UPDATING FRAMEWORK FOR SITE-SPECIFIC ATTENUATION RELATION OF SEISMIC GROUND MOTION IN THAILAND

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MEE08162

ABSTRACT

We propose the attenuation relations for peak ground acceleration (PGA) and 5% damped spectral acceleration (Sa) applicable to the CMMT site which is located on rock. The CMMT site is located in Chiang Mai, the northern part of Thailand. Thailand has only a few ground motion data and most of peak ground acceleration are smaller than 1 gal. To overcome this difficulty, a Bayesian update technique was used to construct the attenuation relations for Thailand based on a past attenuation relation proposed by Idriss (1993). In this study, we added a correction term (site effect term) and error term to the Idriss attenuation relation using the Bayesian update technique. From the comparison of the prediction by the Idriss attenuation relation and the observed data, we found that the Idriss attenuation relation overestimates PGA but underestimates Sa. The prediction from the updated attenuation relation for PGA and Sa proposed by this study is much closer to the observations than those by the Idriss attenuation relation.

Keywords: Attenuation relation, Bayesian updating, Site-specific.

1. INTRODUCTION

Thailand does not have an attenuation relation constructed by Thai data and uses attenuation relations made by data of seismic prone countries such as Japan, USA and etc. Many researchers in Thailand tried to find a suitable attenuation model for Thailand from Japanese and the United States attenuation relations. Among 18 attenuation relations, Idriss (1993) examined difference between attenuation equations and observed data by using the square root of mean square (RMS). It was found that the attenuation relation proposed by Idriss (1993) was the most suitable model for Thailand (Charoenyuth, 2007).

Thailand has only a few ground motion data and most of peak ground acceleration are smaller than 1 gal. Therefore, it is difficult to make attenuation relation with Thailand data by using classical statistics. The classical statistics can make attenuation relation by regression analysis of large data set, while Bayesian statistics can make attenuation relation by updating existing attenuation relation with a small number of ground motion data.

2. DATA

The ground motion data used in this study have been recorded at the CMMT station from the seismic network of Thai Meteorological Department (TMD); they are 111 components of strong motion data of 37 earthquakes with sampling rate 100 Hz from 2006 to 2008. The moment magnitudes of the events are larger than 4. The rupture distance is within 2600 km.

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We used TMD earthquake catalog (events in Thailand and adjacent areas), Harvard Centroid Moment Tensor (CMT) catalog (2006-2009) and the catalog of United States Geological Survey (USGS) which were downloaded from their websites. We selected earthquakes that occurred between -8° to 32° N in latitude and 90°E to 110°E in longitude whose magnitudes are in the range from 4.5 to 9.0. Most of events, 33 of 37, are included in the CMT catalog, while the information for the other events were taken from TMD and PDE-USGS catalogs.

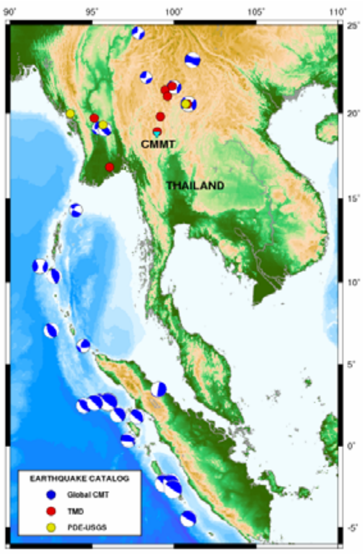

Figure 1. The focal mechanisms and epicenter of 37 events used in this study

Figure 1 shows the location of the CMMT station. Figure 1 also shows the focal mechanisms from the Havard CMT catalog, epicenters from the TMD catalog (red circles), and those from the PDE-USGS catalog (yellow circles). Waveform data of the TMD network (SEED format) are converted to SAC format by using the program rdseedv4.8 developed by Incorporated Research Institutions for Seismology (IRIS). This software was downloaded from the IRIS website. Then we use a set of Matlab subroutines named MatSAC that read and write SAC data in Matlab. These Matlab subroutines are developed by Dr. Zhigang Peng from Georgia Institute of Technology School of Earth and Atmospheric Sciences. This Matlab subroutines were downloaded from their website. We applied the band pass filter with corner frequency of 0.1-20 Hz and then used Bayesian Matlab code written by Wang and Takada (2006) to update attenuation relation of PGA and Sa proposed by Idriss (1993).

3. SITE-SPECIFIC ATTENUATION RELATION BASED ON BAYESIAN STATISTICS

Bayes' Theorem is a theorem to obtain a posterior probability reflecting the fact that new data are observed.

$$f(\theta \mid y) = cL(\theta \mid y)\, p(\theta) \qquad (1)$$

where θ is an unknown estimator (random variable), y is observed data, c is normalizing factor, $p(\theta)$ is prior distribution associated with θ before new data are observed, $L(\theta \mid y)$ is likelihood function and $f(\theta \mid y)$ is posterior distribution associated with after new data is observed.

3.1. Prior distribution of θ

The prior distribution can be used to express any subjective belief which exists before obtaining new observed data. We know little about θ (non-informative case) for Thailand and we assume independence between site effect (s) and variance of error (σ_ε^2). Using Jeffrey's rule, it is shown that non-informative prior for a parameter s is locally uniform and $p(\sigma_\varepsilon^2)\ \alpha\ \dfrac{1}{\sigma_\varepsilon^2}$ for σ_ε^2. Therefore, the non-informative prior is

$$p(s,\ \sigma_\varepsilon^2)\ \alpha\ \frac{1}{\sigma_\varepsilon^2} \qquad (2)$$

3.2. Likelihood function

For an inexact model in the following eq. 3, a random correction term γ_k has to be added to maintain the equality for the k-th observation among n observations in the specified observatory.

$$y_k = s + \hat{f}_k(m,r,..) + \gamma_k \qquad \text{k=1,2,…,n} \tag{3}$$

where y_k is predicted ground motion, s is site factor, $\hat{f}_k(m,r,..)$ is median of past attenuation relation proposed by Idriss (1993) and γ_k accounts for the model error and measurement error. If the measurement error for a subset of the variables is judged to be small, the corresponding measured values can be considered to represent the true values. Often it is not possible to distinguish the two errors and it is assumed to be normal distribution with zero mean and variance of error (σ_ε^2). The following likelihood function is obtained.

$$L(s,\sigma_\varepsilon^2)\ \alpha\ \left(\sigma_\varepsilon^2\right)^{-n/2} \exp\left\{-\frac{1}{2}\left[\sum_{i=1}^{n}\frac{\left(y_i - \hat{g}_i\left(m_i, r_i, ...\right) - s\right)^2}{\sigma_\varepsilon^2}\right]\right\} \tag{4}$$

Defining the logarithmic deviation as the difference between the log of the observation and that of the value predicted from the past attenuation relation $\left(\varepsilon = y - \hat{f}(m,r)\right)$ and expanding the sum in the argument of the exponential function, and taking into consideration $s_\varepsilon^2 + m_\varepsilon^2 = \frac{1}{n}\sum_{k=1}^{n}\varepsilon_k^2$, where m_ε is the sample mean and s_ε^2 is the sample variance of the logarithmic deviations ε_k. The likelihood can be written as

$$L(s,\sigma_\varepsilon^2)\ \alpha\ \left(\sigma_\varepsilon^2\right)^{-n/2} \exp\left\{-\frac{1}{2}\left[\frac{\left(s - m_\varepsilon\right)^2 + s_\varepsilon^2}{\sigma_\varepsilon^2 / n}\right]\right\} \tag{5}$$

3.3. Posterior Distribution

The marginal density of σ_ε^2, $f\left(\sigma_\varepsilon^2\right)$ is obtained by multiplying the likelihood function with the prior density $p(s,\sigma_\varepsilon^2)$ and dividing by the conditional PDF $f\left(s/\sigma_\varepsilon^2\right)$

$$f\left(\sigma_\varepsilon^2\right) = \frac{f\left(s,\sigma_\varepsilon^2\right)}{f\left(s/\sigma_\varepsilon^2\right)} \propto \frac{L\left(s,\sigma_\varepsilon^2\right)p\left(s,\sigma_\varepsilon^2\right)}{f\left(s/\sigma_\varepsilon^2\right)} \tag{6}$$

One option for model identification is to use point estimates of the parameters θ. The mean estimates of parameters are adopted herein, so that the point estimators of s and σ_ε^2 are

$$\overline{s} = E\left[s\right] = m_\varepsilon \tag{7}$$

$$\overline{\sigma_\varepsilon^2} = E\left[\sigma_\varepsilon^2\right] = \frac{ns_\varepsilon^2}{n-3} \tag{8}$$

4. PROPOSED ATTENUATION RELATION FOR SITE CMMT

4.1 Proposed Attenuation Relation of PGA for CMMT Site

Bayesian theorem can make attenuation relation for PGA by updating attenuation relation for PGA proposed by Idriss (1993) with 37 observed data from site CMMT. The equation is as follows:

$$\ln Y = [C_1 + \exp(C_2 + C_3 M)] - [\exp(C_4 + C_5 M)]\ln(r_{rup} + 20) + 0.2F + \overline{S} + \varepsilon \qquad (9)$$

where Y is horizontal PGA (g), M is local magnitude for M≤6 and surface wave magnitude M > 6 (in essence, M represents moment magnitude), r_{rup} is shortest distance to the rupture plane (km), F is fault mechanism such that F=0 for strike slip, 0.5 for oblique and 1 for reverse, ε is an error term (random variable), The mean of deviation $E[\sigma_\varepsilon] = 1.12$, $\overline{S}$ is the mean of site factor term $E[\theta] = -2.78$.

$C_1 = -0.150$, $C_2 = 2.261$, $C_3 = -0.083$, $C_4 = 1.602$ and $C_5 = -0.142$ for $M \leq 6.0$

$C_1 = -0.050$, $C_2 = 3.477$, $C_3 = -0.284$, $C_4 = 2.475$ and $C_5 = -0.286$ for $M > 6.0$

The left panel of Fig. 2 shows the comparison between the original Idriss attenuation curve of PGA and the observed PGA and the right panel of Fig.2 shows the comparison between the updated Idriss attenuation curve (this study) of PGA and the observed PGA and the two dashed curves represent the uncertainty of this attenuation relation. It can be seen that the prediction of the updated attenuation relation for PGA (this study) is closer to the observed PGA than the Idriss attenuation relation.

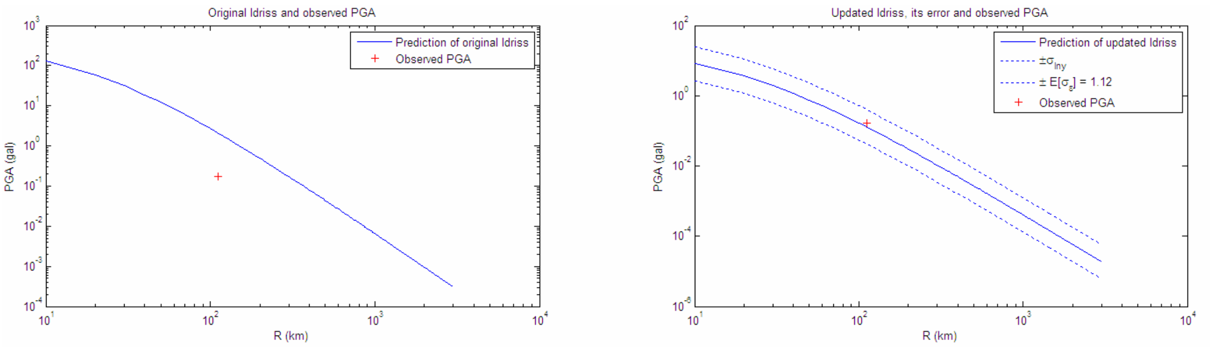

Figure 2. The comparison of the attenuation relation for PGA of the original Idriss and this study to the observed PGA for the earthquake (Source : TMD) occurred on 19 August 2007 (time 11:17:02 (UTC), the epicenter at Thailand-Myanmar boarder, Magnitude 4.0, rupture distance 117 km and Horizontal PGA 0.2 gal).

4.2. Proposed Attenuation Relation of Sa for CMMT Site

The Bayesian theorem can make attenuation relation for Sa by updating the attenuation relation for Sa proposed by Idriss (1993) with 37 observed data from site CMMT. The equation is as follows:

$$\ln(Y) = [\alpha_0 + \exp(\alpha_1 + \alpha_2 M)] + [\beta_0 - \exp(\beta_1 + \beta_2 M)]\ln(r_{rup} + 20) + 0.2F + \overline{S} + \varepsilon \qquad (10)$$

where Y is spectral acceleration. The variables M, r_{rup}, F, $\overline{S}$ and ε in this equation have the same meaning with eq. 9. The variables $\overline{S}$ and ε for each period are shown in Table 1.

Based on 37 observed data from site CMMT, the site effect term ($\overline{S}$) and error term (ε) for each period were obtained with Bayesian theorem (Table1). Values of α_0, α_1, α_2 and β_0 for pseudo absolute horizontal spectral acceleration for 22 periods at 5% spectral damping are given in Table 1.

β_1 = 1.602 and β_2 = -0.142 for M≤6

β_1 = 2.475 and β_2 = -0.286 for M>6

Figure 3 shows the comparison among the original Idriss attenuation curve of Sa (the blue dashed curve), the observed Sa (the red curve) and this study (the black dashed and doted curves). The two dashed curves show the uncertainty ($\pm E[\sigma_\varepsilon]$) of the attenuation relation of this study. It can be seen that the prediction of the updated attenuation relation for Sa (this study) is closer to the observed Sa than the original Idriss attenuation relation.

Table 1. Updated results on attenuation relation of Sa for CMMT site

Period (s)	α_0	β_0	$\bar{S}$	$E[\sigma_\varepsilon]$	M>6		M≤6	
					α_1	α_2	α_1	α_2
0.03	-0.050	0	3.03	1.94	3.477	-0.284	2.261	-0.083
0.05	-0.278	0.066	3.63	1.53	3.426	-0.269	2.365	-0.092
0.075	-0.308	0.070	3.48	1.84	3.359	-0.252	2.334	-0.081
0.1	-0.318	0.072	3.34	1.98	3.327	-0.243	2.319	-0.075
0.11	-0.328	0.073	3.30	2.07	3.289	-0.236	2.294	-0.070
0.13	-0.338	0.075	3.25	2.19	3.233	-0.225	2.255	-0.062
0.15	-0.348	0.076	3.25	2.24	3.185	-0.216	2.219	-0.055
0.2	-0.358	0.078	3.16	2.26	3.100	-0.201	2.146	-0.042
0.25	-0.429	0.080	3.22	2.51	3.034	-0.190	2.073	-0.030
0.3	-0.486	0.082	3.23	2.65	2.982	-0.182	2.010	-0.020
0.35	-0.535	0.087	3.27	2.61	2.943	-0.177	1.977	-0.016
0.4	-0.577	0.092	3.37	2.59	2.906	-0.173	1.921	-0.009
0.5	-0.648	0.099	3.46	2.66	2.850	-0.169	1.818	0.003
0.6	-0.705	0.105	3.62	2.61	2.803	-0.166	1.704	0.017
0.7	-0.754	0.111	3.75	2.60	2.765	-0.165	1.644	0.022
0.8	-0.796	0.115	3.89	2.49	2.728	-0.164	1.593	0.025
0.9	-0.834	0.119	4.04	2.54	2.694	-0.163	1.482	0.039
1	-0.867	0.123	4.16	2.63	2.662	-0.162	1.432	0.043
1.5	-0.970	0.136	4.62	2.48	2.536	-0.160	1.072	0.084
2	-1.046	0.146	4.80	2.56	2.447	-0.160	0.762	0.121
3	-1.143	0.160	4.62	2.50	2.295	-0.159	0.194	0.191
4	-1.177	0.169	4.09	2.59	2.169	-0.159	-0.466	0.280
5	-1.214	0.177	3.95	2.96	2.042	-0.157	-1.361	0.410

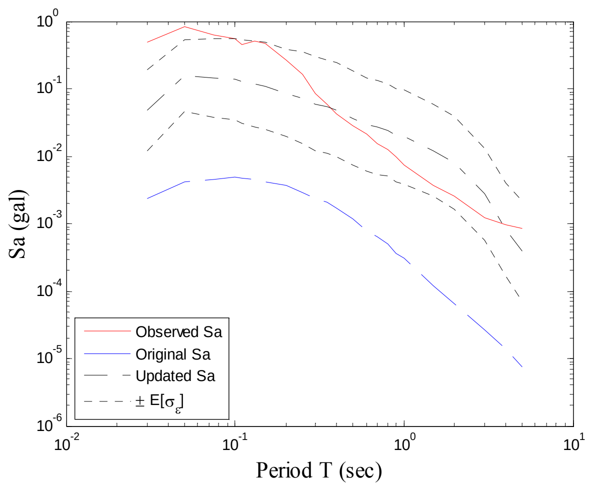

Figure 3. The comparison among the attenuation relation for Sa of the original Idriss, this study and the observed Sa of earthquake (Source : TMD) that occurred on 19 August 2007 (time 11:17:02 (UTC), the epicenter at Thailand-Myanmar boarder, Magnitude 4.0 and rupture distance 117).

5. CONCLUSIONS

The attenuation relations for PGA and Sa for the CMMT station in Thailand have been proposed in this study. These attenuation relations for PGA and Sa were determined based on the Bayesian updating technique by using 111 components of strong motion data of 37 earthquake events. By using the Bayesian updating technique we constructed site-specific attenuation relation base on the past proposed attenuation relation (Idriss, 1993). The specific site in this study is the CMMT station which is located on the rock site.

In this study, we added correction term (site effect) and error to the Idriss attenuation relation by using the Bayesian updated technique. The parameters in the Bayesian approach are treated as random variables only for the CMMT site, while the original attenuation relation does not have site effect term; the error of this attenuation relation is point estimators and used for all sites. The error of attenuation model proposed in this study accounts for all uncertainties including model error and measurement error which is useful in the probabilistic hazard analysis, risk analysis and many other engineering fields.

The prediction of the updated attenuation relation for PGA (This study) is smaller than the Idriss attenuation relation. The residual value (natural logarithmic unit) is calculated by the difference between the observed and the predicted ground motions. The residuals of PGA of the Idriss attenuation relation are negatively biased. Therefore we can conclude that the PGA of the Idriss attenuation relation are overestimates. The comparison between the attenuation relation for Sa of Idriss shows that the Sa of the Idriss attenuation relation are underestimates. The predictions of the updated attenuation relation for PGA and Sa (This study) are closer to the observed PGA and Sa than the Idriss attenuation relation.

The Bayesian update technique used in this study is suitable for making attenuation relation for Thailand and can be used with new observations. It is expected that this method will be applied to observation sites throughout the country.

AKNOWLEDGEMENT

I would like to give my sincere thanks to Dr. Tatsuhiko Hara, Dr. Tosiaki Yokoi and Mr. Masahiro Ohbuchi for their valuable suggestion and help on my study.

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