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Ground Motion Observation of Sabah Earthquakes on the Use of Next Generation Attenuation (NGA) Ground-Motion Models

To cite this article: N S H Harith *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **682** 012050

Ground Motion Observation of Sabah Earthquakes on the Use of Next Generation Attenuation (NGA) Ground-Motion Models

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Abstract. Ground motion prediction equations (GMPEs) are being used for the estimation of the ground motion parameters which are needed for the design and evaluation of important structures. The seismic hazard may contribute greatly to the total risk; therefore the selection of appropriate GMPEs may have a substantial influence on the design and safety evaluation. For low-seismicity areas, however, the available database of strong ground motion measurements is limited, with determination of an appropriate GMPE been a rather difficult task. The objective of this study is to evaluate the next generation attenuation (NGA) ground-motion models to be applied in Sabah region. In this study, six next generation attenuation (NGA) models have been selected to be evaluated. The representation of all NGA models, are compared with the Sabah ground motion database comprises 209 two horizontal-component acceleration time series recorded within 10 to 1000 km of source to site distances for 173 earthquakes with moment magnitudes (M_W) ranging between 3.0–6.0. The comparisons are made using analyses of root of the mean square (RMS) and residuals. Two GMPEs present better residual fits than other models with smaller RMS value and indicates better estimation of the peak ground acceleration (PGA). Based on these findings, it is recommended on using the NGA relations for seismic hazard assessment of Sabah.

Keywords: Next generation attenuation (NGA) models; ground motion; Sabah; peak ground acceleration; Seismic hazard assessment.

1. Introduction

Many predictive relations are nowadays available for different regions of the world for peak ground acceleration (PGA) and these are mostly derived from strong motion records. There are a few studies that derived the attenuation of the PGA from weak motion recordings, although several small magnitude earthquakes have produced PGA values of engineering interest. Ground motion prediction equations (GMPEs) are used for the estimation of the ground motion parameters which are needed for the design and evaluation of important structure. The seismic hazard may contribute greatly to the total risk, therefore the selection of appropriate GMPEs may have a substantial influence on the design and safety evaluation. Seismic hazard analysis differs in terms of the definition of seismic sources and the

IOP Conf. Series: Earth and Environmental Science **682** (2021) 012050 doi:10.1088/1755-1315/682/1/012050

GMPE model. All GMPE models presented here have parameterization such as the moment magnitude, distance, and local site condition. For low-seismicity areas, however, the available database of strong ground motion measurements is limited, with determination of an appropriate ground motion prediction equation being a rather difficult task.
In the recent past, sufficient ground motion records from low-to-moderate magnitudes have become available since there are various lists of currently. Available GMPE, as compiled in Douglas [1-4]. Even though, not all the GMPE suitable for handling accurately the low-to-moderate earthquake conditions in Sabah. The GMPEs that are available make it possible to be investigated and tested their sensitivity with the ground motion records [5]. Many GMPE databases are necessary to illustrate the situation that may occur, in accordance with Iztok and Peter [6], the NGA models developed by using regional data can be transferred to another region. Those underlying physics ideally should be manifest in how a GMPE represents the scaling of a particular PGA with respect to magnitude, distance, and site condition. Those issues are explored subsequently in this article. The six NGA GMPEs are presented by Abrahamson and Silva [7], Boore and Atkinson [8], Campbell and Bozorgnia [9], Chiou and Youngs [10], Idriss [11] and Graizer and Kalkan [12].

2. Earthquake Database

In accordance with previous historical earthquake records and studies in seismic monitoring in Sabah by previous researchers [13-18], the seismicity is classified as a low to moderate earthquake. There have been a growing number of earthquakes in the past 120 years in this area since first being monitored by Leyu [19]. The highest intensity of these earthquakes reached VIII degrees. The earthquake epicentre of the collected earthquake can be seen in Figure 1 together with the location of seismic stations (named as KKM, KDM, SDM, SPM, LDM and TSM) since its first installation in 2004.

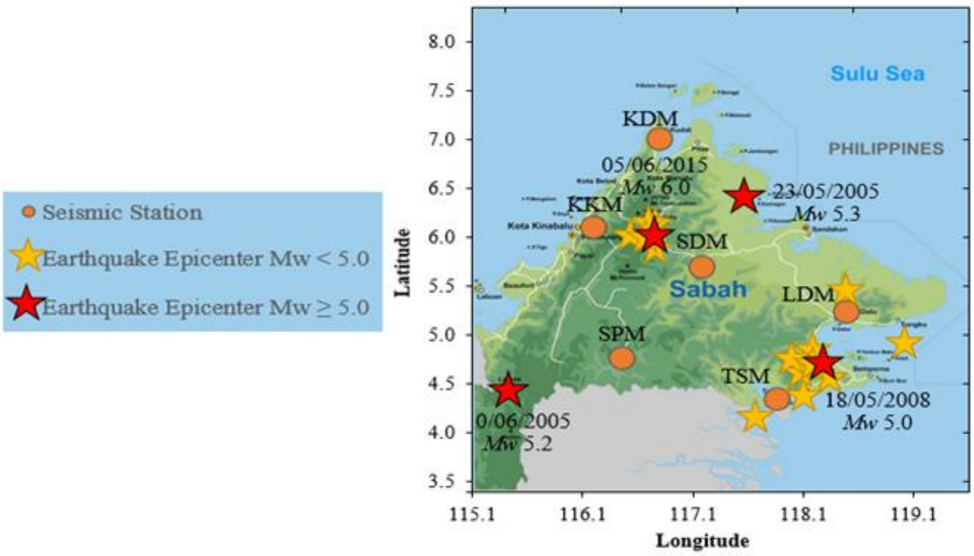

Figure 1. Seismic stations in Sabah and the earthquake epicentre occurred with magnitude less and more than M_W 5.0

The site conditions on soil type A has been considered in the analysis. There have been 10 earthquake events with 46 earthquake record of time history from Sabah. These records are retrieved from 6 seismic stations. However, the modelling and characterization of earthquake records in a small number may rise uncertainties. All measurements have some degree of uncertainty when the earthquakes do not occur too often in time at the place where recording devices are present. The historical earthquake records in Sabah have only been compiled and interpreted over a few years. The combination of all earthquake recording data gives the total of 209. The distribution of all peak ground acceleration (PGA) records with respect to magnitude and distance are shown in Figure 2. The PGA value considered this study is the geometric mean of peak values of two horizontal and orthogonal components of ground acceleration of a site. In general, the recorded PGA values are low because of the moderate magnitudes of the events and the epicentral distances to the stations. Records used in this study have PGA ranging from 0.001 to 6.38 cm/s^2. Figure 3 shows a sample of ground motion recorded data where the first and second columns present the EW and NS component. The ground motion time history is recorded from the epicenter of the 30th May 2005 earthquake carrying a moment magnitude of 5.3 with 90.8 km from the SDM station. The time 0.0 s refers to the rupture initiation time and the record has been baseline corrected and low-cut filtered at 0.13 Hz to remove low-frequency components contaminated by local geology and environmental noises.

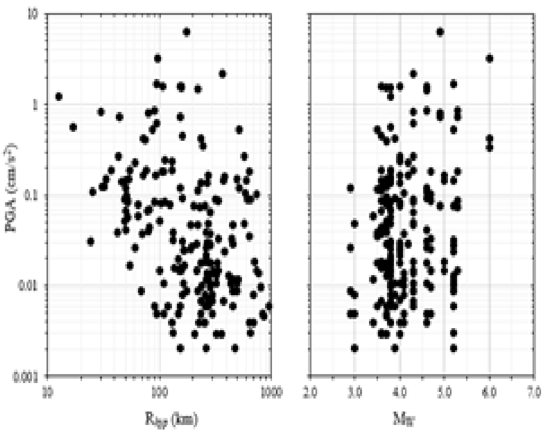

Figure 2. Distribution of peak ground acceleration (cm/s^2) versus hypo-central distance (R_{hyp}) and moment magnitude M_W on soil class A.

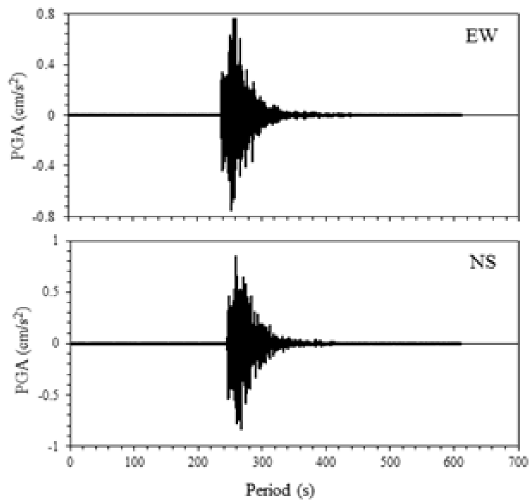

Figure 3. Recorded time histories from local-fault event on 30th May 2005 (M_W: 5.3, R_{hyp}: 90.8 km).

3. Next Generation Attenuation (NGA) Ground-Motion Models

Ground-motion prediction equations (GMPEs) have recently been developed in the Next Generation Attenuation (NGA) for application to shallow crustal earthquakes. Even though it has been developed for tectonically active regions, they can apply from different region [10]. These models were developed by regression analysis using different sets of ground motion records, which might be from different parts of the world. The range of magnitude and distance used in the development of each model is provided in Table 1. Most models for active tectonic regions used records at a distance less than 300 km. These limiting distances represent the applicable ranges of distance where the models provide reliable estimates of ground motions and different attenuation models without providing too many different estimates. In this study, six next generation attenuation (NGA) models, namely Abrahamson and Silva [7], Boore and Atkinson [8], Campbell and Bozorgnia [9], Chiou and Youngs [10], Idriss [11] and Graizer and Kalkan [12]. These NGAs are abbreviated respectively as AS08, BA08, CB08, CY08, ID08 and GK09.

Table 1. Ranges of compatible selected GMPE models

GMPEs	Model	Distance range (km)	Magnitude range
Abrahamson and Silva [7]	AS08	0 – 200	5.0 – 8.5
Boore and Atkinson [8]	BA08	0 – 400	5.0 – 8.0
Campbell and Bozorgnia [9]	CB08	0 – 200	4.0 – 8.5
Chiou and Youngs [10]	CY08	0 – 200	4.0 – 8.5
Idriss [11]	ID08	0 – 200	5.0 – 8.5
Graizer and Kalkan [12]	GK09	0 – 250	4.9 – 7.9

Because of the relative sophistication of the NGA, it is of interest to evaluate whether they can be applied in specific geographic regions such as Sabah. The compatibility of each model of NGA by specifically testing the ability of the NGA to capture the earthquake characters such as earthquake source, propagation path, and geological condition. Site response is not included in this analysis since all the records are in rock condition with shear wave velocity of 1500 m/s.

4. Results and Discussion

The six NGA models mentioned above are tested in the range of magnitude considered between M_W 3.0 and 6.0 in total 209 recordings with hypocentre distances up to 1000 km. The hypocentre is the earthquake originates deep below the ground surface. Seismic hazard analysis differs in terms of the definition of seismic sources and the GMPE model. To fulfil the criteria of Sabah being affected mostly by shallow crustal faults, six well-known NGA are compared with the maximum value of the two horizontal components of PGA value. In residual analysis the prediction error for each observation and standard deviation of the errors or root of the mean square (RMS) for each event are computed for each model. The error is defined as the difference between the logarithmic value of estimated PGA and logarithmic value of recorded PGA. The smaller RMS value indicates better estimation of the PGA. The larger RMS indicates a poorer performance of the GMPE.

Since Sabah has affected by low and moderate earthquake, the fittings are separated for both cases of less than magnitude M_W 5.0 and more than or equal to magnitude M_W 5.0. The NGA models are fitted for less than M_W 5.0 as shown in Figure 4. The RMS value for Campbell and Bozorgnia [9] is the lowest among GMPE models. Graizer and Kalkan [12] shows most unlikely fitted with the PGA with the highest RMS value. For all the plots of NGA, the lines such as models of Abrahamson and Silva [7], Boore and Atkinson [8], Campbell and Bozorgnia [9] and Chiou and Youngs [10] move consistent with the magnitude and distance except for the plots of Idriss [11] and Graizer and Kalkan [12]. The plots for model Idriss [11] and Graizer and Kalkan [12] can be concluded that the estimated value is higher than the actual PGA.

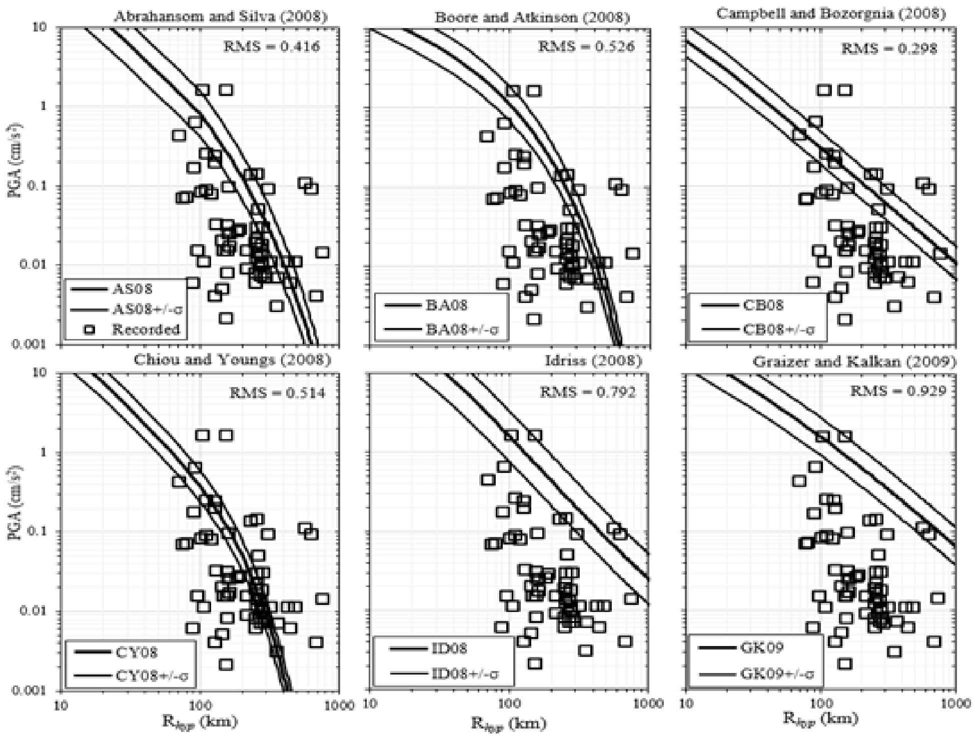

Figure 4. Comparison of peak ground acceleration values computed at 0 s for magnitude less than M_W 5.0

The next set of plots (Figure 5) show the comparison of PGA values recorded from the magnitude larger than or equal to magnitude M_W 5.0. Again, the Campbell and Bozorgnia [9] model yield the smallest RMS. The pattern shown on the plot almost the same as the result for magnitude less than M_W 5.0 where the models of Abrahamson and Silva [7], Boore and Atkinson [8], Campbell and Bozorgnia [9] and Chiou and Youngs [10] move consistent with the magnitude and distance except for plots by Idriss [11] and Graizer and Kalkan [12].

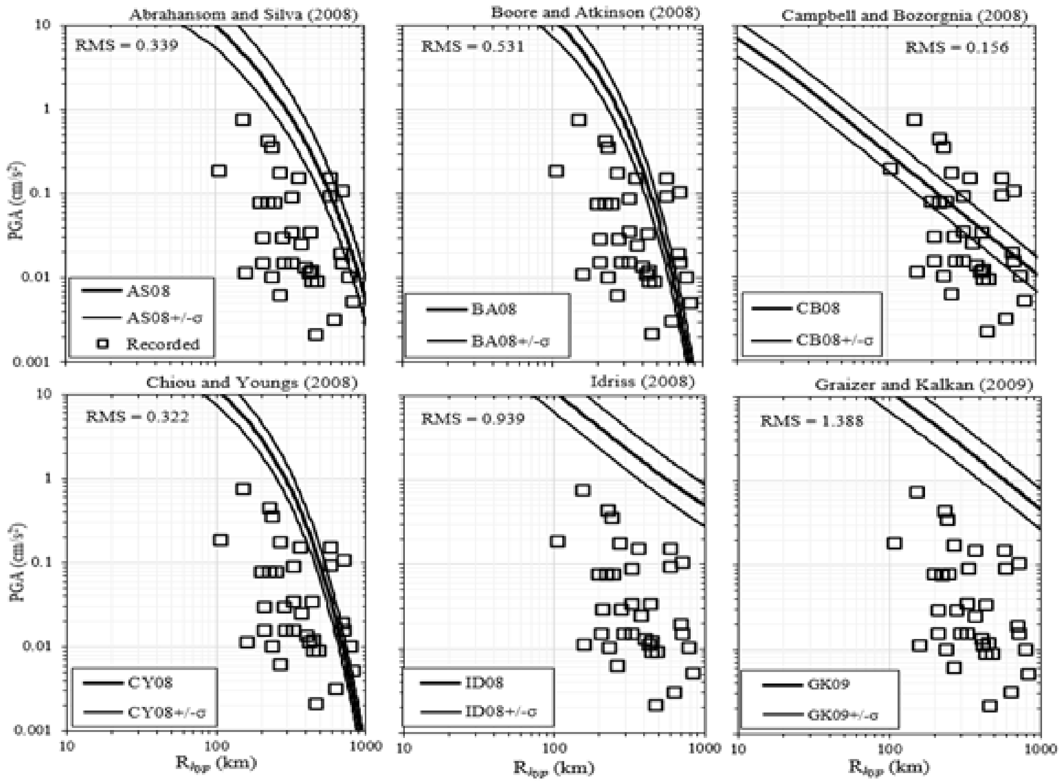

Figure 5. Comparison of peak ground acceleration values computed at 0 s for magnitude more than M_W 5.0

To measure the accuracy of the NGA prediction with the data, the standard errors (σ) of predictions are calculated by defining residuals and examining residual plots. The Figure 6 illustrates the residuals versus distance of the PGA measured and the predicted value of a regression model of NGA. The Abrahamson and Silva [7] and Campbell and Bozorgnia [9] present better residual fits than other models. It can observe for models Boore and Atkinson [8] and Chiou and Youngs [10] that are able to predict the ground-motion records fairly good. The two other models, Idriss [11] and Graizer and Kalkan [12] show the poorest fit with over-predict the data. It is again demonstrated in this comparison that the models cannot match very well with the existing data records.

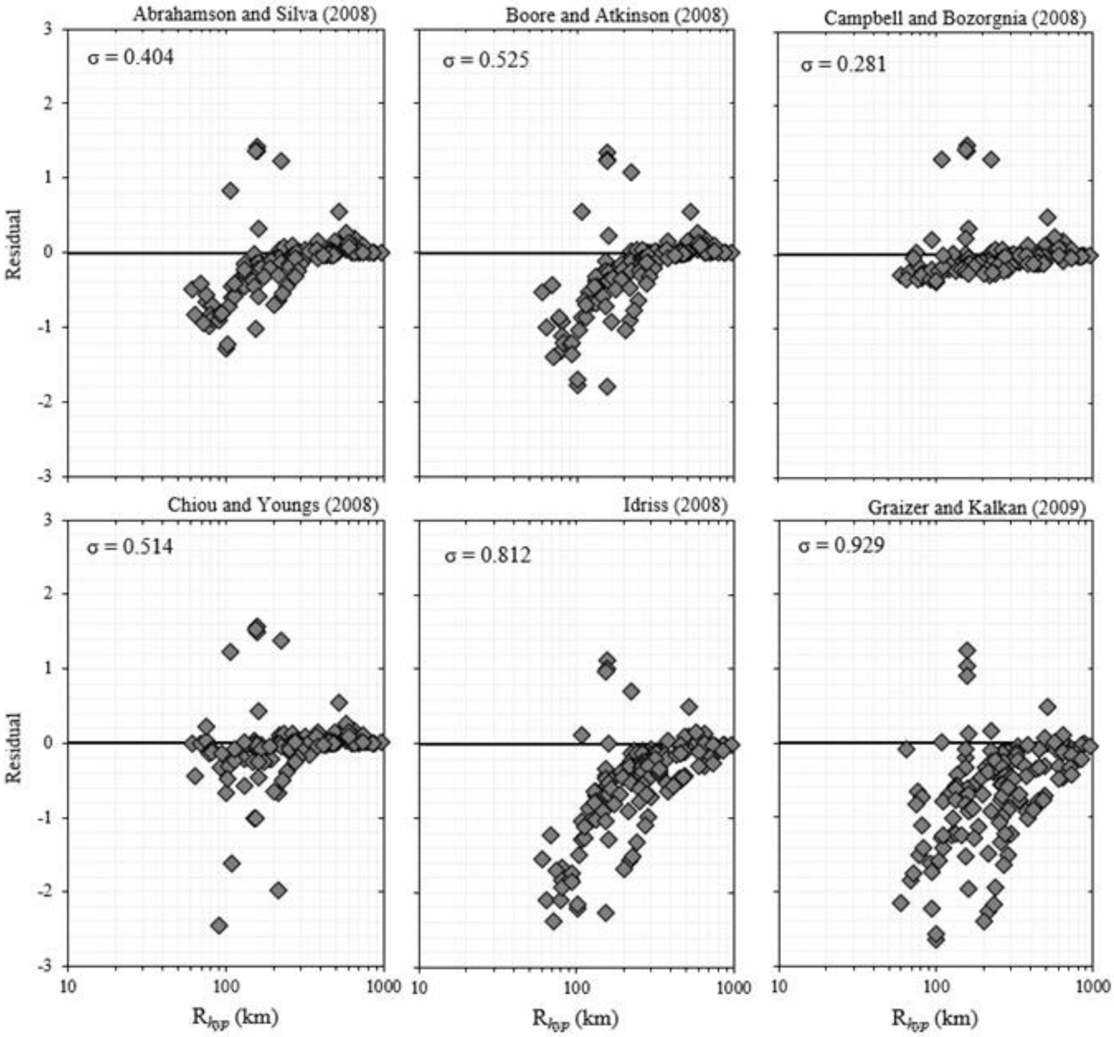

Figure 6. Residuals computed for each NGA models

It appears that the models of Abrahamson and Silva [7] and Campbell and Bozorgnia [9] can be used in seismic hazard analysis for Sabah. The plots of RMS and residual show that there is significant variability in the predicted ground motions. Nevertheless, in order to evaluate a full epistemic uncertainties of the relative performance of the NGA used in seismic hazard analysis, logic tree weighting models can be introduced by rank the models of Abrahamson and Silva [7] and Campbell and Bozorgnia [9] followed by the models of Boore and Atkinson [8] and Chiou and Youngs [10]. The evaluation of the other two models; Idriss [11] and Graizer and Kalkan [12] seem to show inconsistency with the records.

5. Conclusion

The NGA models needed to be selected to predict the ground motions produced by local earthquakes. The choice of the models was guided both by expert opinion and using the results of the testing on the data available. The data available are restricted with 209 recordings, but still it is worth evaluating the fit with respect to the global models. The aim of the study was to test systematically NGA models against local earthquake recordings of Sabah with range of magnitude M_W 3.0 to 6.0. Among the NGA models, the Campbell and Bozorgnia appears to be the model which is providing the best fit to local PGA datasets. The good performance of this model, suggesting that it can be applied for predicting ground motions for all ranges of magnitude. It should also be emphasized that the previous researchers assess model performance in a positive sense. However, the models of Boore and Atkinson and Chiou and Youngs show relatively poor performance. Campbell and Bozorgnia model show the resulting residual in an average close to zero. In conclusion, it is recommended to use the Abrahamson and Silva, Boore and Atkinson, Campbell and Bozorgnia and Chiou and Youngs models to evaluate seismic hazard assessment for Sabah.

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Acknowledgments

The authors would like to thank and acknowledge the financial support from Faculty of Engineering, Universiti Malaysia Sabah under Dana NIC Grant Scheme SDN0041-2019 and Universiti Malaysia Pahang under the research grant (RDU/UMP) vote number RDU190339. We wholeheartedly thank the anonymous reviewers for their helpful comments.