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# Seismic hazard analysis for East Malaysia; based on a proposed ground motion prediction equation

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**Abstract.** The seismic hazard analysis requires an estimation of ground motion intensity where the process needs to use a compatible ground motion prediction equation or GMPE, which provides ground acceleration estimates in a function of earthquake magnitude and distance. Hence, the effect of current equation often does not accurately represent the earthquake condition in East Malaysia region. In this study, the characteristics of low-to-moderate databases were used and derived by regression analysis in terms of horizontal peak ground acceleration (PGA). The appropriate GMPE design for East Malaysia is based on the ground motion records compiled from strike slip earthquakes that occurred within 10 to 1,350 km. This earthquake data is based on actual data recorded at a broad range of magnitude levels within a wide range of distances. The new equation is used to predict the PGA value throughout East Malaysia by probabilistic method. PSHA is a method to analyse seismic hazard assessment using probability concept by considering the uncertainties of the size, location and rate of occurrence of earthquake and the variation of ground motion characteristics. The four well-known existing attenuation functions are evaluated with current equation to highlight their limitations in magnitude and distance. With a more complete collection of earthquake databases, GMPE has become more reliable. The GMPE of peak ground acceleration for low-to-moderate earthquake at long distance was found to be logarithmically distributed. The equation provides ease in both implementation and interpretation of physical parameters with a comparable standard deviation.

## 1. Introduction

Seismic hazard analysis could be critical when it comes to selecting the suitable attenuation function relationship. There can be many parameters inside this equation, these parameters are usually based on the magnitude and distance. Attenuation function can be described as how an earthquake ground-shaking decreases within several distance away from the source of the earthquake. However, it is essential in seismic hazard studies to estimate the ground motions generated by the seismic sources, which have been mentioned in numerous studies on earthquake in Malaysia [1 – 6]. Usually, the equations selected for the seismic hazard studies are the models established from foreign data.



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There are various lists of current available attenuation functions, as seen in Douglas [7 – 9]. The compilation of various ground motion equations from different countries can be seen from the subduction, and both active and stable tectonic region. These attenuation functions have been applied by many researchers worldwide in engineering and seismological disciplines. Unfortunately, the attenuation function that specifically fits with the condition of East Malaysia is rather low to none. The attenuation function that is available may not be suitable to handle and accurately represent the low-to-moderate earthquake condition in East Malaysia. Generally, earthquakes with magnitude less than 4 are considered minor and unlikely to cause damage, whereas those with magnitude 6 or greater are considered major events, capable of causing great damage in some cases. In the East Malaysia, a number of low-to-moderate from  $M_w$  2.9 – 6.3 shallow depth earthquake events of Modified Mercalli Intensities (MMI) ranging from IV to VII will cause slight to moderate damage to buildings. The statement made by Delavaud et al. [10] mentioned that the conditions with low magnitude may have a significant impact to hazardous level.

As in the case of German, Bangkok, and Hong Kong, where these areas have a seismic condition of low-to-moderate earthquake. The main factor of a higher risk is due to the less awareness of people, especially the one who lives in a stable region. There is a reason where the need of a seismic hazard has been increasing proportionately with population and the development of the state. As an example, there has been a concern by several researchers, such as Grünthal and Bosse [11], Nordenson and Bell [12] and Kracke and Heinrich [13], which mentioned that the risk may higher in developing countries with a low-to-moderate seismicity region.

In accordance to the history and pattern of earthquake in Malaysia, the situation can be categorized as low-to-moderate within a remote distance zone. The same condition happens with other countries such as Thailand, German and India [13 – 16]. These countries, while being considered as a stable region, is unfortunately still affected by large earthquakes from the neighbour countries. The variation of estimation with the corresponding PGA value for East Malaysia region can be summarized in Table 1. The lowest possible PGA for 10% and 2% probability are 10 and 1  $\text{cm/s}^2$  with the maximum PGA of 320 and 650  $\text{cm/s}^2$ , respectively. There are several large different PGA between the provided results. Therefore, an attempt to provide suitable PGA is done by designing new ground motion prediction equation (GMPE) based on the actual recorded data. An analysis on the observed PGA in this plot shows that there is an inconsistency and over-prediction of the ground motions.

**Table 1.** Range of the predicted PGA values for 2% and 10% probability of exceeds.

References	2% ( $\text{cm/s}^2$ )	10% ( $\text{cm/s}^2$ )
Giardini [17]	-	80 -160
Majid et al. [18]	180 - 340	-
Adnan et al. [5]	160 - 180	60 -120
USGS [19]	-	10 - 200
Leyu et al. [20]	390 - 650	-
Malaysian Annex [21]	0 - 300	0 - 170

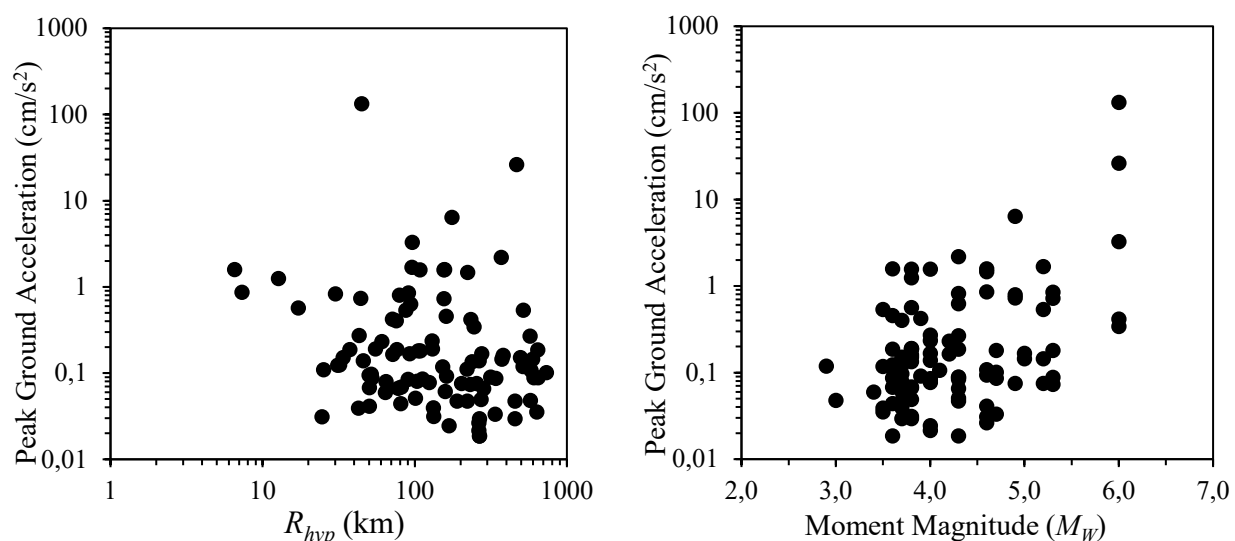
## 2. Development of GMPE

PSHA requires a strong Ground Motion Prediction Equation (GMPE) to estimate earthquake ground motion parameters characterizing the earthquake source, propagation path and geological condition. Seismic hazard analysis is different in terms of definition of seismic sources and GMPE. Unfortunately, there has been no derived GMPE for the condition in the East Malaysia [5]. The available GMPE may

not be suitable to accurately handle a low-to-moderate earthquake condition in East Malaysia as applied to other models, which might provide different estimates at a large distance [22, 23].

The GMPE model is derived for East Malaysia by predicting the horizontal components of ground motions. The time history databases around East Malaysia were collected from the local MMD seismological network station, with the data spanning from 2004 to 2012, including the latest 5 June 2015 earthquake with 6.0  $M_W$ . The earthquake epicentre of the collected earthquake can be seen in Fig. 5 together with the location of seismic stations around East Malaysia. The network has been operating for roughly 11 years, with 30 permanent seismic stations installed through all of Malaysia. They consist of broadband and short period accelerometric sensors on real-time monitoring.

The site conditions in each accelerometric network vary from one station to the other. The detailed study on the site conditions of the accelerometric stations refers to the information provided by the network. The shear-wave velocity in the top of 30 m or  $V_{S30}$  has been used. The site categories corresponding to the standard manual Eurocode, EC8 class have been calibrated in this study (1000 m/s for A, 600 for B, 250 for C and 100 for D). The supplied data, however, lacks adequate soil types B, C and D. Thus, the site conditions on soil type A has been considered in the analysis and the data recorded from other types of soils are disposed of. In total, 111 earthquake time history including local earthquake events were selected. These records come from 42 earthquakes retrieved from 28 seismic stations. The distribution of all selected records with respect to magnitude and distance are shown in figure 1. It shows that there is a lack of data from magnitude  $M_W$  of 5.5 and above.



**Figure 1.** Distribution of the used data in terms of magnitude and distance on EC8 soil class A.

The new GMPE for rock sites in East Malaysia is developed for peak ground acceleration. The model is derived using a local dataset from strike slip earthquakes that consists of corrected and processed accelerograms at a distance between 10 and 1000 km with moment magnitudes in a range of 3.0 and 5.5. The process of filtering earthquake time history is performed on the earthquake records prior to processing, in accordance with Boore and Bommer [24]. The original earthquake records are put through base line correction and then plotted as a time history. Earthquake records are selected manually and exclude damaged or questionable records. Records with square waves due to the ground-motion values being too small are also excluded. Any collection of data in a small distance range will have a range of amplitudes because of the natural variability in the ground motion (due to such things as source, path and site variability).

At distances far enough from the source (depending on magnitude), some of the values in the collection will be below the amplitude cut-off and would therefore be excluded [25]. The rupture initiation time and the record has been baseline-corrected and low-pass filtered at 0.13 Hz to remove

high-frequency components contaminated by local geology and environmental noises. The models of GMPE are based on the Zare et al. [26], since there are currently no available models for East Malaysia. This equation is derived by the least-square method for the estimation of peak ground acceleration (PGA) in units of  $\text{cm/s}^2$ . The estimated equation of these response parameters are given in terms of the standard deviation of logarithms. The model components related to moment magnitude,  $M_W$ , and hypocentral distance,  $R_{hyp}$  can be seen in the generic form below.

$$\text{Log}(PGA) = a_1 M_W + a_2 R_{hyp} - a_4 \text{Log} R_{hyp} + a_3 + \varepsilon_{\text{Log}(PGA)} \quad (1)$$

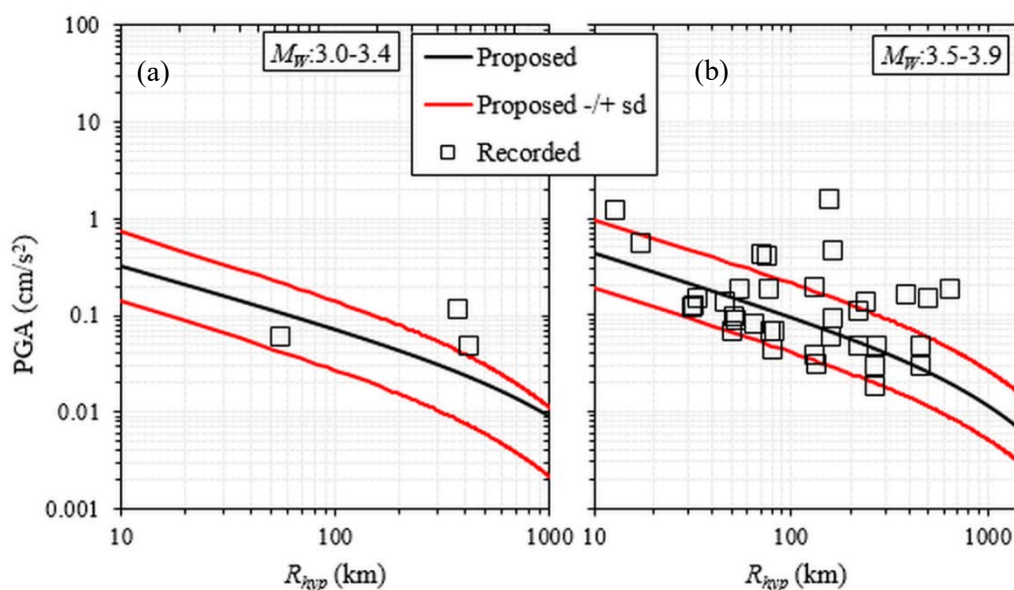
From the equation,  $M_W$  is the moment magnitude,  $R_{hyp}$  is distance of hypocentral, while  $a_1$  to  $a_4$  are the regression coefficients. The modelling earthquake with distance  $R_{hyp}$  caters for the near and far-field events.  $R_{hyp}$  is used in this model, since focal depth influences the GMPE for near-source distance [27]. The regression analyses were fit with the method of nonlinear least-squares, in which each earthquake was constrained to have a zero residual mean. The ground motion behavior of the East Malaysia region is expressed in the equation below;

$$\text{Log}(A) = 0.2408 M_W - 0.0030 R_{hyp} + 0.63372 \text{Log} R_{hyp} - 0.623 \quad (2)$$

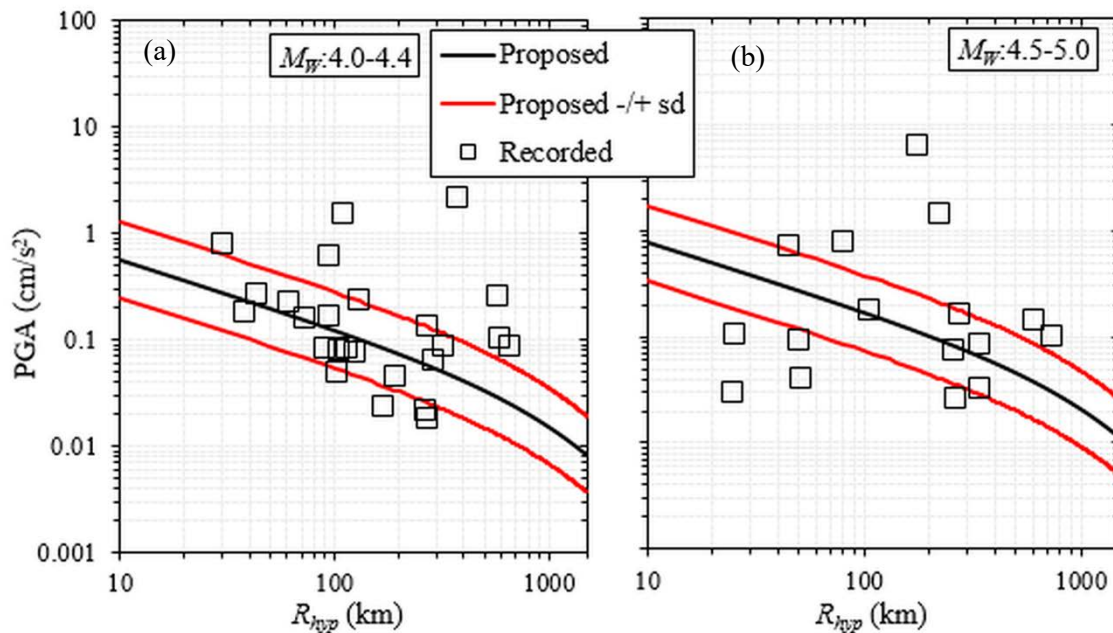
In the above equations, the standard deviation is 0.357, and the obtained PGA value is the geometric maximum value of the two horizontal components of peak ground acceleration ( $\text{cm/s}^2$ ). The coefficients and associated standard deviations are derived in each equation based on the recorded time history from the earthquake stations.

### 3. Results and discussion

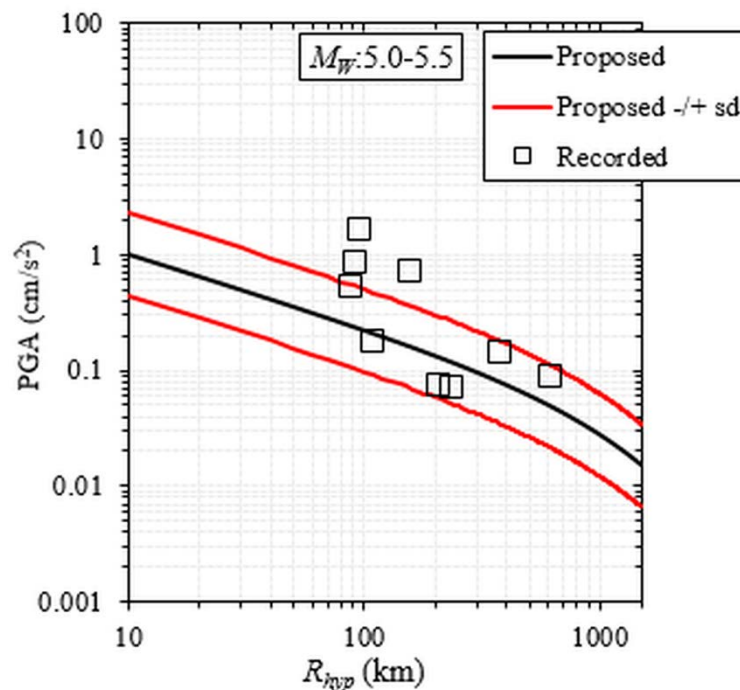
The equation of new proposed GMPE are derived with a 5% PGA estimation for critical damping ratio using a set of 111 earthquake records from 42 events. Figure 4.1 shows the decay of maximum PGA values with distance for magnitude  $M_W$  3.0 to 5.5 of strike slip earthquakes at bedrock. The PGA was estimated by the newly developed GMPE, the median plus minus one standard deviation ( $\pm \text{sd}$ ) are compared to the actual records. They are classified into  $M_W$  3.0 to 5.5 for the plot. The earthquake magnitude range is set between the range of  $M_W$  3.0 to 3.9 (figure 2),  $M_W$  4.0 to 5.0 (figure 3) and  $M_W$  5.0 to 5.5 (figure 4).



**Figure 2.** Comparison of the newly developed GMPE with the PGA recorded at bedrock for different range of magnitude; (a)  $M_W$  3.0 – 3.4 and (b)  $M_W$  3.5 – 3.9.



**Figure 3.** Comparison of newly developed GMPE with the PGA recorded at bedrock for different range of magnitude; (a)  $M_W$  4.0 – 4.4 and (b)  $M_W$  4.5 – 5.0.



**Figure 4.** Comparison of newly developed GMPE with the PGA recorded at bedrock for different range of magnitude;  $M_W$  5.0 – 5.5.

A good prediction can be observed in all range of magnitude. Analysis on the PGA observed in this plot shows there is a consistent prediction of the ground motions. There are uncertainties in these records that need to be further reviewed with the seismological parameters, as the current model depends a lot in the reliability of the available input and information. Nevertheless, the curve-fitting of the new GMPE is considered to match better with the PGA records at a distance of more than 10 km.



In general, the plot of the new generated GMPE seems to provide a better estimation with the collected field records compared to the other GMPEs from the study conducted by Harith [28]. The study shows that the observation recorded from small to large magnitude earthquakes varies in the seismic trend in East Malaysia. It appears that the equation accurately represents an earthquake condition in East Malaysia. Even though some of the data recorded did not fall within the range, the plots show that there are still significant variability in the predicted ground motions from each range of magnitude. Nevertheless, it is still considered a further modification and refinement, especially with the number of recorded data for all ranges of magnitude.

#### 4. Conclusion

The available GMPE may not be suitable to accurately handle the low-to-moderate earthquake condition in East Malaysia, as the application of other models might provide different hazard estimates. In this study, the plot of the new generated GMPE seems to provide better estimates with the collected field records for all ranges of magnitude. The newly developed attenuation curves show a consistent trend with the recorded earthquake data. It proves the significance and applicability of this equation at low-to-moderate magnitude. It appears that the equation accurately represents an earthquake condition in East Malaysia.

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