SUITABLE ATTENUATION MODEL FOR THAILAND

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ABSTRACT :

To establish seismic design criteria for buildings in Thailand, probabilistic hazard analysis requires estimation of ground motion intensity such as peak ground acceleration (PGA) or spectral acceleration. This estimation process needs to use an attenuation relationship, which provides PGA estimates as a function of earthquake magnitude, distance, and other seismic parameters. However, Thailand does not have enough strong motion records to develop a reliable attenuation model for the region, so existing models from other parts of the world have to be adopted. Unfortunately, different available attenuation models provide significantly different estimates at large distance, which is the case for sites in Thailand. Thus, the appropriate model for Thailand should be determined by comparing PGA estimates by each model to ground motions recorded in Thailand. In this study, twenty attenuation equations previously developed for shallow crustal earthquakes in both active tectonic and stable continental regions, and for subduction earthquakes were evaluated using a total of 163 ground motions recorded by Thai Meteorological Department (TMD) from 45 earthquake events between July 2006 and July 2007. PGA estimated by attenuation models for earthquake magnitude ranging from 4 to 7 were plotted and compared to the field records. The square root of mean of square (RMS) of the differences between estimated PGA and actual records was also computed for each attenuation model to quantify how well the model predicts ground motions. It was found that the attenuation models proposed by Idriss (1993), Sadigh et al. (1997), and Toro (2002) have the lowest RMS for shallow crustal earthquakes. And the model by Crouse (1991) has the lowest RMS for subduction earthquakes. Therefore, these models are the most suitable attenuation models for Thailand.

KEYWORDS: Attenuation model, Peak ground acceleration, Ground motion estimation

1. INTRODUCTION

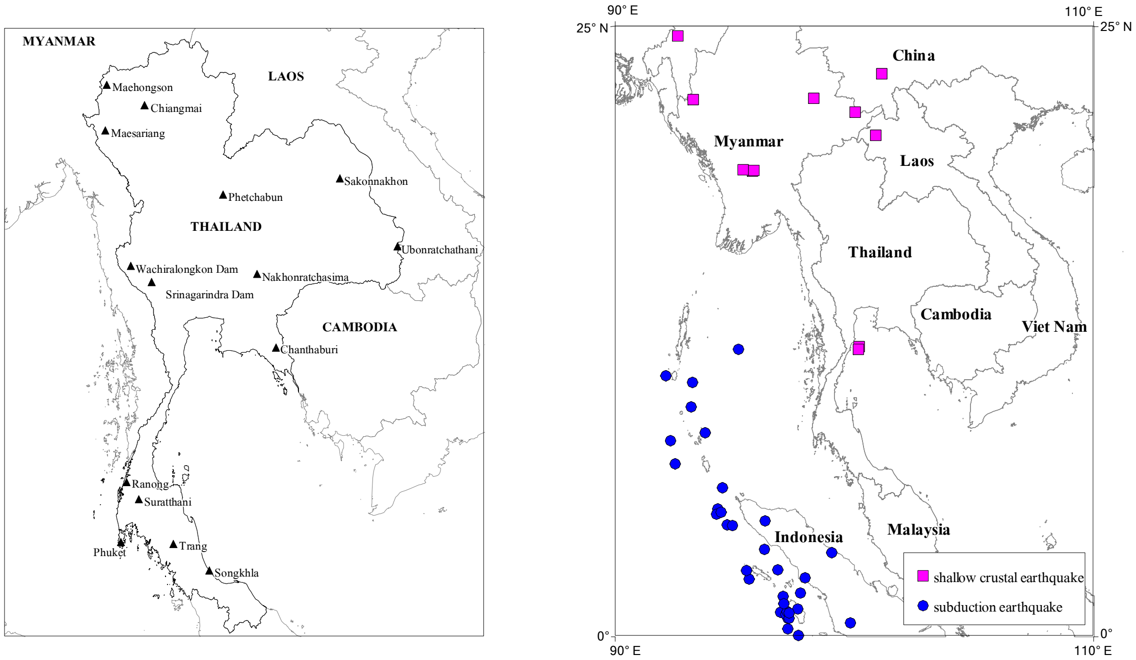
Although Thailand did not suffer from any major ground shaking disaster during the past few hundred years, earthquake ground motions could be felt in Thailand from time to time, mostly from distant earthquakes. The Department of Public Works thus enforced seismic design of buildings in the Northern and Western regions of the country since 1997 and recently included Bangkok metropolitan area in the seismic zone that requires earthquake resistant design. A key question is how strong of the ground motion that buildings in Thailand should be designed for. This question is hard to answer because there is virtually no strong earthquake ground motion recorded in Thailand. A seismic hazard map for Thailand could be developed based on earthquake source zones identifiable from earthquake catalogs and ground motion estimation using some attenuation models.

An attenuation model provides estimation of ground motion intensity, e.g., peak ground acceleration (PGA) or spectral pseudo-acceleration, as a function of earthquake magnitude, site-to-source distance, and other essential seismic parameters. It is one of the most important components in seismic hazard analysis because the ground motion intensity could vary significantly depending on attenuation models to be used. Thailand is still lacking earthquake ground motion records necessary for developing a reliable attenuation model for the region. Therefore, attenuation models developed from other regions of the world need to be adopted to best represent the geological as well as seismological attributes of the region. While different attenuation models result in different estimation, it is questionable which attenuation models are suitable for Thailand.

This study attempts to determine the most suitable attenuation relationships by comparing PGA estimates from twenty attenuation equations to a limited number of records that recently became available from Thai Meteorological Department (TMD). Suitability of attenuation models in estimating spectral acceleration for Thailand is still an ongoing research.

2. GROUND MOTION RECORDS

After the devastating Sumatra earthquake in December 2004, TMD has installed new digital broadband recording instruments at 15 stations throughout the country in 2006 (Figure 1a). Since then 163 earthquake ground motion records from 45 events (Figure 1b) have been recorded between July 2006 and July 2007. The epicenter locations, date, time, and moment magnitudes of those 45 events were obtained from Harvard Central Moment Tensor Catalog. Only earthquakes that have magnitudes greater than 4 and epicenters located in latitude between 0 and 25°N and longitude between 90 to 110°E were considered.



(a) (b)

Figure 1 (a) 15 seismic stations of TMD; (b) 45 earthquakes during which ground motions were recorded;

The 45 earthquake events are categorized into shallow crustal earthquakes or subduction earthquakes. Out of the 163 records, 55 were from shallow crustal earthquakes whereas the other 108 records were from subduction earthquakes. Also, the site conditions at the TMD recording stations are categorized into rock or soil site class based on average shear wave velocity in the top 30 meter of the ground ($V_{s,30}$) and through site visits and consultation with geologists.

A plausible estimate of shear wave velocity is calculated from available borehole standard penetration test (SPT) nearest to the recording station published by the Department of Public Works using empirical relationship between blow count and shear wave velocity. The station that has $V_{s,30}$ greater than 360 m/s is classified as a rock site. Otherwise it is classified as a soil site. The number of records in each category is shown in Table 1.

The distribution of records with respect to magnitude and site-to-source distance is shown in Figure 2a. Ground motion records used in this study were obtained from earthquake moment magnitude (M_w) between 4.7 to 6.3 and recorded at distance ranging from 231 to 2090 km. There is still a lack of data from earthquakes with moment magnitude Mw greater than 6.3 as expected for a region of low seismicity. Higher proportion of data is clustered at long distances as most events have epicenters located in Myanmar, Andaman Sea, and Sumatra. Around 66% of the data is categorized as subduction earthquakes while the remaining 34% is classified as shallow crustal earthquakes. Figure 2b shows the variation of PGA values with distance. The PGA value considered this study is the geometric mean of peak values of two horizontal and orthogonal components of ground acceleration at a site. Records used in this study have PGA ranging from 0.000001g to 0.00343g. 62% of the PGA records were taken from rock sites while the rest were measured at soil sites. As expected, PGA records from soil sites tend to be larger than those from rock sites.

Table 1 Classification of records by source and site condition

Source	**Site condition**		**Total**
	Rock	**Soil**	
Subduction earthquake	62	46	108
Shallow crustal earthquake	39	16	55
Total	101	62	163

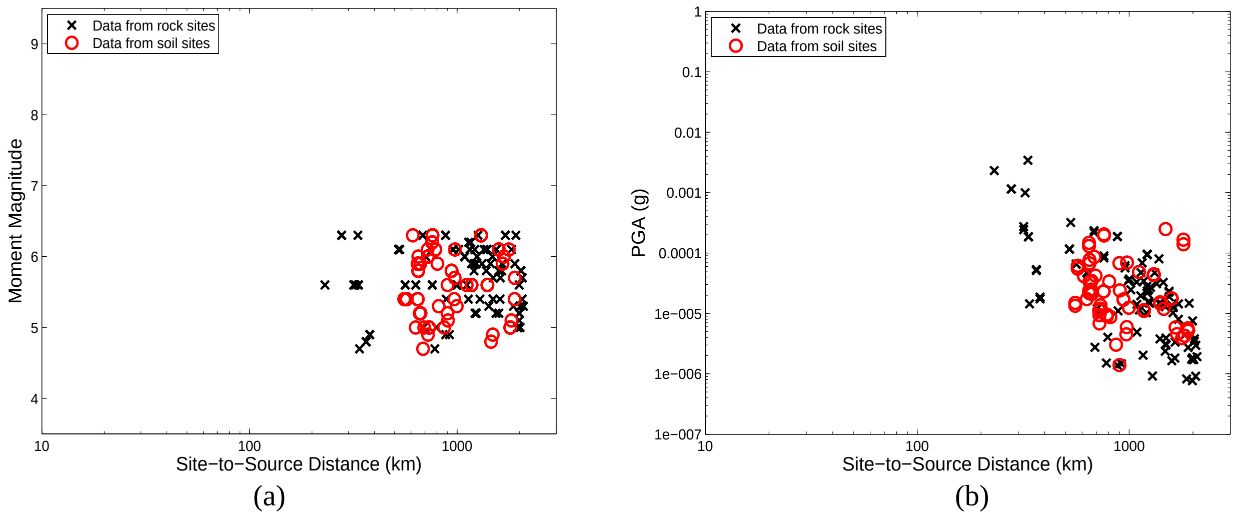


Figure 2 Distributions of earthquake ground motion records used in this study (a) moment magnitude versus site-to-source distance; and (b) peak ground acceleration versus site-to-source distance.

3. ATTENUATION MODELS

This study considers attenuation models for both shallow crustal and subduction earthquakes. Each type of attenuation model is to be compared to the corresponding records. For shallow crustal earthquakes, it has been controversial whether model for active tectonic region or stable continental region is more appropriate for Thailand because Thailand is located at considerable distance from plate boundaries, which is in Myanmar and Andaman Sea. So, this study considers both active tectonic region and stable continental region models for shallow crustal earthquakes.

Twenty well-known attenuation models were selected as shown in Table 2. Fifteen models are for shallow crustal earthquakes and five models for subduction earthquakes. Out of the fifteen models, eleven are for active tectonic regions and four for stable continental regions. 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 also provided in Table 2. Most models for active tectonic regions used records at distance less than 200 km, whereas models for stable continental regions used records at distance less than 500 km. The models for subduction earthquakes used records at longer distance. These limiting distances represent the applicable ranges of distance where the models provide reliable estimates of ground motions and different attenuation models would not provide too different estimates.

However, probabilistic seismic hazard analyses of sites in Thailand often require estimation of ground motions at distances farther than those ranges because Thailand is located at considerable distance from plate boundaries. Nevertheless, some estimates need to be obtained from some attenuation models, i.e., the model whose estimates best match the actual records at large distance in Thailand. Although these attenuation models are not strictly applicable for such large distances, they could be useful for the purpose mentioned above.

In this study, only two next generation attenuation (NGA) models— Boore and Atkinson (2008) and Idriss (2008)—were included because other NGA models require seismic parameters that are not currently available for the earthquakes and stations considered.

Table 2 Ranges of suitable applicability of selected attenuation models

Attenuation model	**Distance range (km)**	**Magnitude range**
Active Tectonic Region		
Ambraseys et al. (2005)	0-100	5.0-7.6
Abrahamson and Silva (1997)	0-220	4.4-7.4
Boore and Atkinson (2008)	0-400	5.0-8.0
Boore et al. (1997)	0-118	5.2-7.7
Campbell (1997)	3-60	4.7-8.0
Esteva and Villaverde (1973)	15-150	-
Idriss (1993)	1-100	4.6-7.4
Idriss (2008)	0-200	4.6-7.4
Sadigh et al. (1997)	0-100	4.0-8.0
Spudich et al. (1997)	0-70	5.0-7.7
Sabetta and Pugliese (1987)	1.5-180	4.6-6.8
Stable Continental Region		
Atkinson and Boore (1997b)	10-500	4.0-7.5
Dahle et al. (1995)	6-490	3.0-8.0
Hwang and Huo (1997)	5-200	5.0-7.5
Toro (2002)	1-500	5.0-8.0
Subduction Zone		
Atkinson and Boore (1997a)	10-400	4.0-8.0
Crouse (1991)	8-850	4.8-8.2
Fukushima and Tanaka (1991)	10-300	4.5-8.2
Megawati et al. (2005)	198-1422	4.5-8.0
Petersen et al. (2004)	10-500	5.0-8.2

4. COMPARISON OF ATTENUATION MODELS AND RECORDED DATA

PGA estimated by attenuation models for active tectonic regions are compared to actual records on rock sites in Figure 3. Similar comparisons for stable continental regions and subduction earthquakes are shown in Figures 4 and 5, respectively. The actual records were binned into Mw= 5 and 6 for plotting. In general, models for active tectonic regions seem to produce a trend consistent with the collected field records based on the plot of attenuation curves. Most of the models appear to correspond substantially with the recorded PGA. In stable continental regions, the advantage of using the models is that a broader range of applicability exists. On the other hand, evaluation of models for subduction earthquakes with the field records confined in a narrow distance range may not reflect the actual attenuation rate.

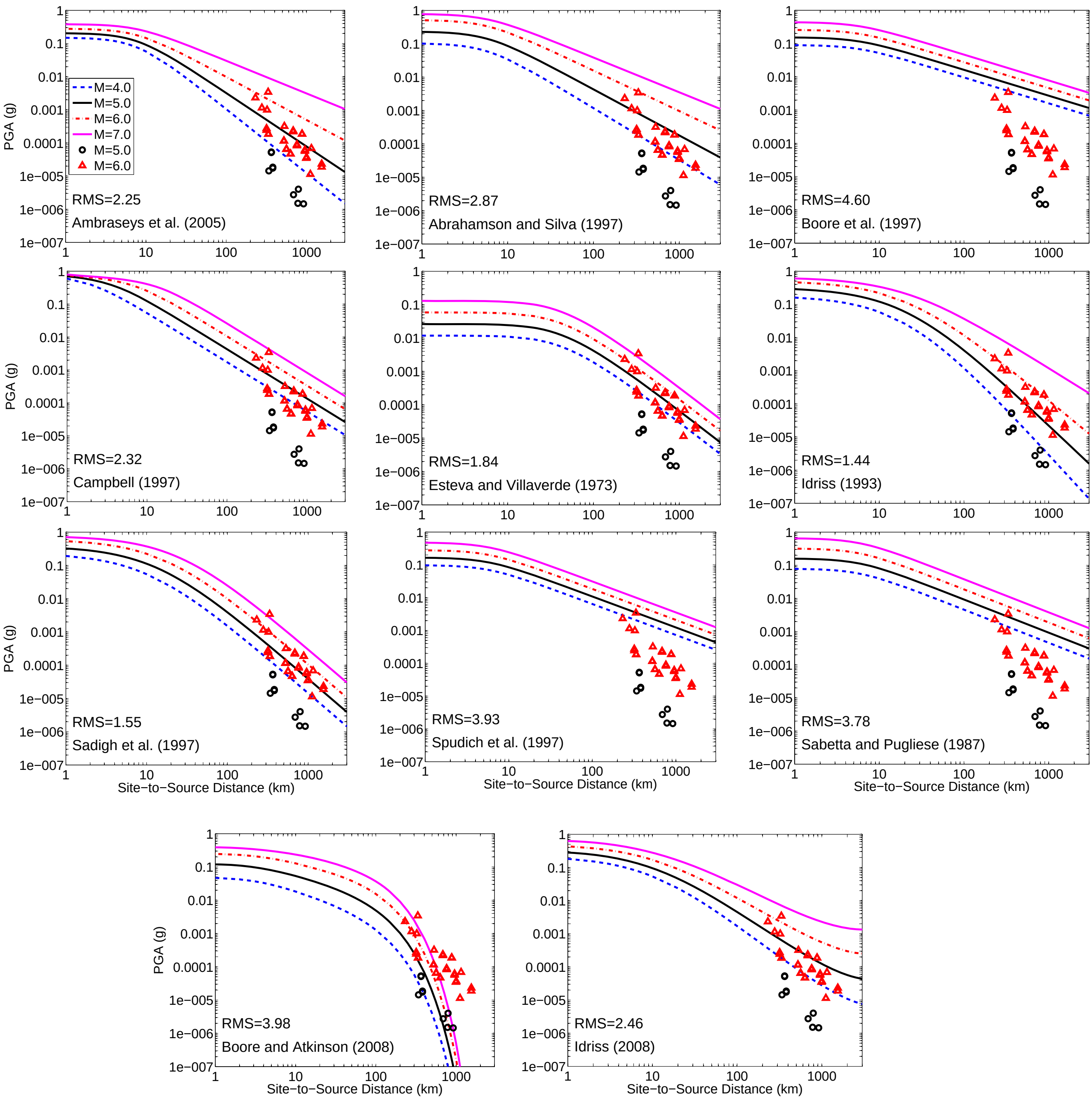


Figure 3 Comparison of attenuation curves for active tectonic regions and recorded PGA on rock sites in Thailand from shallow crustal earthquakes.

From Figure 3, attenuation models by Idriss (1993) and Sadigh et al. (1997) seem to provide PGA estimates that match well with the actual records. To quantify the goodness of fit for each attenuation equation, square root of mean of square of errors (RMS) was calculated for each model to measure the difference between estimated and recorded PGA. The error is defined as the difference between logarithmic value of estimated PGA and logarithmic value of recorded PGA. The smaller RMS value indicates better estimation of PGA. RMS values are summarized in Table 3 and also shown in Figures 3, 4, and 5.

As expected, RMS for Idriss (1993) and Sadigh et al. (1997) are the lowest among attenuation models for active tectonic regions, while Toro (2002) model has lowest RMS for stable continental regions. For subduction earthquakes, Crouse (1991) has the lowest RMS and seems to fit well with the actual records.

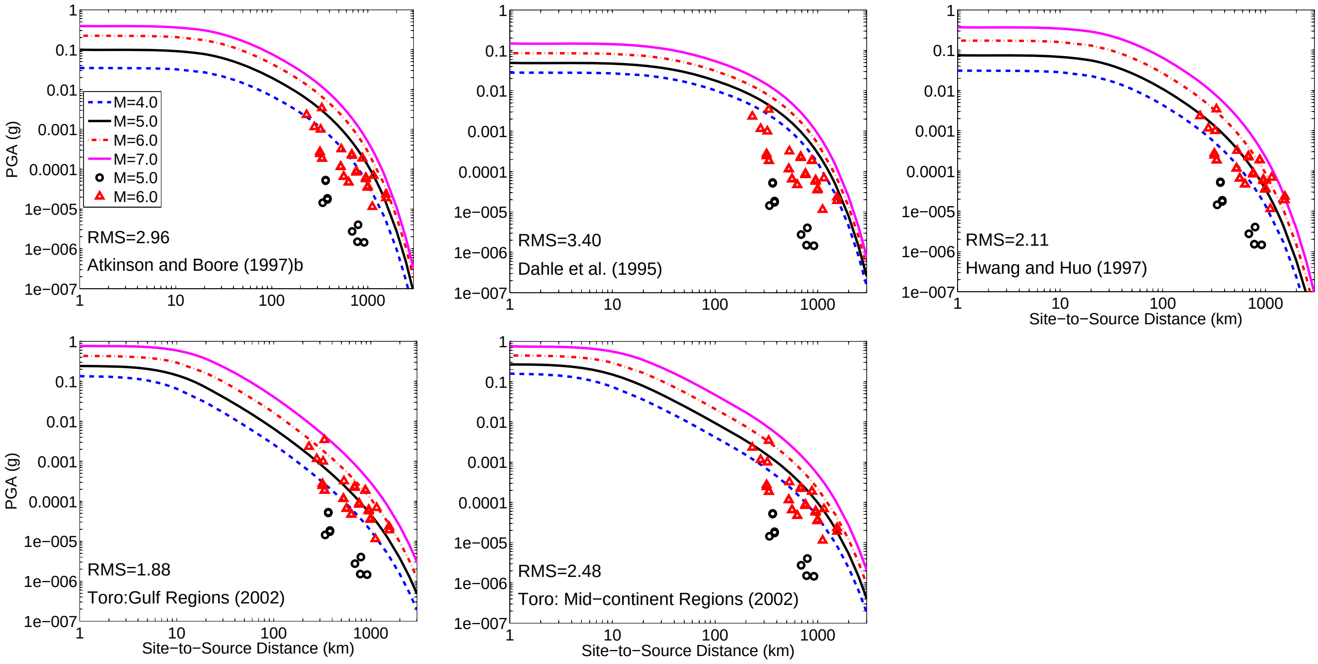


Figure 4 Comparison of attenuation curves for stable continental regions and recorded PGA on rock sites in Thailand from shallow crustal earthquakes.

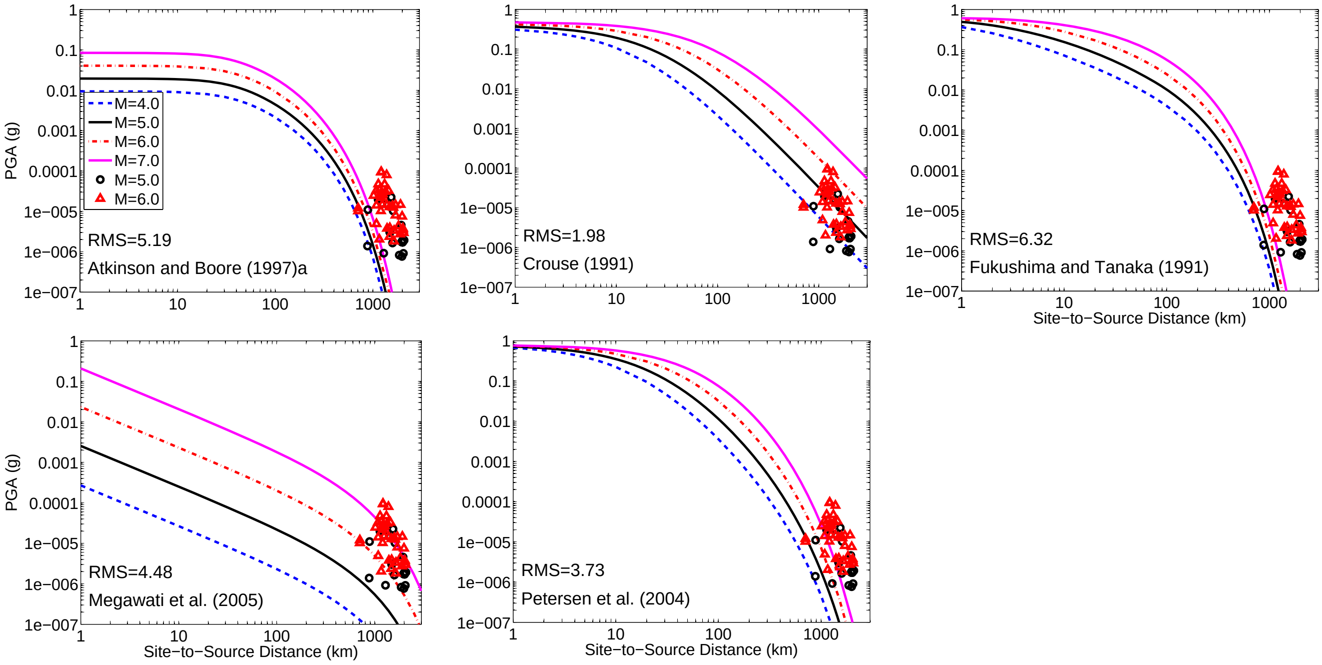


Figure 5 Comparison of attenuation curves for subduction earthquakes and recorded PGA on rock sites in Thailand.

Table 3 Summary of square root of mean of square of errors (RMS)

Attenuation models	Site condition	
	Rock	Soil
Active Tectonic Region		
Ambraseys et al. (2005)	2.25	2.46
Abrahamson and Silva (1997)	2.87	3.21
Boore and Atkinson (2008)	3.98	-
Boore et al. (1997)	4.60	4.70
Campbell (1997)	2.32	2.68
Esteva and Villaverde (1973)	1.84	-
Idriss (1993)	**1.44**	-
Idriss (2008)	2.46	-
Sadigh et al. (1997)	**1.55**	-
Spudich et al. (1997)	3.93	4.08
Sabetta and Pugliese (1987)	3.78	4.12
Stable Continental Region		
Atkinson and Boore (1997b)	2.96	-
Dahle et al. (1995)	3.40	2.37
Hwang and Huo (1997)	2.11	-
Toro: Gulf Regions (2002)	**1.88**	-
Toro: Mid-continent Regions (2002)	2.48	-
Subduction Zone		
Atkinson and Boore (1997a)	5.19	-
Crouse (1991)	**1.98**	-
Fukushima and Tanaka (1991)	6.32	4.14
Megawati et al. (2005)	4.48	-
Petersen et al. (2004)	3.73	2.68

5. CONCLUSIONS

Based on the database used in this research, suitable attenuation models for estimating PGA on rock sites in Thailand due to shallow crustal earthquakes include the models of Idriss (1993), Sadigh et al. (1997) and Toro (2002). And suitable attenuation models for estimating PGA on rock sites in Thailand due to subduction earthquakes is the model by Crouse (1991). An attenuation relationship specifically for Thailand could be developed only after more recorded data from large magnitude and small distance are obtained.

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