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DETERMINISTIC SEISMIC HAZARD ANALYSIS IN THAILAND USING ACTIVE FAULT DATA

Apichat Janpila[1], Piyawat Foytong[1*], Anat Ruangrassamee[2], Natthapong Areemit[1]

[1]*Sustainable Infrastructure Research and Development Center, Department of Civil Engineering, Faculty of Engineering, Khon Kaen University, Khon Kaen, 40002, Thailand*
[2]*Department of Civil Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, 10330, Thailand*

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ABSTRACT

To develop seismic design criteria for buildings, seismic hazard analysis is required to estimate the ground motion intensity with criteria such as peak ground acceleration (PGA). The seismic hazard can be analyzed by using two approaches: deterministic seismic hazard analysis (DSHA) and probabilistic seismic hazard analysis (PSHA). In these two approaches, the seismic hazard is evaluated from past earthquake events and active faults data. In Thailand, seismic hazard is classified in the low lying regions; however, in recently years, earthquakes have occurred frequently in the North of Thailand. To prevent and reduce damage due to earthquakes in the future, determination of seismic hazard is needed. This research proposes a deterministic seismic hazard map evaluated from nineteen active faults affecting Thailand. Two types of active faults are considered: first, an active fault in a subduction zone and second, a crustal fault. The seismic hazard is evaluated by using a ground motion prediction equation (GMPEs). Four GMPEs are weighted equally for seismic crustal fault, and two GMPEs are weighted equally for a seismic subduction zone. The hypocentral distance is used to evaluate the seismic hazard for all ground motion prediction equations. The Northern part and the Western part of Thailand are high seismic hazard regions, because there are active faults with the large possibility of earthquakes of a maximum magnitude. The seismic hazards in the North, West and Northeast of Thailand are about 0.60 g. The seismic hazard in Bangkok is about 0.25 g due to the Three Pagoda fault and Sri Sawat fault. The seismic hazard in the South of Thailand is about 0.40 g.

Keywords: Active faults; Deterministic seismic hazard assessment; Seismic hazard map of Thailand

1. INTRODUCTION

Thailand is in the low level seismic hazard region, however, in recent years, earthquakes have occurred frequently in the North of Thailand. Major earthquakes affect Thailand, such as those which caused damage to construction, buildings and/or killed humans, namely the May 16, 2007 earthquake, the March 24, 2011 earthquake and the May 5, 2014 earthquake. The epicenter of the May 16, 2007 earthquake was in Laos PDR with a magnitude of 6.3. The damage occurred in a school, a hospital and an historic construction (Earthquake Statistics of Thailand, 2016). The epicenter of the March 24, 2011 earthquake was in Myanmar with a magnitude of 6.8. The vibration of this event could be felt in the Northeast and in Bangkok.

*Corresponding author's email: piyafo@kku.ac.th, Tel. +668-1735-0409
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There was one person who died in this event. The epicenter of the May 5, 2014 earthquake was in Chaing Rai province with a magnitude of 6.3. This event was the most serious earthquake in Thailand. The damage occurred in many types of construction, including buildings, killed one person and injured many people (Earthquake Statistics of Thailand, 2016; Thai Meteorological Department, 2014).

To prevent and reduce damage due to earthquakes in the future, assessment of the seismic hazard is needed. The seismic hazard is evaluated by two approaches, the deterministic seismic hazard analysis and the probabilistic seismic hazard analysis. The deterministic seismic hazard analysis evaluates hazard from the most severe earthquake event (Costa et al., 1993). The probabilistic seismic hazard analysis evaluates hazard from the past earthquake events database (Cornell, 1968). The seismic hazard result obtained by these two methods is the peak ground acceleration (PGA) at the base rock level. Many researches concern the seismic hazards of Thailand (Wanitchai & Lisantono, 1996; Palasri, 2006; Pailoplee et al., 2008; Pailoplee et al., 2009; Ornthammarath et al., 2010). The proposed seismic hazards are in the range of 0−3 g. This research proposes a seismic hazard map to be evaluated by deterministic seismic hazard analyses from the active faults. The active faults are summarized from the available information on earthquake sources, which have affected Thailand to date.

2. METHODOLOGY

The methodology of deterministic seismic hazard analysis consists of two primary processes, as follows: (1) to specify seismic sources and evaluate the probability of maximum earthquake magnitude; and (2) to evaluate the maximum seismic intensity at each point by using the ground motion prediction equation (GMPEs). Details of the processes are as follows.

2.1. Seismic Sources and the Probability of Maximum Earthquake Magnitude

An earthquake is the result of the sudden release energy of an active fault. The active faults are classified into two primary types: first, an active fault in the subduction zone and second, a crustal fault. The active faults are summarized from the available information. The active faults affecting the seismic hazard in Thailand are shown in Figure 1. The probability of maximum earthquake magnitude (M_W) of each fault is calculated by the equation proposed by Wells and Coppersmith (1994) as shown in Equation 1. The probability of maximum earthquake magnitude is only a function of fault surface rupture length (SRL). The summary of fault data parameters used in this research, namely are surface rupture length (SRL), slip rates and probability of maximum earthquake magnitude (M_W) of the active faults that are listed in Table 1. However, the probability of maximum earthquake magnitude in relation to some active faults was evaluated from their respective slip rates, which is more precise than being evaluated by using Equation 1 below. The probability of maximum earthquake magnitude of faults evaluated from their slip rates are noted by a star.

$$M_w = 5.08 + 1.16\log(\text{SRL}) \tag{1}$$

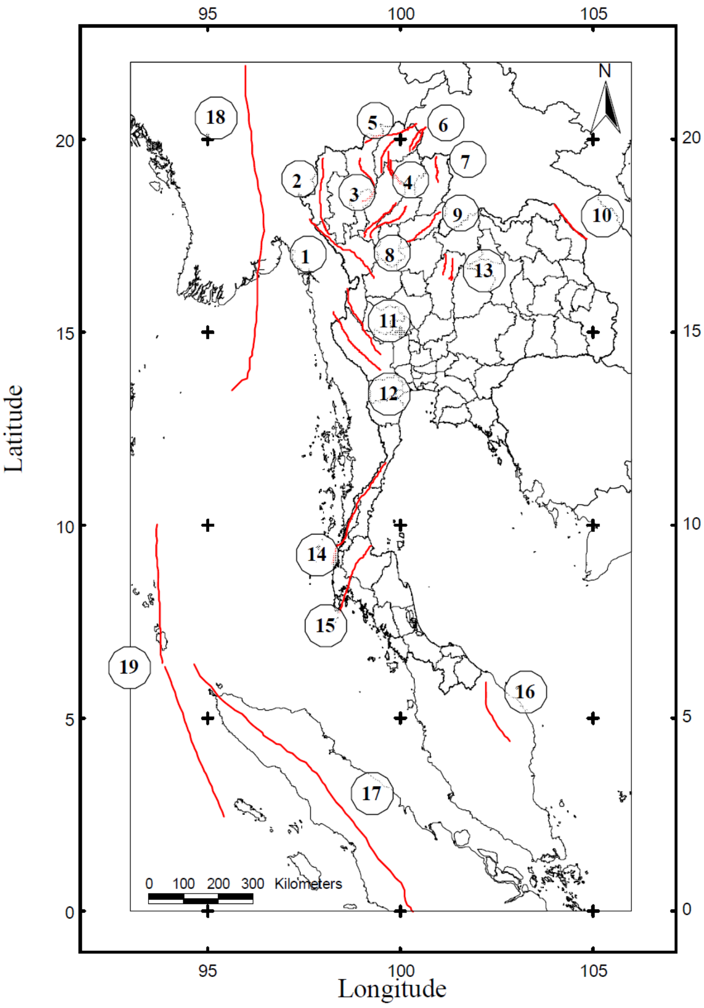


Figure 1 Locations of seismic active faults

Table 1 Summary active fault data parameters

No.	Name	SRL(km)	Slip rates (mm/yr)	Magnitude (M_w)
1	Moei	259	0.73	7.9
2	Mae Hong Sorn	223	-	6.9
3	Mae Tha	47	0.80	7.0
4	Phayao	100	0.10	6.6
5	Mae Chan	118	0.36	7.5*
6	Mae Ing	38	-	6.9
7	Pua	76	0.60	6.8
8	Thoen	140	2.00	6.8
9	Uttaladith	130	0.10	6.7
10	Thakhaek	250	-	7.9
11	Sri Sawat	43	2.00	7.0
12	Three Pagoda	141	2.00	7.6
13	Phetchabun	110	-	7.4
14	Ranong	46	1.00	7.0
15	Klongmarui	212	0.10	7.5*
16	Libir	170	-	7.7
17	Great-Sumatra	958	23.00	8.5
18	Sagaing	969	18.00	7.9*
19	Andaman subduction zones	900	47.00	9.2

*Characteristic magnitude fixed based on worldwide analog

2.1.1. Subduction source zones

The seismic fault in subduction zones affecting the seismic hazard in Thailand is identified as the fault at the connection between the Indian Plate and the Burma Plate. The length of this fault is of 3,388 km along the north-south axis. The estimated probabilty of maximum earthquake magnitude of this fault is at a magnitude 9.1 which is less than the 2004 earthquake with the maximum earthquake magnitude of about a magnitude 9.2 (Petersen et al., 2007). The faults of this event were divided into two segments, the Southern segment and the Northern segment (Koshimura & Takashima, 2005) which is fault No.19 in Figure 1. The Southern segment was at 94.8E and 2.5N with the length of 500 km. The Northern segment was at 92.0E and 6.5N with the length of 400 km.

2.1.2. Crustal fault

Active crustal faults in Thailand are mostly in the North and the West. The locations of active faults are shown in Figure 1. In the North of Thailand, there are 9 major faults (Charusiri, 2005; Pailoplee et al., 2009), (No.1–No.9) which are the Moei fault, Mae Hong Sorn fault, Mae Tha fault, Phayao fault, Mae Chan fault, Mae Ing fault, Pua fault, Thoen fault and Uttaladith fault. Most of the active faults are oriented along the north-south axis. The longest fault is the Moei fault with a length of 259 km; its probability of maximum earthquake magnitude is about a magnitude 7.9. There is only the Thakhaek fault (No.10) in the North East of Thailand that offers a similar magnitude. The Thakhaek fault is oriented in the Northwest to the Southeast with the length of 250 km (DMR, 2006). The probability of a maximum earthquake magnitude is about a magnitude 7.9.

The active faults located in the West of Thailand are the Sri Sawat fault (No. 11) and the Three Pagoda fault (No. 12). Most of the faults are oriented in the Northwest to the Southeast direction. The longest fault is 141 km and its probability of maximum earthquake magnitude is about a magnitude 7.6. In the central region, there is only Phetchabun fault (No.13). The Phetchabun fault consists of two (2) segments oriented along the North-South axis with a length of 110 km (DMR, 2012). The probability of maximum earthquake magnitude is about a magnitude 7.4. The active faults located in the South of Thailand are the Ranong fault (No. 14) and Klongmarui fault (No. 15). Both of these are oriented in the Northwest to the Southeast direction. The longest fault is the Klongmarui fault with the length of 212 km. The probability of maximum earthquake magnitude is about a magnitude 7.5.

In this research, three active crustal faults are located out of the Thai region, namely the Great-Sumatra (No. 17), the Sagaing (No. 18), and the Andaman subduction zones (No. 19). The Sagaing fault is in Myanmar with a length of 969 km and the probability of maximum earthquake magnitude is about a magnitude 7.9. The Libir fault is in Malaysia with a length of 170 km and its probability of maximum magnitude is about a magnitude 7.7. The Great-Sumatra fault is in Sumatra Island, Indonesia with a length of 958 km and its probability of maximum earthquake magnitude is about a magnitude 8.5.

2.2. Ground Motion Prediction Equation

The seismic hazard is evaluated by using a ground motion prediction equation (GMPEs). The ground motion prediction equation expresses the seismic hazard in terms of peak ground acceleration (PGA). The PGA estimates the functions of magnitude, distance and other variables related to local site conditions. The ground motion prediction equation is classified from seismic sources. Two models of ground motion prediction equations are considered in this study; first is the ground motion: a prediction equation for subduction earthquakes and the second is the ground motion prediction equation for shallow crustal earthquakes. However, there is no ground motion prediction equation constructed for this region of Thailand. The motion prediction equations appropriate for the Thai region were proposed by previous researches (Palasri, 2006; Chintanapakdee et al., 2008; Pailoplee et al., 2008; Pailoplee et al., 2009; Ornthammarath et al., 2010). The ground motion prediction equation for shallow crustal earthquakes is included in those equations proposed by Idriss (1993), Sadigh et al. (1997), Toro (2002), and Campbell and Bozorgnia, (2008). The ground motion prediction equations for subduction zones are equations proposed by Youngs et al. (1997) and Atkinson and Boore, (2003).

When an earthquake event occurs, the distance form source to site can be measured as the epicentral distance and hypocentral distance as shown in Figure 2. The epicentral distance is the horizontal distance from the projected point to the ground surface of the earthquake epicenter to site. The hypocentral distance is the oblique distance from the earthquake epicenter to site directly.

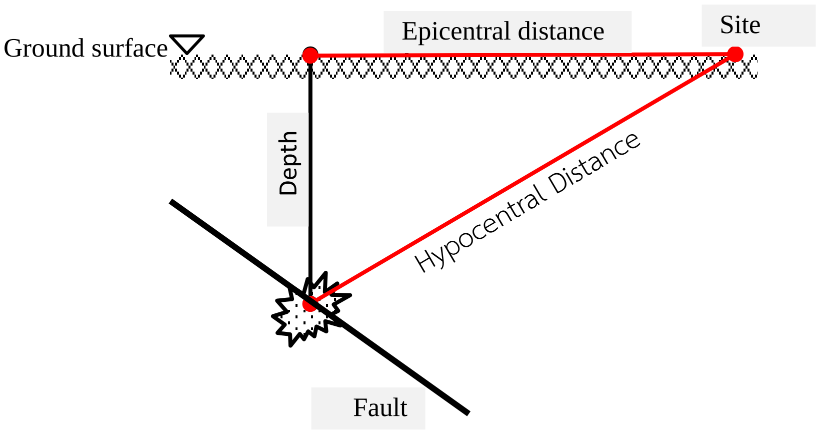
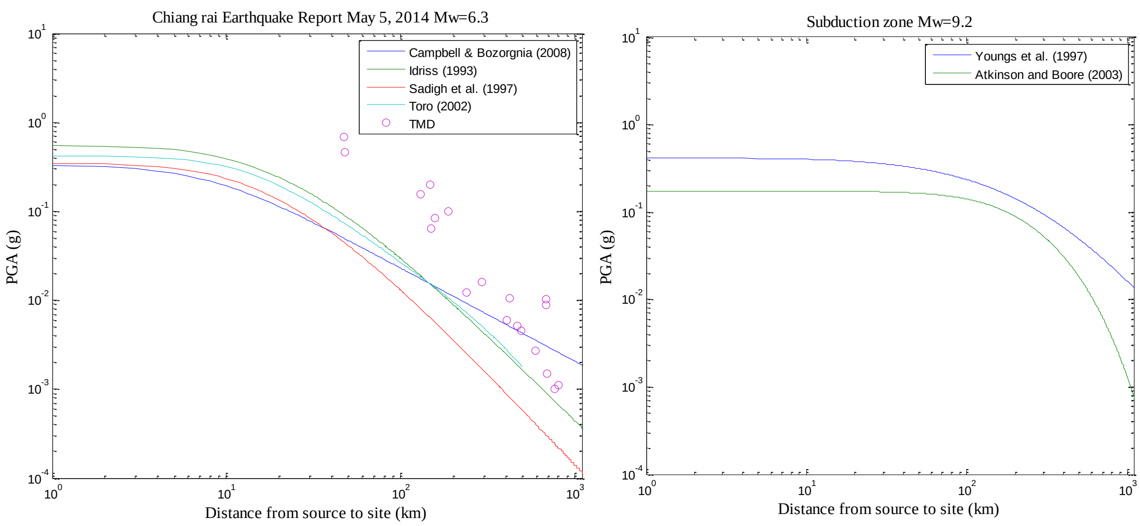


Figure 2 Distance from seismic source to site

The distance in the ground motion prediction equations proposed by Idriss (1993) and Toro (2002) is defined as the epicentral distance. The distance in the ground motion prediction equations proposed by Sadigh et al. (1997), Campbell and Bozorgnia (2008), Youngs et al. (1997), and Atkinson and Boore (2003) is the hypocentral distance. The different definitions of distance result in different seismic hazard results. Therefore, in this research, the hypocentral distance is used to evaluate the seismic hazard for all ground motion prediction equations.



(a) Shallow crustal earthquakes (b) Subduction zone

Figure 3 Ground motion prediction equations

The comparison of ground motion prediction equations for shallow crustal earthquakes and subduction zones are plotted in Figures 3a and 3b, respectively. For the ground motion prediction equations for shallow crustal earthquakes, the recorded data from the Thai Meteorological Department (2014) is also plotted. The recorded data is based on the May 5, 2014 earthquake with a magnitude of 6.3. The earthquake epicenter was 7 km in depth and was located in Chiang Rai Province. From the comparison, the most appropriate ground motion prediction equation cannot be selected. Hence, in this research all ground motion prediction equations are weighted equally.

3. RESULTS AND DISCUSSION

The seismic hazard map is evaluated by the deterministic seismic hazard analysis from the active fault data. The active fault data are summarized from the available information on earthquake sources the affected Thailand at a particular time. The results of maximum PGA at base rock level and the seismic hazard location of each fault are listed in Table 2. The deterministic seismic hazard map of Thailand is shown in Figure 4.

The Northern part and the Western part of Thailand are high seismic hazard regions, because there are active faults with a high probability of maximum earthquake magnitude. The high seismic hazards of the Northern part of Thailand are in Nan, Prayao, Chiang Rai, Mae Hong Sorn, Tak, Lampang and Uttaradit provinces with the maximum PGA of about 0.60 g. For the Western part, high seismic hazards are in Kahchanaburi and Uthai Thani province; those are along the Three Pagoda fault and the Sri Sawat fault, with the maximum PGA of about 0.55 g.

Table 2 Peak ground acceleration on rock site for each fault

No.	Name	PGA, (g)	Latitude	Longitude	Location
1	Moei	0.61	16.40	99.30	Kam Phaeng Phet
2	Mae Hong Sorn	0.43	19.15	98.00	Mae Hong Sorn
3	Mae Tha	0.44	18.55	99.25	Lamphun
4	Phayao	0.39	19.20	99.70	Lampang
5	Mae Chan	0.53	20.15	99.95	Chiang Rai
6	Mae Ing	0.43	19.75	100.00	Chiang Rai
7	Pua	0.41	19.45	100.90	Nan
8	Thoen	0.41	17.60	99.10	Lampang
9	Uttaladith	0.40	17.50	100.25	Utttaradit
10	Thakhaek	0.61	17.50	104.70	Nakhon Phanom
11	Sri Sawat	0.44	15.90	98.65	Tak
12	Three Pagoda	0.55	14.30	99.15	Kahchanaburi
13	Phetchabun	0.51	16.65	101.35	Phetchabun
14	Ranong	0.44	10.90	99.15	Chumphon
15	Klongmarui	0.41	7.80	98.45	Phuket
16	Libir	0.57	4.90	102.45	Gua Musang (Malaysia)
17	Great-Sumatra	0.41	6.10	95.80	Banda Aceh (Indonesia)
18	Sagaing	0.61	14.75	96.20	Rangoon (Myanmar)
19	Andaman subduction zones	0.30	8.85	93.70	Andaman Sea

The seismic hazard in Bangkok is about 0.25 g due to the Three Pagoda fault and Sri Sawat fault. In the Northeast, the high seismic hazards occurred in Bueng Kan, Nakhon Phanom and Sakon Nakhon provinces which are close to the Thakhaek fault with a maximum PGA of about 0.60 g. For the South, the seismic hazards are in Prachup Khiri Khan, Champhon, Ranong, Phangnga, Phuket, Surat Thani, Phangnga, Krabi and Narathiwat province. The maximum PGA is about 0.40 g, which occurred in Phuket province.

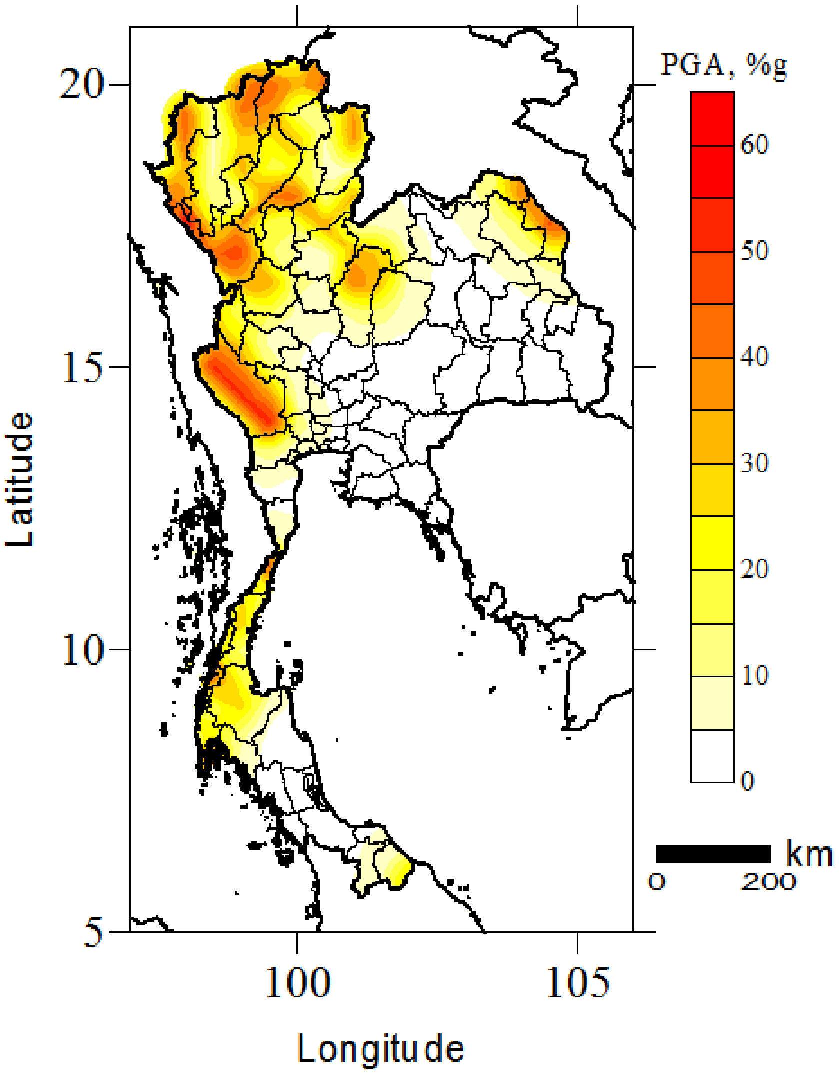


Figure 4 Deterministic seismic hazard of Thailand using active faults

4. CONCLUSION

The seismic hazard map of Thailand is developed by using the deterministic seismic hazard analysis approach to evaluate seismic intensity at the base rock, which will be used in the seismic design criteria for building. The seismic hazard is evaluated from the active fault sources. From the results, the seismic hazard is high in the Northern part, the Northeast part and the Western part of Thailand with the maximum PGA of about 0.60 g. In the Northern part and the Western part, the seismic hazard is distributed in all regions due to the active faults with the high probability of maximum earthquake magnitude. In the Northeast part, the high seismic intensity is along the Thakhaek fault only. The seismic hazard in Bangkok of about 0.25 g is due to the Three Pagoda fault and the Sri Sawat fault. For the Southern part, the maximum PGA is about 0.40 g, which occurred in Phuket province due to the subduction zone.

5. ACKNOWLEDGEMENT

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