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The Prediction of Earthquake Ground Motions by Regression Model

Pithan Pairojn and Sirithip Wasinrat

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Abstract

The prediction of earthquake ground motion is the first priority in the seismic design of a building. This investigation is aimed at proposing regression models for average peak horizontal ground acceleration of earthquakes recorded by seismometers installed at a station in Chiang Mai, Thailand. The majority of earthquakes measured in Chiang Mai occur in seven areas; namely, the regions around Sumatra, Nicobar Island, the Andaman Sea, Myanmar, Laos, China's western region, and China's southern region. The earthquakes' epicenters range from about 10 to 2600 km away from Chiang Mai. The proposed model used 73 earthquakes recorded from 2006 to 2012 and was subdivided according to the magnitudes of the events and earthquake source zones. It was found that the average peak horizontal ground acceleration by regression models was attenuated by the distance from the epicenters. The results of the regression model were in agreement with the records of seven recent earthquakes obtained from Chiang Mai's seismic station. The regression model has been used in the design of buildings.

Keywords: prediction, earthquake, ground motion, regression model, average peak horizontal ground acceleration

1. Introduction

Southeast Asia was shaped as a result of the interaction between the Indo-Australian, Eurasian, Philippine, and West Pacific tectonic plates. Thailand located inside the Eurasian plate, is delimited by the Andaman thrust within the west, the Sunda Arc within the south, and also the Philippine trench within the east [1]. As a result of recent awareness of earthquake hazards, the Thai Meteorological Department has established quite 20 seismometer
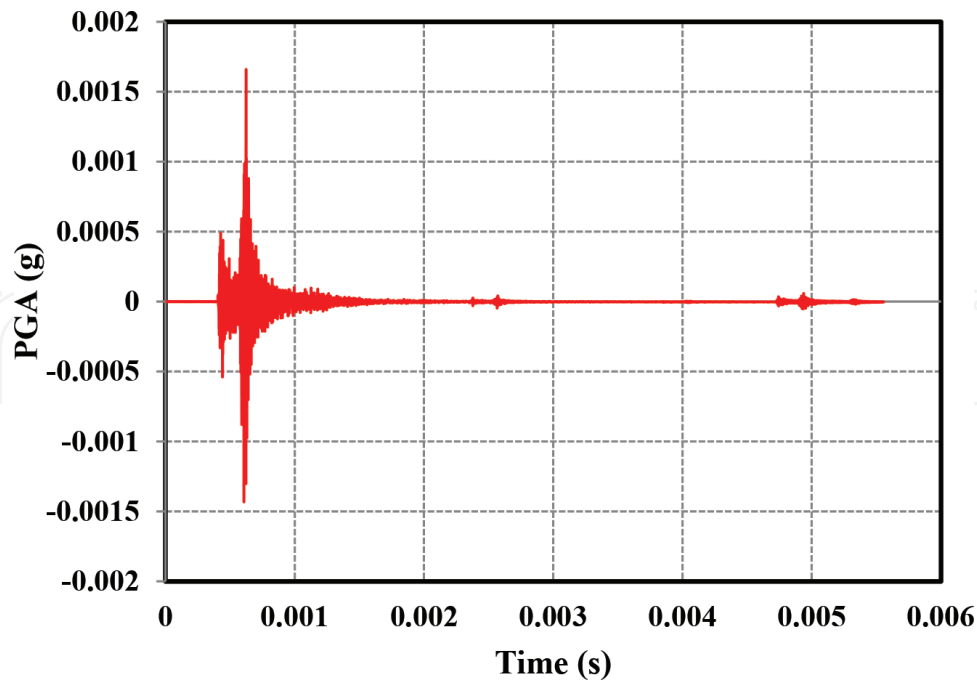
Figure 1. Earthquake sampling E-W components of the Chiang Mai station (UTC: 5/6/2014 00:50:16, Lat = 19.73 N, Lon = 99.69E, Mw = 5. 9, distance = 128 km, and epicenter: Chiang Rai) (Thai Meteorological Department).

stations Thailand. **Figure 1** shows samples of ground motion records at a Chiang Mai station (in northern Thailand) from an earthquake event in the regions around Chiang Rai (M 5.9). The distance from the epicenter of the earthquake is about 128 km. One will observe a small peak ground acceleration (PGA) ($\approx 2.29 \times 10^{-3}$ g) in the vertical component, and a peak horizontal ground acceleration in the horizontal components (E-W component $\approx 1.63 \times 10^{-3}$ g and N-S component $\approx 1.19 \times 10^{-3}$ g). The researcher calculated average peak horizontal ground acceleration (PHA_{avg}) $\approx 1.04 \times 10^{-3}$ g.

The attenuation relationship for PHA_{avg} for the Chiang Mai station in Thailand has been proposed in this investigation. The attenuation relationship for PHA_{avg} was determined based on the multiple linear regression (MLR) models by using 132 components of strong motion data from 66 earthquake events. By using the MLR models, the researcher constructed site-specific attenuation relation based on a previously proposed attenuation relation [2–3]. The specific site in this investigation is a Chiang Mai seismic station (CMMT) station located on the rock site.

2. Characteristics of ground motion in Thailand

Because Thailand is not a country prone to earthquakes, most of the earthquakes felt in Thailand occur outside the country, in places such as Sumatra, Nicobar Island, the Andaman Sea, Myanmar, Laos, and in the west and south areas of China. However, inside the country, Thailand has active faults, which can cause small-to-moderate earthquakes in areas such as Chiang Mai.

Pairojn and Wasinrat [4] presented the observed earthquakes recorded by the Chiang Mai station in northern Thailand from 07/10/2006 to 11/11/2012, as shown in **Figure 2**.
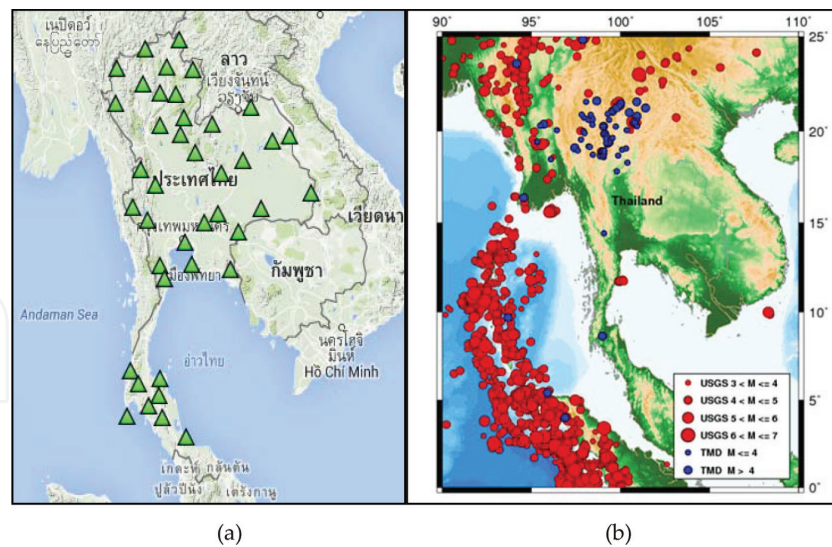
Figure 2. The location of (a) 41 seismic stations in Thailand, and (b) 73 earthquake events used in this investigation (Thai Meteorological Department).

3. Site classification

In this study, the researcher chose to investigate data from shear wave velocity (Vs) recorded at the Chiang Mai seismic station (CMMT) in northern Thailand, located on a rocky site

Figure 3. Installation of velocity sensor and accelerometer at CMMT seismic station (Thai Meteorological Department) [5].

(NEHRP site class). The CMMT station used Trillium 120 velocity sensors and TSA100S accelerometers, as seen in **Figure 3**.

4. Ground motion prediction

Recently, several ground-motion prediction equations (GMPEs) have been developed. Douglas [6] summarizes all empirical ground-motion prediction equations (GMPEs) used to estimate earthquake peak ground acceleration (PGA) and elastic response spectral ordinates published between 1964 and 2017. Most empirical ground motion attenuation relations are derived from numerical analyses.

For Thailand, Idriss's model [2–3] was selected because it has an appropriate attenuation relation. Idriss suggested that the attenuation relation for motions in western North America [2–3]. The available data included 572 individual horizontal components in rock sites that were used to derive this attenuation model. This study focuses on $M \leq 6.0$ and $M > 6.0$ using local M_L and surface wave magnitude M_S scales, respectively. The range of applicability is 1–100 km for distance and 4.6–7.4 for M [2–3]. The peak ground acceleration (Y) at rock sites was derived as following equation:

$$ln(Y) = \left[\alpha_0 + exp(\alpha_1 + \alpha_2 M)\right] + \left[\beta_0 - exp(\beta_1 + \beta_2 M)\right] ln(R + 20) + aF \tag{1}$$

where Y is in g (m/s^2), $a = 0.2$, for $M \leq 6$ $\alpha_0 = -0.150$, $\alpha_1 = 2.261$, $\alpha_2 = -0.083$, $\beta_0 = 0$, $\beta_1 = 1.602$, $\beta_2 = -0.142$ and $\sigma = 1.39 - 0.14 M$ and for $M > 6$ $\alpha_0 = -0.050$, $\alpha_1 = 3.477$, $\alpha_2 = -0.284$, $\beta_0 = 0$, $\beta_1 = 2.475$, $\beta_2 = -0.286$ and for $M < 7.25$ $\sigma = 1.39 - 0.14 M$, and for $M \geq 7.25$ $\sigma = 0.38$. ($F = 0$ for Strike slip, $F = 0.5$ for Oblique, $F = 1$ for Reverse).

This chapter uses the method of ground-motion prediction under regression analysis [5].

4.1. Concept of multiple linear regression models

Regression analysis is a conceptually simple method for investigating functional relationships among variables. The relationship is explained by an equation or a model combining the response (Y) and predictor variables (X_1, X_2, …, X_p) [7]. This relationship can be derived from the regression model.

$$Y = f\left(X_1, X_2, …, X_p\right) + \varepsilon, \tag{2}$$

Where ε is assumed to be a random error representing the deviation in the approximation and p is the number of predictor variables. The function $f(X_1, X_2, …, X_p)$ can be classified into two types: linear and non-linear. An example of a linear function is:

$$Y = \beta_0 + \beta_1 X + \varepsilon, \tag{3}$$

while an example of a non-linear function is:

$$Y = \beta_0 + \beta_1 \ln X + \varepsilon. \tag{4}$$

Note that the term linear here does not describe the relationship between Y and X. This model is linear because in each case the parameters enter linearly, although the relationship between Y and X is non-linear. This can be transformed as follows:

$$Y = \beta_0 + \beta_1 X_1 + \varepsilon, \tag{5}$$

where in the equation we have $X_1 = \ln X$. The variables here are transformed [7].

A regression model containing only one predictor variable is called a simple linear regression. The model containing more than one predictor variable is called a multiple linear regression (MLR). The multiple linear regression model is:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2, \ldots, \beta_p X_p + \varepsilon, \tag{6}$$

where $\beta_0, \beta_1, \beta_2, \ldots, \beta_p$ called the regression parameters or coefficients are unknown constants to be estimated from the data. The purpose of the analysis is to estimate the regression parameters or to fit the model to the collected data using the chosen estimation method. The most commonly used method of estimation is called the least squares method (LSE). The LSE method is a procedure to minimize the sum of a squared residual, the difference between an observed value, and the fitted value provided by a model. The LSE method assumes that the error terms are normally distributed, vary constantly, and are independent of each other. The estimated MLR model becomes:

$$\hat{Y} = \hat{\beta}_0 + \hat{\beta}_1 X_1 + \hat{\beta}_2 X_2, \ldots, \hat{\beta}_p X_p. \tag{7}$$

The value of $\hat{Y}$ is called the predicted value or fitted value. The estimated regression parameters are $\hat{\beta}_0, \hat{\beta}_1, \hat{\beta}_2, \ldots, \hat{\beta}_p$. To estimate the MLR models, many types of software are used, for example, R, SPSS, and so on.

4.2. The multiple linear regression for predicting earthquake ground motion

Pairojn and Wasinrat [4] proposed the MLR model to predict average peak horizontal ground acceleration, PHA_{avg} ($\hat{Y}$), in Thailand by including magnitude, and distance as predictor variables. The model was conducted from **Table 1**. The MLR model can be generalized as follows:

$$ln(\hat{Y}) = -5.4239 + 1.7410\ M - 2.3469\ lnR \tag{8}$$

where M represents the magnitude and R represents the distance. The natural *log* (*ln*) of Y and R are used to transform the linear relationship between Y and R, and lnY and M. The value of $R^2 = 0.8438$ indicated that the earthquake ground motion is predicted by magnitude and distance equal to 84.38%. The results showed that the MLR model is able to predict the average of PHA in Thailand to a greater degree than Idriss's model (**Figure 4**).
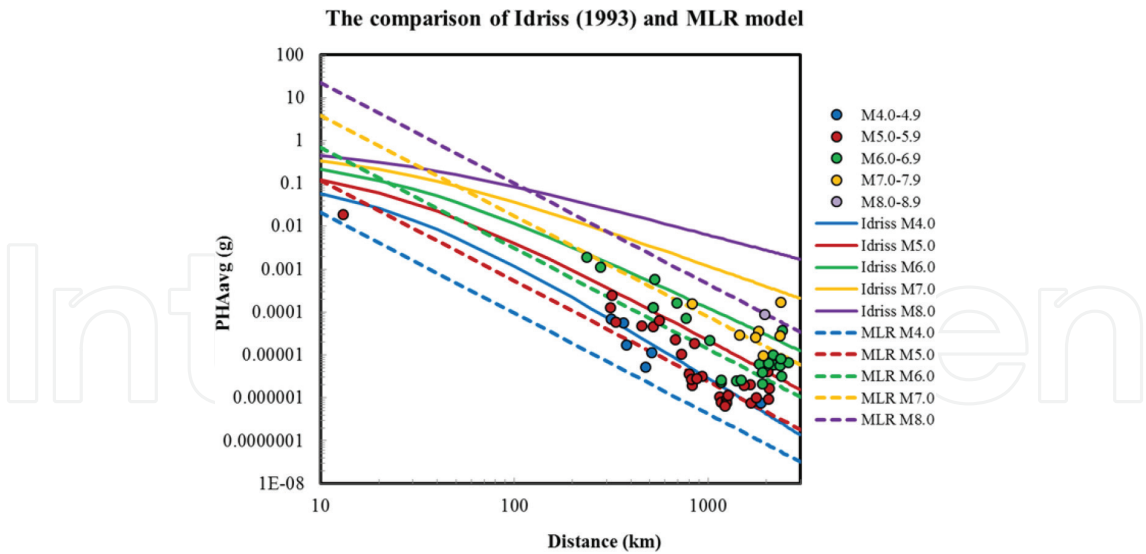
Figure 4. The comparison of MLR and Idriss's models at CMMT seismic station [4].

5. The practicality of ground motion prediction

The MLR model was used on seven new earthquake events that occurred from 05/05/2014 to 05/12/2014. The data are shown in **Table 1**.

The predicted PHA values from Eq. (8) and Eq. (1) are presented in **Table 2** (**Figures 5–7**).

The root mean square error (RMSE) is used for comparing the predicted PHA values from MLR model to the observed PHA values. The RMSE measures the error between a predicted value and an observed value, defined as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(\hat{Y}_i - Y_i\right)^2}{n}} \tag{9}$$

where $\hat{Y}_i$ is the predicted values from MLR model and Y_i is the observed values from n observations. The RMSE value is 0.00009.

No.	Date	Time UTC	Epicenter	Magnitude, M (Mw)	Distance, R (km)	PHAavg, Y (g)
1	5/5/2014	12:06:19	Chiang Rai	5.1	121	0.0002990
2	5/5/2014	12:20:57	Chiang Rai	5.2	140	0.0003755
3	5/5/2014	21:17:05	Chiang Rai	5.1	119	0.0005555
4	5/5/2014	23:04:55	Chiang Rai	5.2	121	0.0003380
5	6/5/2014	00:50:16	Chiang Rai	5.9	128	0.0014140
6	6/5/2014	0:58:19	Chiang Rai	5.6	116	0.0010405
7	12/5/2014	11:05:29	Chiang Rai	5.0	137	0.0002955

Table 1. Seven new earthquake events.

Model	Predicted PHA values						
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
MLR	0.000410	0.000346	0.000426	0.000488	0.001446	0.001080	0.000257
Idriss	0.002751	0.002751	0.002751	0.002751	0.002751	0.002751	0.002751

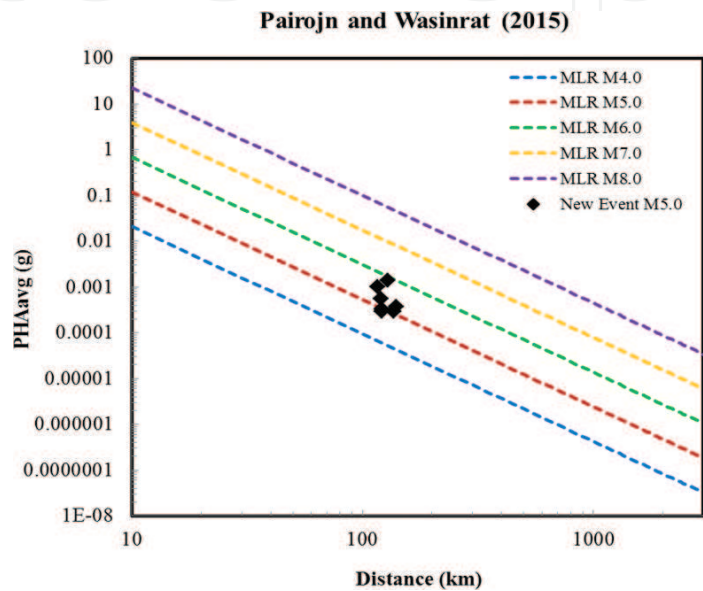**Table 2.** The predicted peak horizontal ground acceleration from MLR model and Idriss's model.

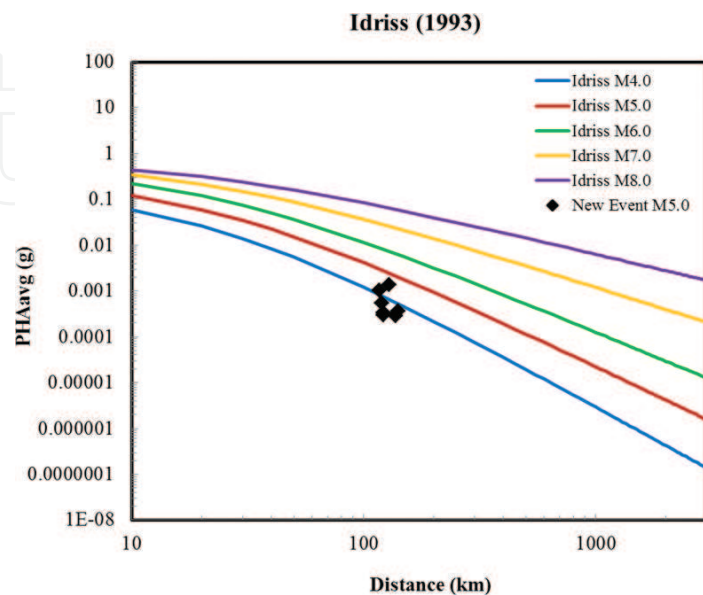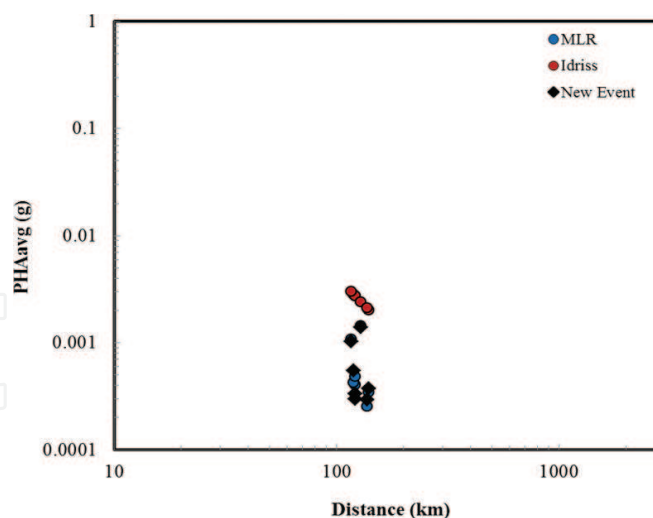**Figure 5.** The predicted peak horizontal ground acceleration from MLR model.

Figure 6. The predicted peak horizontal ground acceleration from Idriss's model.

Figure 7. A comparison of MLR and Idriss's model for new earthquake events.

6. Conclusions

The MLR model is presented for developing a previous attenuation relationship based on observations. The MLR model is suitable for measuring the attenuation relationship for Thailand because Thailand has few instances of motion data, with most peak ground acceleration being measured at less than 0.1 g. It is expected that this method can be applied to observation sites throughout the country. The MLR model has been used for probabilistic hazard analysis, risk analysis, building design analysis, and many other fields, that is, and construction of nuclear power plants, dams, bridges, and high-rise buildings.

Acknowledgements

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References

[1] Fenton C, Charusiri P, Wood S. Recent paleoseismic investigations in Northern and Western Thailand. Annuals of Geophysics. 2003;**46**:957-981

[2] Idriss IM. Procedures for Selecting Earthquake Ground Motions at Rock Sites. In: Report No. NIST GCR 93-625. Report to National Institute of Standards and Technology, Gaithersburg, Maryland, Center for Geotechnical Modeling, Department of Civil and Environmental Engineering: University of California; 1993

[3] Ornthammarath T, Warnitchai P, Worakanchana K, Zaman S, Sigbjörnsson R, Lai CG. Probabilistic seismic hazard assessment for Thailand. Bulletin of Earthquake Engineering. 2011;**9**(2):367-394

[4] Pairojn P, Wasinrat S. Earthquake ground motions prediction in Thailand by multiple linear regression model. Electronic Journal of Geotechnical Engineering. 2015;**20**(25):12113-12124

[5] Thai Meteorological Department. Earthquake [Internet]. 2004. Available from: https://www.tmd.go.th/info/info.php?FileID=77 [Accessed: February 4, 2018]

[6] Douglas J. Ground Motion Prediction Equations [Internet]. 2017. Available from: http://www.gmpe.org.uk [Accessed: January 27, 2018]

[7] Chatterjee S, Hadi AS, editors. Regression Analysis by Example. 4th ed. New Jersey: John Wiley & Sons, Inc.; 2006