Chapter 12
Seismic Vulnerability Assessment of Existing RC Buildings in Ranau, Sabah Malaysia

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Abstract Malaysia is located in a low seismicity area, thus the buildings in Malaysia were not designed as seismic resistant structures. However, on 5 June 2015, Malaysian was been shocked by the 5.9M Ranau Earthquake which killed 18 climbers of 5 nationalities and was recorded as the largest earthquake in Malaysia since 1976. The earthquake affected some buildings in the nearby area. The damaged associated with these events reflected the construction practice in Malaysia. The low awareness among the general public towards structural safety and the inability of regulatory bodies and technical professionals in maintaining quality standards in constructions has created an urgent need to educate the leaders, public, city planners, architects and the engineering professionals about the consequences of earthquakes. As a step in understanding the seismic risk to buildings in Malaysia, there is a need to determine the vulnerability of existing buildings, particularly in Ranau, Sabah, as this region has been identified as high seismicity area in Malaysia. When classes of buildings are considered for risk assessment, the vulnerability can be established in terms of their structural characteristics, and suitable modifiers to the vulnerability function can be established in terms of their geometrical characteristics. In this study, the seismic capacity of the selected existing RC buildings has been evaluated through nonlinear dynamic simulations. Seismic response has been analysed, considering various peaks and integral intensity measures and various response parameters, such as ductility. A structural performance and damage level for each studied type are presented.

Keywords RC buildings · Earthquake affected buildings · Risk assessment · Numerical analysis

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12.1 Introduction

On Friday, 5 June 2015, a 5.9 Richter scale earthquake rocked Sabah as shown in Fig. 1.1. The earthquake, with a depth of 10 km, occurred at 6.1°N 116.6°E, 16 km from Ranau, Sabah and the tremors were felt throughout Sabah, particularly Kundasang, Tambunan, Pedalaman, Tuaran, Kota Kinabalu and Kota Belud (Felix Tongkul 2016). The location and intensity of at the Ranau area has been predicted in the Seismic Hazard Map established in 2005 (Adnan et al. 2005; Harith et al. 2015)

The earthquake also shook Mount Kinabalu, Sabah the highest mountain in Malaysia. A total of 18 people of 5 nationalities (Singaporean, Malaysian, Chinese, Japanese and Filipino) was confirmed dead. The victims, climbers and a mountain guide died due to severe injuries caused by massive falling rocks and boulders induced by the ground motion. The 5.9M Ranau Earthquake was recorded as causing the highest number of casualties and greatest structural damage in Malaysian history. Cracks were reported in residential buildings, commercial buildings, resorts and hotels as well as places of worship. Even infrastructures, which are normally employed in an emergency, such as the hospital, schools and police department were not spared. Figure 1.2 shows the damage found on some buildings. The most serious damage occurred in the rest house near the summit of Mount Kinabalu (Fig. 1.2b) and buildings in Kota Belut and Tuaran were similarly affected by the earthquake. Typical types of damage reported were brick wall shear failure cracks, cracks in columns and beams, roof failure, failure of supporting columns or tilts, concrete spalling and shattered windows (ATC, 1996 and American Society of Civil Engineer 2013).
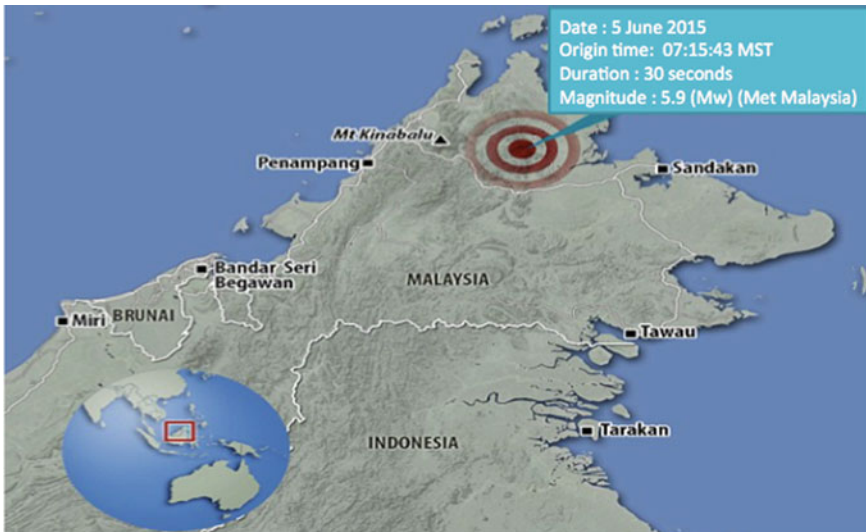

Fig. 12.1 5.9M Ranau Earthquake, Sabah on 5 June 2015 (Felix Tongkul 2016)

<div align="center">(a)   (b)</div>

Fig. 12.2 Damage to buildings due to Ranau Earthquake **a** shear failure at residential, **b** column failure at rest house

There were worries about whether the continuous swaying of buildings and vibration of some parts of the non-structural elements, such as doors and windows, would happen continuously and affect the integrity of the whole buildings. Therefore, the objectives of this study are to simulate the earthquake loads acting on the existing reinforced concrete buildings in the Ranau area and study their effects through finite element modelling to develop demand–capacity curves in order to investigate the vulnerability of the building due to earthquake motion.

12.2   Numerical Analysis

Nonlinear analysis using the ETABS building analysis and design program, SAP2000 Integrated Structural Analysis and Design Software, was used to conduct the study. In addition, the model also performed the demand and capacity analyses (DCA) (Fardis et al. 2005). Three existing reinforced concrete buildings in the Ranau area were modelled to represent the building main frames, according to their structural drawings and material properties. These were: Building 1; Asrama Perempuan, SMK Mat Salleh, Building 2; Asrama Lelaki, SMK Mat Salleh and Building 3; Kompleks Pentadbiran Kerajaan Persekutuan.

The earthquake loads were then statically combined with the dead and live loads to estimate the structural adequacy of the building (Copra and Goel 1999). Response spectrum analysis was implemented to study the performance of the building subjected to earthquake. The model was analysed nonlinearly by applying a series of seismic loadings to determine the failure mechanism. Nonlinear static (pushover) analysis was carried out to estimate the strength, ductility and expected performance of the designed buildings in finite element modelling (FEM) analysis. The accuracy of pushover analysis depends on a number of factors including the distribution of the lateral load and type of buildings. The procedure used to obtain

Table 12.1 Mode shapes

No.	Building name	Mode shapes (sec) and directions			
		1	2	3	4
1	Asrama SMK Mat Salleh—Asrama Perempuan Ranau	0.60y	0.59t	0.39x	0.24t
2	Asrama SMK Mat Salleh—Asrama Lelaki Ranau	0.87y	0.86t	0.70x	0.29t
3	Kompleks Pentadbiran Kerajaan Persekutuan, Ranau	0.84x	0.79y	0.70r	0.32t

Note x = x translational direction; y = y translational direction, r = random, t = torsional

the performance point was represented by the expected peak displacement of the structure, the point of intersection between the capacity spectrum and demand spectrum. The analysis was able to observe the earthquake-resistant design and detailing by monitoring the strength and ductility capacity of the building.

12.3 Results and Discussion

12.3.1 Free Vibration Analysis

The free vibration study concluded that the dynamic characteristics of the finite element models are acceptable when compared with the equations in Euro Code 8 (EuroCode8) and the International Building Code (IBC). The summarized values of the first four mode shapes are listed in Table 3.1 and are used for verifying the dynamic behaviour of the models and their suitability for further analysis.

12.3.2 Linear Analysis

12.3.2.1 Base Shear Force of Buildings

The performance of buildings in linear capacity was analysed according to Eurocode 8: (1) static lateral force analysis method (SLA) and (2) response spectra analysis method (RSA). The intention of these analyses at the linear stage was to verify the adequacy of the beams' and columns' capacity against the internal forces developed under both static and dynamic analyses. The percentage of building weights is mostly higher from previous study due to the high recommended PGA values of 0.14 and 0.18 g.

Table 12.2 Demand–capacity

No.	Building name	Demand–capacity	
		2D	3D
1	Asrama SMK Mat Salleh—Asrama Perempuan Ranau	OP	IO
2	Asrama SMK Mat Salleh—Asrama Lelaki Ranau	OP	IO
3	Kompleks Pentadbiran Kerajaan Persekutuan, Ranau	OP	OP

Generally, the results from response spectrum analysis show higher values in moment and axial forces for columns, in comparison with lateral load analysis. The results for the beams also show a similar trend. These phenomena could be due to the higher contribution of the mode shapes in the responses for complicated structures, which is not captured in the lateral load analysis. It indicates that the structural members may be cracked and damaged under earthquake loading.

Linear static and dynamic analyses were performed in this study. The buildings were identified to be sufficient to take earthquake forces, based on the locations of the buildings in Sabah. In general, columns are performed under the allowable limits of bending and shear. Nevertheless, the beams of the buildings require stronger sections to take bending forces from the earthquake loads.

12.3.3 Nonlinear Analysis

From the demand–capacity results shown in Table 3.2, it can be concluded that there are no indications that major cracks will occur. However, minor cracks will occur to almost all buildings except for Building No. 3.

12.4 Conclusion

For an earthquake intensity level in Sabah of about 0.20 g, it is predicted that buildings will not have any problem with the seismic load from the six time-histories used for the analyses. They are all within OP level.

12.5 Recommendations

Further analyses need to be performed, especially to study the behaviour of retrofitted buildings and compared with the current conditions. In summary, buildings with developed plastic hinge rotations at the bottom of columns at ground level are proposed to be installed with bracings or dampers at the building bottom levels, in their weak frame directions only.

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