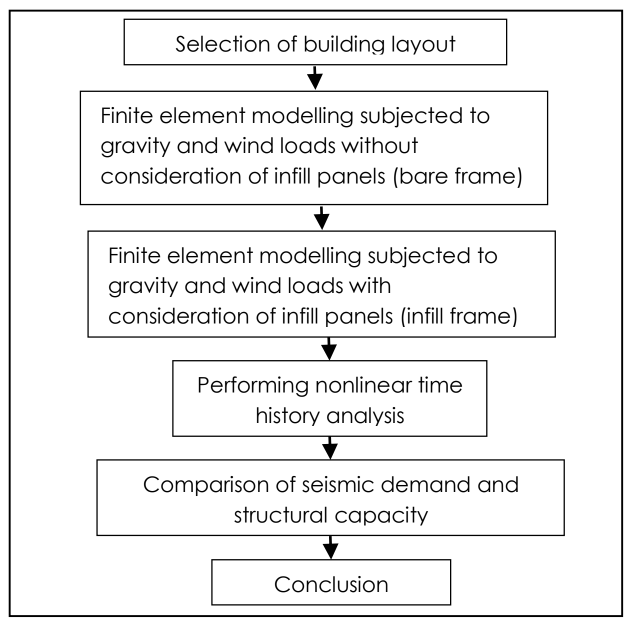
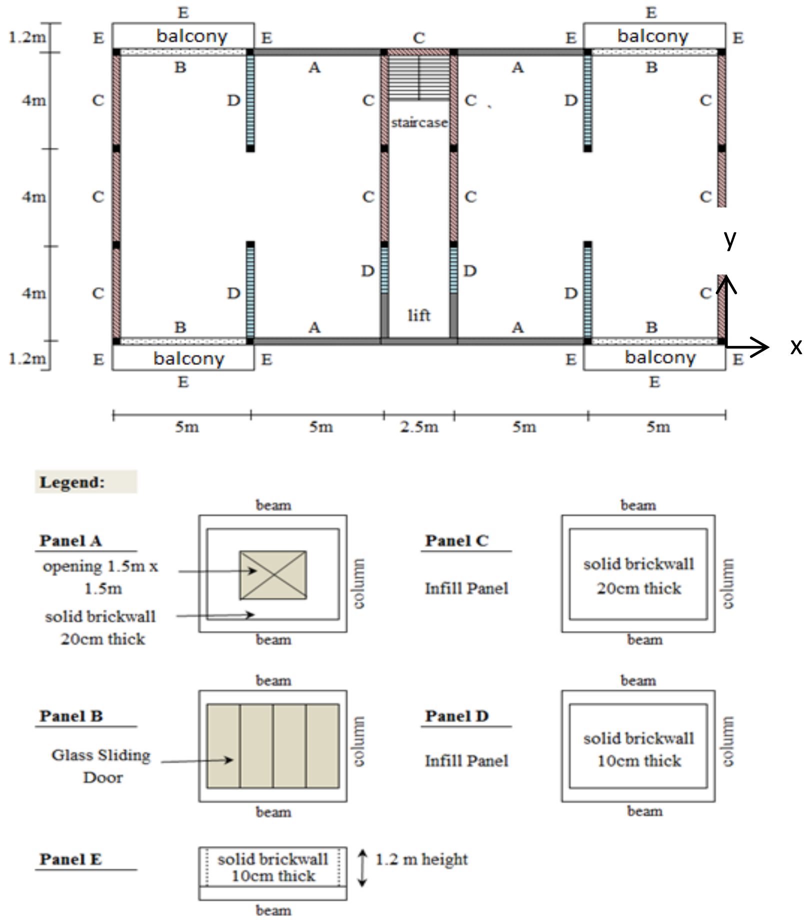


Figure 2 Procedure of analyses

3.0 SELECTION OF BUILDING

A typical residential building layout in Malaysia is selected to represent the local MRF RC structures. The buildings were initially designed by considering gravity and wind load only. In order to investigate the effect of heights of buildings on their seismic response, three different range of building height were selected including four, seven and 10-story. The buildings were designed according to BS8110 code [13]. The compressive strength of the concrete and yield strength of steel reinforcement were selected as 30Mpa and 400Mpa respectively. The shear wall element located around the lift were included in the building's models except for the four-story frame since it is ordinary case for the Malaysia's building to have a lift core if the story of the building is greater than four. The plan view of selected buildings is shown in Figure 3. Figure 4 displays the typical 3D-view of each story.



Notes: All dimensions are not in scale.

Figure 3 Building Layout

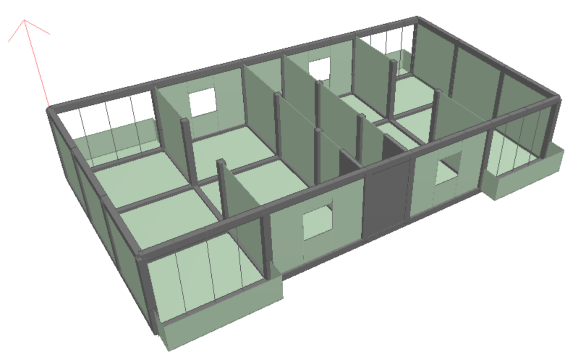


Figure 4 Typical 3-D layout view for each floor

4.0 FINITE ELEMENT (FE) MODELS

FE models were established in ETABs software [12]. Beam and columns were modeled using frame element. Concrete shear wall around the lifts were modeled using shell element. For non-linear analysis, discrete plastic hinge method, according to the recommendation of FEMA356 [13], was employed to consider inelastic behavior of beam and columns. In this method plastic hinges are assigned to both end of beam and column. Non-linear properties of plastic hinge were selected from tables provided in FEMA356. Non-linear behavior of concrete shear walls was taken into account through fiber element method. In this method concrete walls are divided into concrete and steel elements and nonlinear material properties are assigned to them. Herein, nonlinear material properties for concrete and reinforcement were selected according to recommendation of FEMA356. Table 1 displays linear material properties used in this study and Table 2 shows the selected nonlinear material properties used in this study.

Table 1 Linear Material Properties Used For Concrete and Steel Reinforcement

	Modulus Of Elasticity, E (Mpa)	Compressive Strength	Tensile Strength	Poisson Ratio
Concrete	25000	30	-	0.2
Steel Reinforcement	200000	-	400	0.3

Table 2 Nonlinear Material Properties Used For Concrete and Steel Reinforcement

	Ultimate Tensile Strain	Ultimate Compressive Strain
Concrete	-	0.005
Steel Reinforcement	0.05	0.02

All buildings were designed for wind and gravity load. The wind and gravity load were applied according to UBC 97 [14] and BS8110 [15], respectively. Nonlinear time history analysis were performed for two conditions, at first the effect of infill walls was not included in the FE models (to simulate bare frame). Second, the effect of infill walls was included in the FE models (to simulate infill frame). Stiffness and nonlinear behavior of infill walls were simulated using previous studies [1]. From the previous study, infill panel effect is considered in the FE model through adding diagonal braces into the frames. The widths of braces have been calculated according to the studies conducted by [16]. Nonlinear behavior of infill panels were selected according to study conducted by [1] as shown in Figure 5. The FE models of bare four, seven and 10-story structures are shown in Figure 6.

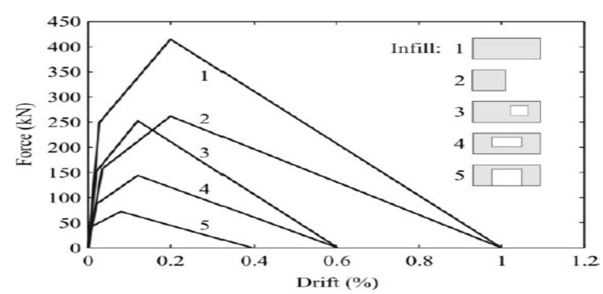


Figure 5 The force-displacement relationship of the diagonal struts (in compression) of infill panels, measured in the horizontal direction [1]

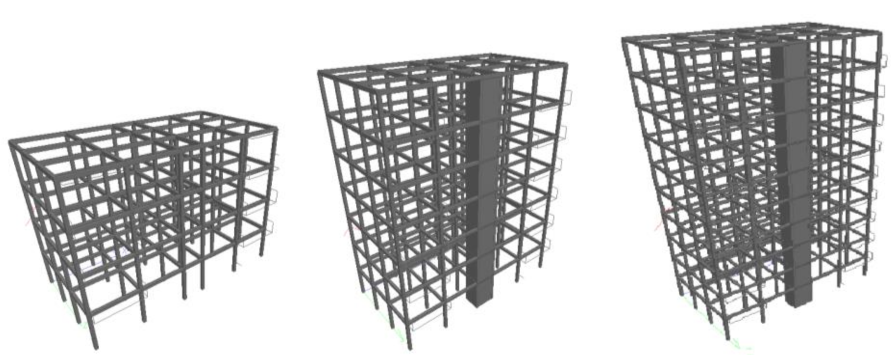


Figure 6 FE models of 4, 7 and 10-story model

5.0 NON-LINEAR TIME-HISTORY ANALYSIS

Nonlinear time history analysis is known to be the most accurate method for evaluating the inelastic seismic response of RC structures, particularly as a result of its peculiar ability to take into account the real characteristics of the seismic input and the evolution of the structural response (cyclic degrading behavior and dissipation capacities) [7]. In order to conduct the non-linear time-history analysis, seven sets of ground motions record were selected from Pacific Earthquake Engineering Research Center (PEER) ground motion database. The selected ground motion data are shown in Table 3. Selection of earthquake records was based on soil type and source- to-site distance of the earthquake records. All earthquake records were scaled to 0.05g, 0.1g and 0.15g before being used in the time history analysis to suit Malaysian seismicity level [11].

Table 3 Selected ground motion record

No	Record	Station	Year	Duration (Sec.)	PGA (g)	PGV	PGD
1	Chi-Chi, Taiwan	CHY004	1999	90	0.1	15.8	15.41
2	Chi-Chi, Taiwan	CHY008	1999	90	0.13	28.9	20.2
3	Kocaeli, Turkey	Ambarli	1999	80	0.249	40	30.08
4	Loma Prieta	1002 APEEL 2- Redwood City	1989	36	0.274	53.6	12.68
5	Loma Prieta	58117 Treasure Island	1989	40	0.159	32.8	11.52
6	Morgan Hill	58375 APEEL 1- Redwood City	1984	36	0.068	3.9	0.63
7	Northridge	90011 Montebello-Bluff Rd.	1994	22	0.179	9.4	1.48

°PGA = Peak Ground Acceleration
°PGV = Peak Ground Velocity
°PGD = Peak Ground Displacement

6.0 RESULT AND DISCUSSION

6.1 Modal Analysis

Modal analysis is the study of the dynamic properties and response of structures under vibrational excitation. Table 4 shows the first four natural periods of all models. In this table "s" stands for story and "INF" shows the presence of infill panel in the finite element models. From Table 4, it can be seen that consideration of infill panel in the FE models has significantly reduced the natural period of structure which is attributed to the stiffness of infill walls. Taking the first mode shape as reference, reduction in natural period due to the presence of infill walls is more evident for the taller buildings. Natural period of the infill 10-story building is 55% of that of the corresponding bare frame. The seven and four-story infill buildings show a reduction of 50% and 29% compared to the corresponding bare buildings. It is also evident that when buildings are not designed for earthquake loads their first natural period is significantly more than the expected value of seismically designed structures. This is more pronounced for the four-story building which is due to the absence of concrete walls around the lift area.

Table 4 Natural period of the designed structures

	Natural Period (Sec.)			
	1st mode	2nd mode	3rd mode	4th mode
4s	1.23	1.21	1.17	0.43
4s INF	0.90	0.88	0.84	0.16
7s	1.49	1.07	0.82	0.53
7s INF	0.75	0.46	0.45	0.20
10s	1.88	1.51	1.25	0.66
10s INF	0.84	0.65	0.61	0.27

6.2 Time History Analysis

Non-linear time history analysis was carried out using the seven sets of ground motion records as listed in Table 4. Seismic responses were analyzed based on the maximum story displacement and maximum story drift for each set of the records similar to the studies conducted by [6] and [7]. It should be mentioned that the obtained results display the average of seven earthquake records following the recommendations of UBC 97 [14].

i) Maximum Story Displacement Demands

The graphs of story height against maximum displacement demands were plotted for all studied structures. For each analysis, comparison between structures with and without infill panels is presented. In addition, the effect of different Peak Ground Accelerations (PGAs) on the maximum displacement demands can be seen in the presented diagrams.

Figure 7 to Figure 9 show the plot of building height against envelope of maximum displacement demands for the critical direction of four, seven, and 10-story buildings, respectively. In general, it can be observed that for all buildings the lateral displacement demands of bare structures are significantly larger than those with infill panel. It is also seen that, increase in the PGAs has more impact on the maximum displacement demands of bare buildings compared to those that have infill panel. Increase in the PGA of earthquake records form 0.05g to 0.1g has almost doubled the displacement demands of seven and 10-story buildings. However, for four-story building the significant increase in the lateral displacement demands occurs when PGA increases from 0.1g to 0.15g. This implies that for bare buildings taller structures have less preserved over strength compared to short one. On the other hand, as can be seen from Figure 6, for the four-story infill building increase in the PGA from 0.05g to 0.1g has more impact on the lateral displacement demands in comparison to increase from 0.1g to 0.15g. For seven and 10-story infill buildings gradual increase in the value of PGA from 0.05g to 0.15 g results in almost linear increase in the lateral displacement demands. This implies that, for the studied infill buildings, the four-story structure has higher probability for soft-story phenomenon when compared to the seven and 10-story buildings.

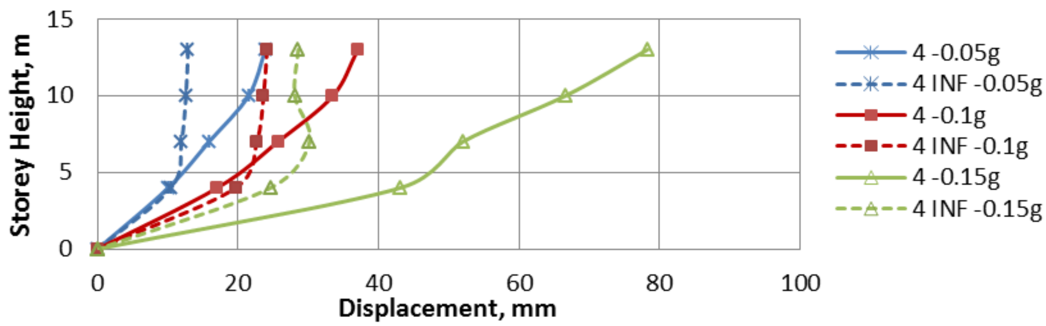


Figure 7 The Maximum Lateral Displacements of four-story Building

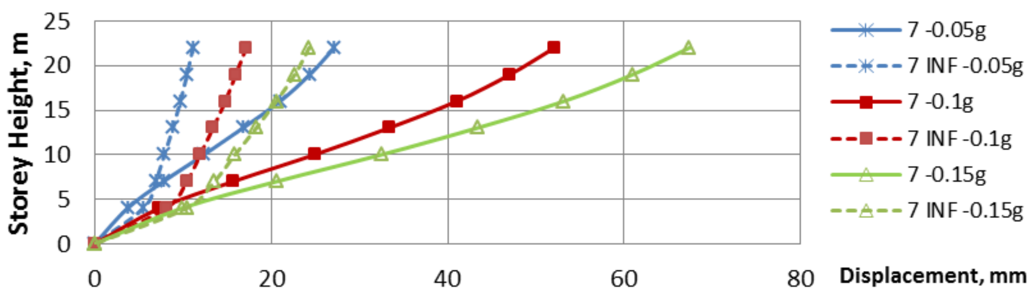


Figure 8 The Maximum lateral Displacements of seven-story Building

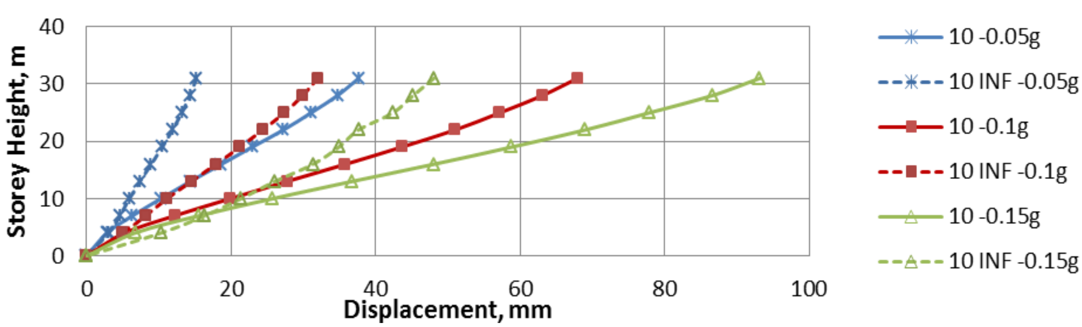


Figure 9 The Maximum Lateral Displacements of 10-story Building

ii) Maximum Story Drifts

Inter-story drift has been widely used by researchers to evaluate the overall intensity of seismic induced damages to structures [17-22]. Figures. 10 to 12 show the plot of story height against obtained inter-story drifts for the critical direction of four, seven and 10-story buildings, respectively. As shown in the figures, significant increase in the inter-story drift demands can be noted for buildings when the seismic intensity increases. In addition, remarkable differences can be observed between bare frame and infill frame. Generally, inter-story drift demands of bare buildings are larger than the inter-story drift demands of infill buildings. This is because of presence of infills which guarantees higher overall stiffness and strength, thus reducing the inter-story drift demands [6].

It is noteworthy that, in addition to the seismic intensities, the inter-story drift demands of structures especially for upper floors are also dependent on the numbers of stories of each building. For instance, the seven-story infill building shows lower inter-story drift demands compared to the corresponding bare structure. However, when the 10-story building is subjected to higher seismic intensity (i.e., 0.15g) for some levels infill building has higher inter-story drift demands compared to the bare frame. It shows that irregular distribution of infill walls along the height (i.e. pilotis type) can change the distribution of damage throughout the structure. This observation is similar to the findings of other researchers [2].

Sudden increase in the first floor's drift demands compared to upper floors in four, seven, and 10-story buildings indicates the potential of soft-story phenomenon in all structures. However, it should be mentioned that, the increase in the inter-story drift demands at the first floor of infill buildings are more evident than bare structures. This indicates that the soft-story collapse can be the typical form of damage to the studied pilot is infill structures if the considered seismic intensities were stronger.

It is also worth mentioning that ATC 40 [23] recommends inter-story drift ratios of 1%, 2% and 3% as thresholds of immediate occupancy (IO), life safety (LS) and collapse prevention (CP) damage limit states for concrete structures, respectively. Since the maximum inter-story drift demands obtained for all building types are less than 1%, it might be concluded that all structures can satisfy the IO performance level when the PGA of earthquake is less than 0.15g. Such conclusion can only be driven if the studied buildings could comply with the requirements of minimum ductility level as proposed by seismic codes. However, since the studied buildings are assumed to be lack of such ductile detailing they may get damaged even under lower inter-story drift ratios [24]. The appropriate inter-story drift capacity of each seismic performance level can be determined through monitoring plastic hinge formations. Such study is beyond the scope of this article and can be carried out in the next researches.

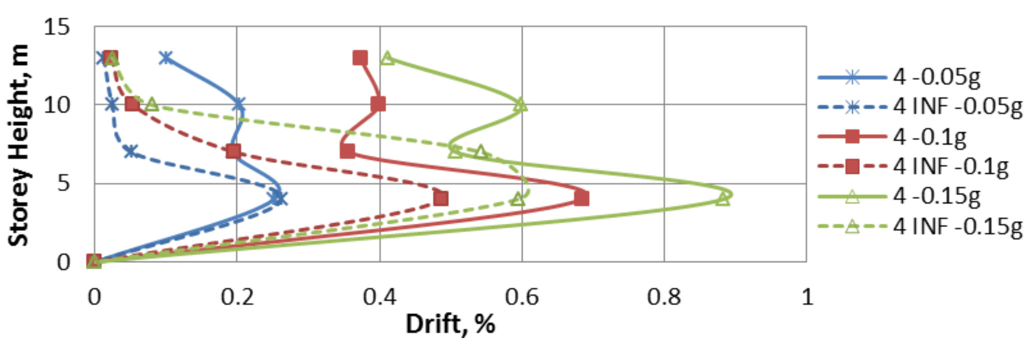


Figure 10 The Maximum Story Drift of four-story Building

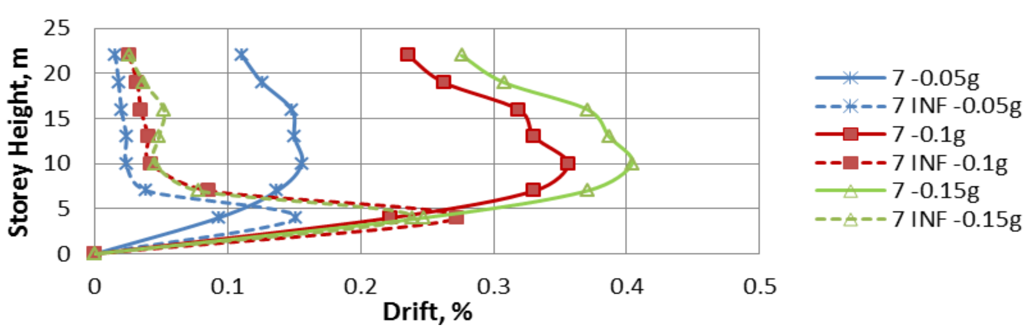


Figure 11 The Maximum Story Drift of seven-story Building

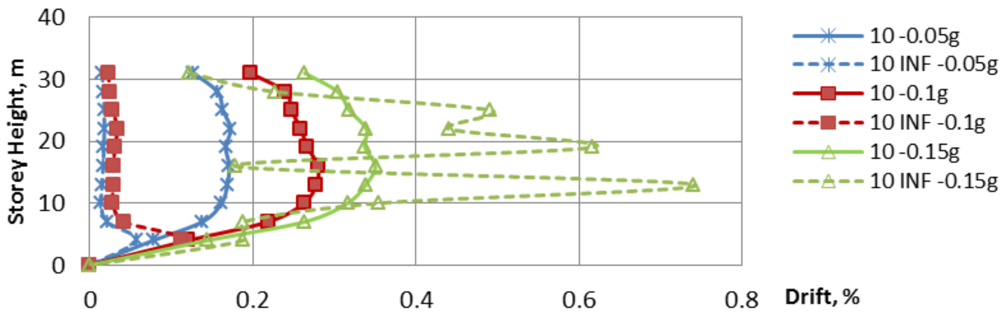


Figure 12 The Maximum Story Drift of 10-story Building

7.0 CONCLUSION

The main aim of this study was to evaluate seismic behavior of low-ductile RC moment resistance frame (MRF) structures under far field earthquake with consideration of soft-story phenomenon that is common in Malaysian's building construction. Comparison was made between RC MRF without infill walls and RC MRF with infill walls. By analyzing the behavior of three bare buildings prior to three infill buildings, the influences of infill walls were discovered. As expected, presence of infill walls increased the overall stiffness and strength of the buildings. This resulted in the reduction of natural period and inter-story drift demands in infill buildings compared to the bare structures. It was observed that, seismic behavior of the studied buildings, in addition to seismic intensity, was dependent on the numbers of stories. Comparison of inter-story drift demands at upper floors of a 10-story infill building with a 10-story bare structure showed the negative effect of irregular distribution of infill walls on the seismic response of the studied buildings. It was found that, the discontinuation of infill walls to the ground floor (as a common design trend in Malaysia) could significantly increase the seismic vulnerability of buildings and lead to soft-story mechanism. As much as infill walls can have beneficial effect to structures during earthquake, their irregular positioning in plan, and especially in elevation can significantly influence the global seismic behavior of RC frames and give negative impact.

Acknowledgement

This research is funded by the Fundamental Research Grant Scheme from the Ministry of Higher Education of Malaysia. The authors are therefore would like to acknowledge this resource.

References

[1] Matjaz Dolsek and Peter Fajfar. 2008. The Effect of Masonry Infills on the Seismic Response of a Four-Story Reinforced Concrete. *Journal Engineering Structure*. 30: 1991-2001.

[2] Marco Vona. 2014. Fragility Curves of Existing RC Buildings Based on Specific Structural Performance Levels. *Open Journal of Civil Engineering*. 4: 120-134.

[3] Angelo, Masi. 2003. Seismic Vulnerability Assessment of Gravity Load Designed R/C Frames. *Bulletin of Earthquake Engineering*. 1: 371-395.

[4] Fardis, M. N. 2006. Seismic Design Issues For Masonry-Infilled RC Frames. *Proceedings Of The First European Conference On Earthquake Engineering And Seismology*. Paper 313.

[5] Guido Magenes and Stefano Pampanin. 2004. Seismic Reponse Of Gravity-Load Design Frames With Masonry Infills. *13th World Conference on Earthquake Engineering Vancouver*, B.C. Canada, August 1-6.

[6] Daniele Perrone, Marianovella Leone, Maria Antonietta Aiello. 2014. Influence of Infill Properties on Ductility of RC Existing Frames. *International Journal of Recent Technology and Engineering*. 3.

[7] Angelo Masi and Marco Vona. 2012. Vulnerability Assessment Of Gravity-Load Designed RC Buildings: Evaluation Of Seismic Capacity Through Non-Linear Dynamic Analyses. *Engineering Structures*. 45: 257-269.

[8] Bal, I. E., Crowley, H., Pinho R. and Gulai F. G. 2007. Structural Characteristics Of Turkish RC Building Stock Northern Marmara Region For Loss Assessment Application. *Iuss Press Report*, Pavia, Italy. ISBN: 978-88-6198-003-7.

[9] Ozan Cem Celik, and Bruce R. Ellingwood. 2009. Seismic Risk Assessment of Gravity Load Designed Reinforced Concrete Frames Subjected to Mid-America Ground Motions. *J. Struct. Eng*. 135: 414-424.

[10] Polese M, Verderame GM, Mariniello C, Iervolino I, Manfredi G. 2008. Vulnerability Analysis For Gravity Load Designed RC Buildings In Naples-Italy. *Journal Earthquake Engineering*. 12(S2): 234-245.

[11] Adnan, A., Hendriyawan, Marto, A., and Irsyam, M. (2006). Development of Seismic Hazard Map for Peninsular Malaysia. *Proceedings on Malaysian Science and Technology Congress*. PWTC Kuala Lumpur, Malaysia. 1-26 September.

[12] Computers and Structures, Inc. 2013. Etabs: Integrated Design Building Software, User Guide, Berkeley.

[13] FEMA 356. 2000. Prestandard and Commentary for the Seismic Rehabilitation of Buildings, prepared by the Building Seismic Safety Council for the Federal Emergency Management Agency, Washington, D.C.

[14] Uniform Building Code. 1997. UBC Division III: Wind Design, International Code Council, California.

[15] British Standards Institution. 1997. BS 8110, Reinforced Concrete Design, British Standard Institution, UK,

[16] B. Stafford Smith, C. Carter. 1969. A Method of Analysis for Infilled Frames. *Ice Proceedings*. 44(1): 31-48.

[17] Vafaei, M., Adnan, A. B., & Abd. Rahman, A. B. 2013. Real-Time Seismic Damage Detection Of Concrete Shear Walls Using Artificial Neural Networks. *Journal of Earthquake Engineering*. 17(1): 137-154.

[18] Vafaei, M., bin Adnan, A., & Yadollahi, M. 2011. Seismic Damage Detection Using Pushover Analysis. *Advanced Materials Research*: 255(2496-2499).

[19] El Howary, H. A. and Mehanny, S. S. F. 2011. Seismic Vulnerability Evaluation of RC Moment Frame Buildings in Moderate Seismic Zones. *Earthquake Engineering and Structural Dynamics*. 40: 215-235.

[20] Javanpour, M. 2012. Assessment of the Seismic Behaviour of the Reinforced Concrete Structures Based on the Probabilities, Implementing Fragility Curves. *Journal of Civil Engineering and Science*. 1: 59-64.

[21] Shoraka, M. B., Yang, T. Y. and Elwood, K. J. 2013. Seismic Loss Estimation of Non-Ductile Reinforced Concrete Buildings. *Earthquake Engineering & Structural Dynamics*. 42: 297-310.

[22] Nanos, N. and Elenas, A. 2006. Seismic Duration Effects on the Vulnerability of Buildings. *Proceedings of 1st European Conference on Earthquake Engineering and Seismology*, Geneva, 3-8 September 2006.

[23] Applied Technology Council ATC. 1997b. Commentary on the Guidelines for the Seismic Rehabilitation of Buildings, prepared for the Building Seismic Safety Council, Washington, D.C: Federal Emergency Management Agency, FEMA-274.

[24] Ji, J., Elnashai, A. S., Kuchma, D. A. 2007. An Analytical Framework For Seismic Fragility Analysis Of RC High-Rise Buildings. *Engineering Structures* 29(12): 3197-3209.