Structural Response of Building in Ranau, Kota Kinabalu and Lahad Datu, Sabah Under Different Earthquake Scenarios

Zheng Yang Khoo and Tze Liang Lau

Abstract In June 2015 Malaysia experienced the strongest earthquake in recent years as a magnitude 6.0 earthquake struck Ranau and damaged many buildings in the region of Ranau and Kundasang. Since this earthquake event, seismic design for East Malaysia has become a concern for many engineers and researchers to prevent seismic damage of important structures and infrastructures in the future. This paper covers the structural analysis of a typical four storey reinforced concrete building in three main cities of Sabah namely Ranau, Kota Kinabalu and Lahad Datu. Four earthquake scenarios were considered in the structural analysis including two largest historical earthquakes and two forecast earthquakes. It is found that out of the three cities included in this study, building in Lahad Datu has the most drastic structural response followed by Ranau and Kota Kinabalu. Based on the result of this study, buildings in Ranau and Lahad Datu is expected to experience damage in forecast earthquake. Assessment and retrofitting of important building is required to increase seismic capacity of buildings.

Keywords Earthquake · Seismic · Sabah · Structural response · Building

1 Introduction

Malaysia is regarded as a low seismicity region as it is located outside of the pacific ring of fire. However, in June 2015 Malaysia experienced the strongest earthquake in recent years as 2015 Sabah earthquake struck Ranau, Sabah with a moment magnitude of 6.0. The earthquake resulted 18 fatalities and stranded more than a hundred climbers on Mount Kinabalu. Many buildings in region of Ranau and

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Kundasang suffered significant damage. While the levels of seismicity are low in Peninsular Malaysia, the state of Sabah has long been known as the most tectonically active area in Malaysia due to its relative proximity to the major plate boundary faults in the Philippines and Sulawesi active subduction zones [12]. Study done by Cheng [1] shows that Sandakan, Semporna and Celebes Sea have reached a critical point of accumulating seismic energy. If any trigger factor appears, there is a high possibility for moderate to severe earthquakes to occur. Additionally, there will be high earthquake potential in Lahad Datu, Tawau, Kudat, Ranau, Tarakan and Sitangkai from year 2015 to year 2022 [1].

Following the 5th June 2015 and 8th March 2018 earthquakes that occurred in Sabah with magnitude 6.0 and 5.2 respectively, it is likely that Sabah will experience strong shaking in the future. This is due to the rearrangement of stresses in the crust which alters the shear and normal stress on surrounding faults which can lead the possibility of a subsequent large earthquake occurring [4–10].

In this study, a linear time history analysis was carried out to study structural response of building in Ranau, Kota Kinabalu and Lahad Datu under different seismic scenarios using finite element software ETABS.

2 Linear Time History Analysis of Building in Ranau, Kota Kinabalu and Lahad Datu

2.1 Earthquake Scenarios

Four earthquake scenarios were considered in the structural analysis of building in Ranau, Kota Kinabalu and Lahad Datu. The earthquake scenarios consist of two historical earthquake and two forecast earthquake in Sabah as listed below:

Earthquake scenario 1: 5th June 2015, magnitude 6.0 Ranau Earthquake
Earthquake scenario 2: 26th July 1976, magnitude 6.2 Lahad Datu Earthquake
Earthquake scenario 3: Magnitude 6.5 forecast earthquake in Ranau
Earthquake scenario 4: Magnitude 6.7 forecast earthquake in Lahad Datu.

2.2 Estimation of Ground Motion Parameter

Peak ground acceleration (PGA) was used to define the ground motion in Ranau, Kota Kinabalu and Lahad Datu. Ground motion prediction equation (GMPE) namely the Fukushima and Tanaka [2] model was used to estimate PGA in respective cities. Earthquake source parameter i.e. magnitude and source-to-site distance were used as input parameters for the estimation of PGA at site using the Fukushima and Tanaka [2] model. The Fukushima and Tanaka [2] model was selected for use as it corresponds well with the actual recorded PGA data collected from local seismological stations [4]. The functional form of the Fukushima and Tanaka [2] model is shown in Eq. (1).

$$\log_{10} A = 0.41M - \log_{10}\left(R + 0.032 * 10^{0.41M}\right) - 0.0034R + 1.30 \qquad (1)$$

where,

A mean of the peak acceleration from the two horizontal components (cm/s^2)
R shortest distance between site and fault rupture (km)
M surface-wave magnitude
σ standard deviation = 0.21

The earthquake scenario, location, epicentral distance, ground type and predicted PGA for each building in Ranau, Kota Kinabalu and Lahad Datu are summarized in Table 1. Actual time history of 5th June 2015 Ranau Earthquake was amplified to the predicted PGA for building under scenarios 1 and 3 in order to simulate condition similar to an actual earthquake. Similarly, actual time history of a magnitude 4.8 earthquake which occurred in Lahad Datu on 9th April 2008 was used for scenarios 2 and 4 by amplifying the ground motion amplitude up to the predicted PGA.

Table 1 Earthquake scenarios for time history analysis of building in Ranau, Kota Kinabalu and Lahad Datu

1	Earthquake scenario	5th June 2015 Ranau Earthquake
	Magnitude	6.0
	Latitude 1	6.0474° N
	Longitude 1	116.59° E
	Faulting mechanism	Strike slip
	Target location	SMK Ranau
	Latitude 2	5.9747° N
	Longitude 2	116.6741° E
	Epicentral distance	12.3 km
	Ground type	B (V_{S30} = 388 m/s)
	Predicted PGA	0.2475 g
2	Earthquake scenario	5th June 2015 Ranau Earthquake
	Magnitude	6.0
	Latitude 1	6.0474° N
	Longitude 1	116.59° E
	Faulting mechanism	Strike slip
	Target location	Kota Kinabalu city
	Latitude 2	5.9804° N
	Longitude 2	116.0735° E
	Epicentral distance	57.6 km
	Ground type	Unknown, assume B
	Predicted PGA	0.0559 g

(continued)

Table 1 (continued)

3	Earthquake scenario	26th July 1997 Lahad Datu earthquake
	Magnitude	6.2
	Latitude 1	4.956° N
	Longitude 1	118.308° E
	Faulting mechanism	Normal
	Target location	Lahad Datu town
	Latitude 2	5.0242° N
	Longitude 2	118.3307° E
	Epicentral distance	8.0 km
	Ground type	Unknown, assume B
	Predicted PGA	0.3476 g
4	Earthquake scenario	Magnitude 6.5 forecast earthquake in Ranau
	Magnitude	6.5
	Latitude 1	6.0474° N
	Longitude 1	116.59° E
	Faulting mechanism	Strike slip
	Target location	SMK Ranau
	Latitude 2	5.9747° N
	Longitude 2	116.6741° E
	Epicentral distance	12.3 km
	Ground type	B (V_{S30} = 388 m/s)
	Predicted PGA	0.3152 g
5	Earthquake scenario	Magnitude 6.5 forecast earthquake in Ranau
	Magnitude	6.5
	Latitude 1	6.0474° N
	Longitude 1	116.59° E
	Faulting mechanism	Strike slip
	Target location	Kota Kinabalu city
	Latitude 2	5.9804° N
	Longitude 2	116.0735° E
	Epicentral distance	57.6 km
	Ground type	Unknown, assume B
	Predicted PGA	0.0844 g
6	Earthquake scenario	Magnitude 6.7 forecast earthquake in Lahad Datu
	Magnitude	6.7
	Latitude 1	4.956° N
	Longitude 1	118.308° E
	Faulting mechanism	Normal
	Target location	Lahad Datu town
	Latitude 2	5.0242° N
	Longitude 2	118.3307° E
	Epicentral distance	8.0 km
	Ground type	Unknown, assume B
	Predicted PGA	0.4124 g

2.3 Building Model

A typical four storey residential building was used for the study of structural response of building in Ranau, Kota Kinabalu and Lahad Datu under seismic loading. The ETABS model of the four storey residential building is shown in Fig. 1. A linear time history analysis was carried out using the finite element software ETABS considering moderate seismic event and damage to the building is to be prevented. The building is modelled with moment resisting reinforced concrete frame with masonry infill walls. Contribution of lateral stiffness of the masonry infill walls to the structural was modelled using single equivalent diagonal struts method. The equivalent strut width was calculated using Eq. (2) developed by Tamboli and Umesh [11]. The material properties and element size of the model is shown in Table 2. The loading assigned to the building is shown in Table 3. This building model was chosen for study because low-rise to medium-rise buildings are more commonly found in many regions in East Malaysia. Many institutional as well as residential buildings are in the form of medium-rise buildings. In addition, high-rise buildings are designed to withstand wind load and thus have the capacity to resist lateral loading up to a certain degree and are less susceptible to light and

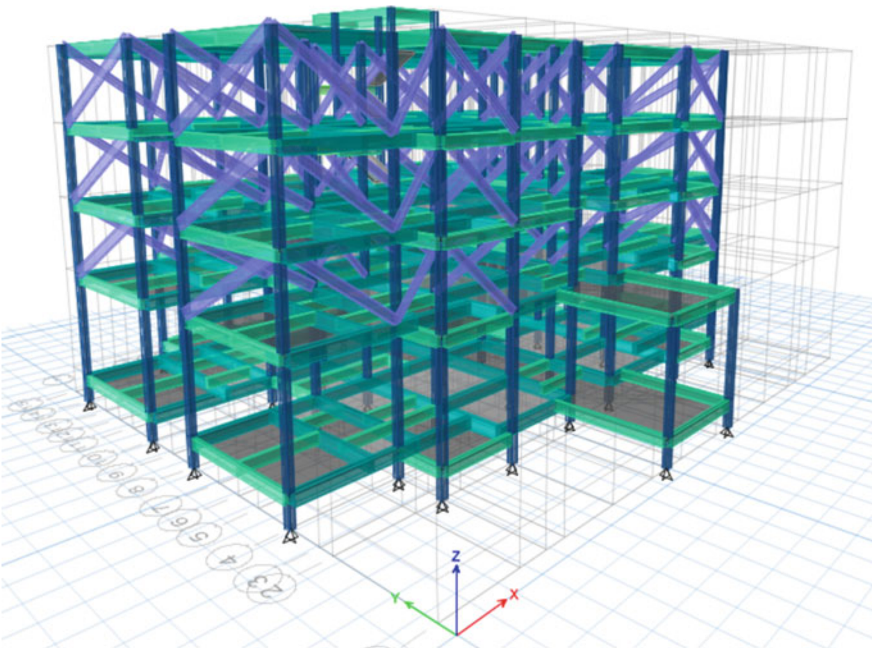

Fig. 1 Building model in ETABS

Table 2 Material properties and size of structural elements of model

Material properties	
Concrete	Grade: C30/37
	Compressive strength = 30 MPa
	Unit weight = 24 kN/m^3
	Modulus of elasticity = 33,000 MPa
	Poisson's ration = 0.2
Steel	Tensile strength = 460 MPa
	Unit weight = 77 kN/m^3
	Modulus of elasticity = 199,948 MPa
Infill wall strut	Modulus of elasticity = 14,000 MPa
Size of structural elements	
Column	250 mm × 250 mm
Primary beam	250 mm × 500 mm
Secondary beam	150 mm × 450 mm
Slab thickness	150 mm

moderate earthquakes. Low-rise and medium-rise buildings also have higher natural frequency compared to high-rise buildings, making them more prone to high frequency seismic waves at near source-to-site distances due to resonance effect.

$$\begin{aligned}&\text{Width of diagonal strut, } w = 0.175(\lambda' h)^{-0.4} d' \\ &\text{where} \\ &\text{Contact length parameter}(\lambda') = \sqrt{4\frac{E_i t \sin(2\theta)}{4E_h I_c h'}}\end{aligned} \quad (2)$$

E_i modulus of elasticity of infill material
E_f modulus of elasticity of frame material
L beam length between centre lines of columns
L' length of infill wall
h column height between centre line of beams
h' height of infill wall
I_c moment of inertia of column
t thickness of infill wall
d' diagonal length of strut
θ angle between diagonal of infill wall and the horizontal in radian.

3 Results and Discussion

3.1 Structural Response of Building in Ranau, Kota Kinabalu and Lahad Datu

Under the earthquake scenarios stated in Table 1, linear time history analysis was conducted using ETABS. The result of the structural response of a typical four storey residential building under seismic load in different cities in Sabah i.e. Ranau, Kota Kinabalu and Lahad Datu are shown in Figs. 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 and 13. Earthquake scenarios 1 and 2 are from actual past earthquake events in Sabah. Whereas scenarios 3 and 4 are forecast earthquakes at higher magnitude to study how the buildings will react if a larger magnitude is to occur in Sabah. Figures 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 and 13 show the maximum displacement, interstorey drift, base shear and overturning moment of the building under these conditions. In seismic engineering, large displacement of structure is undesirable as large displacement creates an eccentricity between the column with vertical gravity load which results in second order effects and additional moments at moment carrying connections. Besides, tall building with large displacement under lateral can cause the sway out of the boundary and collide with adjacent buildings causing damage. Structural elements should be sufficiently rigid in both directions to ensure the maximum displacement is within the allowable range. In design practices, the maximum displacement of a building is usually limited to height/500. Interstorey drift is important in seismic design to limit damage of non-structural and structural elements. According to Eurocode 8, the interstorey drift for buildings having non-structural elements of brittle materials attached to the structure should be within the limit of 0.005 mm/mm.

Table 3 Loading assigned to model

Load	Dead load (kN/m^2)	Live load (kN/m^2)
M&E services and ceiling	0.5	
Finishes + screed (total 50 mm)	1.2	
Bedroom		3.0
Living room		3.0
Kitchen		4.0
Corridors		4.0
Toilet		2.0
Balcony		2.0
Concrete roof		1.5
Car park		2.5
Storage		5.0
Masonry wall	$2.6 \times 3.2 = 7.8$ kN/m	
Parapet wall	$2.6 \times 1.0 = 2.6$ kN/m	

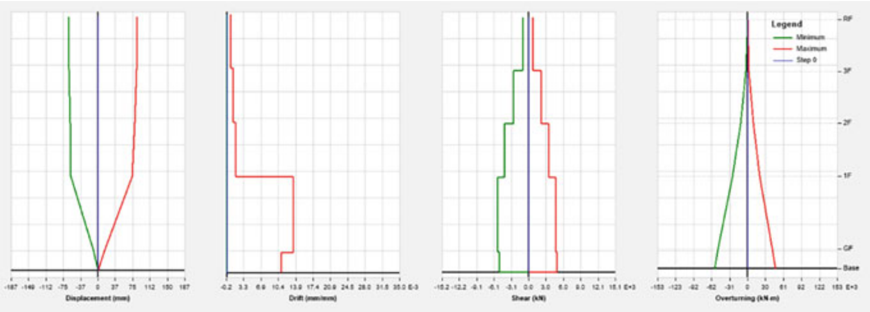

Fig. 2 Structural response in x-axis of building in Ranau under earthquake scenario 1

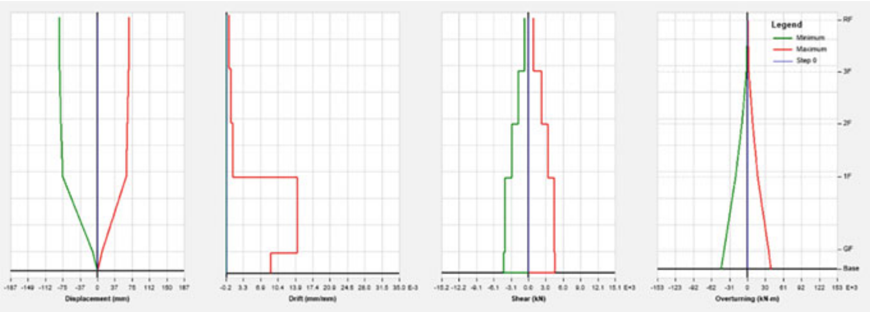

Fig. 3 Structural response in y-axis of building in Ranau under earthquake scenario 1

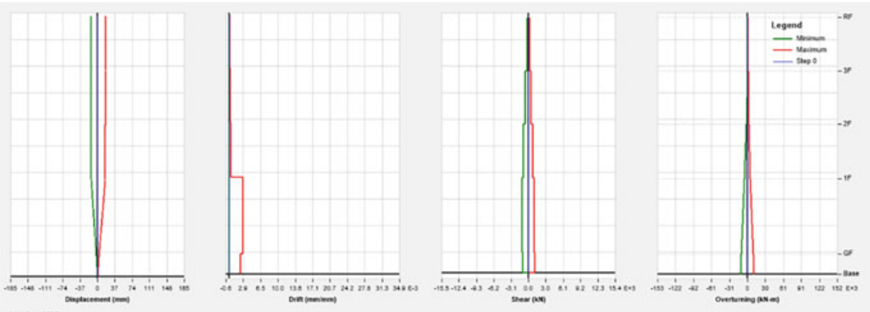

Fig. 4 Structural response in x-axis of building in Kota Kinabalu under earthquake scenario 1

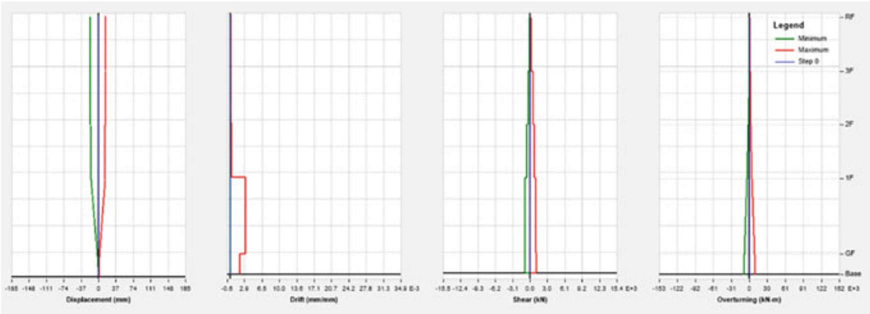

Fig. 5 Structural response in y-axis of building in Kota Kinabalu under earthquake scenario 1

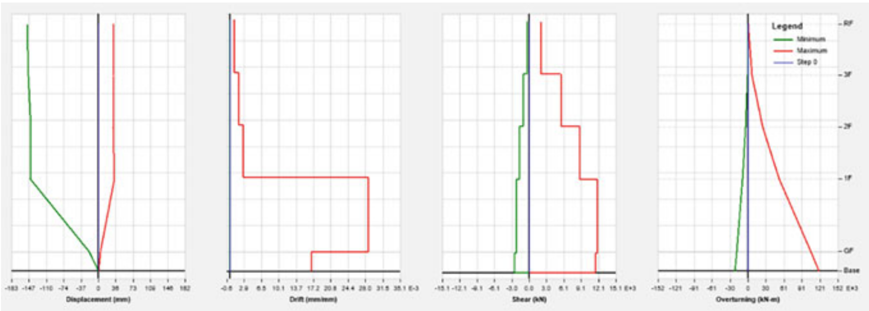

Fig. 6 Structural response in x-axis of building in Lahad Datu under earthquake scenario 2

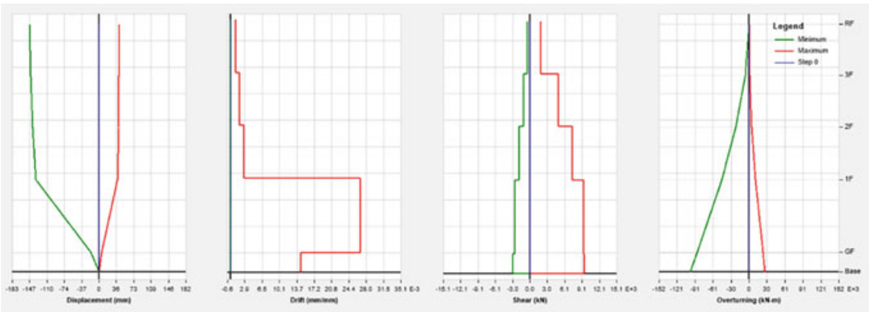

Fig. 7 Structural response in y-axis of building in Lahad Datu under earthquake scenario 2

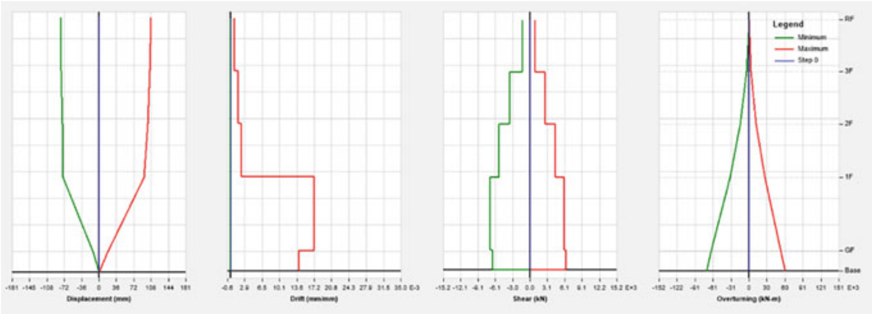

Fig. 8 Structural response in x-axis of building in Ranau under earthquake scenario 3

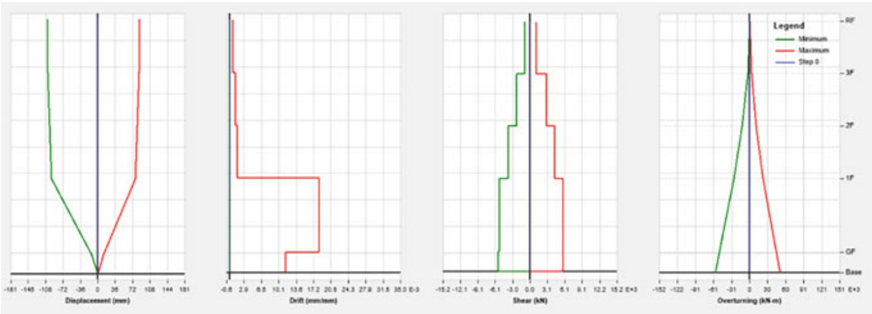

Fig. 9 Structural response in y-axis of building in Ranau under earthquake scenario 3

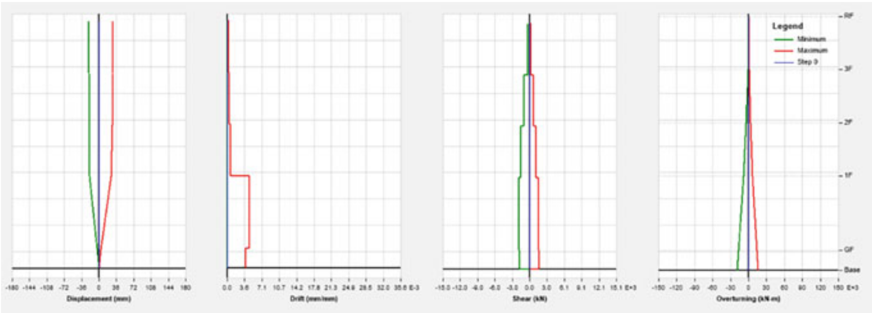

Fig. 10 Structural response in x-axis of building in Kota Kinabalu under earthquake scenario 3

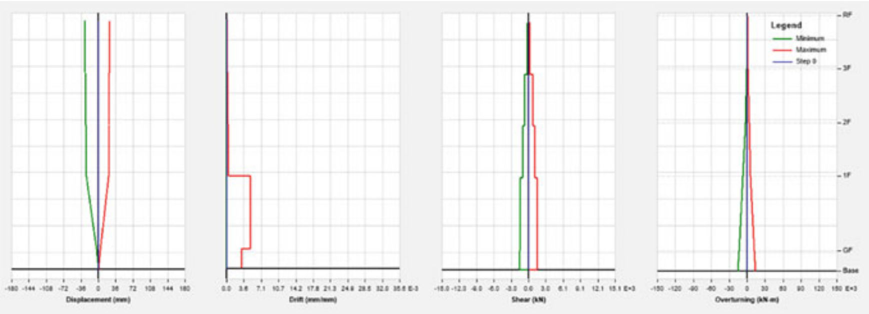

Fig. 11 Structural response in y-axis of building in Kota Kinabalu under earthquake scenario 3

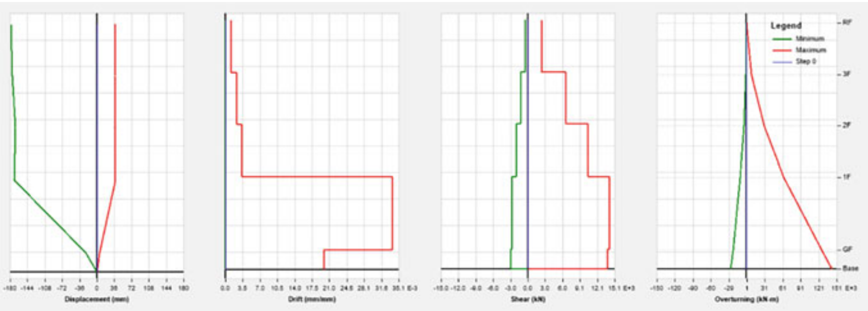

Fig. 12 Structural response in x-axis of building in Lahad Datu under earthquake scenario 4

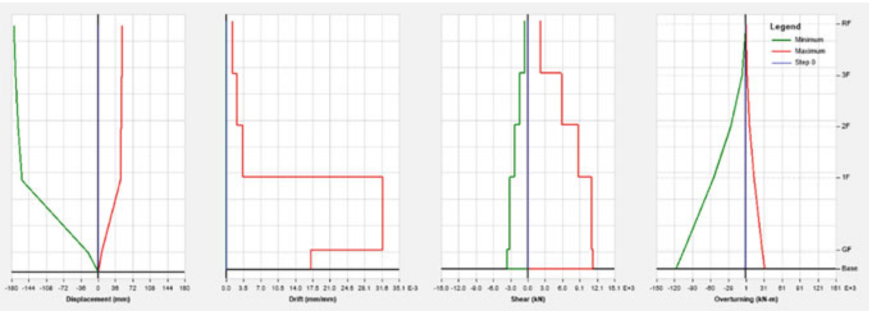

Fig. 13 Structural response in y-axis of building in Lahad Datu under earthquake scenario 4

From Table 4 it can be seen that a four storey building in Kota Kinabalu gives the least severe structure response compared to Ranau and Lahad Datu under soil type B. This is because of the location of Kota Kinabalu which is located furthest away from past earthquake epicentre and potential active fault zones. The

Table 4 Summary of structural response of building

	Displacement (mm)		Drift (10^{-3} mm/mm)		Shear (10^3 kN)		Moment (10^3 kN m)	
	x-axis	y-axis	x-axis	y-axis	x-axis	y-axis	x-axis	y-axis
R.N. (e.s. 1)	85.1	82.7	13.4	14.4	5.5	4.6	56.6	45.7
R.N. (e.s. 3)	108.4	105.4	17.2	18.4	7.1	5.8	72.1	58.2
K.K. (e.s. 1)	18.3	18.0	2.9	3.2	1.2	1.0	12.1	10.3
K.K. (e.s. 3)	29.0	28.2	4.6	4.9	1.9	1.5	19.3	15.6
L.D. (e.s. 2)	151.0	147.9	28.7	26.7	11.9	9.5	119.9	99.4
L.D. (e.s. 4)	179.2	175.5	33.9	31.8	14.2	11.3	142.3	117.9

differences in structural response of building in Kota Kinabalu for earthquake scenario 1 and earthquake scenario 3, were increment of 57.6% in displacement, 55.9% in interstorey drift, 54.2% in base shear and 57.0% in overturning moment. It can be stated that an increased earthquake magnitude from 6 to 6.5 will result in an increase of around 56% in structural response for buildings in Kota Kinabalu.

The structural response in Ranau under seismic load was less severe compared to Lahad Datu but more severe than that of Kota Kinabalu. The differences in structural response for earthquake scenario 1 and earthquake scenario 3, were increment in 27.4% in displacement, 24.6% in interstorey drift, 27.6% in base shear and 27.4% in overturning moment. It can be stated that an increased earthquake magnitude from 6 to 6.5 will result in an increase of around 27% in structural response for buildings in Ranau. From the result of scenario 1 which is a simulation of the ground condition in Ranau during the 2015 Ranau earthquake, the interstorey drift obtained was 0.0144 mm/mm which is higher than the limit stipulated in the Eurocode 8 which is 0.005 mm/mm. This may be the reason to why buildings were damaged in the Ranau region during the earthquake.

The structural response was the most severe for Lahad Datu because of shortest epicentral distance and highest earthquake magnitude. The differences in structural response for earthquake scenario 2 and earthquake scenario 4, were increment in 18.7% in displacement, 18.6% in interstorey drift, 19.1% in base shear and 18.7% in overturning moment. It may be noted there was an increase in around 19% in structural response due to an increased earthquake magnitude from 6.2 to 6.7 in Lahad Datu.

From Figs. 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 and 13, it can be observed that the maximum interstorey drift is between ground floor and first floor of the building. This is because the building is modelled as a soft storey building and the ground floor consists of open frame and wide space which is usually used as a car parking space in residential building. Moreover the floor height between ground floor and first floor (4.5 m) is larger than the other floors (3.2 m). Due to the open frame, there is no contribution of stiffness from masonry infill walls. Therefore, the soft storey is more seismically vulnerable and a significant source of serious earthquake damage. This also explained the structural damage of buildings in Ranau during the

Fig. 14 Damaged column beam joint of SMK Ranau building

5th June 2015 earthquake in which significant damage was found mainly at column beam joints at first floor. Figure 14 shows damaged column beam joint of SMK Ranau building. In terms of seismic regulations, irregular condition such as a soft storey structure requires the application of special considerations in their structural design and analysis [3].

4 Conclusion

In recent years, East Malaysia had experienced frequent earthquake events especially in the region of Sabah. Some of the buildings damaged in earthquake events has been deemed unsafe, causing major concerns of engineers and researchers on the design of buildings in seismic prone regions in East Malaysia. This study can give us a better understanding of building structural response under different earthquake scenarios in East Malaysia. Based on results, the structural response of building in Lahad Datu is the most severe followed by Ranau and Kota Kinabalu because Lahad Datu is located nearest to past earthquake epicentre and potential fault zone. Results from the simulated structure response of building in Ranau due to the 2015 Ranau Earthquake suggest that the seismic load has caused an interstorey drift 0.0144 mm/mm exceeding the limit of 0.005 mm/mm stipulated in Eurocode 8 which explained the damage of buildings during the earthquake. Comparing the forecast earthquake with the largest historical earthquake, the structural responses are expected to increase 55–60% in Kota Kinabalu, 25–30% in Ranau and 20% in Lahad Datu. Buildings in Ranau and Lahad Datu were expected to experience damage in forecast earthquakes due to the fact that the interstorey drift and maximum displacement obtained from the analysis exceeded the design limitation of 0.005 and height/500 respectively, by a significant amount. Assessment and retrofitting of important building are required to increase seismic capacity of building. Whereas for Kota Kinabalu, the simulated structural response for the past earthquake of 2015 is within the design limitations which indicates no severe damage of building during the earthquake. Under the forecast earthquake scenario, building in Kota Kinabalu showed structural response close the design limitations for both interstorey drift and maximum displacement. There is a need to verify that structural members of important building have sufficient capacity to withstand additional stresses developed due to seismic load and carry out retrofitting work accordingly.

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