Proceedings of the Tenth Pacific Conference on Earthquake Engineering
Building an Earthquake-Resilient Pacific
6-8 November 2015, Sydney, Australia

Draft National Annex to Eurocode 8 for Malaysia and cost implication for residential buildings with thin size elements

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ABSTRACT: A hybrid design response spectrum is developed for Malaysia. A hybrid model consists of both local and distant earthquake. This paper gives a brief explanation on the development and application of seismic loading in Malaysia. Implementation of the proposed seismic loading in Malaysia, due to the aftermath of the Sumatra Earthquake that raised concerns on the structural stability of the buildings in Malaysia. Using the hybrid model, safety and cost implication are investigated for thin size elements commonly used in low rise link houses. These link houses are the most common type of dwellings found in Malaysia. The analysis is carried out taking into account of stiffness reduction and behaviour factor under EC8. The study concludes the impact of the proposed response spectra on the buildings of Malaysia.

1 INTRODUCTION

For decades Malaysian Engineers have neglected Earthquake as a main design factor in buildings. However the major Sumatra earthquake in 2004 raised concerns throughout Malaysia. To address these concerns, The Institution of Engineers Malaysia (IEM) took the initiative and formed a Technical Committee on Earthquake Engineering publishing their first position paper in 2007. Initially the primary concern was the long distant earthquakes from neighbouring Indonesia. Until in 2010, Malaysia itself experienced a series of small earthquakes (M0.3 to M4.2) in the Bukit Tinggi fault zone (fig. 1). This generation of local earthquakes in an inactive intraplate fault further heightened the already raised concerns within the IEM technical committee categorising Malaysia as a low to moderate seismicity region. This also clarified doubts whether Malaysia, located on the stable Sunda plate required a seismic code or not. This lead to gathering of several technical meetings and symposiums by the earthquake committee and the development of the seismic response spectrum. The paper aims to introduce the development of the hybrid model developed for the Malaysian N.A to EC8 and the implication of earthquake design to low rise link houses in Malaysia.

2 DISTANT EARTHQUAKE

Megathrust earthquakes such as Aceh 2004 (M9.3) and Nias 2005 (M8.7) from Indonesia, Sumatra are mainly caused by the movement of the Sunda Arc Subduction fault offshore of Sumatra (fig. 1), approximately 530 km – 730 km from Peninsular Malaysia.

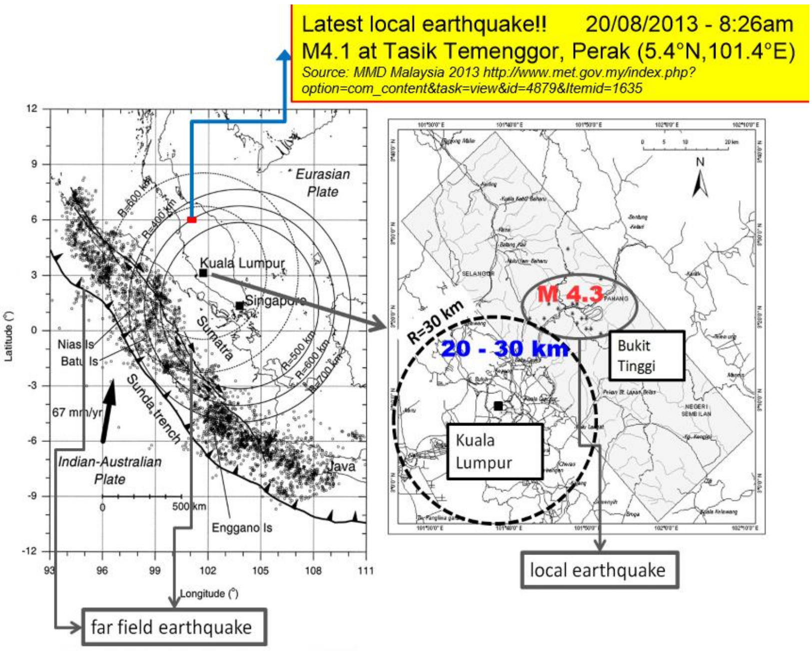

Figure 1. Distant and local earthquake faults in Peninsular Malaysia.

A Uniform Hazard Spectrum (UHS) model for key cities of Malaysia for both 475 years and 2475 years return period has been developed by ARUP (Pappin *et al.*, 2011) based in far field events. Probabilistic Seismic Hazard Assessment (PSHA) has been undertaken for Malaysia based on historical earthquake data of 40 years from the United States Geological Survey (USGS) database starting from 1942, covering an area between latitude 14 °S to 22 °N and longitude 90 °E to 132 °E (Pappin *et al.*, 2011). Note however that there are drawbacks of the Ground Motion Prediction Equation (GMPE) that was employed in the analysis as it was intended to be used for modelling distant large magnitude events making it inappropriate for modelling hazards that are associated with local earthquakes (or earthquakes occurring at close range to Malaysia). The originally developed UHS employed an early ground motion model that was developed by Pan *et al*. (2007) which required corrections as per recommendations by Megawati & Pan (2010). The IEM Technical Committee Working Group 1 was assigned the task of developing the design spectrum, using the original UHS (that was developed by ARUP) but had the results modified as per the latest work of Megawati and Pan (2010) and the latest development of CAM in order to achieve a better and updated UHS for long distant earthquakes. The Component Attenuation Model (CAM) as summarized in Lam *et al.* (2010) has been coded into programme GENQKE (Lam, 1999) for generating synthetic earthquake accelerograms based on stochastic simulations of the seismological model. CAM has successfully simulated distant earthquakes affecting Singapore (Lam *et al.*, 2009). CAM has also been shown to be able to simulate ground motions that match the instrumental field recordings from major events including the Aceh earthquake of 2004 and the Nias earthquake of 2005.

3 LOCAL EARTHQUAKE

With the lack of data for local earthquakes, the major challenge came in the development of the local component of the hybrid model. There is very low frequency of occurrence of intraplate earthquakes in the Sunda plate. Developing a reliable model based on these low quantities of occurrence data is not statistically practicable. Since there is still seismic activity, these activities inside the plate are still comparable globally to areas with enough statistical data of intraplate events (Lam, 2015). Hence collection of intraplate records globally from different parts of the world with similar tectonic settings to develop a model of the rate of occurrence is adopted. An average global activity rate of intraplate earthquake of magnitude greater than 5.66 per square meter per second was estimated at 4.27×10^{22} by Bird (2010). Translating this as 2-3 events occurring in an area of 1 million square kilometer over a period of 50 years. From this translation it can be established that the occurrence of an earthquake in Peninsular Malaysia is 1 to 2 events per century. This does not mean that an event might not occur in

Malaysia in the coming future. Hence establishing the fact that earthquake events may occur even in Malaysia. A design Peak Ground Acceleration (PGA) of 0.1g for a return period of 2745 years is adopted, benchmarking with world average for intraplate earthquakes.

4 DEVELOPMENT OF HYBRID MODEL

The developed hybrid models for rock sites for Peninsular Malaysia, Sarawak and Sabah can be summarized in the form of schematic diagrams as shown in Figures 2a – 2f and associated Table 1. Table 1 summarises PGA values that are recommended for Peninsular Malaysia, Sarawak and Sabah for different importance classes for the Malaysian National Annex (NA) to EC8. The values inside the parentheses show the derivation of design PGA based on the importance factor recommended in the draft NA. In summary, the hybrid model is a combination of results from conventional PSHA of historical earthquakes from regional sources (Model 1) and results from PSHA based on broad source zone modelling in accordance with global seismicity data (Model 2). For Peninsular Malaysia, Model 2 dominates the demand at the short period range, whereas Model 1 dominates the demand at the long period range (fig. 2a - 2b). For Sarawak, Model 2 dominates the demand across the entire period range (fig. 2c – 2d); and for Sabah, Model 1 dominates the whole response spectrum model (fig. 2e – 2f).

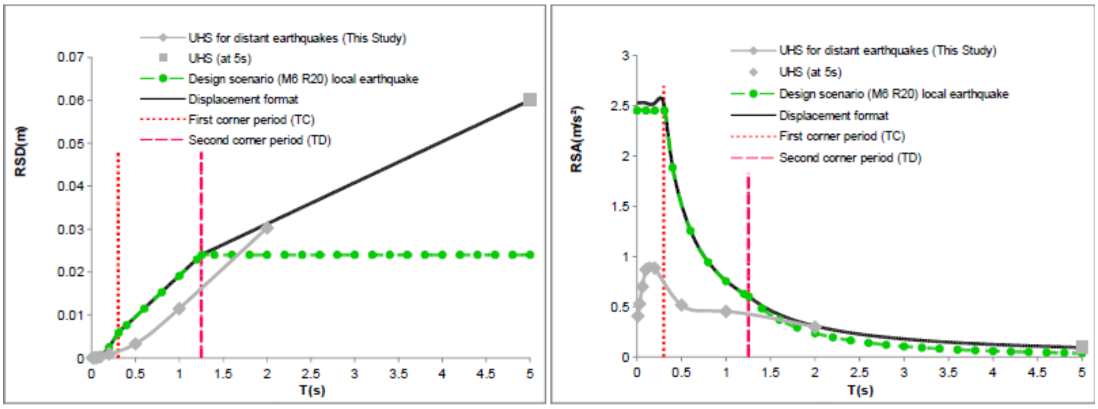

Figure 2a. Superimposing the two components for hybrid model for Peninsular Malaysia

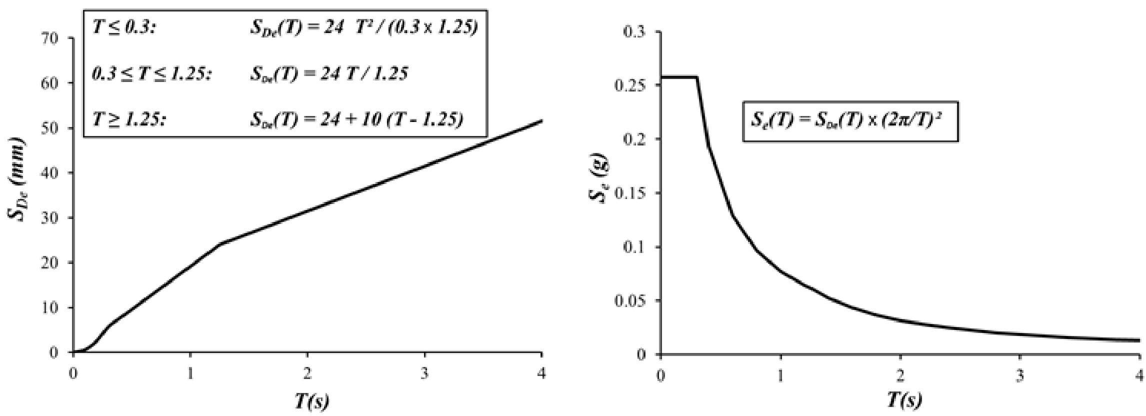

Figure 2b. Hybrid model for Peninsular Malaysia

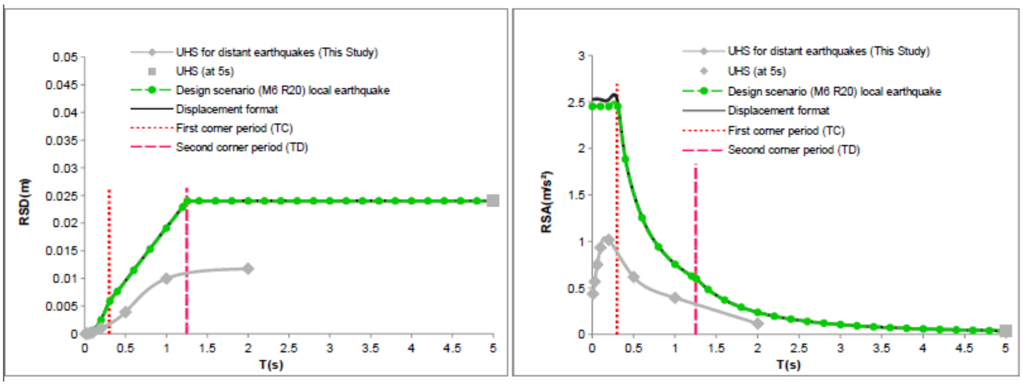

Figure 2c. Superimposing the two components for hybrid model for Sarawak

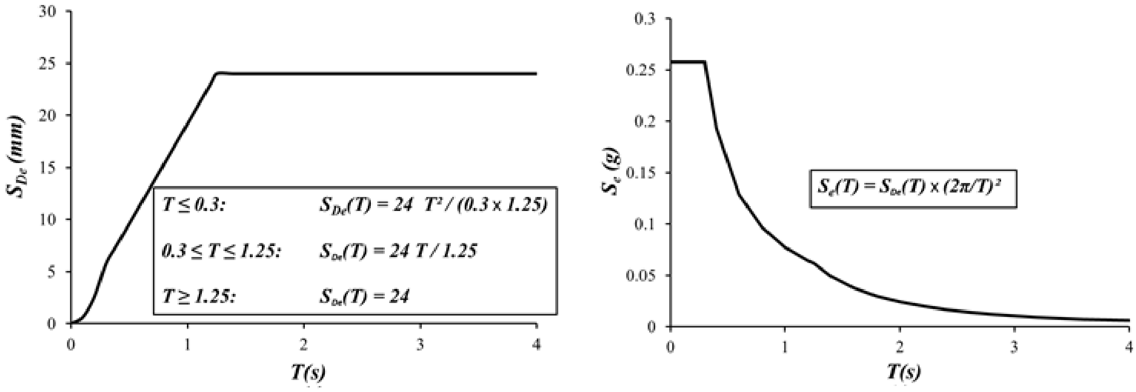

Figure 2d. Hybrid model for Sarawak

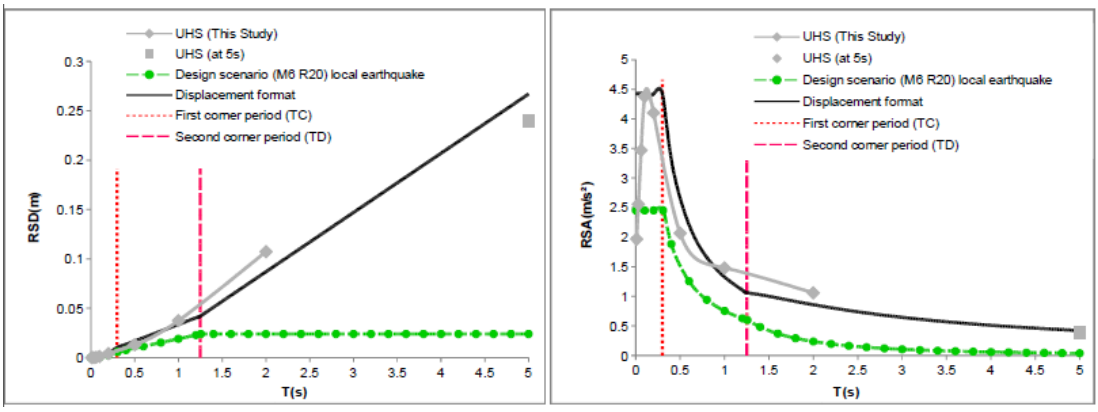

Figure 2e. Superimposing the two components for hybrid model for Sabah

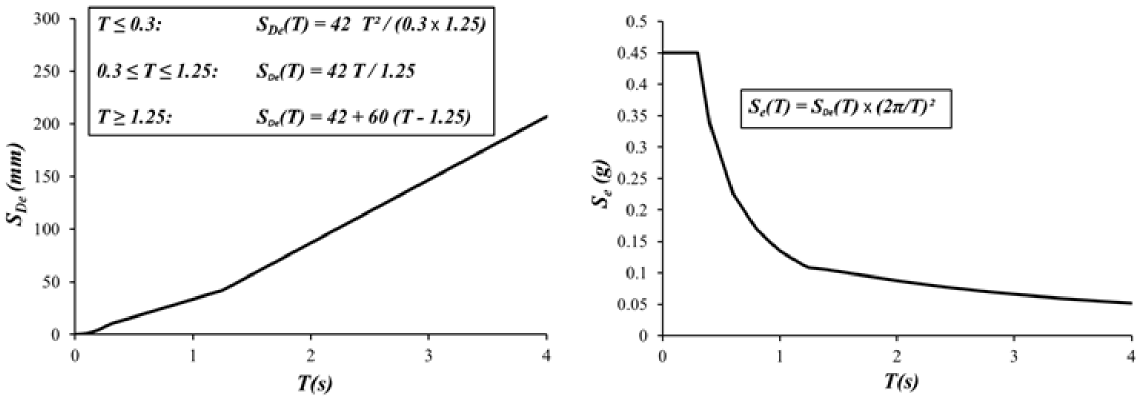

Figure 2f. Hybrid model for Sabah

Table 1. Design PGA on rock sites for Peninsular Malaysia,Sarawak and Sabah

Importance Class	**Descriptions**	**Design PGA (g's) Peninsular Malaysia and Sarawak**	**Design PGA (g's) Sabah**
I	Minor constructions	0.06 (~0.8 x 0.1/1.5)	0.10 (~0.8 x 0.18/1.5)
II	Ordinary buildings (individual dwellings or shops in low rise buildings)	0.07 (~0.1/1.5) Reference PGA (notional 475 years RP)	0.12 (~0.18/1.5) Reference PGA (notional 475 years RP)
III	Buildings of large occupancies (condominiums, shopping centres, schools and public buildings)	0.08 (~1.2 x 0.1/1.5)	0.14 (~1.2 x 0.18/1.5)
IV	Lifeline built facilities (hospitals, emergency services, power plants and communication facilities)	0.10 (consistent with RP of 2475years)	0.18 (consistent with RP of 2475 years)

5 COST ANALYSIS FOR THIN SIZE ELEMENTS

There are over thousands of single and double storey link houses in Malaysia. Being a common feature in Malaysia, the first question that comes to the minds of engineers is how susceptible these buildings are to an earthquake. In order to understand the implications of a seismic event and designing to earthquake loading in Malaysia, a cost study was undertaken to estimate whether there is a significant change in cost on a typical link house of single and double storey. The cost study will provide an easy to understand figure which indicates the amount of cost increase in Malaysia due to the introduction of the seismic design standard.

5.1 General Building description

Link houses are a common feature in Malaysia, where buildings are developed with houses sharing a common partition wall. The houses are commonly 1 to 2 story high (fig. 3).

Figure 3. Typical link houses in Malaysia

A typical link house building (fig. 4a - 4b) developed in Malaysia common for the 3 regions of Malaysia (i.e. Peninsular Malaysia, Sabah and Sarawak) is chosen. The structure is built out of reinforced concrete of grade C20/25, reinforcing steel with yield strength of 460 MPa and 250 MPa, for longitudinal reinforcement and stirrups, respectively. Element sizing of the models are tabulated in Table 2. Two models were developed for each type of building, One was subjected to static loading and one was subjected to both static and earthquake loading. The two replicas was analysed and designed as assuming they are uncracked. They are subjected to pushover analysis in order to determine whether the sections are cracked or not. If the buildings fall under cracked sections, the property of the building is assumed cracked, thus reducing the stiffness of all members by 50% as per EC8 requirements.

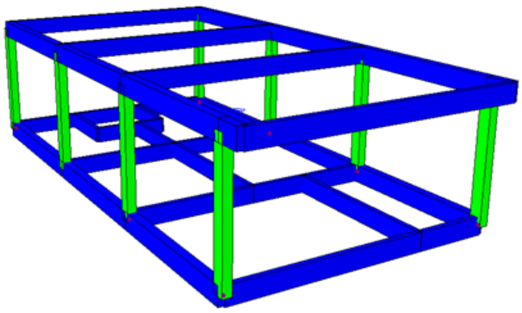

Figure 4a. 1 storey building

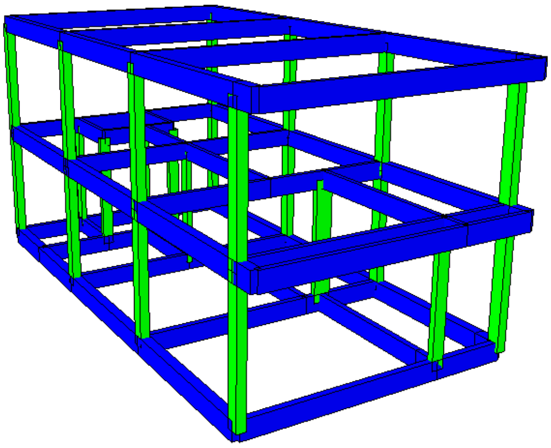

Figure 4b. 2 storey building

Table 2. Beam and Column Sizing for 1story and 2story building models

	1 story building	2 story building
Party Wall Beams	225x450 (mm)	225x450 (mm)
Internal beams	125x450 (mm)	125x450 (mm)
Party wall columns	225x300 (mm)	225x300 (mm)
Internal Columns	-	125x300 (mm)

5.2 **Loading applied**

For gravity loads, a superimposed dead load of 2.5 kPa is adopted and a live load of 1.5 kPa as per Malaysian building regulations (Laws of Malaysia, 2006). Wind load is applied as per BS-EN1991-1-4 2005, with a basic wind speed of 20 m/s inside city. Notional imperfection load is applied taking a maximum inclination of 1/200. This amounts to 0.5% of the ultimate dead and live. Earthquake loading is applied utilizing the Malaysian hybrid design spectrum. All buildings are assumed to be located in stiff soil similar to typical Malaysian soil conditions (Tsang *et al.*, 2015). For computation of natural period, is a function of stiffness and mass of the building. The design seismic mass can be formulated using equation 1.

$$m = \sum G_k, i + \sum \Psi_{E,j} \cdot Q_{kj} \tag{1}$$

Where G_k and Q_k the characteristic dead and imposed mass respectively. Ψ_E is take as 0.3 taking into account the likelihood that imposed load is not present over the entire structure during the earthquake.

5.3 **Pushover Analysis and Stiffness Reduction**

Under the clause 4.3.1 of EC8, the stiffness of the cracked structural elements can be taken as 50% of its original un-cracked stiffness. In order to determine whether the structure is cracked or un-cracked, a pushover analysis is performed. The capacity curve (fig. 5a) gives the maximum displacement in meters of the building against lateral load in kilo newton. The building experiences its first crack at 360kN (α_1). Hence the pushover capacity curve was superimposed over the acceleration displacement response spectrum of Peninsular Malaysia to determine the performance point (fig. 5b). Since the performance point is above the α_1 (which is the first crack) indicating that the structure has cracked.. Hence concluding that the building has cracked and the analysis is carried out under cracked section properties. This reduction in stiffness increased the first mode period of the 1 storey from 0.25 s to 0.35 s and the 2-storey building from 0.48 s to 0.67 s.

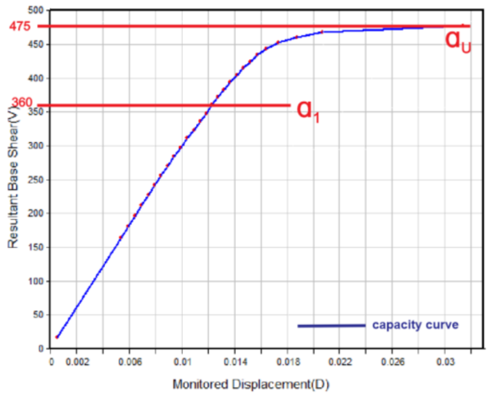

Figure 5a. Pushover capacity curve

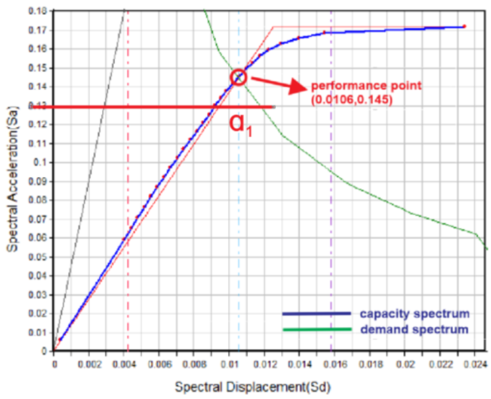

Figure 5b. Pushover demand curve

5.4 **Analysis and Results**

Cost Estimation is calculated under static load conditions (dead load, imposed load, wind load and notional imperfection load) and under combined static and earthquake load. 1 standard deviation is calculated with the 2 samples of 1 story and 2 story and applied to the costing to cover uncertainties.

The highest percentage increase in cost for Sabah is 5% for the 2-storey building and 4.7% for 1 storey. Similarly the structural building cost increase for Peninsular Malaysia/Sarawak is 4.2% for 2-storey and 2.0% (fig. 6). Figure 7 summarises the base shear for the corresponding regions when subjected to earthquake.

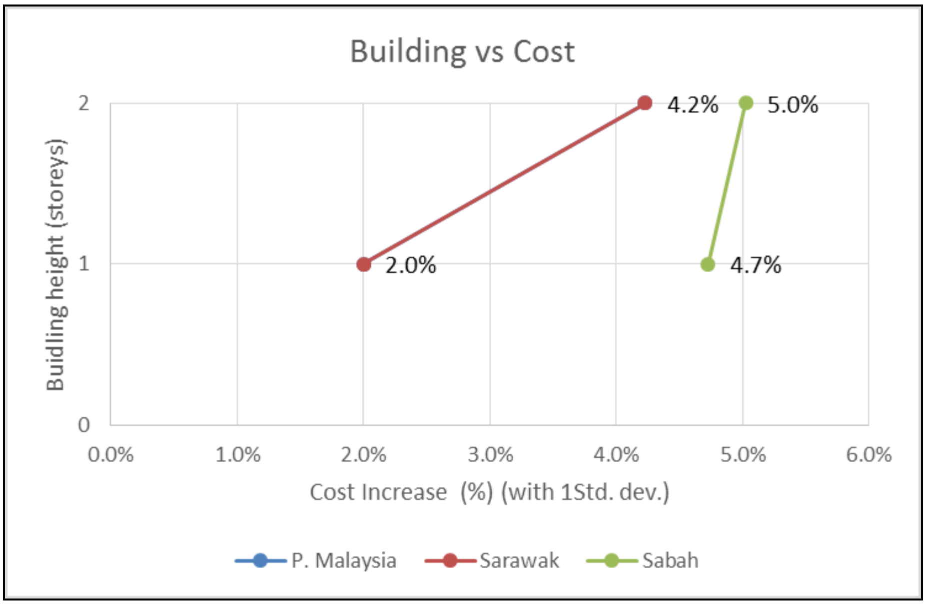

Figure 6. Preliminary cost estimation (Structural building cost)

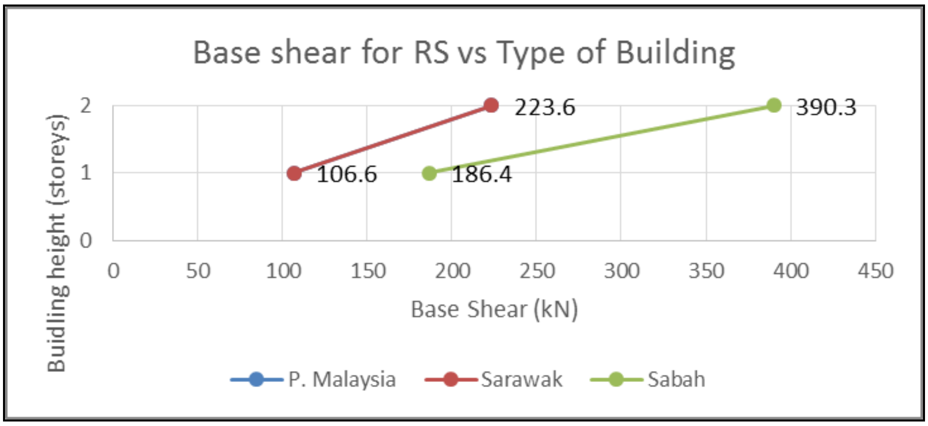

Figure 7. Base shear graph

6 SUMMARY AND CONCLUDING REMARKS

A hybrid model consisting of local and distant earthquake is developed for Malaysia dividing Malaysia into the 3 major regions, Peninsular Malaysia, Sabah and Sarawak. The reference PGA value based on a notional return period of 475 years is accordingly 0.07g (being 2/3 of 0.1g) for Peninsular Malaysia and Sarawak and 0.12g (being 2/3 of 0.18g) for Sabah. Cost estimation (with 1 standard deviation) for Peninsular Malaysia/Sarawak on typical link single 2.0% and double storey link houses 4.2 %. The highest cost increase in Sabah with 5% increase in cost for double storey link house and 4.7% for single storey link house.

ACKNOWLEDGEMENT:

The authors would like to thank the IEM Earthquake Technical Committee for the technical and financial support given to conduct the research. Valuable intellectual inputs by Ir E.P. Lim and Mr A.Z. Zaeem along with the other active participants from EC8 TC are also gratefully acknowledged.

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