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A note on ground motion recorded during Mw 6.1 Mae Lao (Northern Thailand) earthquake on 5 May 2014

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ABSTRACT: This study aims to investigate an Mw 6.1 earthquake that occurred in Northern Thailand on 5 May 2014. The epicenter of this earthquake struck very close to the Mae Lao district which is located near the border of Myanmar, Lao People's Democratic Republic (PDR), and Thailand. This shallow left-lateral strike-slip earthquake occurred on Mae Lao fault which is not previously been identified. Based on the instrumental earthquake catalogue, Mae Lao fault did not produce any earthquake greater than magnitude 6 for at least 100 years. So the 5 May 2014 earthquake is essentially filling the gap of relatively short instrumental earthquake catalogue in this region. The strong ground motion from this event has been recorded in Thailand with the highest peak ground acceleration (PGA) of 0.33 g at 14 km distance at Mae Suai Dam. Large amplitude long period ground motion have been clearly identified, but this might be due to dam response. Comparison between observed strong motion and global empirical had been provided.

1 INTRODUCTION

The Mae Lao (Northern Thailand) Earthquake occurred on 5 May 2014 at 11:08 UTC time. Strong shaking of sufficient amplitude to damage structures occurred over a broad area of approximately 1,000 km^2. The earthquake was reported to have been felt in Bangkok at 650 km distance from the epicentral area. In total, the violent ground shaking caused damage to more than 10,000 buildings, affectng about 500,000 people in Chiang Rai. The heaviest damage occurred in Mae Lao and Pan that were nearest to the fault rupture responsible for the earthquake. The event took place in an area characterized by high seismic hazard; however, the causative fault was previously unidentified (that is not mapped on the active fault map of Thailand). This event represents the second largest earthquake recorded by seismic instruments in Thailand, after the 1935 Mw 6.3 Nan earthquake.

The earthquake occurred along NE-SW left-lateral strike slip Mae Lao fault, located below Mae Lao town. The mainshock was followed by 12 aftershocks of magnitude larger than 4, the strongest ones which occurred on 6 May (Mw = 5.0). The mainshock and its aftershocks have been recorded by several digital stations operated by Thai Metrological Department (TMD), Department of Mineral Resources, and Royal Irrigation Department (RID). A total of 15 broad band velocity-meters and accelerometers were obtained within 200 km for the mainshock, with four being within 50 km of the epicenter. This article provides an overview of the local seismotectonic settings relating to 5 May 2014 event, observed strong motion with available ground motion prediction equations (GMPEs), spectral analysis of recorded ground motion, and observed structural damage has been presented and discussed.

2 HISTORICAL AND RECENT SEISMICITY

Despite its location, which is considered as the most active seismic zone in Thailand, seismic productivity in north Thailand is low, and few earthquakes have been recorded historically. Since 1975 there have been a number of low- to moderate-sized (Mw 4.5–5.9) shallow-depth earthquake events of Modified Mercalli Intensities (MMI) ranging from VI to VII in Thailand, causing slight to moderate damage to buildings. The historical record of earthquake damage in Thailand, which dates back to 1545 A.D. earthquake (MMI VIII) in the northern part of the country (Nutalaya et al. 1985), may have been the result of large magnitude and long-distance earthquakes or large magnitude generated along the crustal faults inside Thailand.

The existing seismic hazard maps in this region (Ornthammarath et al., 2011) estimated peak ground accelerations from these studies for 475- and 2475-year return periods for bedrock conditions are around 0.15g and 0.30g respectively. The latest damaged earthquake in this area occurred on 11 September 1994 at Pan with a moment magnitude of 5.2, which as located around 30 km south of the 2014 tremor, Figure 1. Magnitude and epicenter of the 2014 earthquake are defined by various institutions as given in Table 1.These epicenters are shifted further south from 8 to 10 km from Mae Lao, where the largest damage had been observed. The first motion focal mechanism of 2014 Mae Lao tremor had been determined with an almost pure left-lateral strike slip mechanism. Moreover, the modelled focal mechanism by Global CMT, Table 2, which is based on long period waveform solution, suggests similar fault orientations with more eastwardly location. The earthquake is located in the southwestern part around 15-km distance from Chiang Rai city. It is quite clear that more damage could be expected if the 2014 event rupture further north along Mae Lao fault with increasing magnitude, or if epicenter was shifted further north to a capital of this province since all government infrastructures and dense populated area are located within this zone. Moreover, there were reports of several aftershocks following mainshock for several months as reported by local people and TMD. There were two big aftershocks of M_W 5.0 shook this region one day after main event.

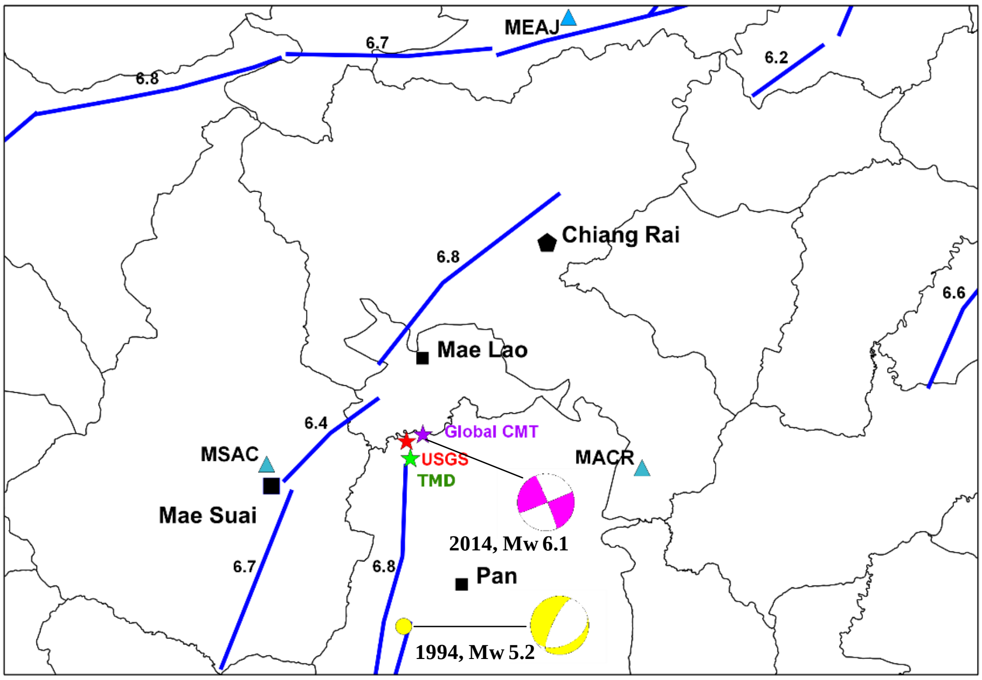

Figure 1. Map of Mae Lao and surrounding towns in Chiang Rai with 2014 Mw 6.1 earthquake epicentre. Epicentral locations determined by different agencies as stars are also shown with instrumental strong motion records shown as blue triangles. The blue lines indicate major active faults as provided by Department of Mineral Resources (DMR).

Table 1. Location and magnitude of 5 May 2014 Mae Lao earthquake

Source	Coordinate		Magnitude	Depth (km)
	N	E		
TMD[a]	19.685	99.687	6.3 (ML)	7.0
USGS[b]	19.656	99.670	6.1 (Mwb)	6.0
Global CMT[c]	19.71	99.70	6.2 (Mw)	12.0

Table 2 Information on the mainshock nodal planes and the moment magnitude (M_W) estimated by various institutions: GCMT, USGS

Source	Nodal Plane 1			Nodal Plane 2		
	Strike	Dip	Rake	Strike	Dip	Rake
W-phase	65	82	-20	158	70	-171
Global CMT	68	88	5	338	85	178

3 RECORDED GROUND MOTION

Ground motion records were obtained from Thai Metrological Department (TMD), Department of Mineral and Resources (DMR), and Royal Irrigation Department (RID). Different seismic instruments have been used to recover strong ground motion composed of PA-23 model of Geotech with 24-bit A/D converter, Kinematrics Etna strong motion instruments with a sampling rate of 200 samples per second, and Nanometric Trillium compact broadband seismometers. All records have been obtained and performed the standard zero–order correction. Each recorded ground motion is visually inspected for obvious errors or multiple earthquake events. The closest distance from the instruments to the surface projection of the fault are taken from the approximated fault location described in section 2. Geological properties of seismic stations and array-microtremor analysis have been used to classify soil type according to NEHRP standard. All report ground motion is a directional-independent average horizontal ground motion (GMrotl50). Peak horizontal acceleration (PHA), peak horizontal velocity, and peak vertical acceleration (PVA) of stations located within 50 km are shown in Table 3 along with significant duration (D 5-95).

The largest PGA of Mw 6.1 earthquake was recorded at Mae Suai Dam with 0.33g at EW component, Figure 2, and this is the highest PGA measured in Thailand; however, the station has been installed on the abutment of composite dam consisting of the Roller Compacted Concrete (RCC) in the middle part of the dam to be the spillway and the earth-fill dam on both abutments. The maximum dam height is about 59 m. Based on damage report in Mae Suai town within 4 km of Mae Suai dam, the number of building damages are lesser than that of Mae Lao town. It might be inferred that high PGA recorded by instrument at abutment reflect a much localized behaviour or response, Ornthammarath and Warnitchai, (2015). Comparison of maximum credible earthquake and design basis earthquake spectra based on Thailand seismic design code (DPT1302-09) have been shown in Figure 3. No significant difference between two spectra (even rotate to Fault Normal and Fault Parallel directions already confirming there is no forward directivity effect. The observed spectral ordinates are less than that of MCE level for periods lower than 0.2s, but it does exceed from 0.4 to 1.0 second, which might be due to dam response.

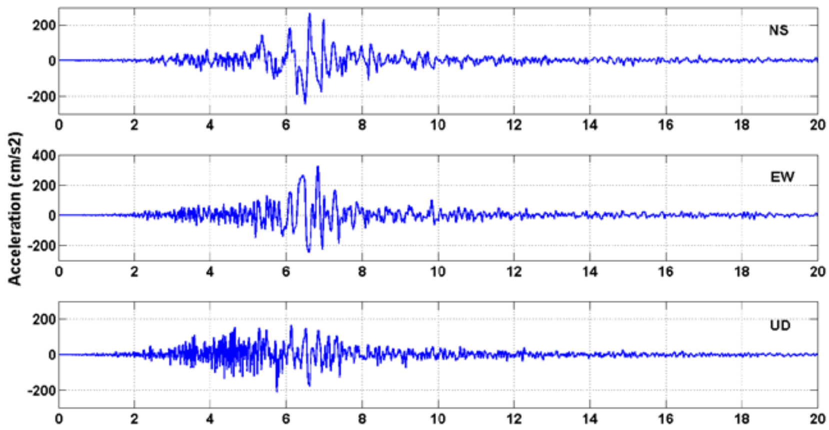

Figure 2. Acceleration time histories for NS, EW, and UD components at MSAC station for 2014, Mw 6.1 mainshock.

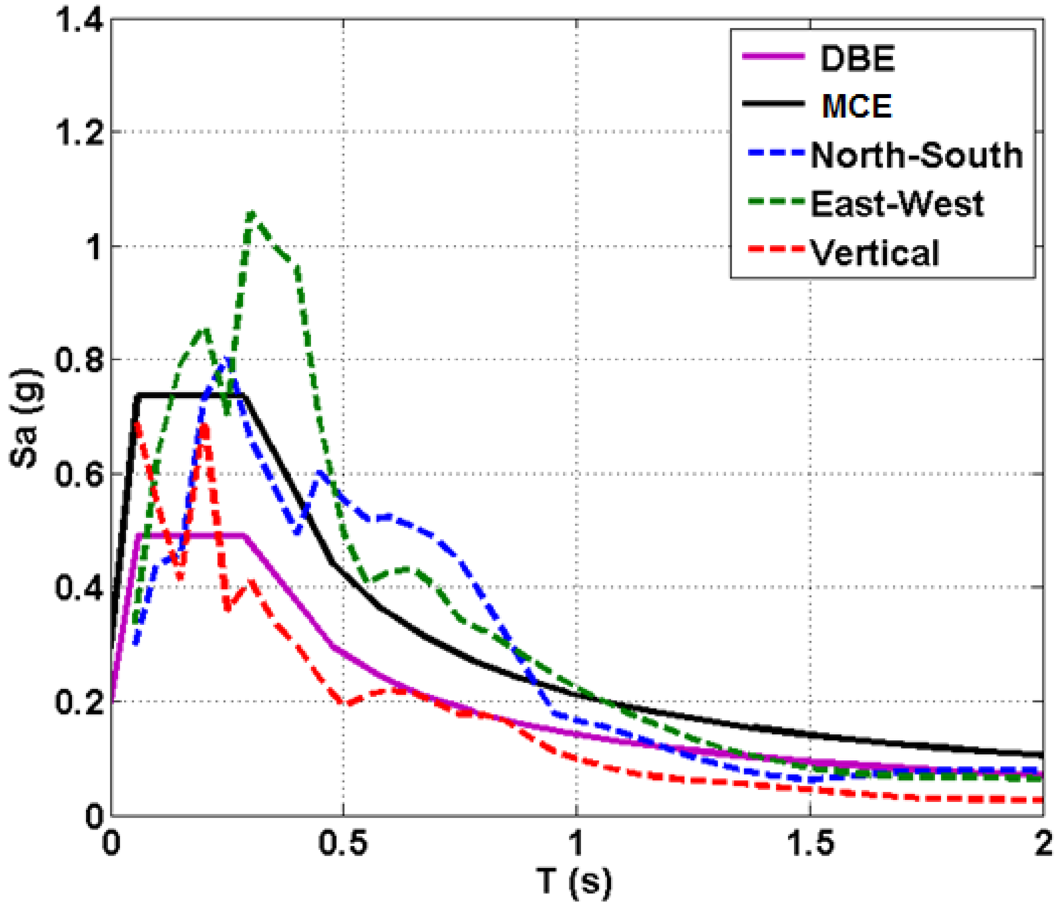

Figure 3. Comparison of 5%-damped response spectra with the maximum credible earthquake (MCE) and design basis earthquake (DBE) spectra of the DPT1302-09 and the observed response spectra at MSAC station are shown.

Table 3. Observed ground motion within 50 kms from Mae Lao Mw 6.1 mainshock

Station	Location		NEHRP site class	Rjb (km)	Source-to-site azimuth (degree)	Ground motion parameters			
	Lat (N)	Long (E)				PHA (g)	PHV (cm/s)	PVA (g)	D5-95 (s)
MSAC	19.679	99.536	B	14	234	0.33	21.6	0.21	4.43, 5.75
MACR	19.675	99.928	D	25	116	0.15	2.8	0.09	13.3, 14.4
MEAJ	20.146	99.852	D	38	20	0.04	2.5		19, 20
PAYA	19.360	99.869	B	48	160	0.06	3.5	0.03	5.16, 6.21

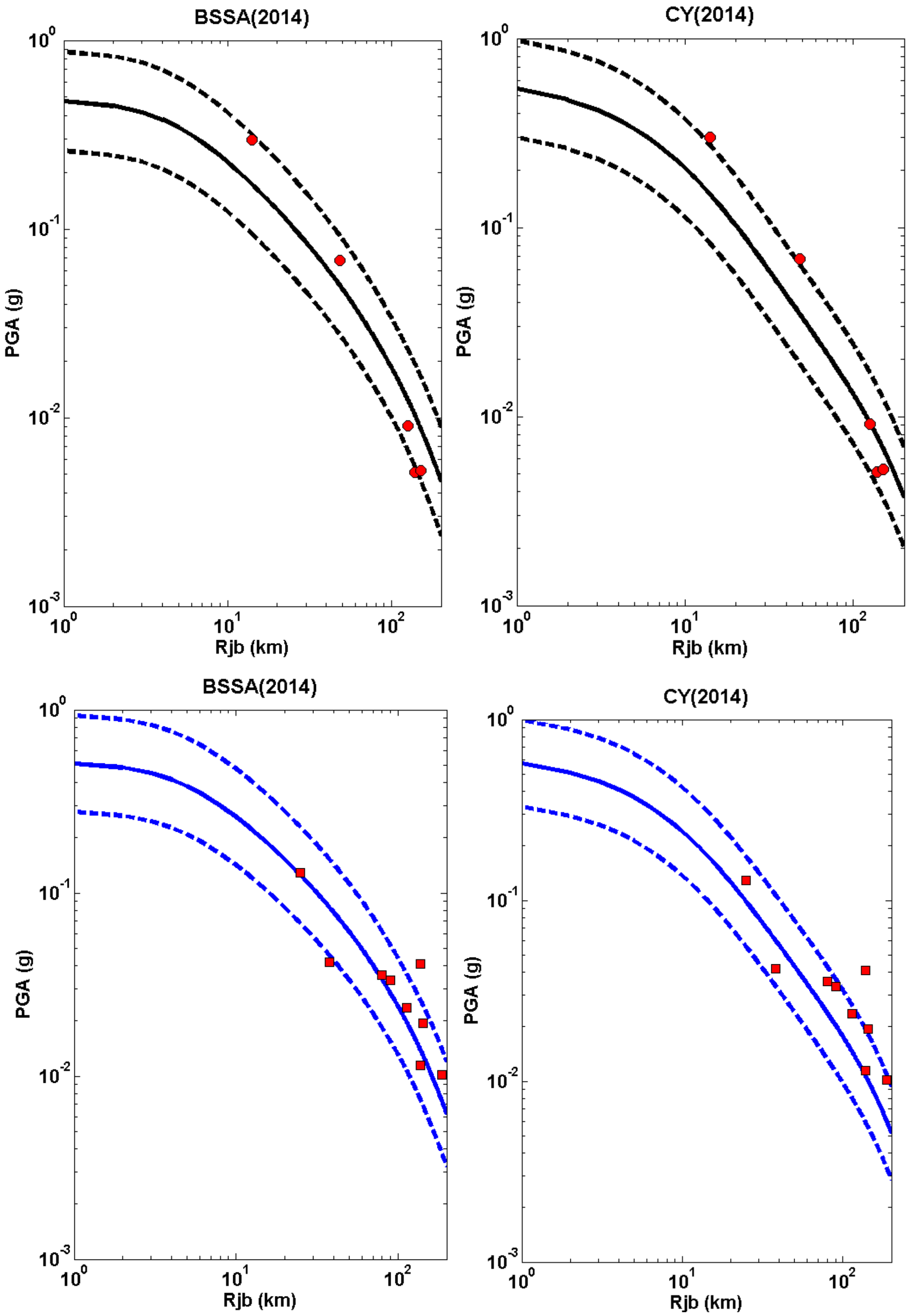

Figure 4. Comparison of PGA from Mae Lao earthquake ground motions to median and median ± one standard deviation of BSSA14 and CY14 for rock and soil condition (black and blue lines, respectively). Observed ground motion is in red circles for rock while red square for soil.

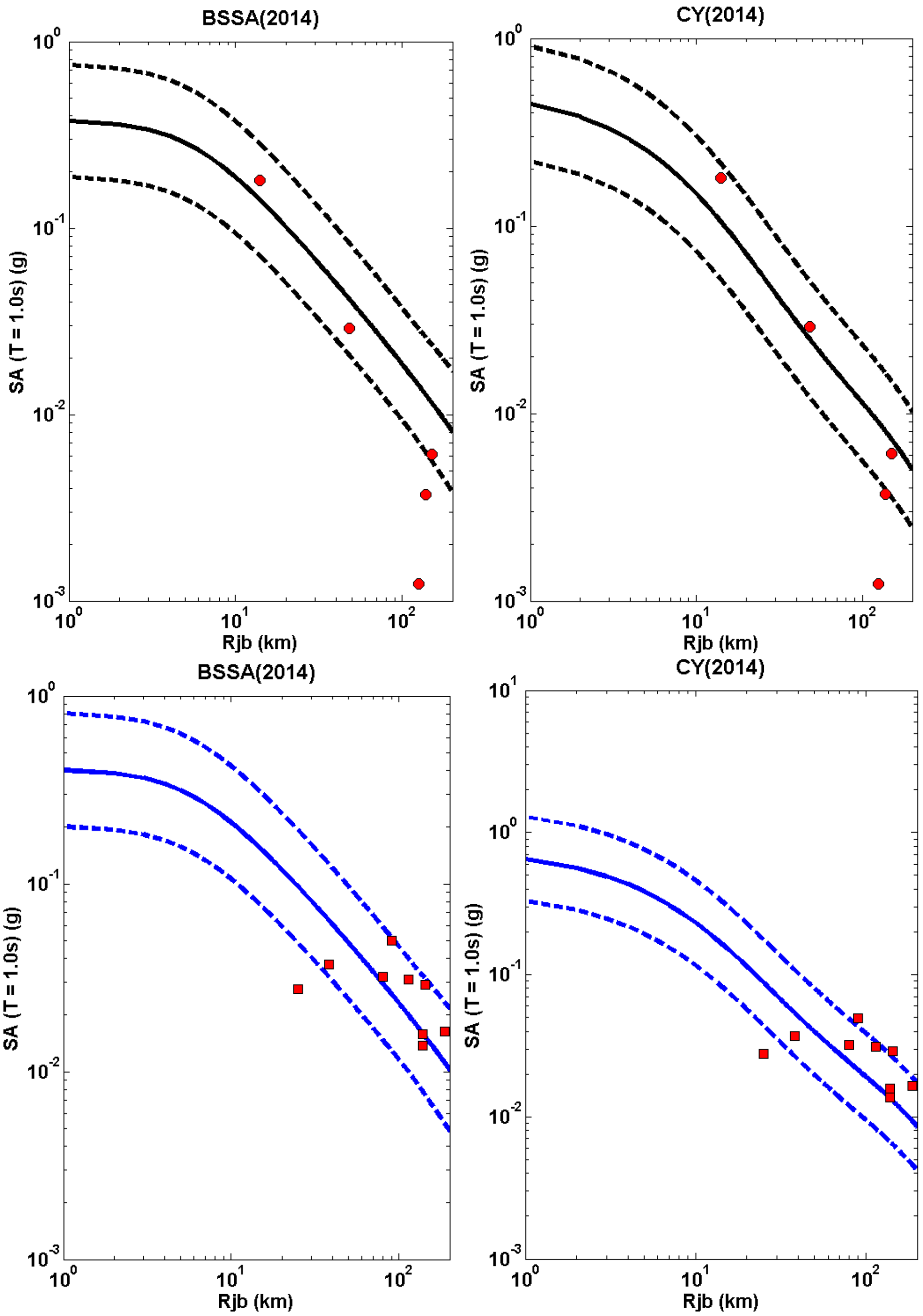

Figure 5. Comparison of SA (T = 1.0s) from Mae Lao earthquake ground motions to median and median ± one standard deviation of BSSA14 and CY14 for rock and soil condition (black and blue lines, respectively). Observed ground motion is in red circles for rock while red square for soil.

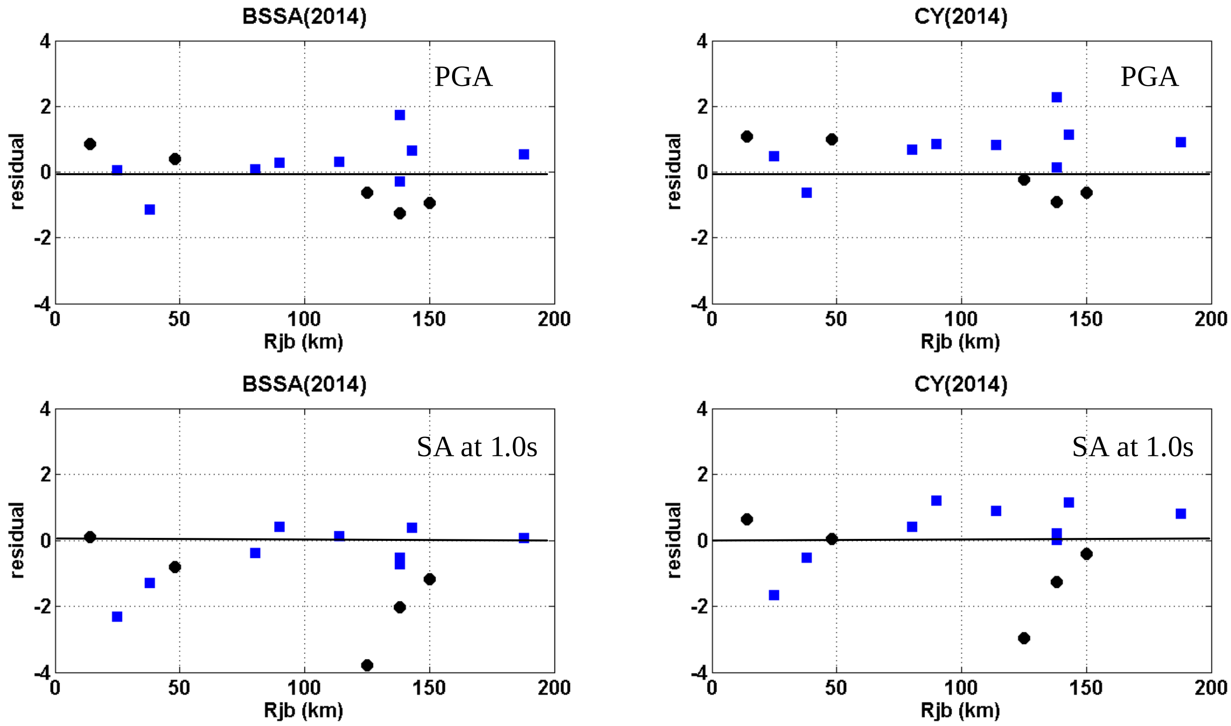

Figure 6. Residual of ground motion parameters from recorded ground motion relative to predictions of a BSSA14 and b CY14 GMPEs.

In addition, the recorded PGA at MACR station has been obtained and this record was partly be distorted since the waveforms were converted from velocity with observed saturation; however, this record provides good approximation regarding to attenuation of strong motion within epicentral area. Comparison of observed ground motion versus distance for M_w 6.1 Mae Lao earthquake to Boore et al. (2014), BSSA14 and Chiou and Youngs (2014), CY14, both of which are developed as part of Next Generation Attenuation (NGA) West 2 project, are shown in Fig. 4 and 5 for PGA and Spectral acceleration (SA) at 1.0 s. The selected VS_{30} for B/C and C/D NEHRP site class in NGA equations are 520 and 360 m/s have been chosen for rock and stiff soil site condition. Median (μ) and± one standard deviation (σ) are shown for both equations, Fig. 4. Comparison of SA (T = 1.0s) from Mae Lao earthquake ground motions to median and median ± one standard deviation of BSSA14 and CY14 for rock and soil condition (black and blue lines, respectively). In addition, to more accurately evaluate the performance of the GMPEs relative to data, the computed residual has been performed to understand the average characteristic of the Mae Lao earthquake ground motion to that of global equations. Observed ground motion is in black circles for rock while blue squares for soil. The residual for each data point comparing to that estimated by GMPEs are defined as:

$$R_i = \frac{ln(SA_i)_{rec} - ln(SA_i)_{GMPE}}{\sigma} \quad (1)$$

, where $(SA_i)_{rec}$= values of SA from recording *i* and $(SA_i)_{GMPE}$= median value of SA from GMPE. Some principal trends illustrated by Figs.4, 5, and 6 are as follows:

- For BSSA14 and CY14 GMPEs, the residual for PGA generally exhibit no significant bias over the applicable distance range from 0 to 200 km; however, larger positive residuals of CY14 comparing to BA14 could be observed. BSSA14 residuals have a non-zero mean but are relatively flat with distance, suggesting BA14 model captures well the attenuation rate for this event.

- For SA at 1.0 s, residuals of both GMPEs at soil sites show slight underprediction in the well-populated distance range of 90 to 190 km, leading to positive residuals. This might indicate that local soil amplification effect needs to be taking into account for long period structures in Northern Thailand. Larger positive residuals of CY14 comparing to BSSA14 could still be observed. However, residuals of SA at 1.0 s for both equations at rock site display contrast behavior with increasingly overestimation resulting to negative residuals.

- At MSAC station, both recorded PGA and SA at 1.0s are underestimated by both relations; however, they are still inside the median plus one standard deviation.

4 CONCLUSION

Based on available instrumental data, a summary of the 5 May 2014 Mw 6.1 Mae Lao earthquake has been presented. The earthquake occurred along the northern section of Phayao fault zone on the extension of Mae Lao fault, where no clear surface expression could be observed. This secondary fault has been less studied than other major active faults in Thaialnd (i.e. Mae Chan, Three Pagodas faults). Observed strong ground motion has been compared with those of global empirical equations, and they are in fair agreement over the distance range for which the model is applicable. On the other hand, for long period ground motion, the large positive residual could be observed, implying underprediction generally occur. In addition, observed 0.33 g PGA at Mae Suai Dam station is currently the largest recorded PGA in Thailand; however, the observed spectra might be locally amplified due to its location situated on top of 59-m height abutment.

ACKNOWLEDGEMENTS

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