Seismic detailing, a compromised principal for seismic design in Malaysia

Mohammadreza Vafaei [1, a*], Sophia C. Alih [1,b]

[1]Faculty of Civil Engineering, Universiti Teknologi Malaysia, Malaysia

[a*]vafaei@utm.my, [b]sophiacalih@utm.my

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Abstract. The main aim of seismic design is to estimate seismic induced actions on structural components and ensure that the seismic resistance systems can cater such actions safely. This has been achieved through either force based concept, practiced in conventional building codes, or performance based seismic design approaches that have been implanted in modern seismic codes. Either of aforementioned methods requires specific structural detailings in order to comply with the expected structural safety levels. Seismic detailing imposes limitaions on the size, shape and reinforcement ratio of concrete beams, columns, shear walls, etc. This study is intended to bring forward some of the important seismic detailings which are neglected in the current construction of buildings in Malaysia. It is shown in this paper that compromise on such important details leads to lower structural performance level even if the seismic actions have been considered in the design. It is also concluded that, a structure which is not designed for seismic actions but has been detailed properly can reach to a significantly safer performance level.

Introduction

Earthquakes are one of the devastating natural phenomena that cause damages to structural and infra-structures. Huge amount of life and economic losses has been reported based on the previous earthquakes. In 2011, according to the analysis conducted by the Center for Disaster Management and Risk Reduction Technology (CEDIM), more than 20,000 people have died, and almost 365 billion U.S dollar of economic losses have been reported due to this natural hazard. Earthquakes are still unpredictable and also cannot be avoided. However, structural damage and social losses from the earthquakes can be mitigated if structures or buildings are able to withstand strong excitations.

Malaysia is located at the tectonically inactive Sunda shelf and situated between major boundaries of tectonic plates; Australia plate and Eurasian plate in the west of Malaysia and Philippine Sea plate and Eurasian plate in the East of Malaysia. Even though the distances from the active seismic sources are more than 300km away, the tremor of earthquakes from Sumatra island of Indonesia and Philippine sometimes can be felt in Malaysia. Several tremors in Malaysia have been recorded. The strongest earthquake recorded in June 2015 with the magnitude of 6 on the Richter scale at Kundasang, Sabah. This earthquake imposed significant structural and nonstructural damages to some public buildings in Ranau and Kundasang. Considering the intensity of this earthquake, the observed damages after the earthquake implied that the damaged buildings did not follow recommendations of seismic codes. This article is intended to unveil such compromised seismic detailing in the construction of structures in Malaysia. It should be mentioned that, at the time of preparation of this paper, most of practice engineers in Malaysia do not consider seismic actions in the design of structures. This article shows that a structure which is not designed for seismic actions but has been detailed properly for higher level of ductility can reach to a significantly safer performance level. Such proper seismic detailing can be readily applied to all new structures in Malaysia even if the design engineers do not have strong background in earthquake engineering.

Compromised seismic detailing in construction industry in Malaysia

Seismic design of structures has two distinct phases. At the first phase, seismic actions are calculated using a specific seismic code. Based on the type and geometry of structures a proper analyzing method is selected and after calculating the seismic base shear it is distributed among structural elements. Seismic actions increase internal forces which result in bigger sizes for beams, columns and shear walls while increasing their reinforcement ratios, as well. The second phase of the seismic design controls the ductility of structural elements through limiting minimum and maximum reinforcement ratios, allowable heights, dimensions and thicknesses of beams, columns and shear walls, etc. In other words, the second phase determines how to detail out structural components in order to make the elements ductile and avoid brittle failures, and the first phase guaranties that enough strength and stiffness is provided. It is worth mentioning that, a seismic design that has not completed the two aforementioned phases can hardly attain the code specified seismic performance levels. While the first phase of seismic design has received great attention by structural engineers in Malaysia the second phase is often neglected.

Confinement through closely spaced stirrups

Providing sufficient confinement in the critical zones of beams, columns and walls through closely spaced stirrups has been addressed by many researchers [1] and its important role has been more pronounced by seismic design codes [2]. However, in the current practice of construction in Malaysia such important ductility criterion is ignored. In order to show the significant role of confinement in the seismic behavior of structures, a 4-storey moment resistance frame (MRF) (shown in Figure 1) is designed for two different load combinations. The first load combination only includes gravity loads (dead load and live load). The required sizes and reinforcement ratios for beams and columns were calculated using BS 8110 [3]. The applied dead and live load on beams at all levels were 25kN/m and 10kN/m, respectively. In the second load combination, in addition to the gravity loads seismic load was also included. Only 10% of effective seismic mass were accounted for calculation of seismic loads. Equivalent static approach recommended in UBC 97 [4] was selected to calculate seismic base shear and applied forces at each level. Tables 1 and 2 display the obtained sizes for beams and columns and display the required reinforcement ratios for the first and second type of load combinations, respectively. It is evident that inclusion of seismic actions in the design of the frame has significantly increased the size of columns and reinforcement ratios. The increase in the size of columns ensures enough lateral stiffness to avoid damage to nonstructural components after frequent low to moderate earthquakes. However, such increase in the sizes and reinforcement ratios may not ensure a ductile behavior during strong ground motions. Nonlinear Pushover analysis [5] was employed to draw capacity curves of the frame under three different conditions including; i) unconfined beams and columns but not designed for earthquake loads, ii) unconfined beams and columns but designed for earthquake loads, and iii) confined beams and columns but not designed for earthquake loads . From the obtained capacity curves, the displacement ductility (defined as displacement at ultimate strength over displacement at the significant yield) of each case can be calculated and compared. As Figure 2 shows when the frame is designed for seismic load it provides higher strength compared to the time in which only gravity loads are used to obtain the sizes of beams and columns. It can also be seen that, confinement alone has negligible effect on the ultimate strength of the frame. However, as can be seen from Figure 2 and Table 3 confinement of beams and columns significantly increases the displacement ductility. Table 3 shows when the frame is designed for earthquake loads but does not comply with the confinement conditions its displacement ductility is slightly more than the time in which the frame is not designed for earthquake load. On the other hand, a frame which is not designed for earthquake load but conform to confinement conditions provides the highest displacement ductility. This simple example can demonstrate the importance of confinement of beams and columns in the seismic behavior of MRF frames. Figure 3 displays a damaged column from the recent earthquake in Sabah due to not complying with confinement condition.

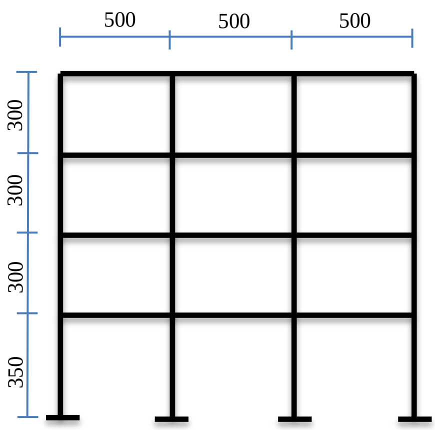

Figure 1: A 4-storey moment resistance concrete frame studied in this research.

Table 1: Size and reinforcment of columns and beams obtained from first loading condition.

Storey level	Column Size (cm) and reinforcement ratio (Exterior)	Column Size (cm) and reinforcement ratio (Interior)	Beam Size (cm) and max. reinforcement ratio
First Storey	30x30x2.79%	30x30x1.79%	40x30x1.06%
Second Storey	30x30x2.79%	30x30x1.79%	40x30x1.0%
Third Storey	30x30x2.79%	30x30x1.37%	40x30x1.0%
Fourth Storey	30x30x2.79%	30x30x1.37%	40x30x1.05%

Table 2: Size and reinforcment of columns and beams obtained from second loading condition.

Storey level	Column Size (cm) and reinforcement ratio (Exterior)	Column Size (cm) and reinforcement ratio (Interior)	Beam Size (cm) and max. reinforcement ratio
First Storey	40x35x4.4%	40x35x4.4%	40x30x1.53%
Second Storey	35x35x3.2%	35x35x3.2%	40x30x1.5%
Third Storey	35x35x3.2%	35x35x2%	40x30x1.22%
Fourth Storey	35x35x3.2%	35x35x2%	40x30x1.10%

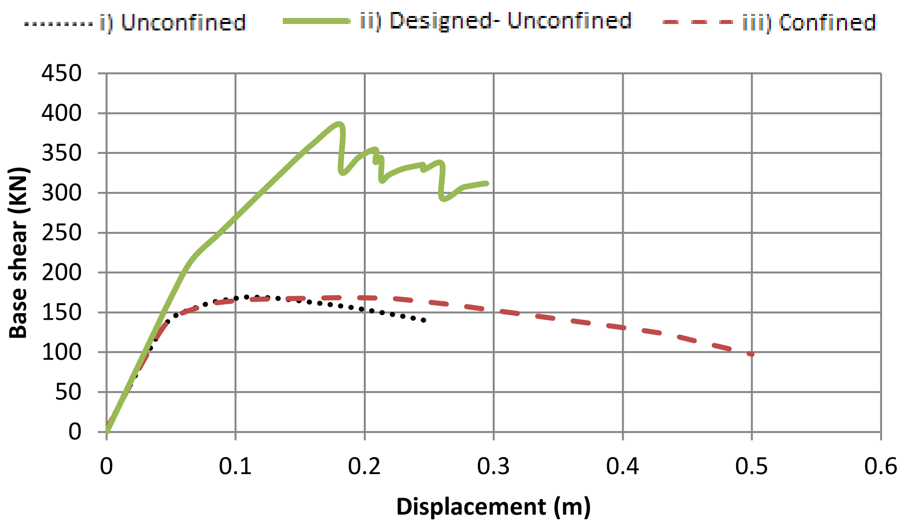

Figure 2: Capacity curve of the studied MRF frame for different conditions.

Table 3: Displacement ductility of the studied frame for different conditions.

	i) Unconfined-Not designed for earthquake	ii) Unconfined- designed for earthquake	iii) Confined- not designed for earthquake
Displacement Ductility	2	2.78	4.1

Figure 3: Damaged column in Sabah earthquake due to lack of confinement.

Soft-Story Phenomena

When the stiffness of one story in a building is significantly less than its adjacent stories during seismic excitations, displacement demand in that story increases tremendously which can results in collapse of that story [6]. In Malaysia, buildings can suffer from the soft-story phenomena mostly due to their architectural design in which infill panels in the ground floor are removed to provide free span for car's parking. Figure 4 displays one of such buildings along with the seismic induced damages to its nonstructural and structural elements after Sabah earthquake. Soft-story phenomena could be readily avoided if the brick walls were added between columns at the ground floor. It should be mentioned that, due to moderate intensity of earthquake this building could survive the soft-story phenomena.

Figure 4: (a) Building with the soft-story problem, (b) Damage to its infill panel and columns.

Anchorage of nonstructural components

Nonstructural components like ceilings, partitions, parapets, etc. are elements that do not participate as a main member in lateral load resistant systems. Extensive studies have been carried out by researchers to understand seismic behavior of nonstructural components. Findings indicate that they can be classified into deformation and acceleration sensitive groups [5]. For example ceilings are considered to be more sensitive to acceleration while partitions are sensitive to deformation. It is worth mentioning that despite not participating in the lateral load resistant system, failure of nonstructural components can results in fatalities and economical losses. Seismic codes have specific regulations for the design of nonstructural components against seismic loads which lead to a satisfactory anchorage. Observations from past earthquakes show that even during moderate earthquakes nonstructural components that have not been anchored properly can fail. Figure 5 displays the failure of ceilings and partitions during Sabah earthquake.

Figure 5 Damage to nonstructural components (a) separation of masonry brick wall from the column, (b) falling of ceilings during Sabah earthquake.

Conclusion

This article addressed some of compromised seismic detailing in the current practice of construction industry in Malaysia. Necessity of confinement in critical zones of beams, columns and walls, avoidance from soft-story phenomena and providing proper anchorage for non-structural components were discussed through observed damages in the recent earthquake in Sabah. It was shown that conforming to confinement condition in beams and columns can significantly improve displacement ductility of a MRF even if it was not designed for seismic actions. On the other hand, it was found that without proper confinement detailing, MRF that has been designed for earthquake load may not perform well against seismic loads.

References

[1] Somma, Giuliana, Alessandro Pieretto, Tiziana Rossetto, and Damian N. Grant. "RC beam to column connection failure assessment and limit state design." *Materials and Structures* 48(4) (2015). 1215-1231.

[2] ACI 318. Building code requirements for structural concrete and commentary. American Concrete Institute, Farmington Hills, MI. (2011).

[3] British Standard Institute BS 8110.Structural use of concrete-Part 1: Code of practice for design and construction. (1997).

[4] Uniform Building Code, UBC-97. American Association of Building Officials, Whittier, CA, (1997).

[5] Federal Emergency Management Agency (FEMA). Pre-standard and Commentary for the Seismic Rehabilitation of Buildings, FEMA 356, Washington, D.C. (2000).

[6] Agha Beigi, H., Christopoulos, C., Sullivan, T., & Calvi, M. Seismic response of a case study soft story frame retrofitted using a GIB system. *Earthquake Engineering & Structural Dynamics*, (2015). *44*(7), 997-1014.