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# Non-Linear Site Response Analysis of Bangkok Subsoils Due to Earthquakes Triggered by Three Pagodas Fault

Muhammad Fatih Qodri<sup>1,a</sup>, Lindung Zalbuin Mase<sup>2,b,\*</sup>, Suched Likitlersuang<sup>3,c</sup>

<sup>1</sup> Department of Civil Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok 10330, Thailand

<sup>2</sup> Department of Civil Engineering, Faculty of Engineering, University of Bengkulu, Bengkulu 38371, Indonesia

<sup>3</sup> Centre of Excellence on Geotechnical and Geoenvironmental Engineering, Department of Civil Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok 10330, Thailand

E-mail: <sup>a</sup>fatih.qodri@mail.ugm.ac.id, <sup>b</sup>lmase@unib.ac.id (Corresponding author), <sup>c</sup>fceslk@chula.ac.th

**Abstract.** Some responses to the remote earthquakes can be possibly felt by people in Bangkok. It indicates that there is seismic wave amplification during the earthquakes. The geological condition and the vibration intensity of the ground are the main factors of the amplification. In this study, the site-specific investigation was conducted in Bangkok including the boring log and shear wave velocity measurement. Analysis of non-linear seismic wave propagation were performed for each studied site. Model of Next Generation Attenuation (NGA) is used to ground motion from the earthquake under the activity of Three Pagodas Fault on the eastern Thailand bordered with Myanmar. The input motions were obtained from the database of Pacific Earthquake Engineering Research (PEER). The key results of ground motion characteristic are reported in this study. In general, the results show the effect of the motion due to earthquake to Bangkok subsoil. The investigated sites could undergo amplification during the earthquake under the scenario of Three Pagodas Fault. The results also suggest the people to consider the earthquake impact which is possibly triggered by the activity of Three Pagodas Fault.

**Keywords:** Earthquake, site response, spectral acceleration, amplification factor.

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## 1. Introduction

Bangkok as capital city of Thailand is importance as the centre of business, tourism, education, and many vital activities. In last decades, there are at least two strong earthquakes in Thailand, as shown in Fig. 1. Mase et al., [1] mentioned that those earthquakes are known as Tarlay Earthquake in 2011 with magnitude of 6.8  $M_w$  and Mae Lao Earthquake in 2014 with magnitude of  $M_w$  6.1 that had epicentre in the northern part of Thailand, i.e. about 700 km away from the capital city (Bangkok). Nutalaya et al. [2] recorded that more than 20 distant earthquakes had shaken in Bangkok and mostly they were from the northern part of Thailand. However, as reported by Mase et al [3] the ground shaking during those earthquakes could result in a resonance effect to the long period structure in Bangkok. Therefore, the development of the structures in Bangkok should consider the seismic design code [4].

It has been recognised that thick layers of soft clays exist in Bangkok area. The thickness of those layers are about 15 to 20 m [5]. Poovarodom and Jirasakjamroonsri [6] suggested that the existence of soft clay layer could trigger the ground amplification during the strong earthquakes. Shibuya [7] also mentioned that the ground shaking due distant earthquake propagated through the Bangkok soft clay layer could be resulting in the huge damage to the high-rise building. Likitlersuang et al. [8] concluded that during the Tarlay Earthquake, the ground amplification in Bangkok is relatively high. There are several active faults in the western Thailand such as Three Pagodas Fault that can threat Bangkok. The fault is only 130 km far away from the city. In this study, several investigation data from the important areas in Bangkok are collected. Next generation attenuation (hereafter NGA) model is then performed to determine maximum peak ground acceleration. Finally, the seismic ground response analysis using the non-linear pressure dependent hyperbolic [9] model is performed. Several key results, such as the amplification factor, the spectral acceleration, and the ground motions at surface are presented.

## 2. Seismic Activities Around Bangkok

Based on Thai Meteorological Department or TMD [10], Thailand has seismic activity distribution of earthquakes. The epicentres of those potential earthquakes are in neighbouring countries as well as inside Thailand. Those are indicated by some active faults that exist as shown in Fig. 1 [10]. Several active faults are in northern area and western area of Thailand. Several faults such as, Mae Chan, Thoen and Phayao are found in the northern part of Thailand, whereas Si Sawat and Three Pagodas faults are found in the western part of Thailand. Currently, Three Pagoda fault has been explored continuously since this fault could trigger the strong earthquake in the future [11]. The seismic hazard curve of Bangkok has been developed by Palasri and

Ruangrassamee [11]. In that study, three seismic hazard curves for the big zones of Thailand, i.e. Chiang Mai, Kanchanaburi, and Bangkok are presented. Palasri and Ruangrassamee [11] have developed the seismic hazard map in Thailand especially in Kanchanaburi Area where Three Pagoda exists. It considers probabilities of exceedance of 2% and 10% and the recurrence periods of 500 years and 2500 years, respectively. According to Palasri and Ruangrassamee [11], the seismic activities from the western area could influence the structural buildings in Bangkok

## 3. Geologic Characteristics

The study area is presented in Fig. 2. In this study, 4 locations including Chulalongkorn University (CU), Kasetsart University (KU), Asian Institute of Technology (AIT), and Bangna Seismic Station (BSS) are investigated. They are the education and socio-economy centres where the population are centralised. The example of site investigation data of studied area is presented in Fig. 3. In general, the geological condition of studied area is relatively similar as presented by Shibuya [7]. The alluvial sedimentary materials composed by clay layers are dominant in Bangkok. Sand layers are also found in sites, especially at the depth of 17 to 80 m depth. Generally, the time-averaged of shear wave velocity to 30 m ( $V_{s30}$ ) depth is about 142 to 179 m/s. Following the criteria of National Earthquake Hazard Reduction Provision or NEHRP [12], those investigated sites are categorised as Site Class E.

## 4. Method

First, the secondary data including site investigation data, geological and seismological aspect in the study area and history of earthquakes events in Thailand are collected. In this study,  $V_s$  is calculated by the empirical equations for the study expressed in the following,

$$V_s = 97N^{0.310} \quad (1)$$

$$V_s = 187 \left( \frac{S_u}{P_a} \right)^{0.372} \quad (2)$$

$$V_s = 228 \left( \frac{S_u}{P_a} \right)^{0.510} \quad (3)$$

where,  $V_s$  is shear wave velocity,  $N$  is a value of standard penetration test (SPT) blows, and  $s_u$  is shear strength of cohesive soil, and  $p_a$  is the atmospheric pressure (100 kPa). Equation (1) is used to estimate  $V_s$  of sand layers (proposed by Imai [13]). For clayey soils, the equation from Likitlersuang and Kyaw [14] is used. Those correlations (the upper bound equation (Eq. (2))) and the lower bound equation (Eq. (3))) are generated based on shear wave velocity measurement and shear strength

under undrained condition ( $s_u$ ). Surarak et al. [5] recommended that the average value may be used to estimate  $V_s$  of Bangkok Clay layers.

The previous study performed by Palasri and Ruangrassamee [11] is the basis in determining the most credible fault. In this study, Three Pagodas Fault is predicted as the most credible fault to trigger earthquakes in the western Thailand. A seismic hazard analysis is further performed to generate the ground motions for the sites. Three Pagodas Fault had triggered the Kanchanaburi earthquake in 1982, with magnitude of 5  $M_w$ . Therefore, the 5  $M_w$  is selected as the maximum possible earthquake magnitude that could occur due to the fault. Afterwards, the ground motion prediction

(GMP) due to the earthquake is conducted by using the NGA model. Plengsiri et al. [15] and Mase et al. [16] mentioned that ground motion prediction of Bangkok Area can be determined based on NGA models. The spectral acceleration is then further analysed by using the spectra matching technique by Seismosoft [17] to generate the ground motion. The earthquake ground motions such as Chichi, Loma Prieta, and Northridge from Pacific Earthquake Engineering Research [18] or PEER that ever recorded with the similar geological condition with Bangkok are selected (Table 1). Additionally, Tarlay Earthquake ground motion is also used as one of the matched motions.



Fig. 1. The locations of faults in Thailand, the epicentres of Tarlay Earthquakes (2011) and Mae Lao Earthquakes (2014), the study area (modified from [19]).



Fig. 2. Site investigation location (modified from [19]).

To observe the seismic behaviour on the sites, non-linear seismic ground response simulation is conducted. In this study, the pressure dependent hyperbolic model proposed [20] is employed in this study. Local Researchers, such as Mase et al. [16] and Plengsiri et al. [15] mentioned that the model is relevant in predicting the ground motion characteristics. The non-linear seismic ground response framework is implemented based on the the wave propagating through the horizontal layers. This method is implemented by Mase et al. [10] and Mase et al. [3 and 16]. The depth below the investigated depth is assumed as the elastic half space. This assumption is taken since the limitation of engineering bedrock information. In line with those studies, the engineering bedrock value is assigned by the value of  $V_s$  of about 760 m/s [21]. This assumption is also used by several researchers such as, Mase et al. [16], Mase [22], and Adampira et al. [23]. For dynamic properties of soils, the shear modulus ratio ( $G/G_{max}$ ) for clayey soils is determined based on the study of Vucetic and Dobry [24], whereas for sandy soils, the ratio of  $G/G_{max}$  is estimated based on Seed and Idriss [25]. Those recommended ratios are also suggested by Adampira et al. [23], Mase et al. [16], and Mase [22]. In this study, the ground motion characteristics, including spectral acceleration at ground surface and amplification factor are elaborated. To estimate the performance of spectral acceleration design for Bangkok from Thai Design Seismic [26], the spectral acceleration comparison is also presented

## 5. Results and Discussion

### 5.1. Seismic Hazard Analysis

The simulated earthquake is designed based on the concept of seismic hazard [22]. Regarding this, designing the motion in Three Pagoda fault can be required and

derived from NGA-West 2 [18]. NGA-West 2, which is widely introduced in 2014, is developed as the update version of the NGA-West 1 released in 2008. To predict the ground motion, several parameters should be determined. Those are considering the earthquake magnitude, source distance, fault type, tectonic setting, local site condition, and ground motion intensity. Abrahamson et al. [27] model is implemented to determine the spectral acceleration on each site. The example of spectral acceleration obtained from Abrahamson et al. [27] model is presented in Fig. 5. Generally, the maximum spectral acceleration from the Abrahamson et al. [27] model ranges from 0.013g to 0.016g with the period of 0.24 second or frequency of about 4.2 Hz. The predicted spectral acceleration is then matched by four ground motions listed in Table 1. From the matched spectral accelerations, the ground motions on each site are generated. The example results of generating the ground motion from the matched spectral acceleration is presented in Fig. 6. In Fig. 6, it can be observed that the peak ground acceleration on each considered ground motion for CU site is ranging from 0.005g to 0.007g. This range is consistent with Plengsiri et al. [15] study. In general, since the investigated sites are located in the same region, therefore the ground motions on other three sites are relatively similar.

### 5.2. Spectral Analysis of Seismic Response

Figure 7 presents the spectral acceleration comparison due to the ground motions on each site. Figure 7 also presents the comparison of spectral acceleration on each site with the designed spectral acceleration for Bangkok. In general, the spectral acceleration at the surface of AIT site has the highest value. It represents the significant condition compared the other sites in the same input spectral acceleration. The increasing value were leading that spectral acceleration increases at shallower depth of bedrock.

Input motions, such as Chichi Earthquake, Loma prieta Earthquake, Northridge Earthquake, and Tarlay earthquake has high spectral response when the natural periods are 0.1 to 0.80s. Generally, the spectral accelerations reach the maximum value at period of 0.3 to 0.7 sec. The ranges are reflecting the building natural period of 3 to 7 stories building (simply predicted by  $T_n = 0.1n$ , with  $n$  as the stories number). Therefore, it could be roughly estimated that the applied ground motions could result in a more serious damage to the medium stories building in Bangkok. For the long period,

the spectral acceleration design is not exceeded by the spectral accelerations from the applied ground motions. It would reflect that the ground applied ground motions are not resulting the serious damage for the high stories building. The results presented in this study are only the effect of the possible earthquake triggering by far field fault, whereas the effect of a closer fault to the study area has not studied yet. If the strong earthquake occurs in a closed distance, a more serious damage to the study area are going to happen. Therefore, the structural design in Bangkok should consider the earthquake design at all.

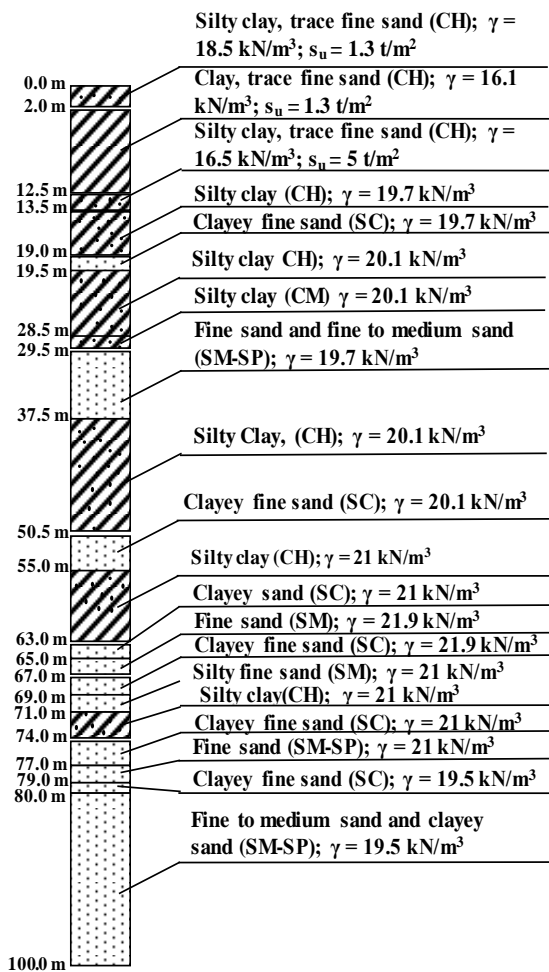


Fig. 3. Site investigation data of CU.

### 5.3. Spectral Analysis of Seismic Response

The example results of maximum peak ground acceleration or  $PGA_{max}$  are presented in Fig. 8. In Fig. 8, the  $PGA$  comparison of the input one and at surface for CU site is presented. In general, the input motions applied in the site tend to enlarge at the ground surface. It indicates that there is amplification of motion on the sites. Among all ground motions, the Chichi earthquake motions undergo the largest amplification.

Other results of  $PGA_{max}$  are summarised in Table 2. Similar with CU site, other sites also undergo the amplification. The amplification factor on the study area generally ranges from 1.410 to 3.445. The comparison of amplification factor on each site is presented in Fig. 9. In

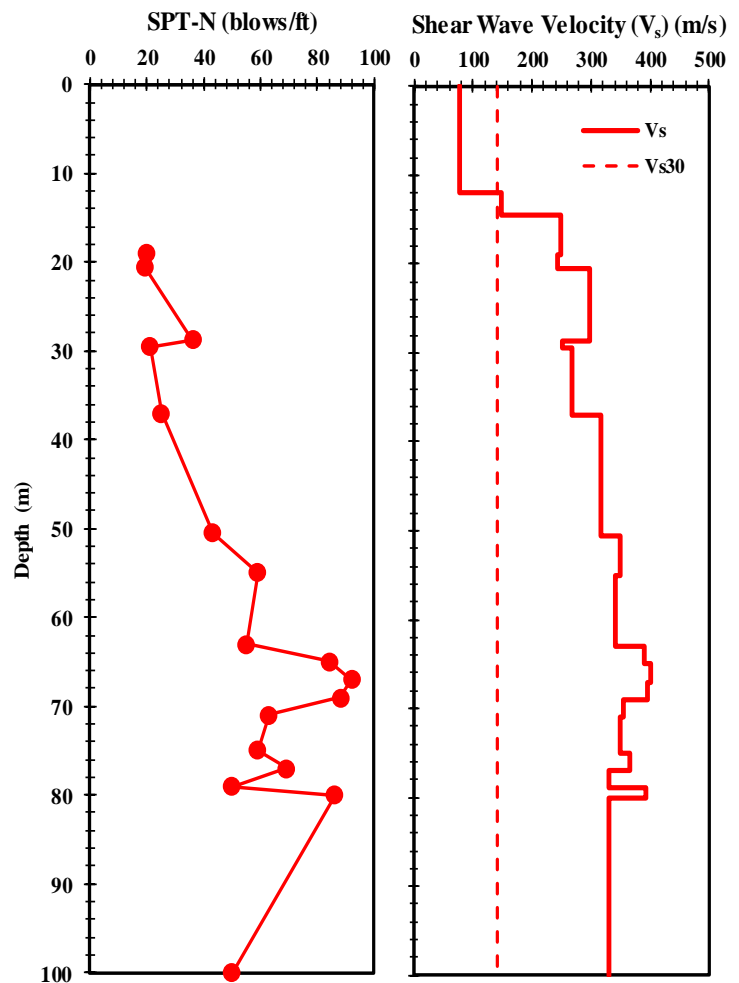


Fig. 9, it can be seen that the largest amplification factor is shown by AIT Site, i.e. due to the Northridge Ground Motion. This may be caused by the similar resonance period of the site and the ground motions applied. Therefore, the propagated wave tends to undergo amplification layer when it travels through the soft layer [28]. Figure 10 presents the trend of amplification factor on each site corresponding to  $V_{s30}$ . It can be seen that  $V_{s30}$  is not always consistent with the amplification factor. This is because ground motion amplification is strongly controlled by the existence of soft layer, whereas  $V_{s30}$  is only a parameter for reflecting the characteristic of sites for the simplification purpose such as seismic zonation [28].

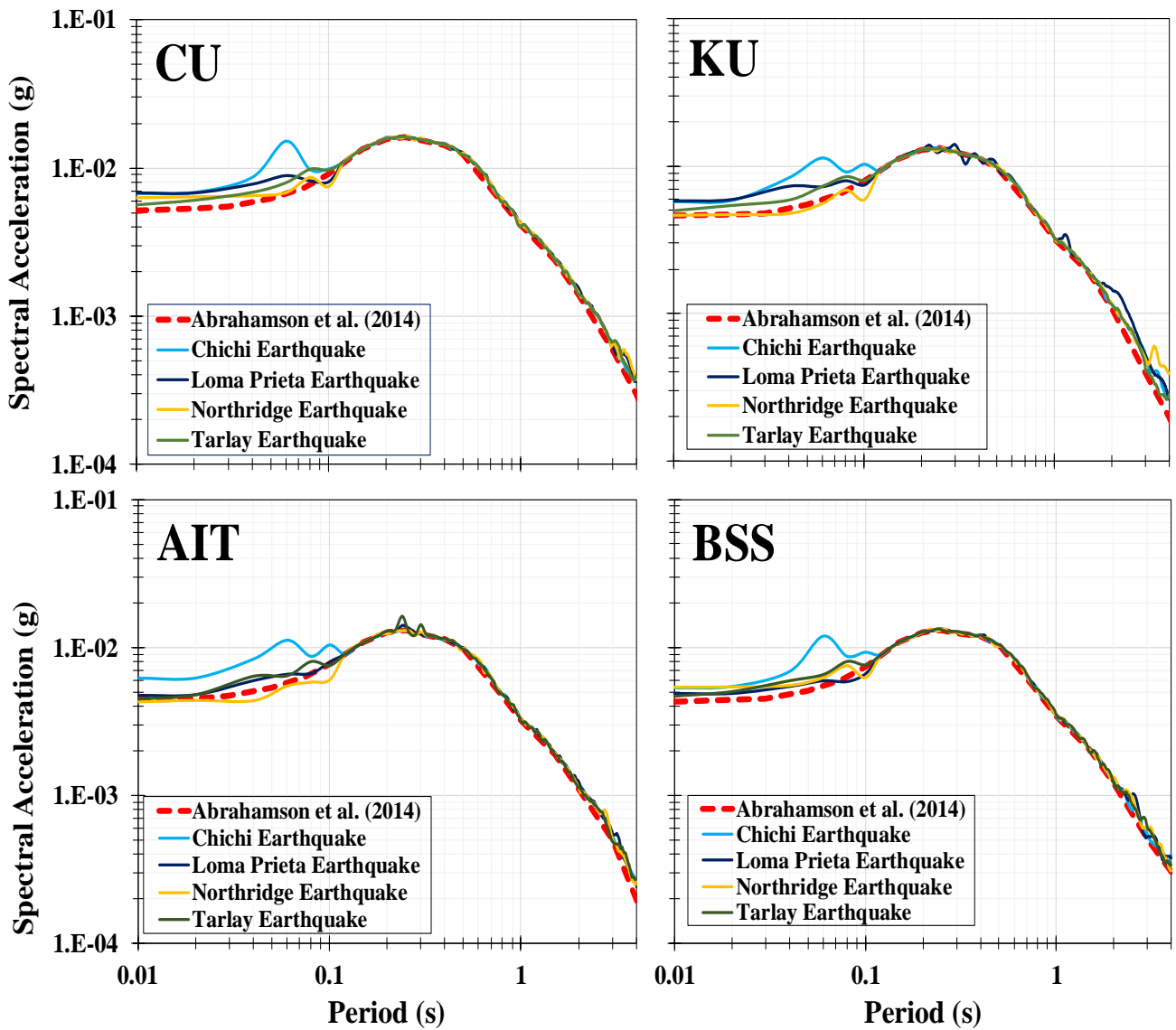


Fig. 4. The spectral matching on each site.

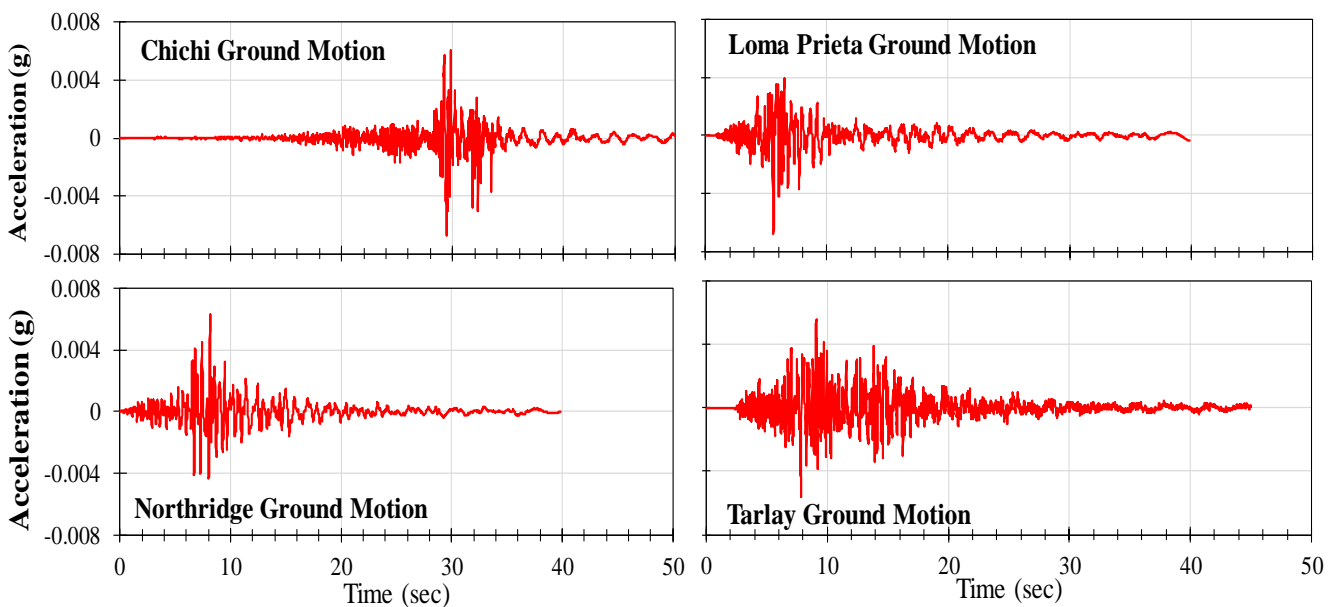


Fig. 5. The example of ground motions resulted from spectral matching for CU site.

Table 1. The earthquake records used in seismic hazard analysis [10 and 17].

Event	Location	Station	Year	Moment Magnitude ( $M_w$ )	Epicentre Distance (km)	$V_{s30}$ (m/s)	Site Class
Chi-Chi	Chichi (Taiwan)	TCU045	1999	6.20	119	150	E
Loma Prieta	Loma Prieta (USA)	Alameda Naval Air	1989	6.93	71	190	D
Northridge	Northridge (USA)	Hemet - Ryan Airfield	1994	6.69	145	291	D
Tarlay	Thailand-Myanmar	Bang Na Seismic Station	2011	6.20	711	133	E

Table 2. The summary of  $PGA_{max}$  and amplification factor on each site.

Chichi Earthquake				Loma Prieta			
Site	$V_{s30}$ (m/s)	PGA input (g)	PGA at ground surface (g)	Amplification Factor (AF)	PGA input (g)	PGA at ground surface (g)	Amplification Factor (AF)
CU	142	0.0067	0.0106	1.576	0.0068	0.0100	1.486
KU	179	0.0058	0.0160	2.780	0.0058	0.0150	2.602
AIT	172	0.0062	0.0151	2.423	0.0048	0.0144	3.035
BSS	153	0.0053	0.0111	2.093	0.0049	0.0097	1.997

Northridge Earthquake				Tarlay Earthquake			
Site	$V_{s30}$ (m/s)	PGA input (g)	PGA at ground surface (g)	Amplification Factor (AF)	PGA input (g)	PGA at ground surface (g)	Amplification Factor (AF)
CU	142	0.00627	0.00884	1.410	0.0056	0.0083	1.475
KU	179	0.00466	0.014169	3.041	0.0050	0.0139	2.785
AIT	172	0.00428	0.014744	3.445	0.0045	0.0123	2.731
BSS	153	0.00466	0.007491	1.608	0.0047	0.0075	1.608

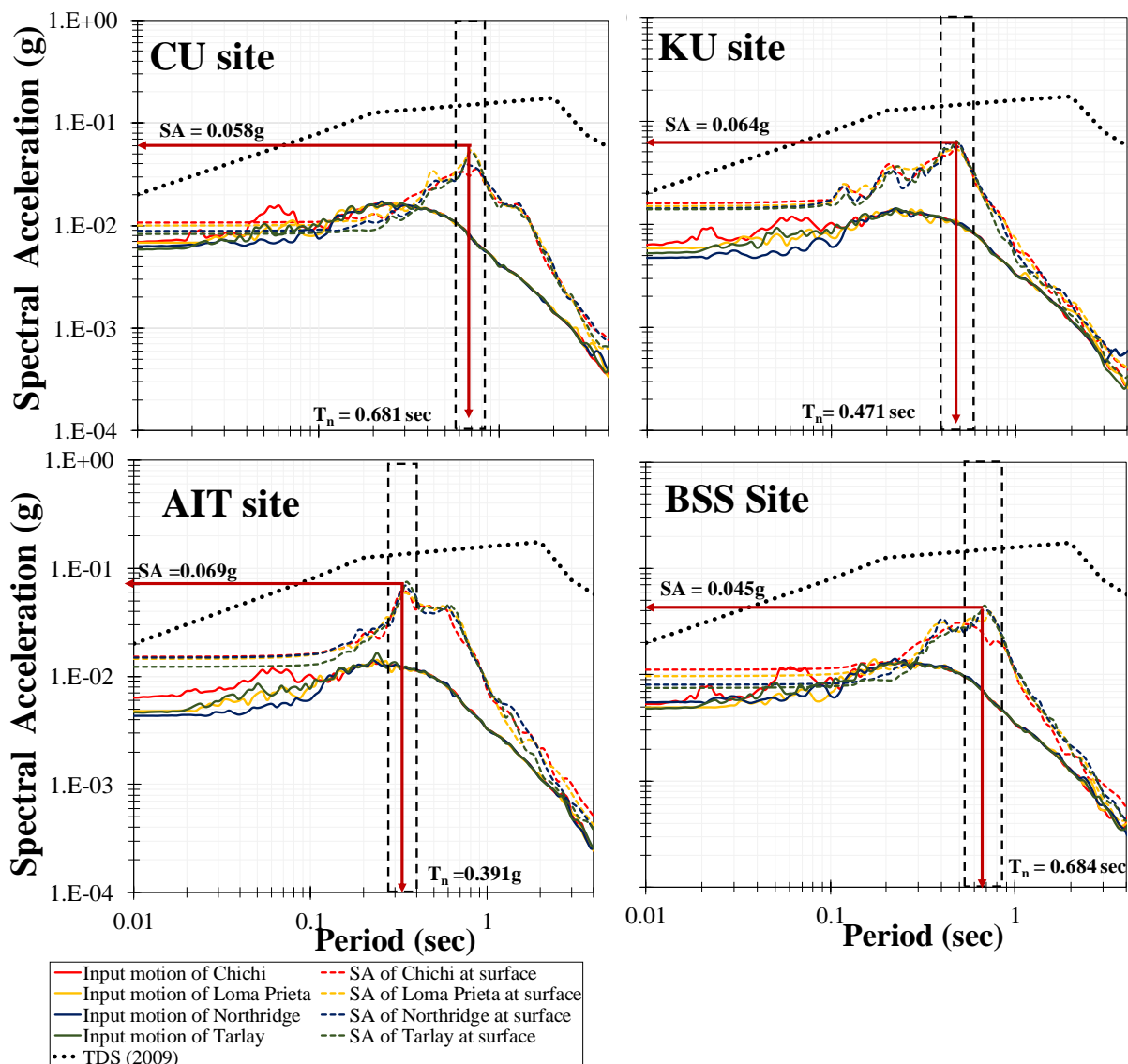


Fig. 6. Spectral acceleration comparison on each site (1) Chichi earthquake, (2) Loma prieta earthquake, (3) Northridge earthquake, and (4) Tarlay earthquake.

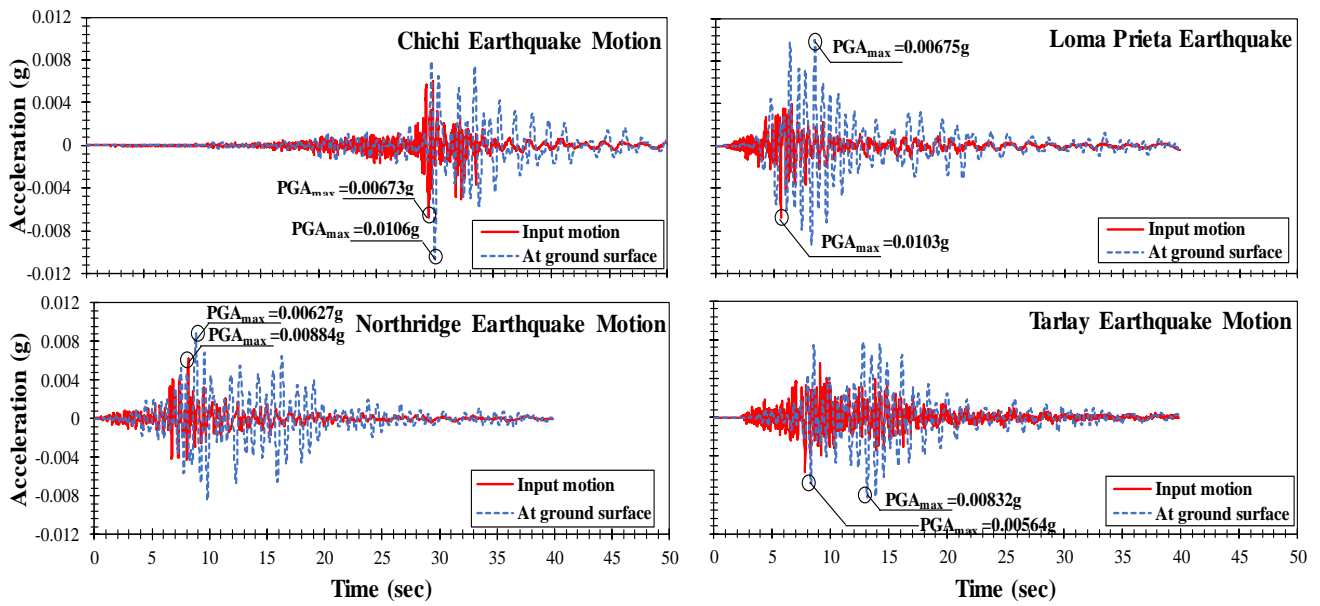


Fig. 7. The comparison of input ground motion and surface ground motion at CU site.

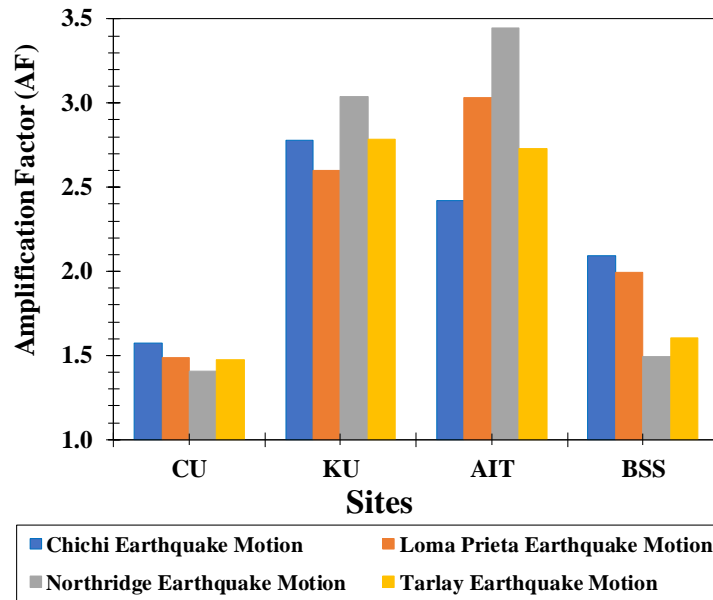


Fig. 8. The comparison of amplification factor on each site.

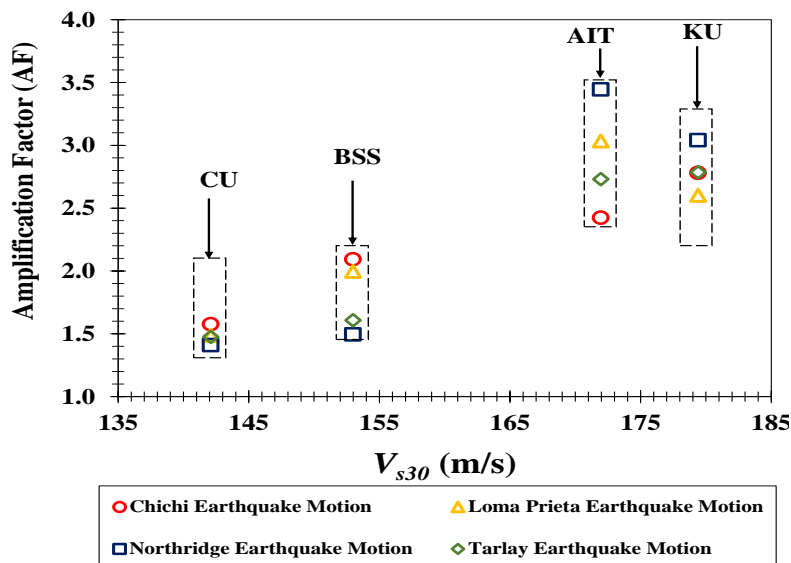


Fig. 9. The comparison of amplification factor and  $V_{s30}$  on each site.



In general, the results of this study are relatively consistent with previous studies resulted from the studies of Poovarodom and Plalinyot [29]. According to it, the amplification factors due to the earthquake in Bangkok could reach up to 6 times. Choi and Stewart [30] also mentioned that the thick soft clay layer is able to significantly influence the amplification factor. In line with those previous studies, this study had confirmed the statement of Warnitchai et al. [31] where the amplification of about 3 to 6 times could be felt in Bangkok Metropolitan Area during the low intensity of input motion.

## 6. Concluding Remarks

A non-linear site response analysis combined with seismic hazard concept is implemented. The spectral acceleration from analysis of non-linear seismic ground response tends to be larger than the input motion. Generally, the amplification factor of the investigated sites is about 1.410 to 3.445 which are consistent with the studies. Spectral acceleration is not exceeding the design spectral acceleration design. It indicates that earthquakes triggering by the Three Pagodas Fault would not result in heavy damage. However, the attention should be addressed to the medium high-rise building if the stronger earthquake from the closed distance fault occurs and effects Bangkok.

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**Muhammad Fatih Qodri** is currently working as a lecturer at Department of Geological Engineering, Institut Teknologi Nasional Yogyakarta. He accomplished his bachelor degree in Geological Engineering Department, Universitas Gadjah Mada, Indonesia in 2016. In 2017, he awarded the Master Degree Program under support of AUN/SEED-Net (JICA) in Civil Engineering, Chulalongkorn University, Thailand. Under Prof. Suched Likitlersuang as his advisor, he completed his Master Degree in 2019. His research interests are geotechnical earthquake engineering, geology, rock mechanic, and natural disaster.



**Lindung Zalbuin** Mase is currently an assistant professor at the Department of Civil Engineering, University of Bengkulu, Indonesia. He is currently assigned as Head of Natural Disaster Research Centre in University of Bengkulu. He worked as a postdoctoral researcher at the Centre of Excellence in Geotechnical and Geoenvironmental Engineering Chulalongkorn University, Bangkok, Thailand from November 2017 to June 2019 and a researcher at Japan-ASEAN Science Technology and Innovation Platform (JASTIP) since 2016. His research interest are geotechnical earthquake engineering, numerical analysis in geomechanics, geoenvironments and geotechnical hazard.



**Suched Likitlersuang** is currently a full professor at the Department of Civil Engineering, Faculty of Engineering, Chulalongkorn University. He joined the Department of Civil Engineering at Chulalongkorn University as a lecturer (2004-2006), as an assistant professor (2006-2009) and as an associate professor (2009-2011). He was promoted to full professorship in 2011. He is also the founder head of the centre of excellence in geotechnical and geoenvironmental engineering. His research interests include constitutive modeling for geomaterial, stress-strain characteristic of soils, numerical analysis in geomechanics, pavement engineering, geoenvironments, geotechnical earthquake engineering and soil bioengineering