Usability of the Next Generation Attenuation Equations for Seismic Hazard Assessment in Malaysia

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ABSTRACT

This study investigated the applicability of five popular seismic attenuation equations developed under the Next Generation Attenuation (NGA) project, for Peninsular Malaysia condition. These five equations were originally developed by Campbell and Bozorgnia, Chiou and Youngs, Boore and Atkinson, Abrahamson and Silva, and Idriss. Published in 2008, these models were actually meant for the Western United States. Therefore, the objective of this study was to investigate the suitability of using these NGA models in predicting ground motion for Peninsular Malaysia. Earthquakes data obtained from the United States Geological Survey database surrounding Peninsular Malaysia were attenuated to a distance of 400 km, indicating similar distance between the Sumatran strike-slip faults to Kuala Lumpur city. Comparisons between the five NGA models revealed that Abrahamson and Silva's model performed better in attenuating longer distance seismic waves as the peak ground acceleration (PGA) value obtained was closer to the pre-existing seismic hazard maps for the region. However, a closer study indicated a strong need for the NGA model to be fine-tuned and calibrated because the gap of discrepancy with the existing PGA values was still not negligible.

Keywords **– NGA, ground motion prediction, seismic, earthquake, seismic attenuation**

I. INTRODUCTION

Despite located in the relatively stable Sunda Shelf, Malaysia faces far-field tremor effects from two nearby earthquake faults; the Sunda megathrust and Sumatran strike-slip fault [1]. Distance between the nearest epicenter ever recorded and capital city of the country is less than 400 km. Therefore, the country faces tremor threats too despite located in an earthquake-free region.

Development of seismic hazard maps for Malaysia started in 2002. Adnan et al [2] developed the deterministic seismic hazard maps for a densely populated city, the Klang Valley. The map was later refined and extended by Hendriyawan [3] in 2006 through probabilistic seismic hazard assessment approach to be used for structural earthquake analysis and design in accordance to the International Building Code, IBC 2000 [4]; and the European Standards, Eurocode 8 [5].

In 2003, the Pacific Earthquake Engineering Research Center (PEER) has appointed five research teams to develop sets of attenuation equations for shallow crustal regions [6]. The name of the project is PEER Next Generation Attenuation (NGA) Project. Among the significances of the NGA Project is the consideration of common worldwide strong-ground-motion recordings. Specific and detailed project information is published in Power et al [7].

Development of NGA is initially meant to empirically attenuate seismic sources for United States regions, or the Western United States to be more exact. As a matter of such, the objectives of this study were to study the suitability of using NGA for seismic attenuation purpose in Peninsular Malaysia (particularly Kuala Lumpur being the capital city) and the effects of its application.

II. NEXT GENERATION ATTENUATION MODELS

There are generally five renowned NGA empirical models developed, published in 2008 by: Campbell and Bozorgnia [8]; Chiou and Youngs [9]; Boore and Atkinson [10]; Abrahamson and Silva [11]; and Idriss [12]. The equations are shown in (1) to (4) respectively, except for Boore and Atkinson's model due to its lengthy details and formulation.

The Campbell and Bozorgnia's NGA model:

$$\ln Y = f_{mag} + f_{dis} + f_{flt} + f_{hng} + f_{site} + f_{sed} + \varepsilon \quad (1)$$

NGA empirical equations of Chiou and Youngs:

$\ln\left(y_{ref\,ij}\right) = c_1 + [c_{1a}F_{RVi} + c_{1b}F_{NMi} +$
c7ZTORi−41−ASi+c10+c7aZTORi−4ASi+c2Mi−6+c2−c3cnln1+ecncM−Mi+c4lnRRUPij+c5cosh c6maxMi−cHM,0+c4a−c4lnR2RUPij+c2RB+cγ1 +cγ2coshmaxMi−cγ3,0RRUPij+c9FHWijtanhRX ijcos2δic9a1−R2JBij+Z2TORiRRUPij+0.001
$(2a)$

$$\begin{aligned}\ln(y_{ij}) &= \ln\left(y_{ref\,ij}\right) + \emptyset_1 . min\left(\ln\left(\frac{V_{S30_j}}{1130}\right), 0\right) \\ &+ \emptyset_2\left\{e^{\emptyset_3\left(min\left(V_{S30_j},1130\right)-360\right)} - e^{\emptyset_3(1130-360)}\right\}\ln\left(\frac{y_{ref\,ij}\,e^{\eta_1} + \emptyset_4}{\emptyset_4}\right) \\ &+ \emptyset_5\left(1 - \frac{1}{\cosh[\emptyset_6 . max(0, Z_{1.0} - \emptyset_7)]}\right) \\ &+ \frac{\emptyset_5}{\cosh[0.15 . max(0, Z_{1.0} - 15)]} + \eta_i \\ &+ \varepsilon_{ij} \quad (2b)\end{aligned}$$

NGA models of Abrahamson and Silva:

$$\begin{aligned}\ln S_a(g) &= f_1(M, R_{rup}) + a_{12}F_{RV} + a_{13}F_N + a_{15}F_{AS} \\ &+ f_5(P\hat{G}A_{1100}, V_{S30}) \\ &+ F_{HW}f_4(R_{jb}, R_{rup}, R_x, W, dip, Z_{top}, M) \\ &+ F_{RV}f_6(Z_{top}) + (1 - F_{RV})f_7(Z_{top}) + f_8(R_{rup}) \\ &+ f_{10}(Z_{1.0}, V_{S30}) \quad (3)\end{aligned}$$

Idriss's empirical model of NGA:

$$\begin{aligned}\text{Ln}[PAA(T)] &= \alpha_1(T) + \alpha_2(T)M \\ &- [\beta_1(T) + \beta_2(T)M]Ln(R_{rup} \\ &+ 10) + \gamma(T)R_{rup} \\ &+ \varphi(T)F \quad (4)\end{aligned}$$

All empirical models listed above are selected equations from the list of entire formulations. Please refer to publications from [8] to [12] for complete sets of equations. Each empirical models presented above utilizes their own different terminology, symbol, abbreviation, input or even coefficient which are not included in this paper for simplicity purpose.

III. RESEARCH METHODOLOGY

The overall framework of the study is shown in the flow chart as illustrated in Fig.1.

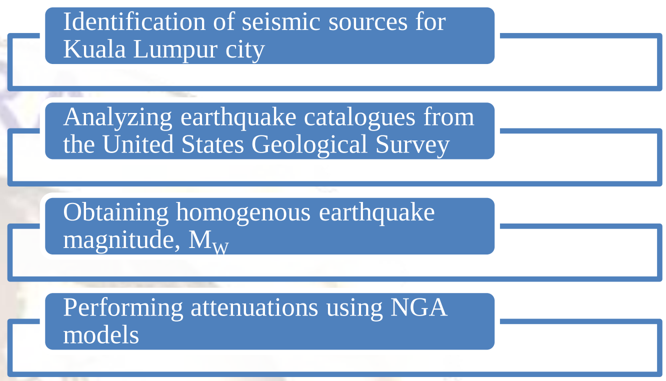

Figure 1: Flow chart of research methodology adopted

The main capital of Malaysia, namely Kuala Lumpur is located approximately 300 to 400 km away from the nearest earthquake fault in Sumatra. This fault is identified to be the Sumatran strike-slip type of fault. Another fault is located further to the West of Sumatra beneath the seabed, known as the Sunda megathrust fault which caused the 2004 immense tsunami to Acheh and Sri Lanka.

Earthquake catalogues from 2nd January 1973 to 31st December 2010 were obtained from the United States Geological Survey (USGS) database. By employing a rectangular area search, earthquake incidents recoded in the area coverage of longitudinal 90^0E to 125^0E and 10^0S to 10^0N latitude were all included. The total amount of earthquake data obtained was 4529 files, ranging from magnitude range (either m_b or M_s) between 5.0 and 9.5.

Since the magnitude of earthquakes obtained from the database list is either mentioned in the appearance of m_b or M_S, each of this value needs to be converted to a consistent or homogenous form of earthquake magnitude. The preferred magnitude, namely the moment magnitude (M_W) was acquired through (5) and (6).

$$M_W = 0.528m^2{}_b - 4.685m_b + 15.519 \quad (5)$$

$$M_W = 0.123M^2{}_S - 0.646M_S + 5.644 \quad (6)$$

The nearest one among the two earthquake faults in the vicinity of Peninsular Malaysia is the Sumatran strike-slip fault on the land of Sumatra. This study adopted only attenuation for seismic sources originated from this fault, with the fault dip angle $\delta = 90^0$. Shear wave velocity was assumed to be constant at 760 m/s and the spectral period of 1.0s was presumed. Rupture distance, R_{RUP} and the site coordinate, R_X were calculated from (7) and (8), respectively.

$$R_X = R_{JB} \sin\alpha \quad (7)$$

$$R_{RUP} = \sqrt{R^2{}_{JB} + Z^2{}_{TOR}} \quad (8)$$

Values of peak ground acceleration (PGA) from R_{JB} = 0 to 400 km were calculated using all five sets of developed NGA equations [8 to 12], at M_w intervals of every 0.5 from 5.0 to 8.5. These attenuated PGA using NGA empirical models will be compared with the existing ground motion prediction equation published by Hendriyawan [3] and Marto [13].

IV. Results and Discussion

Empirical relationships between attenuated peak ground acceleration (PGA) values obtained from the five different sets of NGA models were plotted against R_{JB} in Fig.2 to Fig.9 for M_W = 5.0 to M_W = 8.5 correspondingly. The shapes of the graph plot for each NGA equations have shown good agreement with each other in defining the attenuation relationships. This reveals that the developer teams of NGA models have done a tremendous and good job in forming these equations. Although all the equations are formed similarly in the logarithmic function, each of them uses different input, coefficient and parameter independently.

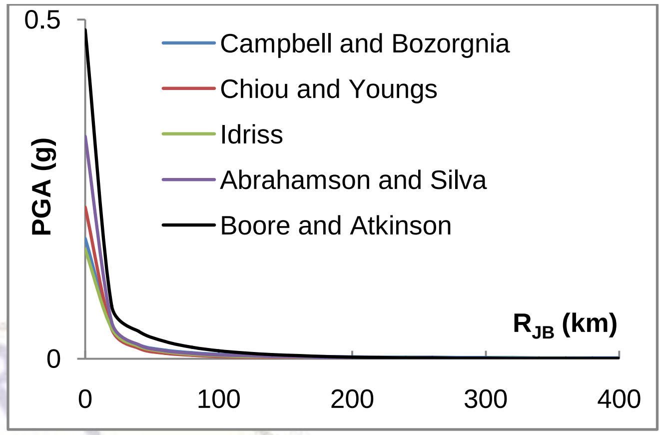

Figure 2: PGA versus R_{JB} for M_W = 5.0

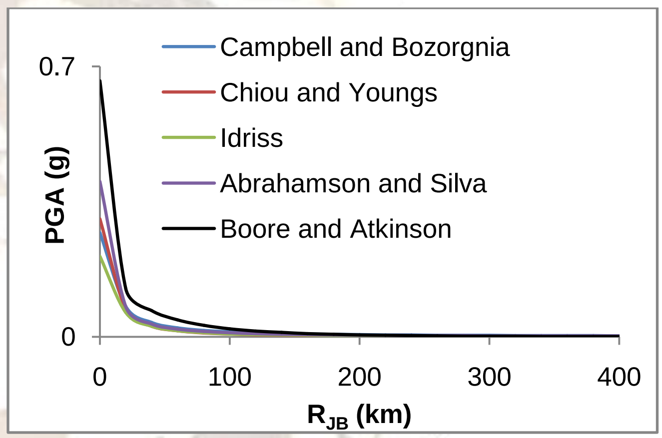

Figure 3: PGA versus R_{JB} for M_W = 5.5

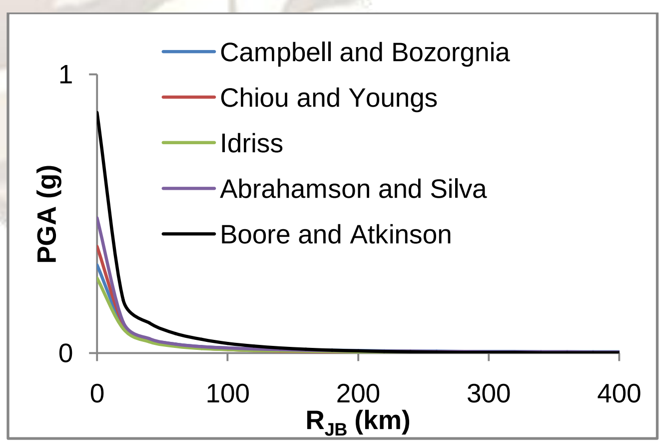

Figure 4: PGA versus R_{JB} for M_W = 6.0

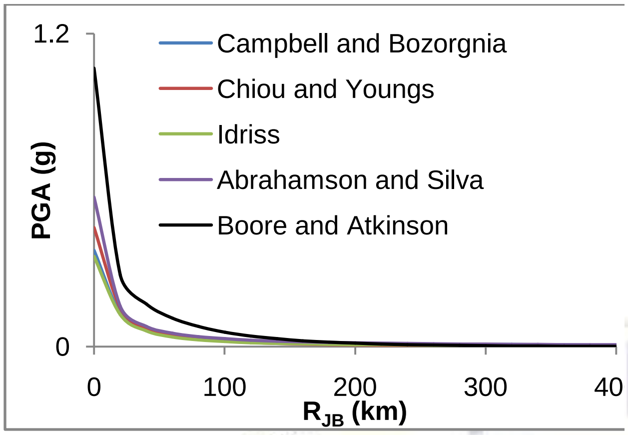

Figure 5: PGA versus R_{JB} for M_W = 6.5

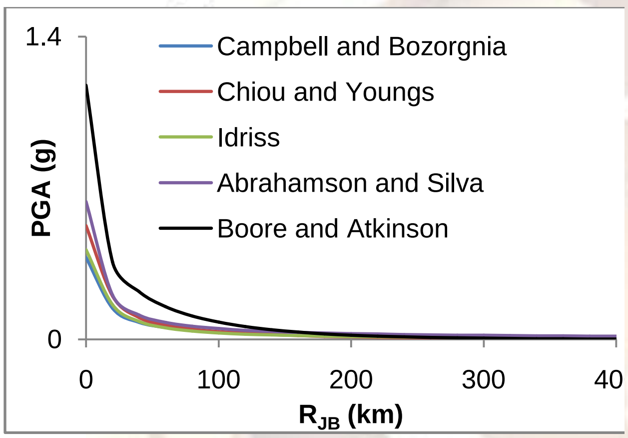

Figure 6: PGA versus R_{JB} for M_W = 7.0

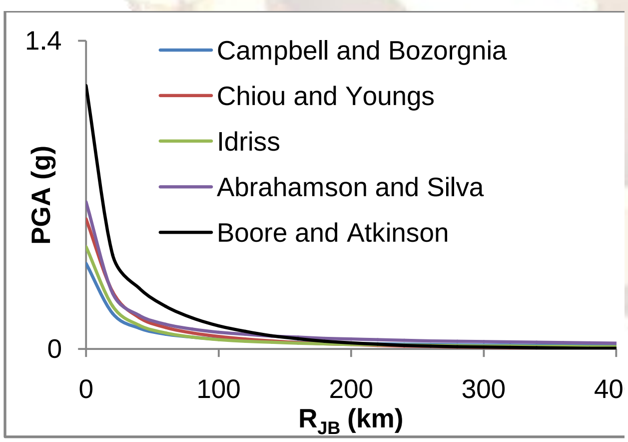

Figure 7: PGA versus R_{JB} for M_W = 7.5

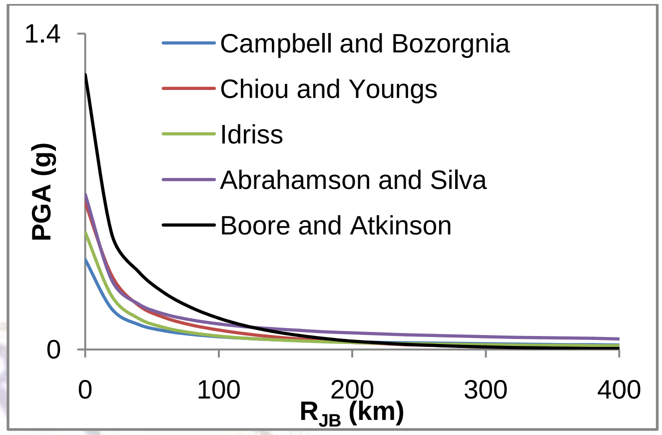

Figure 8: PGA versus R_{JB} for M_W = 8.0

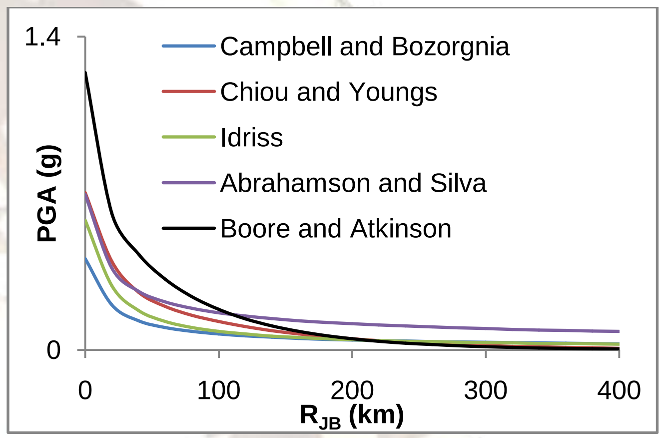

Figure 9: PGA versus R_{JB} for M_W = 8.5

Rapid decrement of PGA values was observed from the seismic source (at R_{JB} = 0) to R_{JB} = 25 km for earthquakes having moment magnitude M_W below 7.5 (Fig.2 to 6). Seismic source having M_W greater than that up to 8.5 were able to propagate further up to R_{JB} = 100 km from epicenter (Fig.7 to 9). It was observed that the Boore and Atkinson's model always indicated a higher PGA value at points closer to seismic source, compared to other equations. Beyond R_{JB} greater than 120 km and M_W more than 7.0, Abrahamson and Silva's model generated higher PGA than the remaining four. This reflected that Abrahamson and Silva's equation seemed to fit better in attenuating longer distance waves.

Observing PGA values obtained from the five empirical models, the equation of Idriss [12] generates relatively the lowest ground acceleration values. Therefore, Idriss's PGA values were used as benchmark in this study to compare with the other remaining four equations. Differences between each model with Idriss's are shown in Fig.10 to 13 for M_W = 5.0, 6.0, 7.0 and 8.5 accordingly. Comparisons were only made for 0 km < R_{JB} < 100 km. This is because all five equations have shown oversaturation behavior for R_{JB} > 100 km. In other words, the PGA values calculated beyond 100 km are getting smaller. Please note that however small these values may be, they are not negligible.

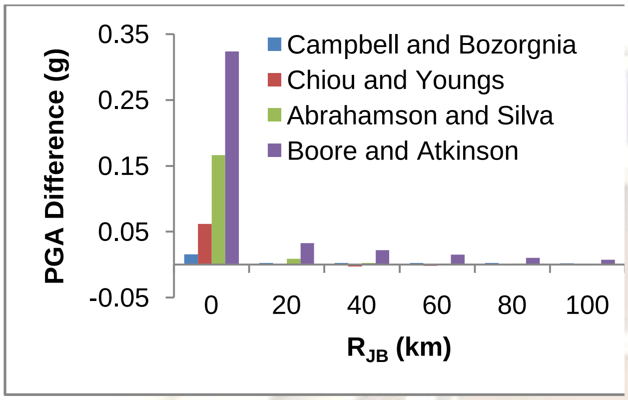

Figure 10: PGA difference for M_W = 5.0

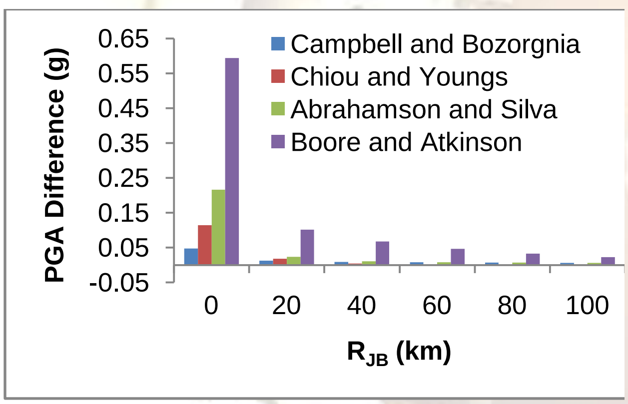

Figure 11: PGA difference for M_W = 6.0

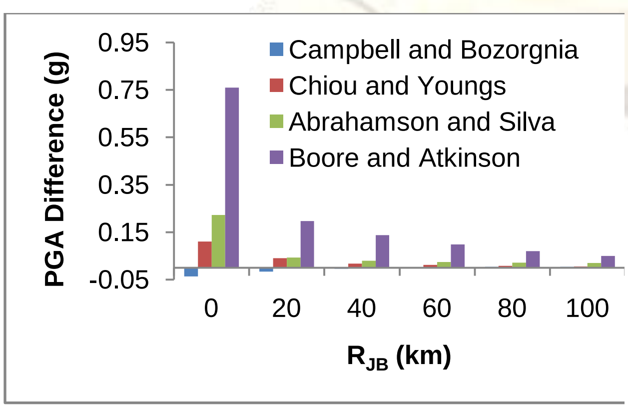

Figure 12: PGA difference for M_W = 7.0

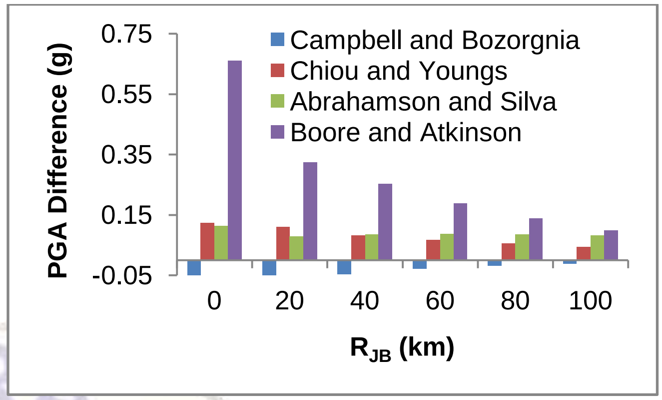

Figure 13: PGA difference for M_W = 8.5

Difference between each sets of equation appeared to be rather significant at R_{JB} = 0 km, even at M_W of 5.0. A margin of approximately 0.3 g was noted between Idriss's model with Boore and Atkinson's. The difference decreased with increment of R_{JB} and became insignificant. Moving from moment magnitude M_W of 5.0 to 8.5, the difference margin between each model was noted to be increasing as well. The largest margin could be up to 0.6 g. At M_W = 8.5, the differences were still significantly observed even at R_{JB} = 100 km. This revealed as the earthquake magnitude increases, variation of each model in predicting its attenuation function for longer distance (far-field) increases as well, compared to each other.

Current pre-existing ground motion prediction equation developed by Hendriyawan [3] suggests PGA value of 0.1 g to 0.2 g for Kuala Lumpur city, based on probabilistic seismic hazard assessment carried out. The pre-existing seismic hazard assessment is meant for return period (T_R) of 500 years and 2500 years at bedrock. The largest PGA value obtained through NGA model is based on Boore and Atkinson's equation, indicating PGA value close to 0.1 g. PGA values from the other four models indicated much lower ground acceleration values. This is because the original sets of NGA models developed in the PEER project are meant for attenuating seismic sources to a distance of not exceeding 200 km. It is expected that beyond 200 km, the NGA equations will generate readings which are extremely small (oversaturation behavior). However, it is worthwhile to mention that despite facing the risk and possibility to show oversaturated PGA, one of the equations has shown PGA of approximating to 0.1 g, which is rather close to the pre-existing ground acceleration maps proposed by Hendriyawan [3].

In other words, the NGA equations indirectly validated the probabilistic seismic hazard maps proposed by Hendriyawan [3]. Looking at a return period of T_R = 2500 years, the pre-existing map's PGA proposal of 0.20 g is not over-demanding, since the Boore and Atkinson's NGA model has obtained 0.10 g despite being in the over-saturation mode.

V. CONCLUSION

Preliminary study on the application of existing Next Generation Attenuation (NGA) ground motion prediction equations for capital city of Malaysia (Kuala Lumpur) has been carried out. The study utilized earthquakes data obtained from the United States Geological Survey (USGS) database as seismic sources. Propagation of seismic waves from the nearest Sumatran strike-slip fault (located approximately 300 to 400 km away) to Kuala Lumpur was predicted using five different sets of NGA equations: Campbell and Bozorgnia; Chiou and Youngs; Abrahamson and Silva; Boore and Atkinson; and Idriss.

All five models agreed with each other well for lower magnitude earthquakes. As the level of magnitude increases, discrepancies between attenuated PGA values among each equation seemed to be increasing correspondingly. Comparison between the NGA models and pre-existing ground motion prediction equation for the country has shown a need to further calibrate or fine-tune these NGA models in order for them to be adopted in Malaysia. Likewise for cases such as in Iranian and European countries where the NGA models required minor alterations before being assimilated into the design codes.

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