IOP Conf. Series: Materials Science and Engineering **431** (2018) 122004 doi:10.1088/1757-899X/431/12/122004

Appraisal of existing lateral load resisting mechanisms for medium rise building in non-seismic region

S A A Nazari, A B Nabilah, F N A Abd.Aziz

Department of Civil Engineering, Faculty of Engineering, Universiti Putra Malaysia

Abstract. Malaysia was considered to be safe against earthquake threat and buildings were not designed for earthquake load. However, the recent earthquake in Ranau, Sabah (2015) and tremors felt in Peninsular Malaysia due to long distance earthquakes in Sumatra raises concern on building safety in this region. In this study, a typical 18-storey building in Malaysia was chosen as a case study. Three different lateral load resisting mechanisms namely moment resisting frame, infill brickwall and shear wall were considered in this study. The capacity of the reinforced concrete structures were predicted using nonlinear pushover analysis and compared to the seismic loads on different soil foundations. It is found that the strength capacity of infilled wall and shear wall increased by 7.3% and 68.2%, while the displacement capacity reduced by 27.5% and 86.5% respectively, compared to the bare frame. It was found that the building founded on flexible soil (with high period) will be most affected by the seismic load compared to the building on hard soil. Overall, the existing building has good resistance and is capable to withstand the seismic load in both Peninsular Malaysia and Sabah.

1. Introduction

Malaysia is located in the stable Sunda Shelf with low to medium seismic events. Thus, Malaysia was considered to be safe against earthquake threat and buildings were not designed for earthquake load. However, the tremors felt from recent earthquake in Ranau, Sabah (2015) and far-field earthquakes from Sumatra, Indonesia have been felt in Peninsular Malaysia. Ranau earthquake was the strongest earthquake striking Ranau at moderate 5.9 of scalar Richter, while, the massive undersea earthquake with moment magnitude, Mw = 9.0 of 26 December 2004 occurred off the north-west coast of Sumatra, Indonesia.

Therefore, Malaysia will soon adopt Eurocode 8 [1] for seismic design of structures to keep buildings safe for people living in it, with seismic load ranges from low to moderate depending on the locations and soil types. New structures will have to be designed for earthquake load, and as a result, existing structures must also be assessed on its strength against the new seismic provision. Due to its high period, the vulnerability of medium rise building resting on flexible soil will be studied.

Around the world, numerous studies have been conducted to access the performance of buildings not designed for seismic load. Magenes and Pampanin (2004) [2] have confirmed the weaknesses of these buildings. As a consequence of poor reinforcement detailing, lack of transverse reinforcement in the joint region as well as absence of any capacity design principles, brittle failure mechanisms are expected at both local and global level. Bracci et al. (1996) [3] evaluated the seismic resistance of 3-storey reinforced concrete (RC) scaled model for a series of tests. It was found that with poor reinforcement detailing, the structures are dominated by strong beam-weak column behaviour. Perrone et al. (2016)

[4] studied the effect of incorporating infill brickwall into the analysis of structures in terms of modal properties. When the percentage of opening exceeds 60%, it could be neglected in the analysis. The existence of brickwall significantly alters the period of structure, and must be included in the analysis for accurate behavior.

Balendra et al. (1999) [5] performed pushover analysis on 3, 6 and 10-storey frames designed according to BS 8110 [6], with and without infill. In general, the structures are found to have significant overstrength and ductility due to redistribution of internal forces in elastic range. However, the presence of infilled walls caused the ductility to be reduced due to premature shear failure. Hau (2003) [7] performed pushover analysis on two shear wall buildings with 16 and 25 stories in Singapore. From the capacity-demand curves, it is shown that the 25-storey building could not withstand the seismic load from worst possible earthquake in Singapore due to failure of the shear wall and should be retrofitted using fiber reinforced polymers.

Literatures stated that the buildings have some overstrength and could withstand earthquakes of small magnitude. However, the analysis did not include the effect of having infill brickwall that will increase the structural stiffness that could reduce the structure's ductility. This study is carried out to investigate the capacity of medium rise building built in Malaysia against lateral load using pushover analysis. The effects of various lateral load resisting mechanism which are moment resisting frame, infill brickwall, and shear wall will be investigated. The study should be able to give recommendations on structure types that would need to be further assessed for its vulnerability.

2. Methodology

2.1. Case study

An 18-storey residential building in Kuala Lumpur was selected in this study, with sufficient as-built information. This structure is an RC frame building, with constant inter-storey height of 2.6 m and 3.3 m height for the first floor. Each block consists of four unit apartments, starting from the first floor, with one open space at the ground level. The three-dimensional (3-D) RC structure were analysed by nonlinear static analysis (Pushover Analysis) using SAP2000 software [8]. The 3-D frame of selected existing building having various types of lateral load resisting mechanism such as RC bare frame, infilled frame and shear wall were considered in this study. The layout of the building is shown in Figure 1, where the infill and shear wall were placed along grid 3/B-D and 3/F-H. Typical beams are of sizes 300x525mm to 300x600mm. The detailing of the structural elements are taken as the as-built drawing of structure.

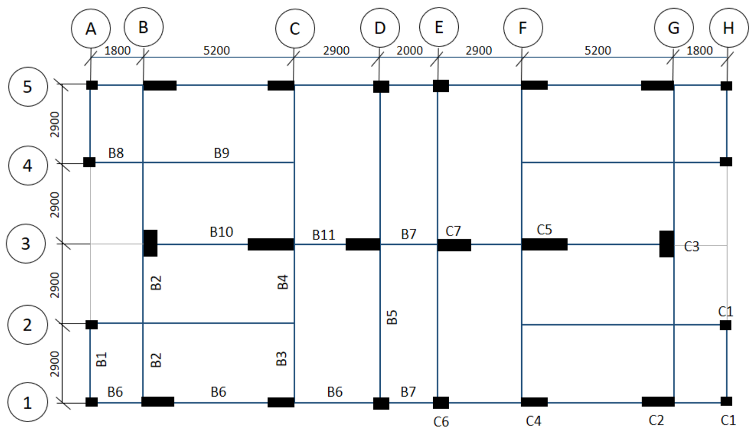


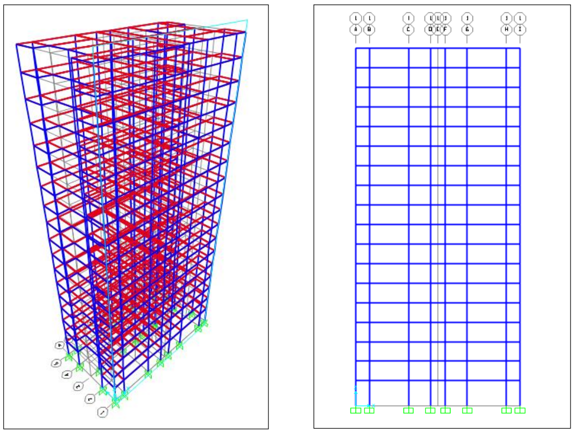
Figure 1. Layout plan of building.

2.2. Modelling of 18-storey building

Figures 2 to 4 show the modelling of three lateral-load resisting mechanisms in SAP2000 software. Figure 2 shows the moment resisting bare frames consist of beams and columns, where the beams are rigidly connected to the columns. There is complete open spaces between the RC frames.

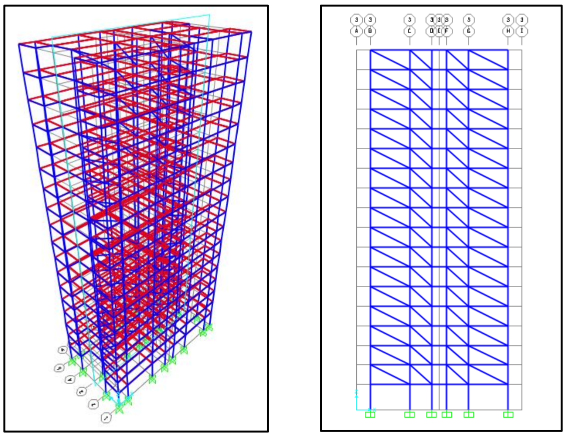
Figure 3 shows the infilled frame, modelled as diagonal member designed to take up compression under lateral load. In Malaysia, the common type of infill is clay brick, bonded together by a layer of mortar (also referred to masonry by FEMA-356 [9]). Based on FEMA-356, the expected compressive strength (f_{me}) of average masonry condition is 5.4 MPa, and the modulus of elasticity is taken as 550f_{me}, which equals to 2960MPa. This value is similar to average clay brick masonry compressive strength obtained by Kaushik et al. (2007) [10] based on experimental tests. The average mortar strength is taken as 15.2 MPa (Kaushik et al., 2007). To determine the stiffness of the masonry infill, the infills are modeled as pin ended diagonal compression strut with width, a, given by FEMA-356. The locations of infill walls are as illustrated in Figure 3(b). The infill walls are terminated at the first floor to ensure open space at the ground level.

In Figure 4, the infilled wall is replaced by shear wall along grid 3/B-D and 3/F-H. The shear wall is continuous down to the first floor and there is no beams and columns, except in first floor. In this analysis, the columns were restrained with respect to all six degrees of freedoms at the base and interaction between soil structure and foundation was not considered.



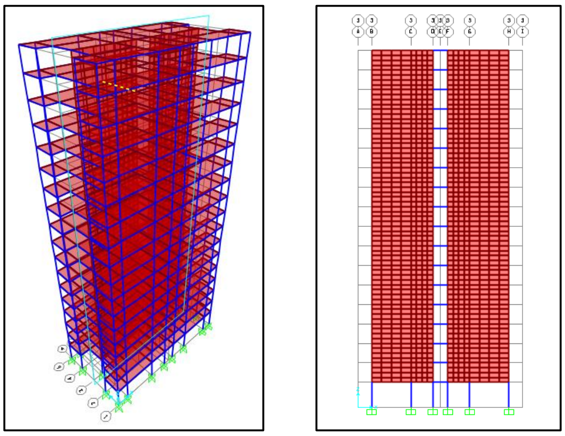
(a) (b)

Figure 2. Model of bare frame, where (a) 3D view and (b) 2D view



(a) (b)

Figure 3. Model of infilled frame, where (a) 3D view and (b) 2D view



(a) (b)

Figure 4. Model of shear wall, where (a) 3D view and (b) 2D view

2.3. Pushover analysis

Pushover analysis is the preferred method for seismic performance evaluation of structures and to identify the mode of final failure. It is the process of the structure being loaded horizontally with an incremental specified loading pattern. The lateral load is applied to the center of mass of the building until a certain level of deformation is reached. For pushover analysis, frames are modelled as beam elements with lumped plasticity using plastic hinges. From the analysis result, a combination of building capacity curve and seismic demand curve also known as demand capacity spectrum can be produced. The building capacity curve are obtained from pushover analysis, while seismic demand curve were determined from the draft of National Annex of Malaysia (2015) [11]. The intersection point between the two curves indicates the performance point of building.

2.4. Plastic hinge

The moment hinges (M3) were assigned to the beams at the two ends and the interacting (P-M2-M3) hinges assigned for all the columns at its upper and lower ends. Axial hinges (P) were assigned to the brick masonry strut element. An example of force-deformation relation for concrete hinges is as shown in Figure 5. The whole curve can be divided in four phases, which point A to B represent the elastic phase, where B is the effective yield point. The yield point was defined as the moment at which the strain in the longitudinal reinforcement reaches the yield strain. The strain hardening phase is represented by point B to C, where the slope is usually 0 to 10% of the elastic slope. The strength degrades significantly at point D, however beyond point E, the strength is reduced to zero. Between point B to C, the performance of the structural members can be evaluated based on the different levels, namely immediate occupancy (IO), life safety (LS) and collapse prevention (CP). They indicate the state of hinges.

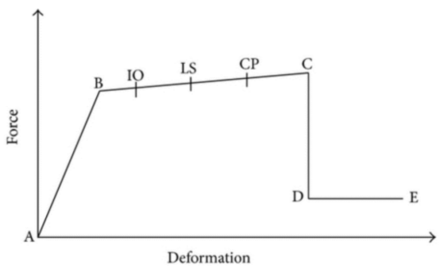


Figure 5. Force-deformation relation for concrete hinges

3. Results and discussions

3.1. Maximum load and displacement

Table 1 shows the maximum loads and displacements for bare frame, infilled frame and shear wall-frame. Loads cause stresses, deformations and displacement in structures. After reaching maximum load, frames may lost its load carrying capacity and cause structural failure. It also shows the difference of these loads and displacement with bare frame in terms of percentage where negative sign indicates decrease in value, and vice versa.

Table 1. Comparisons of different lateral load resisting mechanisms

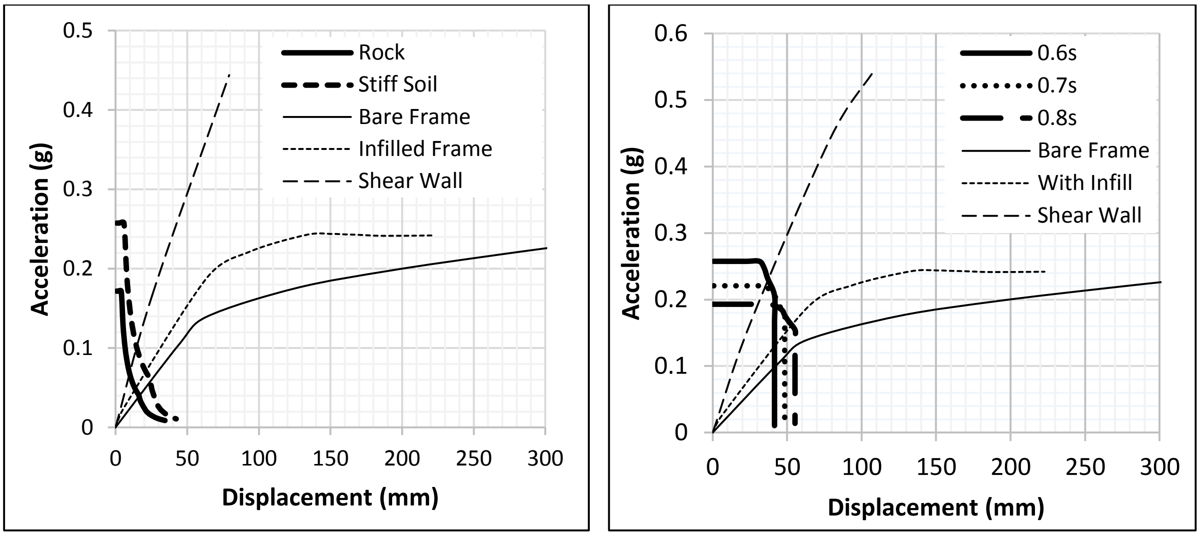
Type of lateral load resisting mechanisms	Maximum load (kN)	Difference with bare frame (%)	Maximum displacement (mm)	Difference with bare frame (%)
Bare frame	5,292	-	621	-
Infilled frame	5,489	7.3	541	-27.5
Shear wall-frame	11,539	68.2	119	-86.5

According to the table, the maximum load in infilled frame is 5489kN, which is increased by 7% more than that of bare frame. Meanwhile, shear wall can carry 68% higher load compared to bare frame with maximum capacity of 11539kN. As shear wall have higher stiffness compared to bare frame, it will resist larger lateral load, however, its maximum displacement is reduced by 86%. Infilled frame, on the other hand, is not as stiff as the shear wall and its maximum displacement is 27% less than the bare frame. This translate to ductility of approximately 7 for bare frame, 3 for infill brickwall and 1.5 for shear wall. This shows that the shear wall, eventhough have higher stiffness, will be more brittle compared to the more flexible structures. Modelling infill brickwall is necessary to ensure that the actual building capacity can be determined, as it changes the maximum load and displacement of the building significantly.

3.2. Demand capacity spectrum

Based on the draft of National Annex (2015) [11], the soil is divided into 3 categories, namely rock, stiff soil and flexible soil. For flexible soil, the demand curve is depended on the period of the soil, ranging from 0.6s to 0.8s. Sabah have higher seismic demand unlike Peninsular Malaysia, due to its proximity to local seismic faults.

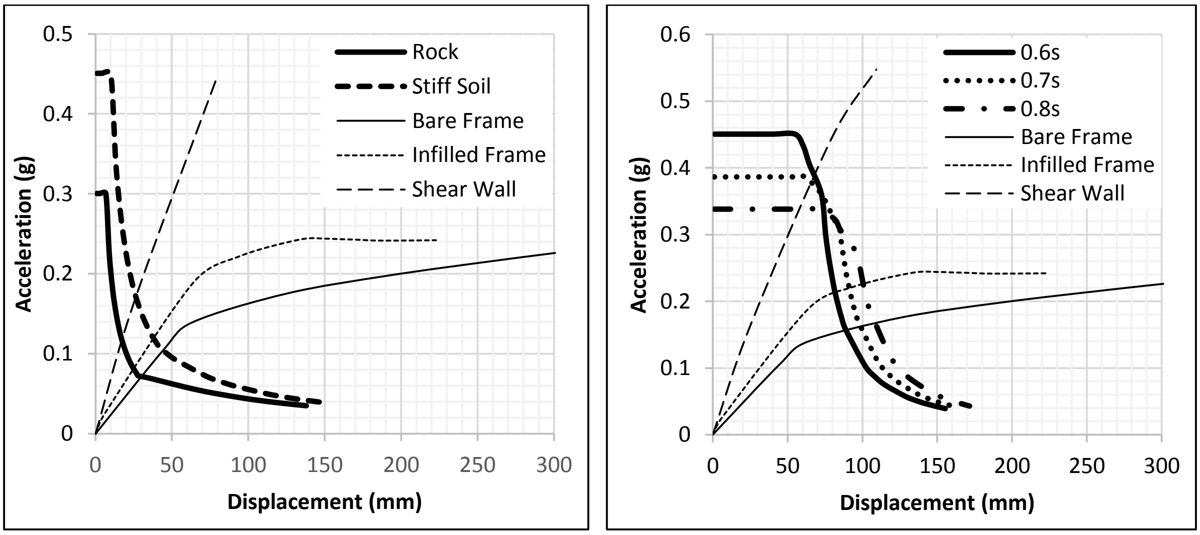
The seismic demand curve for Peninsular Malaysia is compared to the capacity of the structure using capacity-demand curve. Figure 6(a) shows the capacity-demand curve for rock and stiff soil, while Figure 6(b) shows the curve for flexible soil.



(a) (b)

Figure 6. Capacity-demand curves for Peninsular Malaysia for (a) rock and stiff soil, and (b) flexible soil with periods of 0.6s to 0.8s

The seismic demand curve for Sabah is compared to the capacity of the structure using capacity-demand curve. Figure 7(a) shows the capacity-demand curve for rock and stiff soil, while Figure 7(b) shows the curve for flexible soil.



(a) (b)

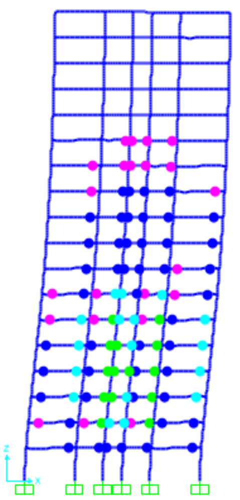
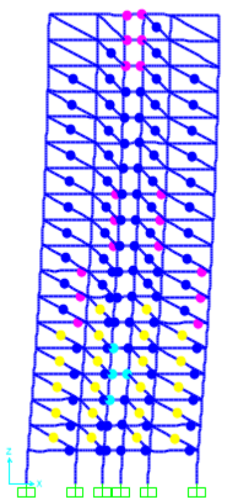
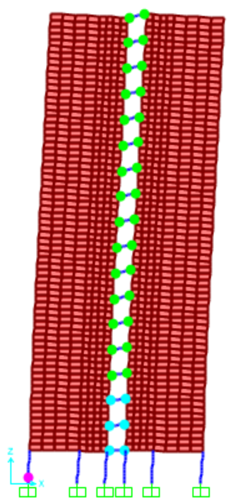
Figure 7. Capacity-demand curves for Sabah for (a) rock and stiff soil, and (b) flexible soil with periods of 0.6s to 0.8s

From dynamic analysis, the period of the bare frame structure is found to be 1.28s, infilled wall is 0.96s and shear wall is 0.77s. This indicates the increase in stiffness provided by each lateral resisting system, translated in the slope of the capacity curves in the figures. Based on Figures 6 and 7, it can be observed that building with 18-storey height will be effected when it rests on flexible soil with high period. This is because this building has relatively higher natural period that coincide with the period of stiff soil, causing amplification to the motion. From the same figure, it shows that all seismic capacity for the three different lateral load-resisting mechanisms exceeds the anticipated seismic demand. The performance point indicate the point where the demand and capacity curves intersect. For Peninsular Malaysia, at the performance point of bare frame on flexible soil with period of 0.7s, out of the 199 hinges formed, 189 hinges are in B to IO stage and 10 hinges in IO to LS stage. No hinge formation occurs in columns, showing that eventhough building was not designed for earthquake, it still exhibit the desirable weak beam- strong column behavior.

The type of lateral load resisting mechanism will affect the period of the structure, and consequently the type of soil that will give the highest motion. This is evident for building in Sabah, where the shear wall building with lower period will be mostly effected by soil period of 0.6s, while higher period buildings (bare frame and infill brickwall) will be effected by higher soil period (0.8s).

For Sabah, the hinge formation at the performance point are shows in Table 2 for different structure types. In bare frame, 14 hinges in beams have reached CP stage, indicating significant damages. However, no hinge occur in the columns. In the infilled frame, almost all of the infill brickwall failed in shear sliding, indicated by the hinge formation in the walls. All of the beams connecting the infills hinges and reaches B to IO stage. For the shear wall, hinges formed in all of the beams between the walls, while one hinges is formed in the bottom columns. Due to its high stiffness, shear wall structure will have to resist higher lateral load. Buildings with soft story, evident in most of residential building in Malaysia (where the wall is terminated at the second floor), will be prone to structural damages of column at the bottom floors. Hence, thorough study is needed to assess the capacity of such buildings.

Table 2. Hinge formation at performance point in Sabah

Bare Frame (0.16g ,100mm)	Infilled Frame (0.22g , 90mm)	Shear Wall (0.38g , 65mm,)
		

3.3. Drift limit

Table 3 shows the building drift index for bare frame, infilled frame and shear wall structures. Drift index is a ratio of maximum deflection to total building height and it is taken at the performance point. It is checked with accepted drift index limit of 0.002 or 1/500.

Table 3. The drift limit index for the building

Type of lateral load resisting mechanisms	Peninsular Malaysia		Sabah	
	Displacement (mm)	Building drift (10^{-3})	Displacement (mm)	Building drift (10^{-3})
Bare frame	50	1.05	100	2.11
Infilled frame	50	1.05	90	1.90
Shear wall-frame	35	0.74	65	1.37

According to the table, the drift limit index for all three different systems located in Peninsular Malaysia were less than 1/500. However for Sabah, the drift limit index for bare frame exceed the accepted drift limit index. This is because higher seismic demand in Sabah causes significant damage to the building.

4. Conclusions

In this study, the seismic responses of 18-storey residential building with three different lateral load resisting mechanisms have been investigated and the objectives of this study have been achieved. Therefore, following are the conclusions from this study:

1. The nonlinear pushover analysis has been employed in this study to determine the capacity of the existing building of 18-storey height located in Kuala Lumpur, which performed by using SAP2000 software. The performance of three different cases of bare frame, infilled frame and shear wall frame were different in terms of damage level.
2. Through the model of existing structure in this study, the structure has a good resistance and capable to withstand the seismic load as the capacity curve of building intersects the demand curve, for both Peninsular Malaysia and Sabah. In addition, Sabah have higher seismic demand due to its proximity to local earthquake faults.
3. It was observed that interaction of infill wall and shear wall in RC frame increased the stiffness and reduced the maximum displacement and ductility of the building. The displacement capacity of infilled wall and shear wall reduced by 27.5% and 86.5% of bare frame, while the strength increased by 7.3% and 68.2% compared to bare frame.
4. Modelling the infill brickwall is important when determining its lateral load capacity as it significantly changes the capacity, stiffness and ductility of buildings.
5. In bare frame, the plastic hinges occur in the beams first, showing a desirable weak beam – strong column. For infilled wall, the walls will resist the lateral load and fail in sliding shear. Lastly for shear wall frame, they behaviour is more brittle, causing failure of columns at very small displacement. Thus, soft story mechanism has to be taken into consideration for analysis of residential buildings in Malaysia.
6. Building with 18-storey height will be effected when it rests on flexible soil with high period. This is because this building has relatively higher natural period that coincide with the period of flexible soil, causing amplification to the motion.

References

[1] Eurocode 8. (2004). Design of structures for earthquake resistance. European Committee for Standardization.
[2] Magenes G. and Pampanin S. (2004). Seismic response of gravity-load design frames with masonry infills. 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada.
[3] Bracci, J. M., Reinhorn, A. M. and Mander, J. B., (1996) “Seismic Resistance of Reinforced Concrete Frame Structures Designed for Gravity Loads: Performance of Structural System”, ACI Structural J., V. 92, No. 5, 1995, pp. 597-609.

[4] Perrone, D., Leone, M., & Aiello, M. A. (2016). Evaluation of the infill influence on the elastic period of existing RC frames. Engineering Structures, 123, 419–433.
[5] Balendra, T., Tan, K. H., & Kong, S. K. (1999). Vulnerability of reinforced concrete frames in low seismic region, when designed according to BS 8110. Earthquake engineering and structural dynamics, 28, 1361-1381.
[6] BS 8110. (1997). Structural use of concrete. Code of practice for design and construction. British Standard.
[7] Hau, K. K. (2003). Overstrength and ductility of reinforced concrete shear-wall frame buildings not designed for seismic loads. PhD Thesis, National University of Singapore.
[8] SAP2000 V5.1. (2011). Computers and Structures, Inc., Berkeley, CA.
[9] FEMA-356. (1997). Prestandard and Commentary for the Seismic Rehabilitation of Buildings. Federal Emergency Management Agency, Washington, D.C.
[10] Kaushik, H. B., Rai, D. C., & Jain, S. K. (2007). Stress-strain characteristics of clay brick masonry under uniaxial compression. Journal of Materials in Civil Engineering (ASCE), 738-739.
[11] Department of Standards Malaysia (2015). Draft Malaysian Standard. Malaysia National Annex to MS EN 1998-1: 2015, Eurocode 8: Design of structures for earthquake resistance Part 1.