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ORIGINAL ARTICLE

The Behaviour of High-Rise Building with or without Shear Wall under Different Earthquakes

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ABSTRACT – On the 5th June 2015, an earthquake hit Ranau, Sabah with a magnitude of 6.0 that caused 18 casualties and several injuries are one of the examples that show Malaysia is not safe from any seismic event. Most of the structure in Malaysia was designed not to include seismic action. Furthermore, an area that has a high density of population such as in the central region (Klang valley) and several main cities in Malaysia has less available land to build landed housing and uses high-rise apartments as an alternative. High-rise buildings that are normally having problems with soft story mechanisms and plan irregularity which could lead to severe damage when earthquakes happen. This study aims to observe the response of high-rise buildings when under different earthquakes in the presence of shear walls. To achieve this objective two models were modelled and analyzed by using ETABS software, the one with a shear wall and the one with no shear wall. The methods used in this study were the response spectrum method and time-history analysis. In the end, the parameters observed were base shear, story stiffness, story drift, and story displacement. The observations highlighted that the effect of earthquake intensities shows a significant effect. The acquired results indicated that the building with the shear wall is more resistant and strong structures as compared to buildings without shear wall when undergoing seismic analysis.

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INTRODUCTION

The thought on Malaysia is safe from any seismic activities to become fumble when an earthquake hit Ranau, Sabah on 5th June 2015. Their earthquake with a magnitude of Mw 6.0 has caused 18 casualties and several injuries and damages to buildings and infrastructures [1,2]. Furthermore, various earthquake that has happened in Malaysia (Table 1) such as Bukit Tinggi and several places in Peninsular should be a concern to Malaysia such as Bukit Tinggi and several places in Peninsular should be a concern to Malaysia although with a lower magnitude [3,4]. Besides, seismic activities in East Malaysia seem to be more active than in Peninsular Malaysia where from 1900 to 2014 70 local earthquakes have been reported with a magnitude of Mw 5.0 and above [5].

Table 1. Local earhtquake in Peninsular Malaysia [3]

Date	Case	Location	Magnitude
2007- 2009	24	Bukit Tinggi, Kuala Lumpur	24
2009	4	Kuala Pilah, Perak	4
2009	1	Jerantut, Pahang	1
2009	1	Manjung, Perak	1
2010	1	Kenyir Dam, Terengganu	1
2012	1	Mersing, Johor	1

It is stated that in [6,7], where the building in Malaysia was typically designed based on BS8110 which is there no consideration to resist the seismic load. Which can lead to a disastrous impact on buildings when the earthquake happens. This can be seen when Ranau has been hit by the earthquake, the damage on structural and non-structural members of the building was spotted [8,9]. Structures without adequate design to resist seismic load could lead to disaster.

High-rise Building

High-rise building housing has been an alternative to landed housing in Malaysia's several main cities that have limited land due to high densities of population. Normally, the architectural design of these types of high-rise apartments

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has floor level specifically for the parking lot and service floor that include restaurants and multipurpose halls. These kinds of structures commonly have problems regarding soft-story mechanisms and irregularity in the plan [10]. To overcome these problems, engineers provide shear walls into the building to increase structural stiffness and performance during earthquakes [11].

Shear Wall

Several papers have been presented to show the effect of shear wall installation on the building. A paper presented, show that by providing shear walls, shear force and column resistant moments are decreased as major forces are tried to resist by shear walls [12]. Also, it is stated that a shear wall to be very effective in resisting lateral loads when it is constructed from the foundation to the top of the building.

The presence of the shear wall in the building regardless of their configuration shows a better performance under seismic load compared to a building that has no shear wall. The effect of irregularity in the plan also can be overcome by providing shear walls into the building [11]. It is observed that the building with the shear wall when compared to the bare frame building produced a lower maximum storey drift, storey displacement, top displacement, and fundamental period of vibration [13,14]. Also, the shear force in the column is lower compare to bare frame building [15].

METHODOLOGY

Selected Buildings

To achieve the objective of this study, two methods were chosen to run the analysis; response spectrum method and time history analysis method by using ETABS software. The seismic vulnerability of two buildings was investigated. Both buildings have 25 storeys (G+24) service apartments with the similar plan for the parking levels and residential storeys were used to observe the effect of the shear wall on the building (Fig. 1 and Fig. 2). Table 2 present the summary of the strucutral detail description for both building.

Table 2. Earthquake information

Parameter	Detail	Value
Number of storeys	Include ground floor	25 (G+24)
Floor height	Ground Floor	5.0 m
	1st to 7th floor	3.3 m
	8th to roof floor	3.0 m
Column size	Ground floor	900 mm x 900 mm
	1st to 7th floor	650 mm x 650 mm
	8th to roof floor	400 mm x 400 mm
Beam size	All beam	350 mm x 550 mm
Slab thickness	Residential	125 mm
	Ground to 7th floor	150 mm
Concrete grade	Column, shear wall, slab (parking area)	35/45
	Beam, slab (residential)	30/37

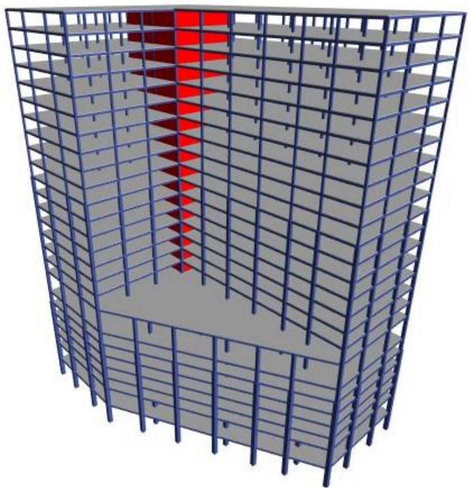

Figure 1. Model 1 (building with shear wall)

Figure 2. Model 2 (building with no shear wall)

Response Spectrum Method

By referring to [16], the author has proposed to consider type 1 elastic spectrum with soil type D which is suited seismic hazard in Sabah. To represent the moderate seismic region in Sabah, the reference peak ground acceleration, equal $\boldsymbol{a_{gR}}$, to 0.16g had been used to develop the elastic response spectrum as recommended by Eurocode 8 (Table 3). Therefore, the parameter to run the response spectrum method where referred to Eurocode 8 and Malaysia National Annex to Eurocode 8 (table 3).

Table 3. Parameter for response spectrum method

Parameter	
Type of spectrum	1
Peak ground acceleration, $\boldsymbol{a_{gR}}$	16%
Soil type	D
Important factor, $\boldsymbol{\gamma_1}$	1.2
Behaviour factor, $\boldsymbol{q}$	3.9

Time History Analysis Method

The ground motion for time histories documented from EL Centro, Japan, and Kathmandu was widely used to examine dynamic response in soil deposits (Table 4) and structure in the region where data such as Malaysia is lacking in recording [17]. Therefore, one of the time histories used in this study is from the strong motion recorded from El Centro Earthquake.

Table 4. Earthquake information

Earthquake	Date	Mw	PGA, g
El Centro	18 May 1940	6.9	0.359
Japan	11 March 2011	9.0	2.755
Kathmandu	25 April 2015	7.8	0.163

RESULT AND DISCUSSION

In this study, to observe the response of the building under different earthquakes these parameters were taken as observation; maximum base shear, storey stiffness, maximum storey displacement and maximum storey drift. Several assumptions have been considered:

- The foundation of the high-rise buildings was considered fixed.
- The reaction from non-structural and secondary structural elements such as masonry walls, the staircase was considered insignificant,
- The effects from irregularity in the plan such as layout and elevation were considered insignificant.
- The effect from shear walls configuration was considered insignificant.

Free Vibration Analysis

The twelve mode shapes of both building with the natural period and natural frequency have been obtained throughout this analysis. Table 5 show the summary of the analysis results. Figure 3 and 4 show the first mode of vibration for both model which are considered the critical mode to the structure because the first mode normally has the longest natural period which is a similar result shown by previous investigation [18,19].

Table 5. Period and frequency for each Mode

Mode	Netural Period , T (sec)		Natural Frequency f (Hz)	
	Model 1	Model 2	Model 1	Model 2
1	1.705	4.801	0.587	0.208
2	1.49	4.715	0.671	0.212
3	1.08	4.394	0.926	0.228
4	0.549	1.722	1.821	0.810
5	0.376	1.696	2.656	0.590
6	0.359	1.610	2.786	0.621
7	0.298	1.007	3.359	0.993
8	0.275	0.996	3.630	1.004
9	0.235	0.939	4.253	1.065
10	0.208	0.177	4.808	1.406
11	0.188	0.703	5.312	1.423
12	0.187	0.665	5.336	1.505

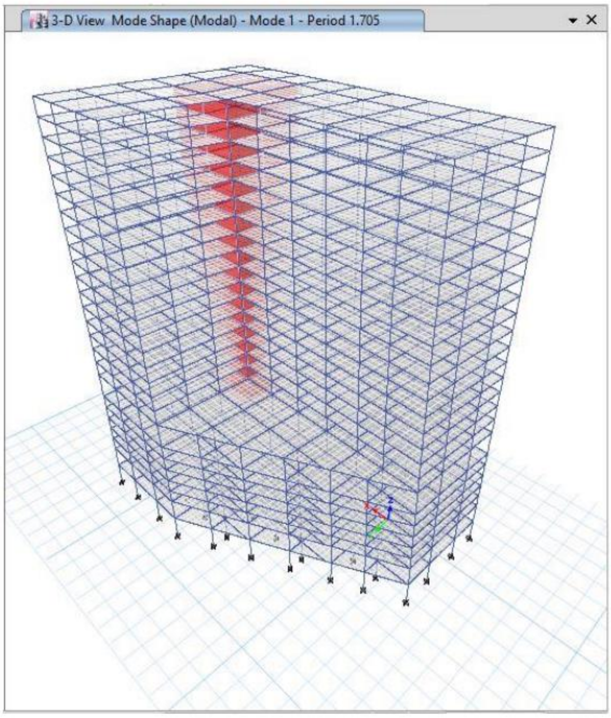

Figure 3. Mode shape 1 (building with shear wall)

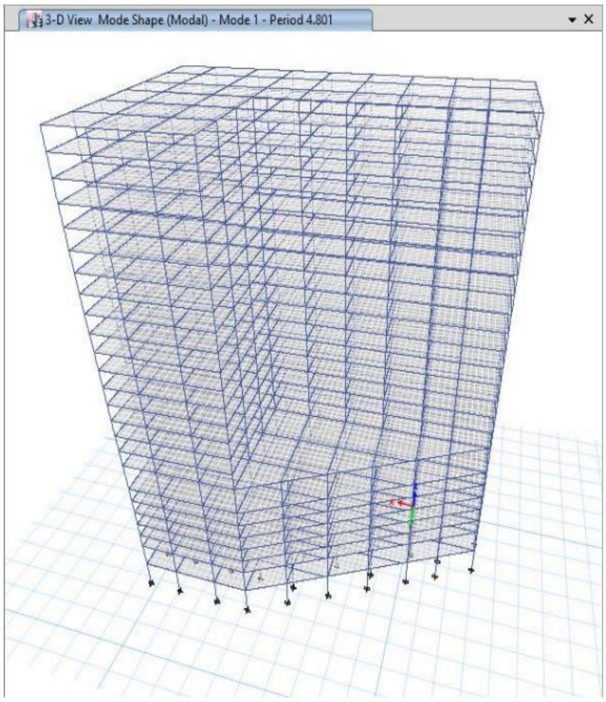

Figure 4. Mode shape 2 (building with no shear wall)

Base Shear

This parameter was observed under both the response spectrum method and time history analysis. Base shear for Model 1 which is for building with the shear wall was higher than Model 2 (Fig. 5 and Fig. 6). Since El- Centro earthquake has a larger peak ground acceleration (PGA), maximum base shear for both models and in both directions shows a huge difference compared to the response spectrum and Kathmandu earthquake. However, the maximum base shear under the Japan earthquake is negligible because there are showing a negative value.

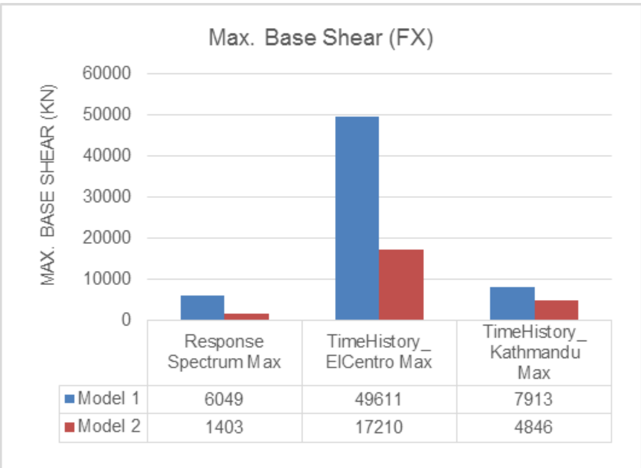

Figure 5. Maximum base shear in X direction

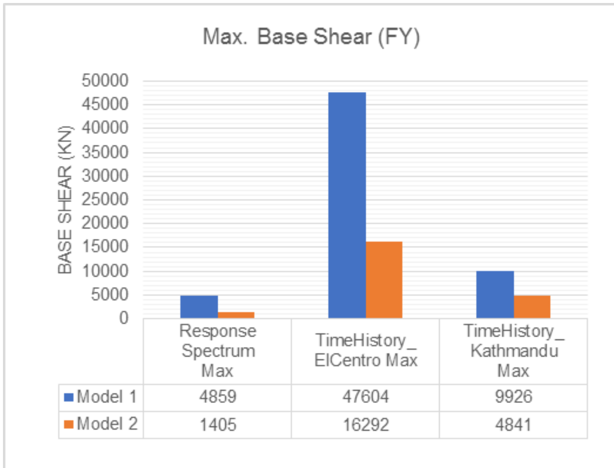

Figure 6. Maximum base shear in Y direction

Storey Stiffness

Storey stiffness values were gained from the response spectrum method. The results show in Fig. 7 and Fig. 8 are storey stiffness for each model in the X and Y direction. Storey stiffness increase as the shear wall is provided into the building model. It can be observed from the above figures, Model 1 produced higher storey stiffness in both X and Y directions. Storey stiffness were decreasing as the storey increased. Therefore, a building that has a shear wall was produce higher storey stiffness than a building that has no shear wall, which is favourable to [19,20].

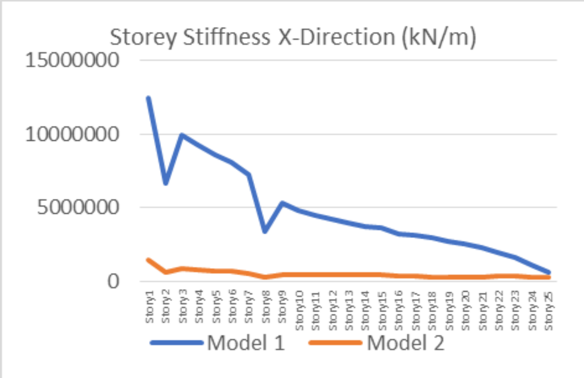

Figure 7. Storey stiffness in X direction

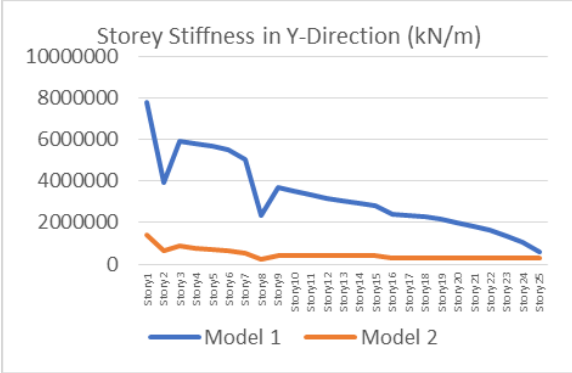

Figure 8. Storey stiffness in Y direction

Maximum Storey Drift

Storey drift was obtained from both methods and compared by two models in each direction (X and Y direction). Since the value given by Japan Timi History is enormous, the comparison is done in a separate Fig. 9 and Fig. 10.

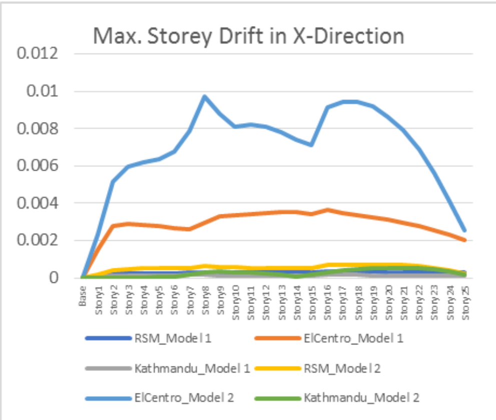

Figure 9. Maximum storey drift in X direction

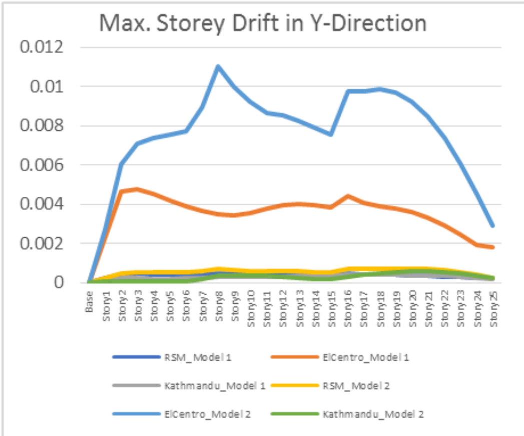

Figure 10. Maximum storey drift in Y direction

Fig. 8 and Fig. 9 shown the overall model 1 experience less storey drift compares to model 2 in both directions. Also, shows how peak ground acceleration affects the result of storey drift. Under the El Centro earthquake, the storey drifts experienced by both models in the X and Y direction are larger than in other load cases. The same case happened to load case for time history Japan earthquake (Fig. 11). The effect of peak ground acceleration can be seen. With peak ground acceleration of 2.755 g, the value for storey drift was too large until it could not be compared with other load cases.

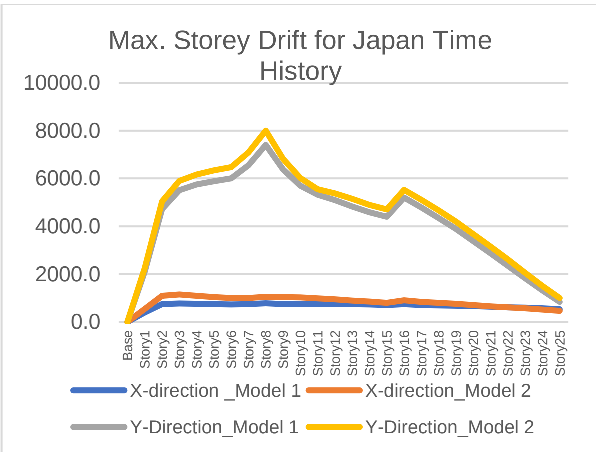

Figure 11. Maximum storey drift for japan time history

Maximum Storey Displacement

From Fig. 12 to Fig. 14, maximum storey displacement was observed, and two models were compared in each direction. Overall, maximum storey displacement gives a similar conclusion same as maximum storey drift. Where Model 1 experienced less maximum storey displacement compared to Model 2. The effect of PGA also can be seen, when the load case under Time History El Centro produced a larger maximum storey displacement compared to another load case. The same situation happens to load case of Time History Japan. Since the value given under this load case is enormous, a separated graph when plotted, show the effect of PGA on the building. Storey displacement and drift produced by building with the shear wall is lower compare to building with no shear wall as mentioned in [18-23].

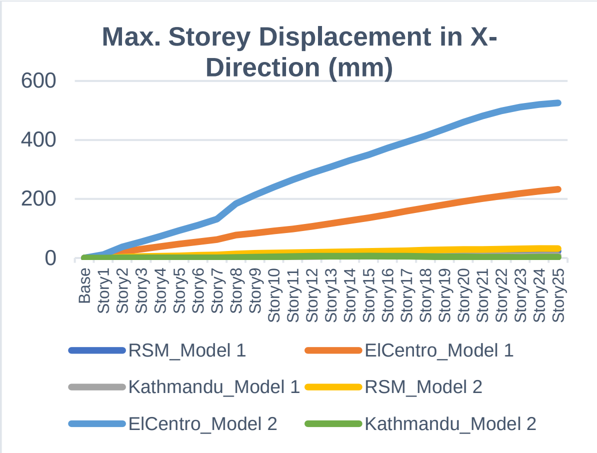

Figure 12. Maximum storey displacement in X direction

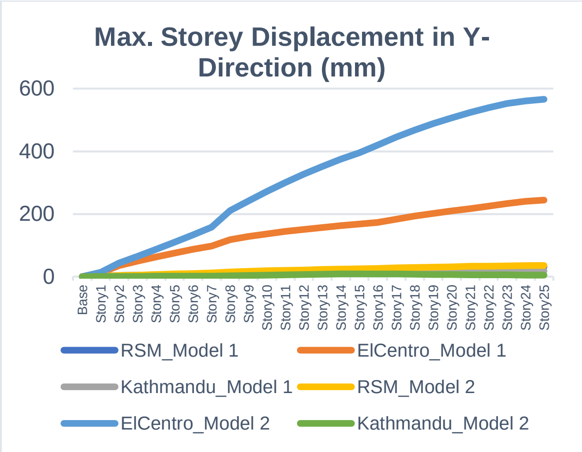

Figure 13. Maximum storey displacement in Y direction

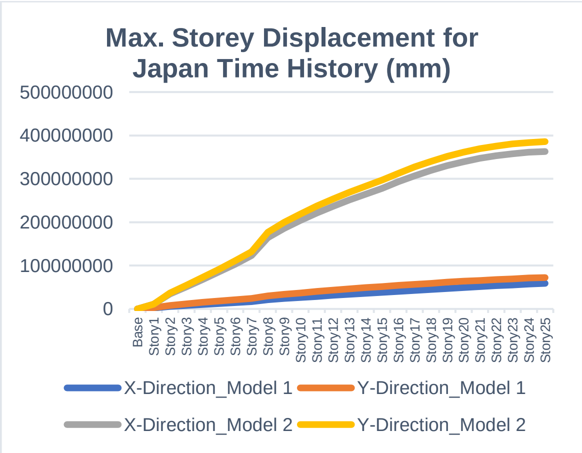

Figure 14. Maximum storey displacement for Japan time history

CONCLUSION

The study to observe the effect of the presence of the shear wall in a high-rise building when under different earthquake were discussed in this paper. By using the Response Spectrum Method and Time History Method, two models of a high-rise building with or without shear wall were analysed in ETABS. The conclusion is as follows:

- Result from base shear show that building with shear wall give greater value that building has no shear wall. Where, under response spectrum and El Centro load case for X direction, Model 1 give the value of 6049 kN and 49611 kN respectively. Whilst, for Model 2 give the value of 1403 kN and 17210 kN under same load case and direction.
- Storey stiffness of a building with the shear wall is higher compared to a building that has no shear wall. In general terms this means that building with shear wall is able to resist higher defomation compare to building without shear wall when subjected to sesimic load.
- From the results, the effect of earthquake intensities shows a significant effect. The results for storey drift and storey displacement under Japan Earthquake, give enormous value compared to the other earthquakes. This shows that the higher the intensities, the higher the storey drift and storey displacement.
- The acquired results indicated that the building with the shear wall is more resistant and strong structures as compared to buildings without shear wall when undergoing seismic analysis

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