โครงการการเรียนการสอนเพื่อเสริมประสบการณ์

พฤติกรรมและพิบัติภัยแผ่นดินไหวตามแนวรถไฟ ในภูมิภาคเอเชียตะวันออกเฉียงใต้

โดย

นายจิรวัฏ ดำรงกิจอภิชาต
เลขประจำตัวนิสิต 5732709723

โครงการนี้เป็นส่วนหนึ่งของการศึกษาระดับปริญญาตรี
ภาควิชาธรณีวิทยา คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2560

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ภาควิชาธรณีวิทยา จุฬาลงกรณ์มหาวิทยาลัย

พุทธศักราช 2560

Earthquake Activities and Hazards along Railways in the Mainland Southeast Asia

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ID: 5732709723

A REPORT SUMMITED IN PARTIAL FUFILLMENT OF THE REQUIMENTs FOR

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หัวข้อโครงงาน	พฤติกรรมและพิบัติภัยแผ่นดินไหวตามแนวรถไฟในภูมิภาคเอเชียตะวันออกเฉียงใต้
โดย	นายจิรวัฏ ดำรงกิจอภิชาต
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อาจารย์ที่ปรึกษาโครงงาน	รศ.ดร.สันติ ภัยหลบลี้

วันที่ส่ง..

วันที่อนุมัติ..

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ที่ปรึกษาโครงการหลัก

(รศ.ดร.สันติ ภัยหลบลี้)

หัวข้อโครงงาน พฤติกรรมและพิบัติภัยแผ่นดินไหวตามแนวรถไฟในภูมิภาคเอเชียตะวันออกเฉียงใต้
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บทคัดย่อ

ในอนาคตประเทศต่าง ๆ ในแผ่นดินใหญ่ในภูมิภาคเอเชียตะวันออกเฉียงใต้จะมีการก่อสร้างเส้นทางรถไฟหลากหลายสายทั้งรถไฟรางคู่และรถไฟความเร็วสูง ในการทำโครงงานวิจัยนี้เพื่อประเมินพิบัติภัยแผ่นดินไหวตามเส้นทางรถไฟในภูมิภาคเอเชียตะวันออกเฉียงใต้และบ่งชี้บริเวณเส้นทางที่มีความเสี่ยงต่อพิบัติภัยแผ่นดินไหว ในโครงงานวิจัยนี้ได้ประเมินพิบัติภัยโดยใช้วิธีการ 2 วิธีคือ การประเมินโดยใช้วิธีกำหนดค่า (DSHA) และวิธีการประมาณค่า (PSHA) แบบ 2% 5% และ 10% ในรอบ 50 ปี และ 5% ในรอบ 100 ปีตามหลักวิธีการประเมินของ Building Code และ JSCE จากการประเมินโดยทั้ง 2 วิธีนั้นพบว่าในบริเวณเส้นทางรถไฟในบริเวณทางทิศตะวันออกของพื้นที่มีค่าความเร่งเชิงพื้นดิน (PGA) ค่อนข้างสูง จากวิธีกำหนดค่าพบว่ามีค่าสูงสุดที่ 0.46g ใกล้สถานีหินธาดาในสหภาพเมียนมาร์และจากวิธีประมาณค่าแบบ 5% ในรอบ 100 ปีพบว่ามีค่าสูงสุดที่ 0.85g ใกล้สถานีหินธาดาในสหภาพเมียนมาร์และจากการบ่งชี้พื้นที่เสี่ยงต่อพิบัติภัยแผ่นดินไหวโดยใช้มาตรฐาน Eurocode 1998-8 พบว่ามีทั้งหมด 8 เส้นทางที่จัดอยู่ในพื้นที่เสี่ยงต่อพิบัติภัยแผ่นดินไหวซึ่งก็คือ เส้นทางทั้งหมดในสหภาพเมียนมาร์ เส้นทางจากเมืองเวียงจันทร์ถึงเมืองคุนหมิงในประเทศลาวและเส้นทางจากกรุงเทพถึงเชียงใหม่และกรุงเทพถึงสถานีน้ำตกในประเทศไทย ซึ่งประกอบไปด้วยรถไฟระบบรางคู่และความเร็วสูง

คำสำคัญ: การประเมินพิบัติภัยแผ่นดินไหว, เส้นทางรถไฟ, ภูมิภาคเอเชียตะวันออกเฉียงใต้, รอยเลื่อน

Project Title Earthquake Activities and Hazards along Railways in the Mainland Southeast Asia

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Department Geology

Project Advisor Assoc. Prof. Dr. Santi Pailoplee

Academic Year 2560

Abstract

In the future, there are plans to construct the many rail transportation in the Mainland Southeast Asia e.g. double rail and high speed rail. This senior project for estimate the seismic hazard along the railways in the Mainland Southeast Asia and specific the routes that have a risk for seismic hazard. This project use 2 methods for estimate the seismic hazard. They are Deterministic Seismic Hazard Analysis method (DSHA) and Probabilistic Seismic Hazard method (PSHA). The PSHA method use Building Code standard (2% POE 50 year and 10% POE 100 year) and JSCE standard (5% POE 50 year and 100 year). From the estimated, the railways in the western of the region have high peak ground acceleration (PGA). From DSHA method, the maximum PGA values is 0.46g near Hinthada station in Myanmar. By the PSHA method 5% POE 100 year, the maximum PGA value is 0.85g near Hinthada station in Myanmar. There are 8 lines that have risk for seismic hazard by Eurocode 1998-8 standard. The lines are all line in Myanmar, Vientiane–Khunming line in Laos and Chiang Mai–Bangkok line and Bangkok–Namtok line in Thailand. The lines that have risk include double rails and high speed rails.

Keyword: Seismic hazard analysis, Railways, Mainland Southeast Asia, Faults

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I would like to offer my special thanks to my advisor Assoc. Prof. Dr. Santi Pailoplee for his valuable and knowledge during development this project from begin until the end. I would like to thank you my aunt Mr. Chaipat Thanawattano for review the language in this project. I would like to offer my appreciated to my family for the great support. Finally, I would like to offer thank you for teachers and staffs in the Department of Geology Faculty of Science Chulalongkorn University and the others who participate in this project for support this project until done.

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Chapter 1

INTRODUCTION

1.1. Background

Rail system has been common transportation system for a long time and very important for quality of living and economic development of many countries. There are railways or facile transportation systems and logistic that cause the civilization is coming in the area. In Southeast Asia, there are many publications of railway construction plans to connect every country in the region, including high-speed trains and many electrical trains in metropolitan areas. Thus, this research, “Investigation of Earthquake Activities and Hazards along Railways in the Mainland Southeast Asia” has high significance because it will enable readers to indicate the seismic hazard high risk areas that could adversely affect people and assets. For example, many railways were damaged by the earthquake in Tohoku in 2011.

Many countries in the world have drawn seismic hazard maps for studying about earthquake vibration and earthquake warning system. In Macedonia, the seismologist estimated seismic hazard activities along highways (Dragi and Vladimir, 2006). There are seismic hazard maps in Oregon, United State of America (Zhenmin et al., 2001). In Japan, there are earthquake alarm systems for Shinkansen rail system for minimizing damages in people’s lives and assets (Shunroku et al., 2011). All of these samples have a lot of advantages for defining seismic hazard activities and reducing the damages from seismic hazard.

1.2. Objective

The key objective of this report is to study and estimate earthquake source and seismic hazard activities behavior along railways in the Mainland Southeast Asia.

1.3. Study Area

The study covers all rail lines in the Mainland Southeast Asia from latitude 1°N to 26°N and longitude 90°E to 110°E (Figure 1.1). The area of this study covers seven countries (Cambodia, Laos, Malaysia, Myanmar, Singapore, Thailand, and Vietnam) and two cities (Bangkok and Singapore). There are three main lines in Cambodia (in cyan) Phnom Penh–Aranyaprathet, Phnom Penh –Klong, and Phnom Penh–Sihanouk. In Laos (in blue), there are two main lines Vientiane–Kunming and Vientiane–Champasak. Malaysia (in purple) have three mainlines Gemas–Singapore, Gemas– Sungai Kolok, and Gemas Padang Besar. There are 5 main lines in Myanmar (in green) Thein Za Yat –Mergui, Yangon–Mandalay, Yangon–Sagiang, Pathein–Kalemyo, and Mandalay–Myitkyina. In Thailand (red), there are six mainlines Bangkok–Chiang Mai, Bangkok–Nong Khai, Bangkok–Aranyaprathet, Bangkok–Sungai Kolok, Bangkok–Namtok, and Bangkok–Ubon Ratchathani. In Vietnam (in yellow), there is one main line Hanoi–Ho Chi Minh City. Finally (Figure 1.1), there are 13 lines in Bangkok (in pink) and 7 lines in Singapore (in orange).

1.4. Expected Result

The seismic hazard map along railways in the Mainland Southeast Asia in DSHA Method (Deterministic Seismic Hazard Analysis) and PSHA Method (Probability Seismic Hazard Analysis) and Indicate the areas that have high risk in seismic hazard activities. This result would be useful for rail transportation projects in the Mainland Southeast Asia and real estate along these railways in the future.

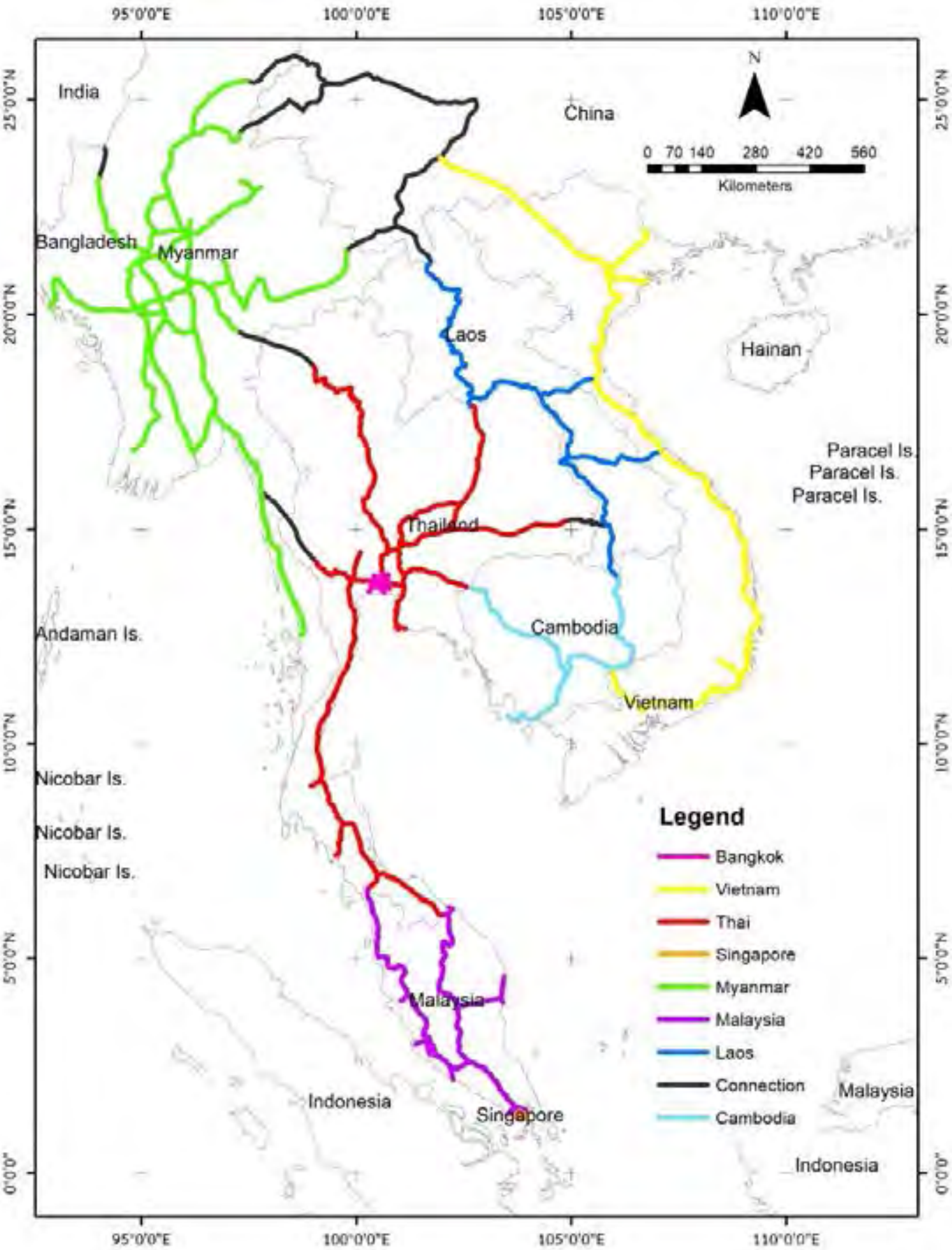

Figure 1.1. Map of Mainland Southeast Asia shows the railways in the each country.

Chapter 2

THEORY AND METHODOLOGY

2.1. Theory

Seismic hazard analysis

Seismic hazard analysis is the estimation the acceleration of ground shaking that have a chance for happen in each area in the future. The seismic hazard analysis is showed by peak ground acceleration (PGA). Peak ground acceleration is the maximum ground shaking acceleration (1g = 9.8m/s^2). In the estimation, the seismologist said that there are 3 factor for determined. First factor is the Earthquake sources. The estimated may use the earthquake sources at least 300 km from the interest area (Gupta et al., 2002). Second factor is strong ground motion attenuation model. The seismic wave is decreased by the distance. The decreasing is up to the geology in the each area. Last factor is site respond. In some case, the seismic wave can be amplified. The amplification is up to the sediment in each area. There are 2 methods for estimated the seismic hazard.

1) Deterministic Seismic Hazard Analysis (DSHA) (Hull et al., 2003) is the method that estimated the worst case method. The DSHA consider the maximum credible earthquake (MCE) and distance from the earthquake sources to the interesting point. This method is the popular for use with the large and important building e.g. dam and nuclear power plant.

2) Probabilistic Seismic Hazard Analysis (PSHA) (Cornell, 1968) is the method that use the probabilistic for predict the origin of the earthquake in each magnitude and the decreasing of the seismic wave by distance.

2.2 Methodology

2.2.1. DSHA Method

The Deterministic Seismic Hazard Analysis have 4 steps.

1) Identification shape and size of the seismic sources that affected the study area and estimated the maximum credible earthquake in the seismic source. The seismologist divide the seismic source into the line source and seismic source zone.

2) The assessment of the distance form seismic source to study area. The earthquake line source is divided into many small area and measure the distance of each area to study area. Then, we use the shortest distance.

3) Estimated the PGA by use the MCE and distances.

4) Compare the PGA values and use the maximum values.

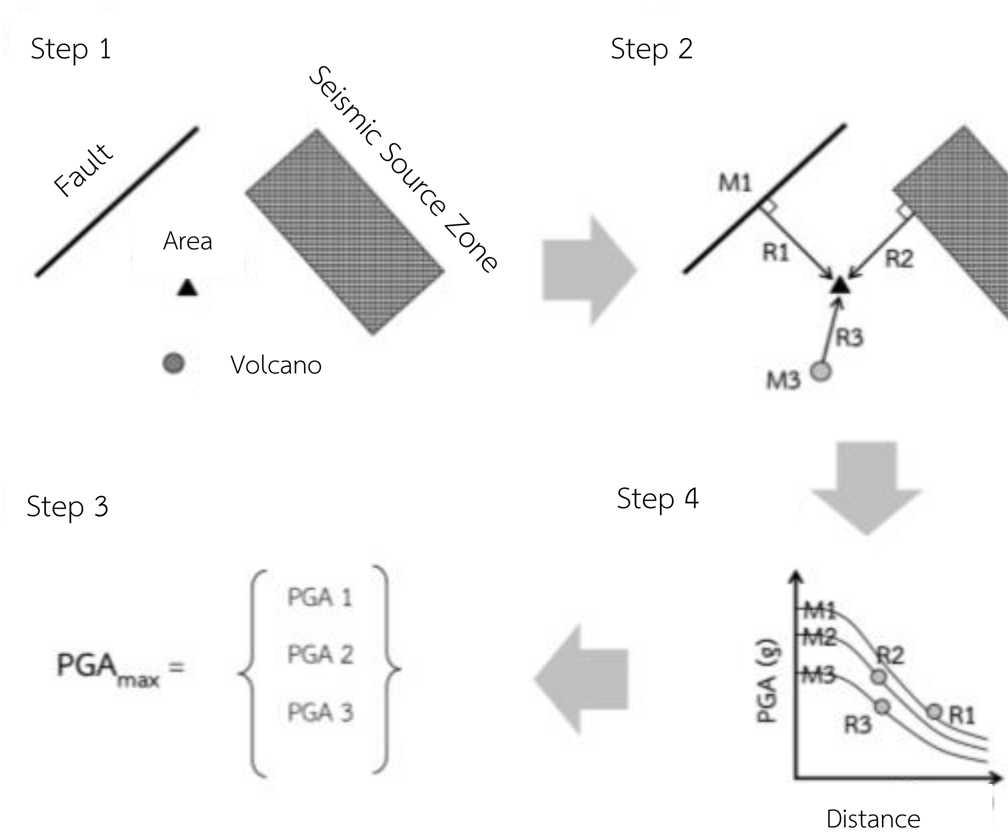

Figure 2.1. Deterministic Seismic Hazard Analysis Method.

2.2.2. PSHA Method

The probabilistic seismic hazard analysis have 4 steps

1) Identification the seismic source that affect the study area. Then, we divide seismic source into sub-areas, and measure distance in each area to study area. After that, estimate probabilistic in each distance.

2) Estimate probabilistic of earthquake in each magnitude. This step can estimated by use the a value, and b value from "frequency magnitude distribution equation"

$$logN_m = a - bM \qquad \text{equation (2.1)}$$

$$\alpha = e^{(aln(10))} \qquad \text{equation (2.2)}$$

$$\beta = bln(10) \qquad \text{equation (2.3)}$$

N_m is the cumulative number of earthquake events that magnitude over M. M is the magnitude of the earthquake. However, the earthquake instrumental have short time record (40-60 years). However, the large earthquake event have long period. The seismologist suggest that use the earthquake instrumental data and geological data (Schwartz and Coppersmith., 1984)

3) Estimated the PGA values by consider every distance and magnitude. Estimation the distance (r) and magnitude (m) into average (PHA). Then, use the Standard Deviation (SD) from the seismic decreasing model, and make the graph that show the poison distribution.

$$P[A(r,m) \geq A_0|r,m] = 1 - \emptyset \frac{logA_0 - log\overline{PHA}}{SD} \qquad \text{equation (2.4)}$$

4) Create the seismic hazard curve. Define $\lambda(A \geq A_0)$ is the probabilistic of PGA ≥ A_0. $f_{ri}(r)$ is the probabilistic of distance, and $f_{mi}(m)$ is the probabilistic of magnitude. P[A(r,m) ≥A_0 | r,m] is the inconsistency of decreasing model. v_i is the rate of origin of "i" earthquake source. The α and β is from the FMD equation

$$\lambda(A \geq A_0) = \sum v_i \iint f_{ri}(r) f_{Mi}(m)\ P[A(r,m) \geq A_0 | r,m] drdm \quad \text{equation (2.5)}$$

$$v_i = \exp(\alpha_i - \beta_i m_0) \quad \text{equation (2.6)}$$

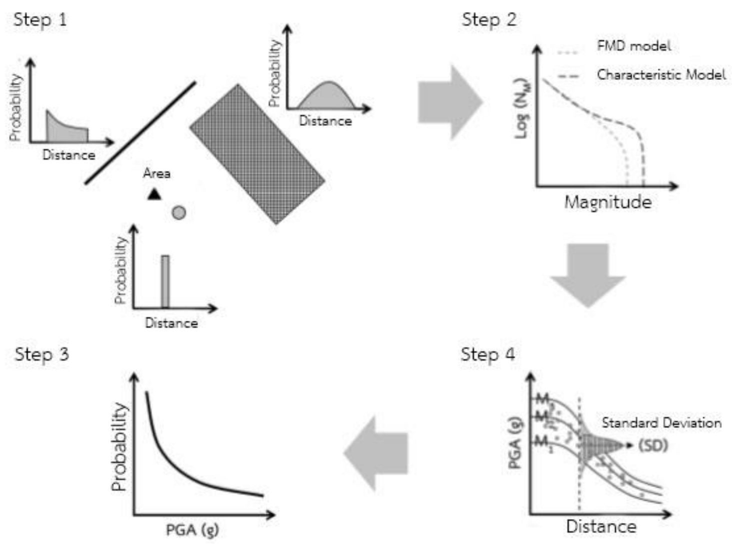

Figure 2.2. Probabilistic Seismic Hazard Analysis Method.

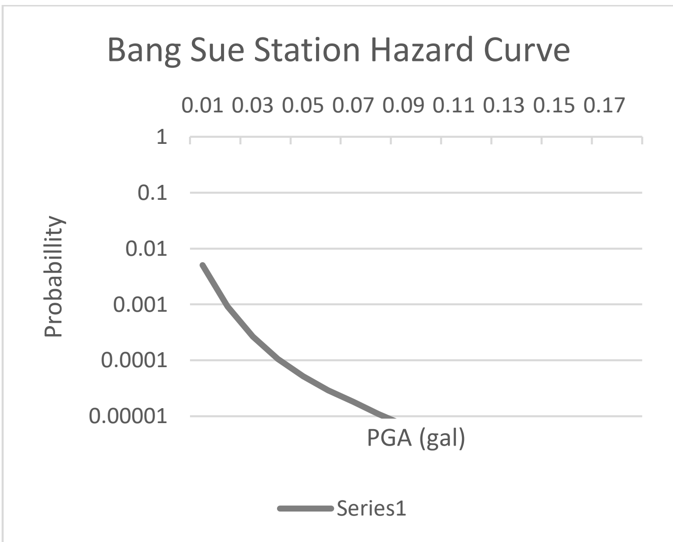

Figure 2.3. Hazard Curve of Bang Sue station.

2.3. Previous Work

The research of the seismic hazard analysis is the estimation of the peak ground acceleration (PGA). The PGA values are in the study area or surround. This research is made for study about seismic hazard and indicate the warning point along the railways in the Mainland Southeast Asia. I accumulate the associate previous work that estimate about seismic hazard.

2.3.1. Deterministic and probabilistic seismic hazard analyses in Thailand and adjacent areas using active fault data (Pailoplee et al., 2009)

They researched about seismic hazard that cause from the active faults in the Thailand and adjacent by use Deterministic method (DSHA) and Probabilistic method (PSHA). The DSHA give the maximum possible PGA values that can be estimated the critical structure e.g. dam. The PSHA method for other structure e.g. buildings, highways, and railways. They used 55 faults data surround Thailand to estimated hazard analysis. From the research, the DSHA method showed that the maximum credible earthquake range from 0g in the area far from active fault to 3g in the area near active fault. The PSHA method, they estimate 2% and 10% in probability of exceedance 50 years and 100 year. The result is in the figure 2.4

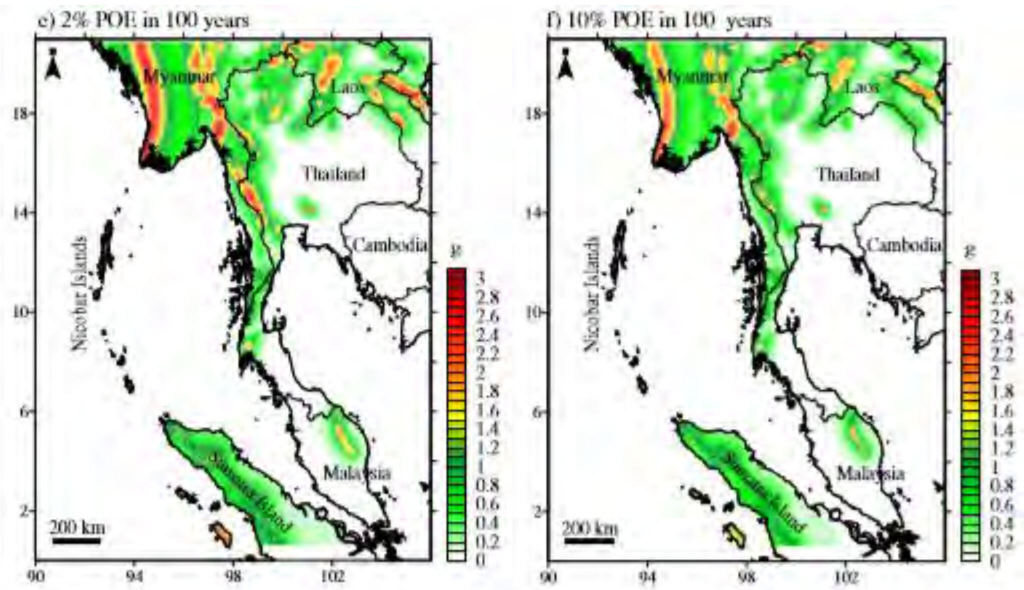

Figure 2.4. PGA 2% and 10% POE 100 year map in Thailand (Pailoplee et al., 2009).

2.3.2. Probabilistic seismic hazard assessment for Thailand (Ornthammarat et al., 2010)

Thailand is on the stable plate. However, there are tectonic setting around Thailand. There are small and small-medium size of earthquake in the northern Thailand. From 1975, we can detect a number of moderated size shallow depth earthquake. From the result, theground motion hazard map 2% in 50 year show that the northern and western of Thailand have highest hazard. Bangkok is nearby sunda subduction zone and active fault that cause the short and long-period of seismic hazard.

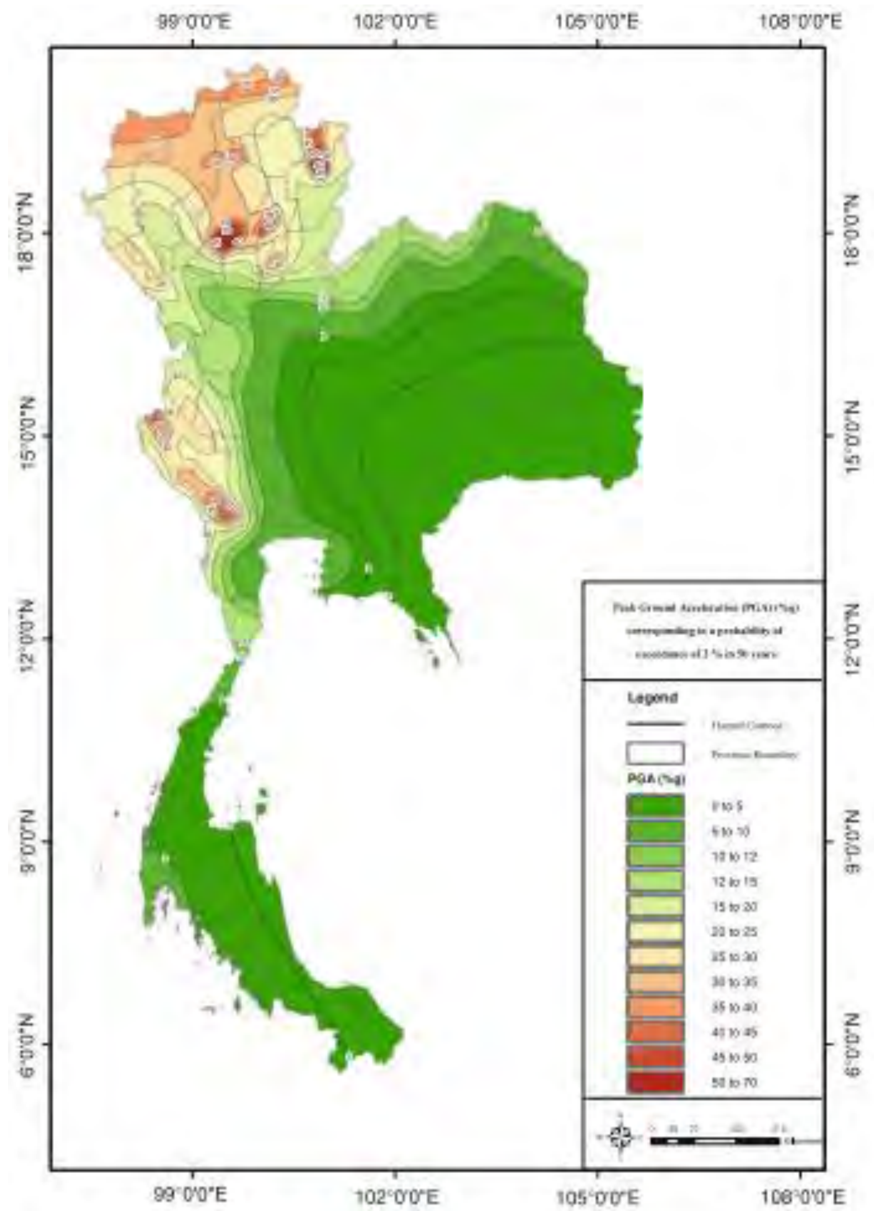

Figure 2.5. Thailand hazard map with 2% POE 50 year (Ornthammarat et al., 2010)

2.3.3 Probabilities of earthquake occurrences in Mainland Southeast Asia (Pailoplee and Choowong, 2012)

In the Mainland Southeast Asia, there are 13 seismic source zones based on recent geological data, tectonic, and seismic data. They estimated the seismic source by use the frequency magnitude distribution equation (FMD). From the results, all of seismic source zone show that the magnitude are less than 6.0 for next 25 year. Sagiang fault zone may generate to 7.5 in 20 years. At the same time, Sumatra-Andaman fault zone may generate 9.0 magnitude earthquake in 50 years.

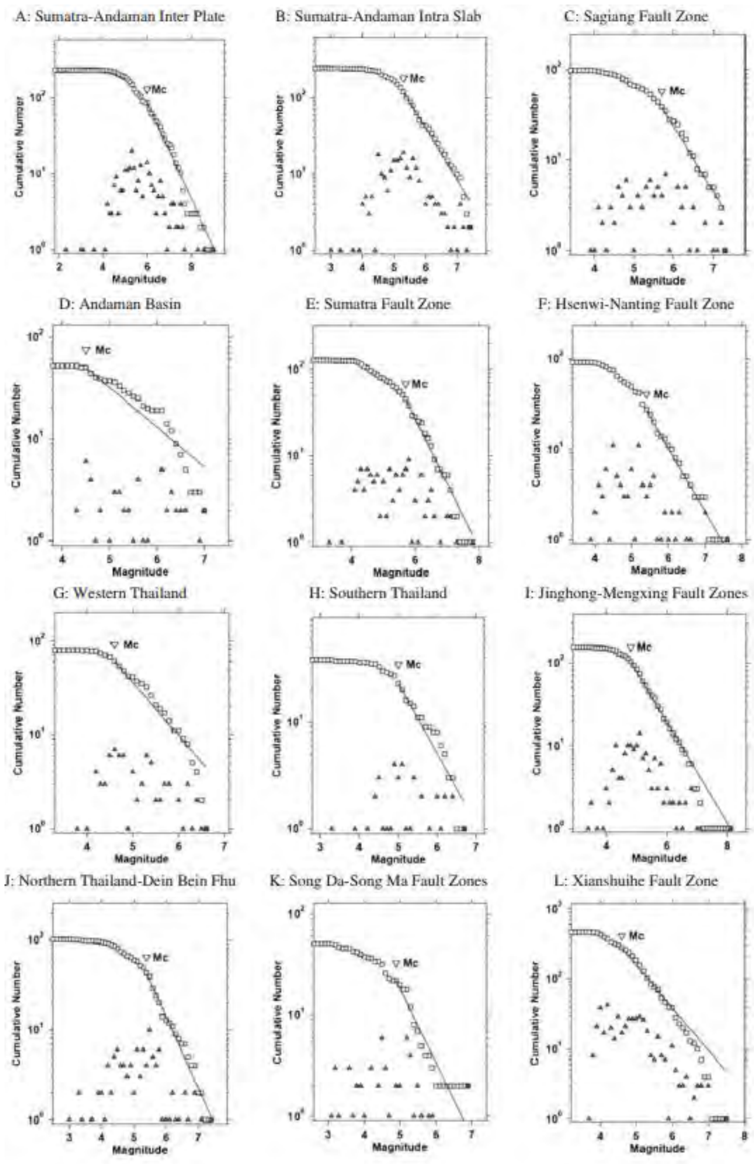

Figure 2.6. FMD plot of seismic source zones in Mainland Southeast Asia (Pailoplee and Choowong, 2012).

Chapter 3

RESULT

3.1 Input Data

3.1.1 Earthquake fault zones

The consideration the seismic source that may have affected the study area should associate seismic source from study area at less 300 km (Gupta et al., 2002). There are 55 fault zones that implicate the study area (Pailoplee et al., 2009).

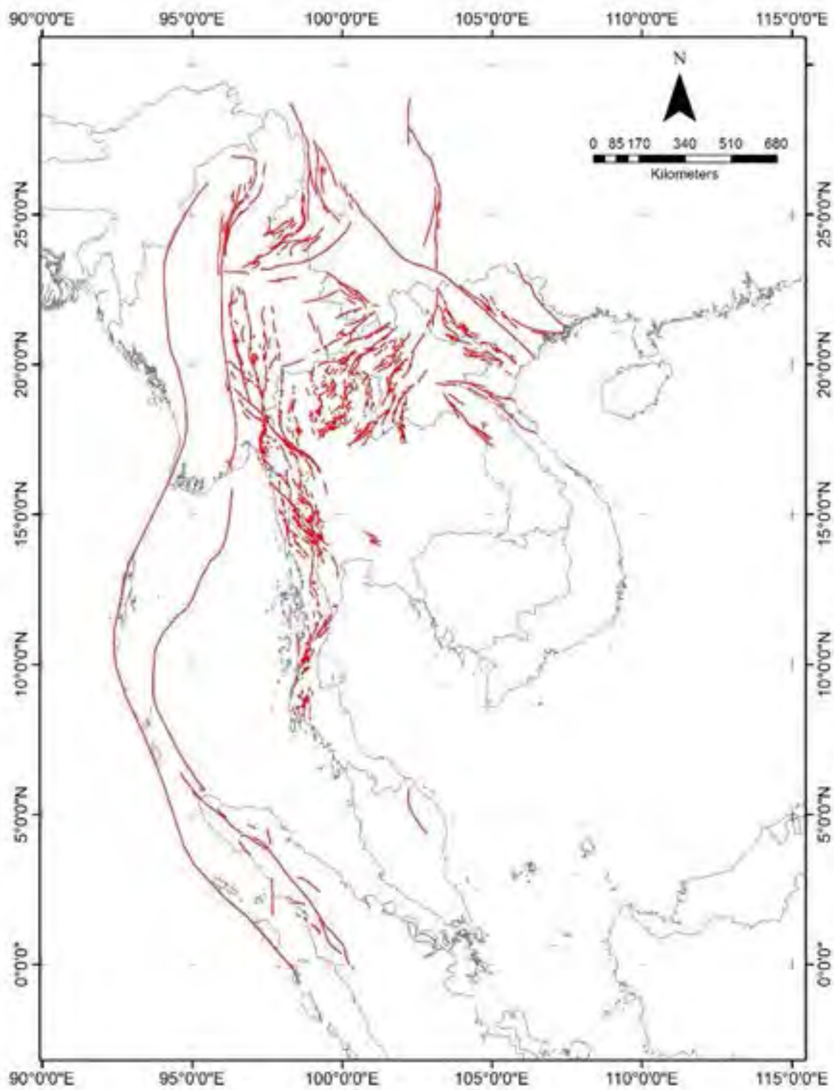

Figure 3.1. Map show associated fault zones (Pailoplee et al., 2009).

Table 3.1. Associated fault zones properties (Pailoplee et al., 2009). S is Strike-slip fault, N is normal fault, R is reverse fault, SRL is fault length, S is slip rate, M_{max} is maximum possible magnitude, A_f is area of fault zone.

Fault No.	Fault zones	Active faults data					Seismic Investigation			Source
		Fault type	SRL (km)	S (mm/yr)	Mmax	Af (km2)	Mmin	a value	b value	
1	Cao Bang-Tien Yen	S	287		7.9	5,000	4.0	1.50	0.34	Cuong et al. (2006)
2	Chiang Rai	S	28		6.8	499	4.0	2.25	0.42	Pailoplee et al. (2009)
3	Chong Shan shear zone	S	298	5.00	8.0	6,166	4.0	7.85	1.34	Akciz et al. (2008)
4	Dein Bein Fu	S	130	2.00	7.5	2,163	4.0	2.68	0.37	Zuchiewicz et al. (2004)
5	Dong Trieru	S,N	187		7.7	3,289	4.0	2.71	0.90	Charusiri et al. (2002)
6	Gaoligong Shan shear zone	S	407	5.00	8.1	7,603	4.0	9.67	1.62	Akciz et al. (2008)
7	Hsewi-Nantiang	S	359	1.00	8.0	6,166	4.0	25.80	4.83	Lacassin et al. (1998)
8	Jinghong	S	53		7.1	935	4.0	2.33	0.40	Lacassin et al. (1998)
9	Kawthuang		36		6.9	615	4.0	1.68	0.25	Pailoplee et al. (2009)
10	Klong Marui	S	29	0.10	6.8	499	4.0	1.68	0.25	Wong et al. (2005)
11	Kungyaungle	S	25	4.00	6.7	405	4.0	1.68	0.25	Wong et al. (2005)
12	Lampang-Thoen	S,N	28	0.83	6.8	499	4.0	2.72	0.55	Charusiri et al. (2004)
13	Lashio	S	50	1.00	7.0	759	4.0	3.15	0.40	Lacassin et al. (1998)
14	Libir		170		7.7	3,289	4.0	3.44	0.60	Metcalfe (2000)
15	Linchang	S	107		7.4	1,754	4.0	2.33	0.29	Lacassin et al. (1998)
16	Loei-Petchabun Suture	S	59		7.1	935	4.0	3.01	0.62	Lepvrier et al. (2004)
17	Longling-Ruili	S	70	5.00	7.2	1,153	4.0	6.42	1.01	Bai and Meju (2003)
18	Mae Chaem		21		6.6	328	4.0	1.89	0.32	Pailoplee et al. (2009)
19	Mae Chan	S	99	3.00	7.4	1,754	4.0	2.64	0.37	Fenton et al. (2003)
20	Mae Hong Sorn-Tak	S	37		6.9	615	4.0	2.65	0.38	Charusiri et al. (2004)
21	Mae Ing	S	38		6.9	615	4.0	2.56	0.38	Ferton et al. (2003)
22	Mae Tha	S	47	0.80	7.0	759	4.0	2.36	0.38	Rhodes et al. (2004)
23	Mae Yom	S	22	0.80	6.6	328	4.0	1.92	0.60	RID (2006)
24	Menglian	S	117	0.50	7.5	2,163	4.0	2.13	0.28	Lacassin et al. (1998)
25	Mengxing	S	75	4.80	7.3	1,422	4.0	2.95	0.40	Lacassin et al. (1998)
26	Moei-Tongyi	S	259	0.73	7.9	5,000	4.0	3.46	0.54	Pailoplee et al. (2009)
27	Nam Ma	S	177	2.40	7.7	3,289	4.0	3.18	0.58	Morley (2007)
28	Nam Peng	S	51		7.1	935	4.0	3.08	0.59	Charusiri et al. (1999)
29	Ongkalak	S,N	47	0.17	7.0	759	4.0	2.52	0.40	Charusiri (2005)
30	Pa Pun	S	143		7.6	2,667	4.0	2.58	0.37	Nutalaya et al. (1985)
31	Pan Luang	S	219		7.8	4,055	4.0	2.98	0.51	Nutalaya et al. (1985)
32	Pha Yao	S,N	20	0.10	6.6	328	4.0	2.95	0.40	Fenton et al. (2003)
33	Phrae	S	28	0.10	6.8	499	4.0	2.68	0.53	Fenton et al. (2003)
34	Pua	N	29	0.60	6.8	499	4.0	2.44	0.55	Fenton et al. (2003)
35	Qiaohou		145		7.6	2,667	4.0	2.35	0.25	Lacassin et al. (1998)
36	Ranong	S	46	1.00	7.0	759	4.0	1.68	0.25	Wong et al. (2005)
37	Red River	S	812	4.00	8.5	17,579	4.0	17.60	3.16	Duong and Feigl (1999)
38	Sagiang-Sumatra	S	958	23.00	8.5	17,579	4.0	6.92	0.86	Bertrand and Rangin (2003)
39	Shan	S	66		7.2	1,153	4.0	2.93	0.39	Pailoplee et al. (2009)
40	Song Ca	S	225		7.8	4,055	4.0	2.58	0.48	Takemoto et al. (2005)
41	Song Chay	S,N	55	2.00	7.1	935	4.0	3.05	0.58	Cuong and Zuchiewicz (2001)
42	Song Da	S	46		7.0	759	4.0	2.73	0.45	Phoung (1991)
43	Song Ma	S	72		7.2	1,153	4.0	6.52	1.06	Phoung (1991)
44	Sri Sawat	S	43	2.00	7.0	759	4.0	2.50	0.40	Songmuang et al. (2007)
45	Andaman subduction	R	3,388	47.00	9.2	76,208	4.0	6.08	0.69	Paul et al. (2001)
46	Tavoy	S	32		6.8	499	4.0	2.80	0.79	Wong et al. (2005)
47	Tenasserim	S	50	4.00	7.0	759	4.0	1.68	0.25	Wong et al. (2005)
48	Tha Khaek	S	250		7.9	5,000	4.0	3.15	0.67	DMR (2006)
49	Three Pagoda	S	141	2.00	7.6	2,667	4.0	2.62	0.51	Fenton et al. (2003)
50	Uttaladith	S	27	0.10	6.7	405	4.0	1.63	0.46	Fenton et al. (2003)
51	Wan Na-awn		69		7.2	1,153	4.0	2.28	0.35	Pailoplee et al. (2009)
52	Wanding	S	199	1.90	7.7	3,289	4.0	5.34	0.93	Morley (2007)
53	Wang Nua		31		6.8	499	4.0	2.27	0.40	Pailoplee et al. (2009)
54	Xianshuihe	S	505	15.00	8.2	9,376	4.0	6.74	1.05	Eleftheria et al. (2004)
55	Hutgyi	S,R	5	0.03	5.9	76	4.0	1.67	0.34	EGAT (2006)

3.1.2. Earthquake Source Zones

From the literature reviews the Mainland Southeast Asia have 13 seismic source zones (Pailoplee et al., 2013). So, there are 13 seismic source zones associating the railways in the Mainland Southeast Asia.

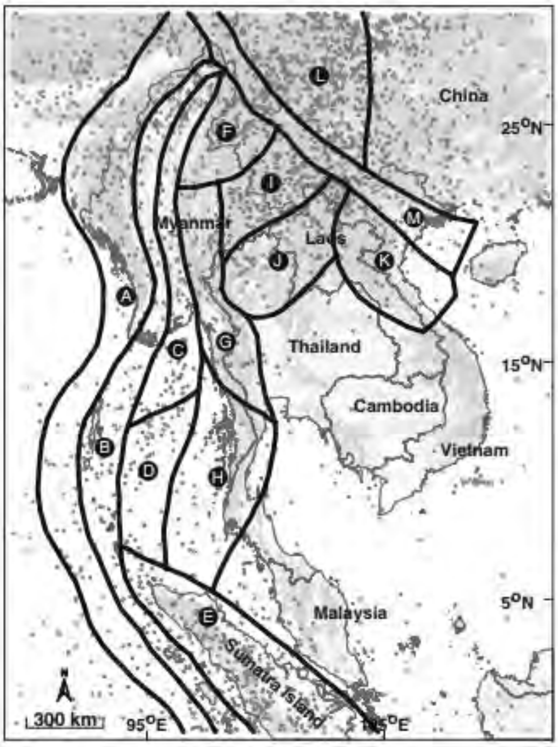

Figure 3.2. Associated seismic source zones (Pailoplee and Choowong, 2012).

Table 3.2. Associated seismic source zones properties (Pailoplee and Choowong, 2012).

Zone	Name	a	b	Mc	α	β	u
A	Sumatra-Andaman Interplate	4.06	0.63	5.6	11418.5	1.5	6.4
B	Sumatra-Andaman Intraslab	4.01	0.68	5.3	10232.9	1.6	5.9
C	Sagaing Fault Zone	4.05	0.72	5.7	11220.2	1.7	5.6
D	Andaman Basin	1.80	0.39	4.5	63.1	0.9	4.6
E	Sumatra Fault Zone	4.25	0.75	5.7	17782.8	1.7	5.7
F	Hsenwi-Nanting Fault Zone	3.57	0.70	5.4	3715.4	1.6	5.1
G	Western Thailand	2.85	0.57	4.6	707.9	1.3	5
H	Southern Thailand	3.10	0.66	5.0	1258.9	1.5	4.7
I	Jinghong-Mengxing Fault Zones	3.28	0.61	4.8	1905.5	1.4	5.4
J	Northern Thailand-Dein Bein Fhu	4.32	0.80	5.4	20893.0	1.8	5.4
K	Song Da-Song Ma Fault Zones	3.48	0.74	4.9	3020.0	1.7	4.7
L	Xianshuihe Fault Zone	3.58	0.61	4.6	3801.9	1.4	5.9
M	Red River Fault Zone	4.32	0.84	4.8	20893.0	1.9	5.1

3.1.3 Site Investigation Railways

In this project, I categorized the railways in the Mainland Southeast Asia by countries which each railway is located. These are Cambodia, Laos, Myanmar, Malaysia, Thailand, and Vietnam. Then, I categorized the other railways by city (Bangkok and Singapore).

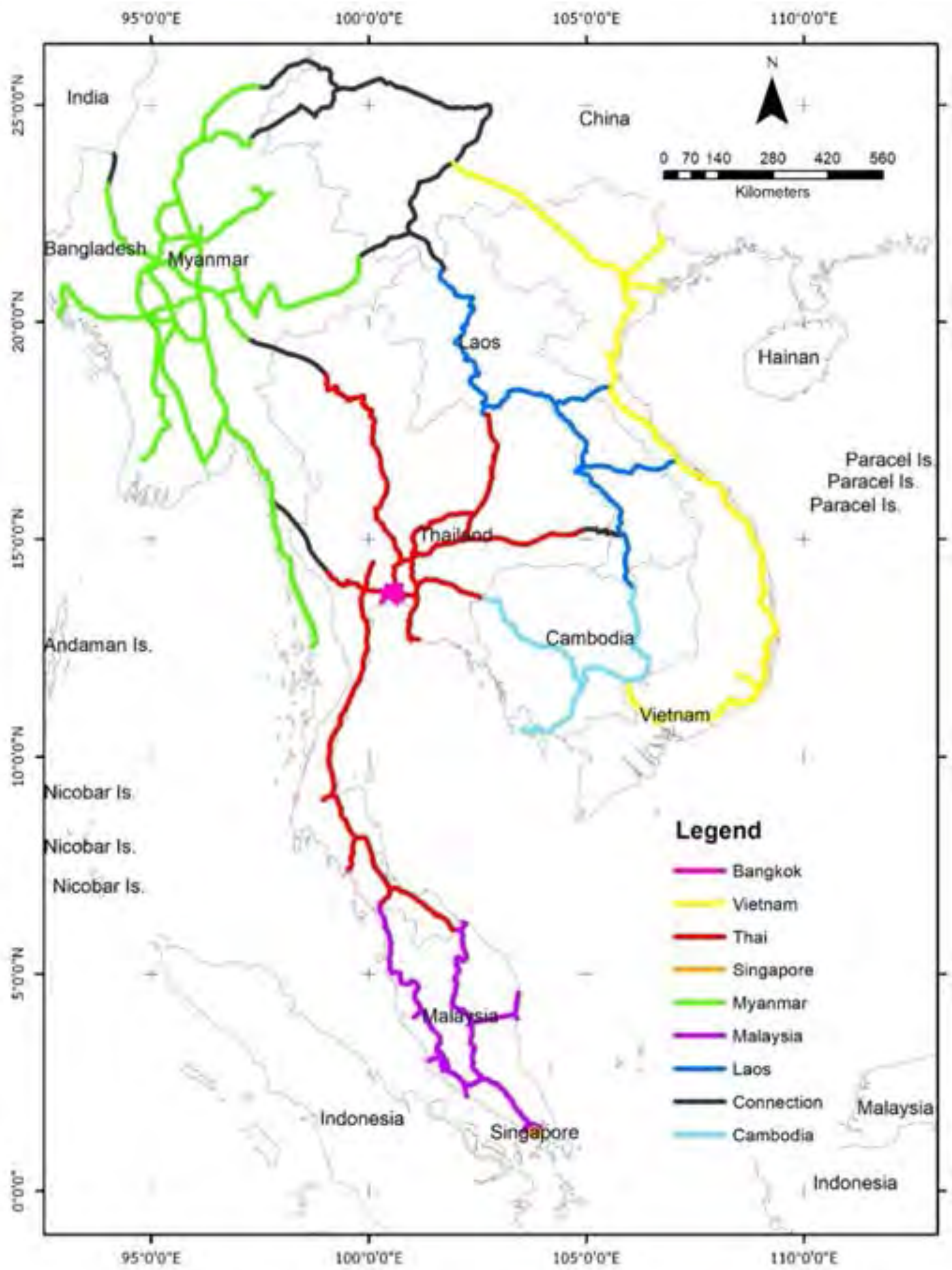

Figure 3.3. Map show railways in the Mainland Southeast Asia.

1) Cambodia. In Cambodia, there are three main lines which are Phnom Penh – Klong (in cyan) about 500 km, Phnom Penh – Sihanouk (in green) about 260 km, and Phnom Penh – Aranyaprathet (in red) about 420 km.

2) Laos. In Laos, there are two main lines which are Vientiane – Champasak about 920 km and Vientiane – Kunming about 630 km.

3) Malaysia. In Malaysia, there are three main lines which are Gemas – Padang Besar (in red) about 720 km, Gemas – Sungai Kolok (in purple) about 570 km, and Gemas – Singapore (in yellow) about 210 km.

4) Myanmar. In Myanmar, there are five main lines which are Thein Za Yat – Mergui (in red) about 710 km, Yangon – Mandalay (in orange) about 640 km, Yangon – Sagiang (in pink) about 850 km, Pathein – Kalemyo (in blue) about 940 km, and Mandalay – Myitkynia (in green) about 590 km.

5) Thailand. In Thailand, there are six main lines which are Bangkok – Chiang Mai (in blue) about 760 km, Bangkok – Sungai Kolok (in red) about 1240 km, Bangkok – Nong Khai (in yellow) about 680 km, Bangkok – Aranyaprathet (in green) about 320 km, Bangkok – Ubon Ratchathani (in purple) about 620 km, and Bangkok – Namtok (in orange) about 200 km.

6) Vietnam. In Vietnam, there is on main line which is Hanoi – Ho Chi Minh City (in green) about 1780 km.

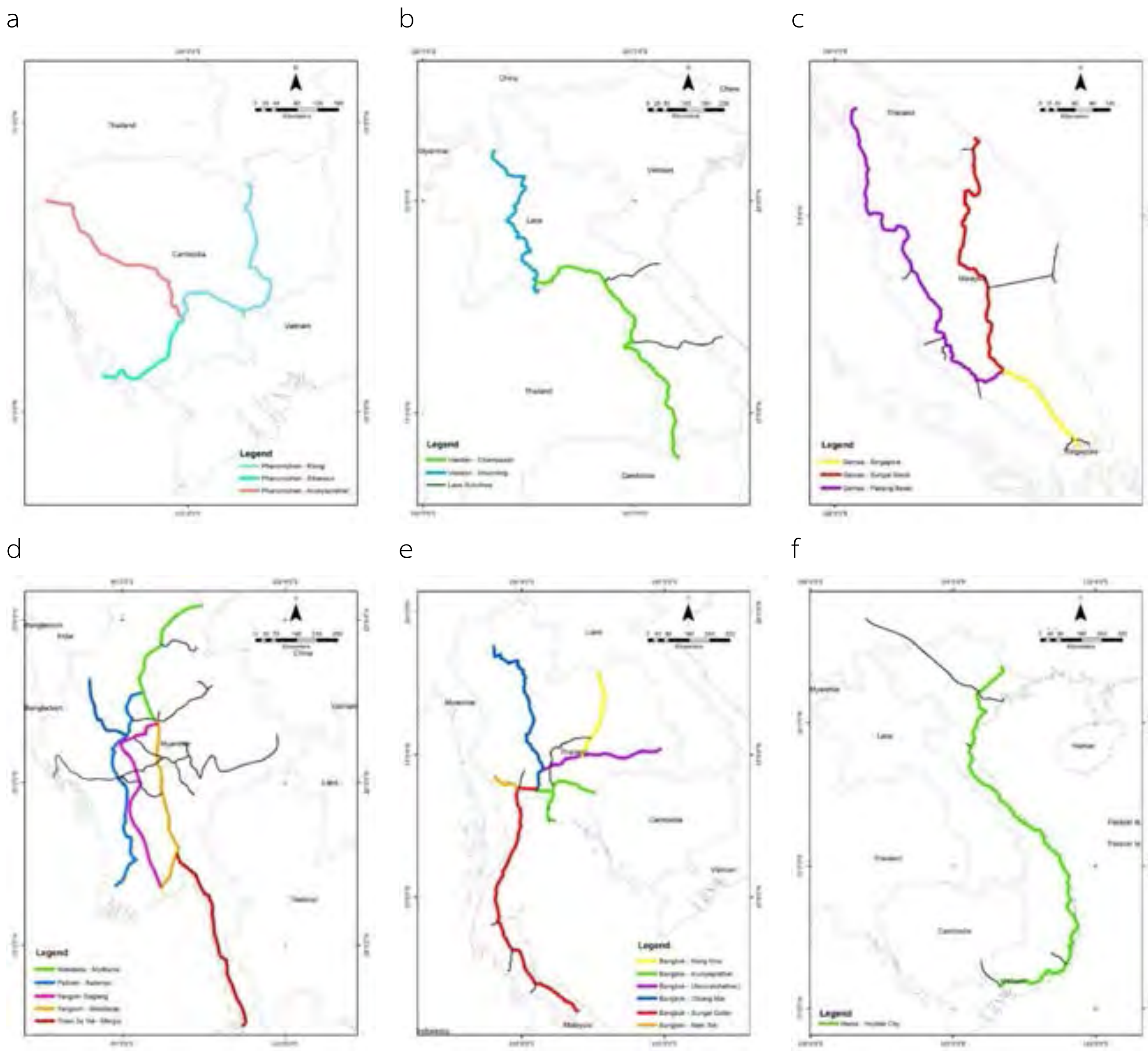

Figure 3.4. Map show the railway lines in (a) Cambodia, (b) Laos, (c) Malaysia, (d) Myanmar, (e) Thailand, and (f) Vietnam.

7) Bangkok. Bangkok has 13 railways which are operated by three operators. First, BTS (Bangkok Mass Transit System Company Ltd.) operates Dark green line and Light green line. Second, BEM (Bangkok Express and Metro Ltd.) operates Blue line, Purple line, Brown line, Orange line, and Yellow line. Lastly, SRT (The State Railways of Thailand) operates Airport rail link and Red line. Apart from these three operators, there remain three lines, i.e. Light blue line, Light red line, and grey line, whose operators are still not specified.

8) Singapore. Singapore has seven lines operated by SMRT Corporation and SBS Transit. There are Circle line (in yellow), Downtown line (in cyan), East West line (in green), North East line (in purple), North South line (in red), North Coast line (in black), and Sentosa Express line (in pink).

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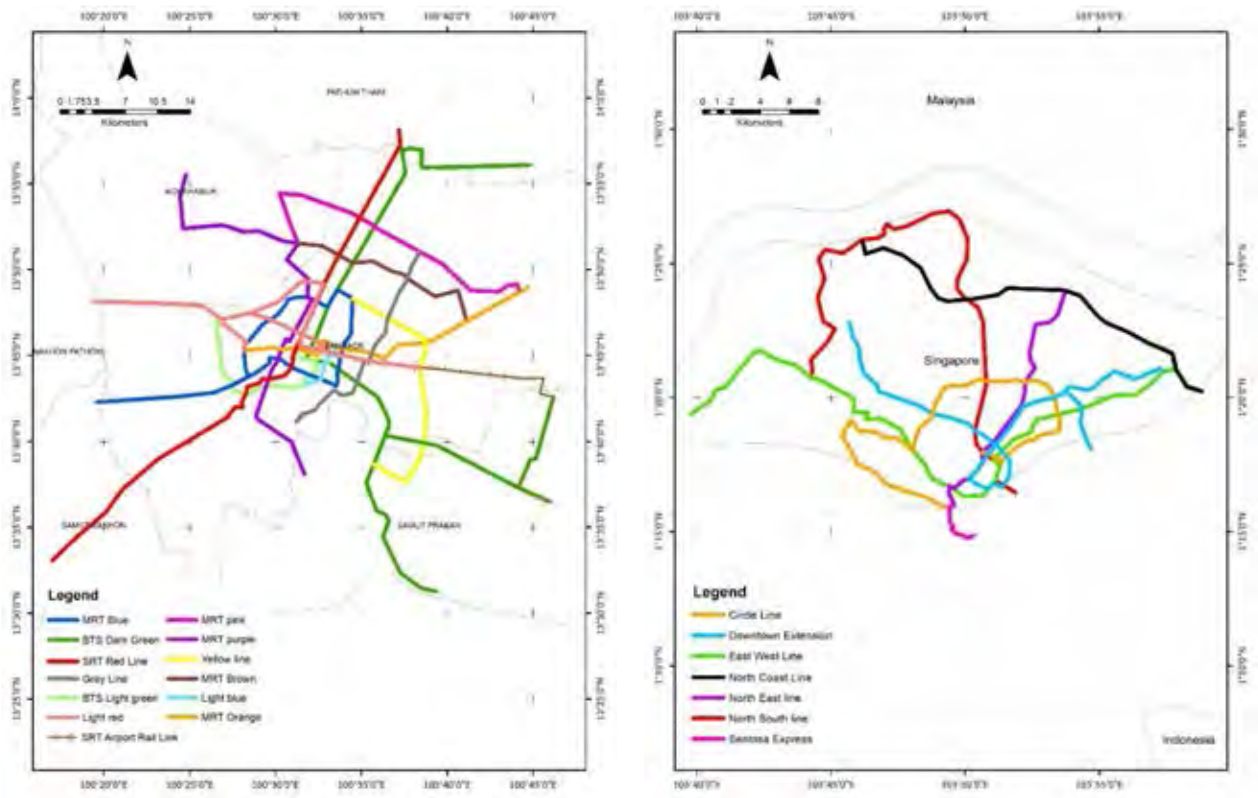

Figure 3.5. Map show all railways in (a) Bangkok and (b) Singapore.

3.2. DSHA Method (Deterministic Seismic Hazard Analysis)

From the estimate, all railway lines in the Mainland Southeast Asia by DSHA (Deterministic Seismic Hazard Analysis) gave results of the seismic hazard map for engineers (PGA map) one map for all railways in the region and eight maps for each country and city in the region. The map displays the data that the PGA (Peak ground Acceleration) varies from 0.00g – 0.46g (1g = 9.8m/s^2). In the northern and western parts have PGA values higher than the southern part of the area. The maximum PGA in the area is 0.46g (1g = 9.8m/s^2) in the Yangon–Mandalay route in Myanmar, the minimum PGA in the area is 0.01g in Cambodia and the average PGA in the area is 0.19g

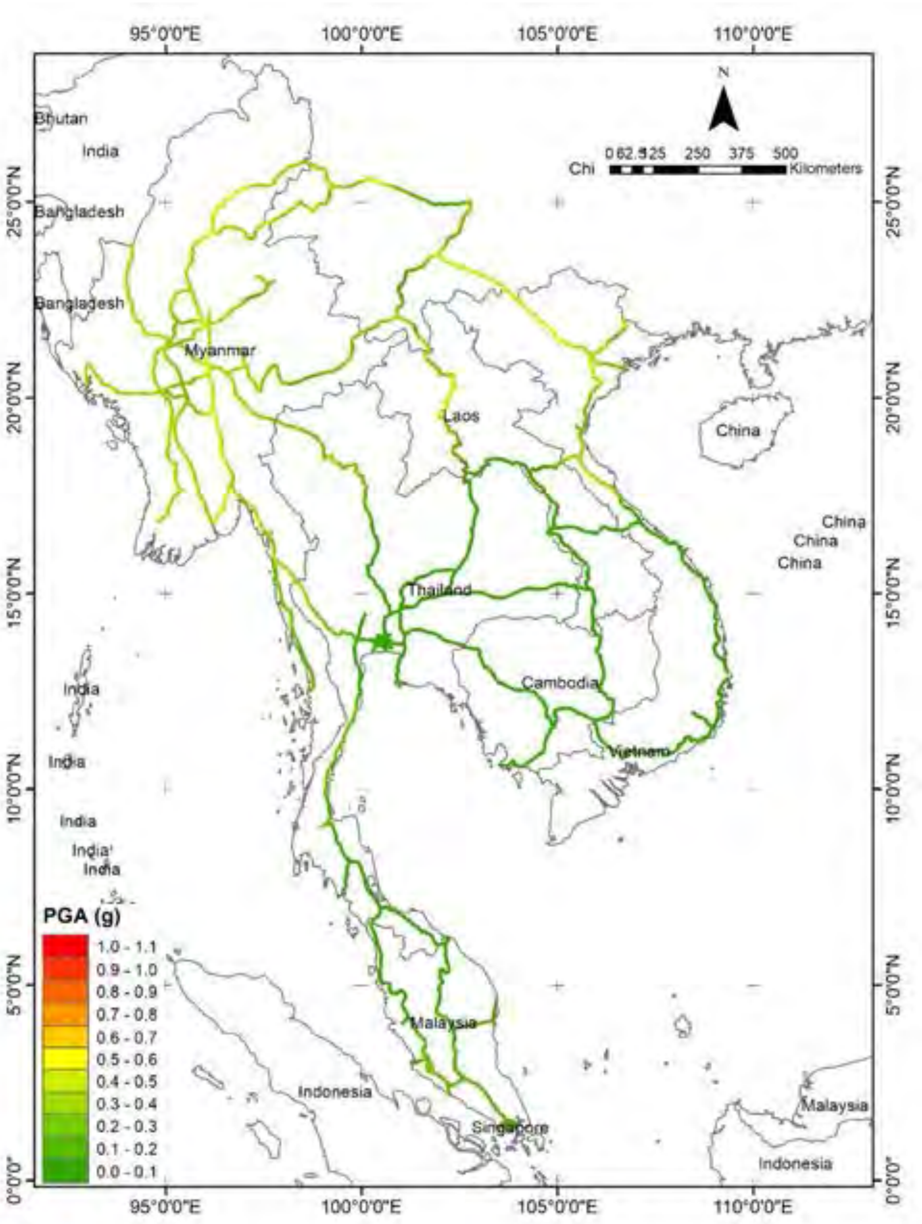

Figure 3.6. Map show PGA map of all railways in the region by DSHA method.

3.3. Hazard Curve in the Important Junction Station

All of stations in the railways have 10 important junction stations. There are Phnom Penh in Cambodia, Vientiane in Laos, Gemas in Malaysia, Mandalay and Yangon in Myanmar, Woodland in Singapore, Bang Sue station, Chiang Mai station, and Padang Besar station in Thailand, and Hanoi in Vietnam. These stations are junction for connecting all of railways in the region and outside of region. Most of them are ports and capital cities which are populated and more civilized areas of the region. Hence, the hazard curve of these stations should be estimated.

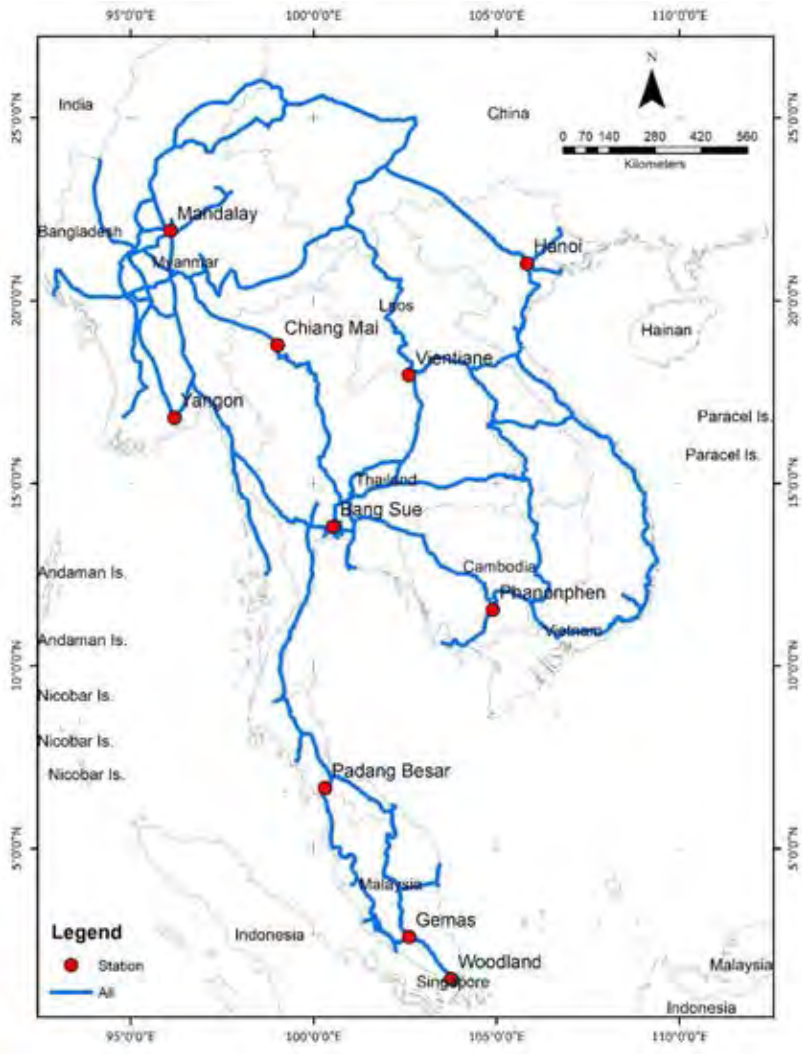

Figure 3.7. Map show site of important junction stations in the region.

The hazard curves show that Mandalay station is the most risky area for seismic hazard, follow by Yangon station and Chiang Mai station. The Hanoi station, Vientiane station, Padang Besar station, Bang Sue station, and Phnom Penh station do not have risk from seismic hazard by Eurocode-8 standard (PGA less than 0.4g or 3.9 m/s^2). The Mandalay station and Yangon station have 5 in 10,000 that risks from seismic hazard (PGA over 0.4g or 3.9 m/s^2). Chiang Mai station have 5 in 100,000 that risk from seismic hazard (PGA over 0.4g or 3.9 m/s^2). By the chance of 1 in 1,000,000, Yangon station may have PGA up to 2g (19.6 m/s^2), but Mandalay station may have PGA value of less than Yangon that 1.6g (15.7 m/s^2). So in the less chance, Yangon station has higher risk than Mandalay station.

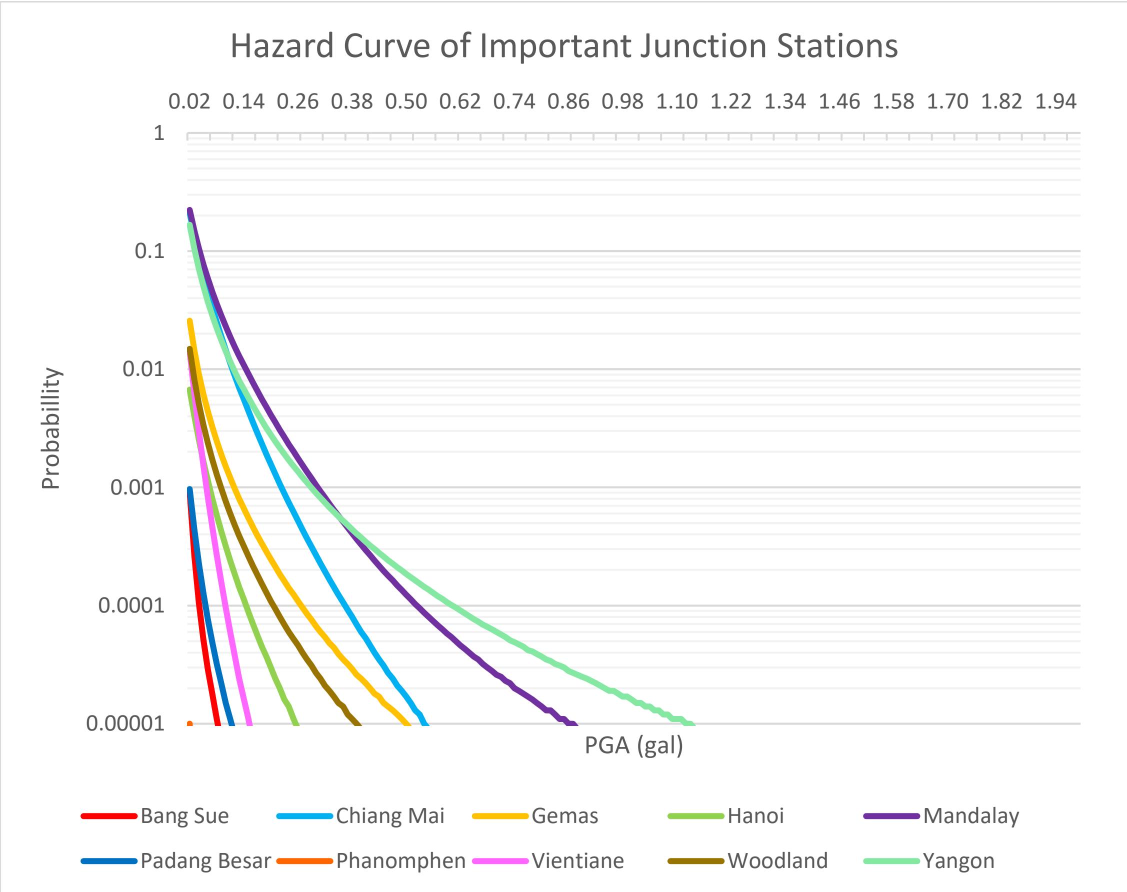

Figure 3.8. Hazard Curve of Important Junction Stations.

3.4. PSHA Method (Probability Seismic Hazard Analysis)

The PSHA Method (Probability Seismic Hazard Analysis) use probabilistic to estimate the PGA (peak ground acceleration). The results from PSHA method is probability of PGA in each point (%) in specific year. I use two standards for the assessment of the possibility of the impact of seismic hazard. The first standard is the building code. There may be communities, buildings, and others along the railways. I use 2% in 50 year and 10% in 50 year from the building code to estimate the area along the railways. The second standard is JSCE (Japan Society of Civil Engineer) standard from Japan. The JSCE standard have a standard for the estimation of the seismic hazard analysis for railways. It use 5% in 50 year and 5% in 100 year to assess the railways

3.4.1 The Building Code

The transportation always brings in civilization into areas along the route. There are new communities, cities, buildings, and so on. The Building Code is the standard that useful to estimate the building in that communities along the railways.

I estimated the PGA along the railways by use 2% in 50 year and 10% in 50 year. Then, I made 2 PGA maps (2% in 50 year map and 10% in 50 year map) from all of the railways and 4 PGA maps from the cities (2% in 50 year map and 10% in 50 year map from Bangkok and Singapore)

1) PGA map 2% in 50 Year and 10 % in 50 Year of all of the railways in the Mainland Southeast Asia. The map 2% in 50 year shows PGA values along the railways in the Mainland Southeast Asia. The maximum value is 0.9g in the Myanmar in Pathien–Kalemyo line. The minimum value is 0 in Cambodia, South Laos, and South Vietnam. The average value is 0.23g. In the Myanmar, western and northern of Thailand, and northern of Laos have high PGA values (yellow to red) that high risk from seismic hazard. I recommended that might use support structure for building along the yellow to red area. However, this project base on basement rock and not include the amplified form sediment in each area. The map 10% in 50 year show PGA values along the railways in the region. The average value is 0.14g. The maximum value is 0.54g in Pathien–Kalemyo line, Myanmar. The minimum value is 0 in Cambodia, Laos, and South Vietnam. There are high PGA in the north and the west of the region (Myanmar and a part of Thailand) which high risk from seismic hazard. However, this project base on basement rock not include the amplified form sediment in each area.

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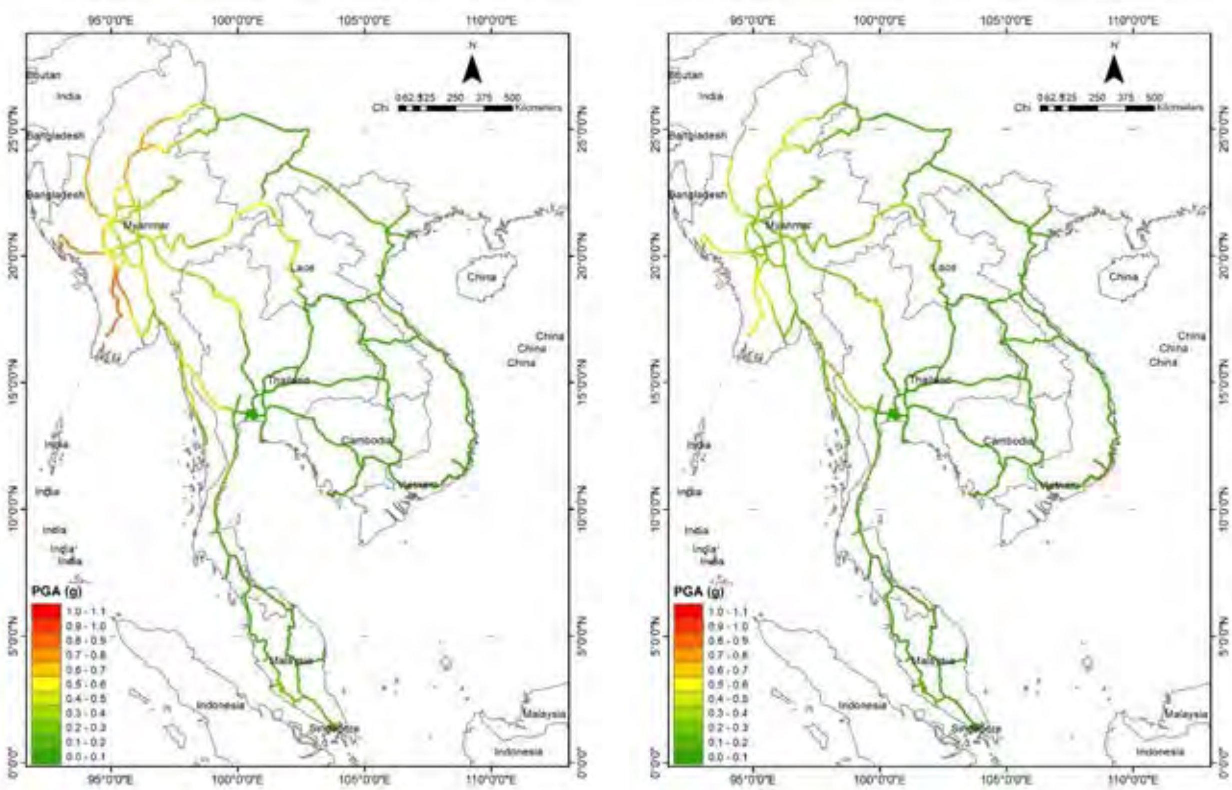

Figure 3.9. Map show PGA (a) 2% in 50 year and (b) 10% in 50 year along the railways in the Mainland Southeast Asia.

2) PGA map 2% in 50 Year and 10% in 50 year of all of the railways in the Bangkok. PGA map 2% in 50 year of all railways in Bangkok shows that maximum PGA is 0.043g, minimum PGA is 0.024g, and average PGA in the area is 0.031g. The west of Bangkok has PGA values higher than the east side, but the PGA values are not much different. However, the PGA values in Bangkok is too low for seismic hazard but Bangkok clay may be amplified the seismic wave and becomes the hazard.

PGA map 10% in 50 year of all railways in Bangkok shows that the average PGA in the Bangkok is 0.019g. The maximum is 0.028g and the minimum is 0.014g. The west of Bangkok has PGA values higher than the east at the same 2% in 50 year. The PGA values of all railways in Bangkok are nearby and too low for hazard. Nonetheless, this project is based on basement rock and does not include amplified seismic wave by sediment in the area.

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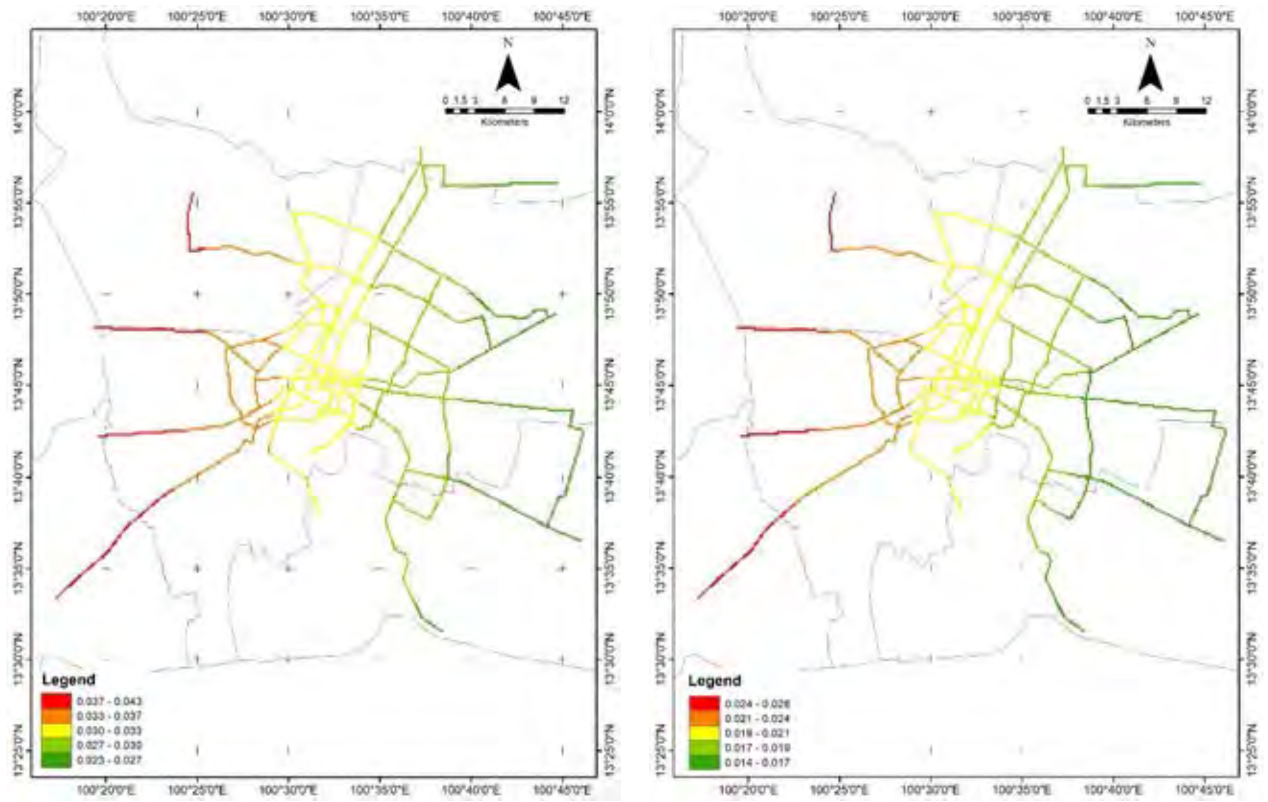

Figure 3.10. Map show PGA (a) 2% in 50 year and (b) 10% in 50 year along the railways in the Bangkok.

3) PGA map 2% in 50 Year and 10% in 50 year of all of the railways in the Singapore. PGA map 2% in 50 year of all railways in Singapore suggests that the average PGA of all railways in Singapore is 0.125g. The maximum PGA is 0.151g and the minimum PGA is 0.105g. The eastern Singapore has lower PGA values than the western part. The difference of maximum point and minimum point is 0.02g, so PGA values in Singapore is not very much. The PGA values are too low for seismic hazard but this project did not cover the amplified seismic wave by sediment. PGA map 10% in 50 year of all railways in Singapore shows that the maximum PGA of all railways in Singapore is 0.078g, and minimum PGA is 0.054g. The average PGA is 0.064g. The maximum value is not different from minimum value, and the PGA values are too low for seismic hazard. Note that this project does not include the amplified of seismic wave from sediment.

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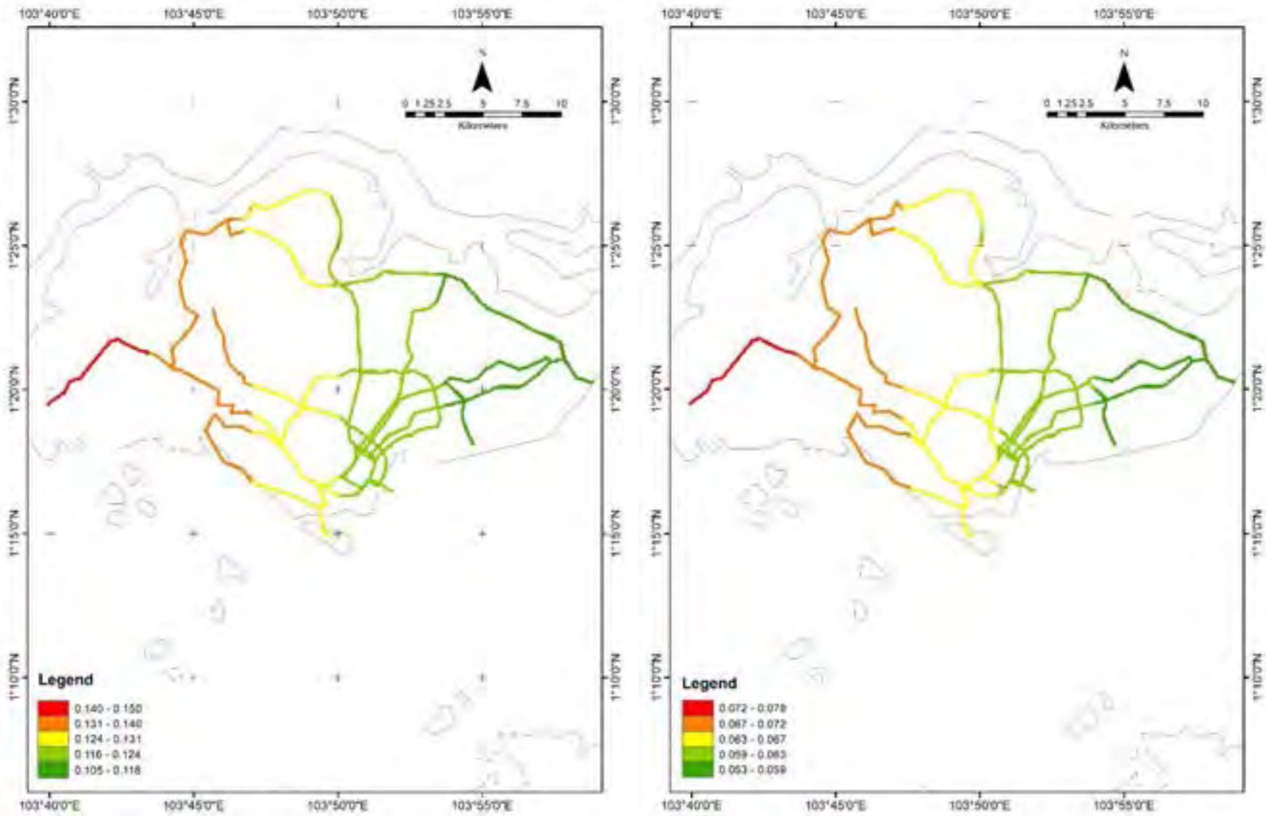


Figure 3.11. Map show PGA (a) 2% in 50 year and (b) 10% in 50 year along the railways in the Singapore.

3.4.2. JSCE standard (Japan Society of Civil Engineer)

Japan has continued to face several disasters during the past decades. The Japanese seismologist have researched and developed the earthquake resistance structure or warning system. They have also created the standard for design the earthquake resistance structure. There are standards for railways under JSCE standard for earthquake resistance. The criteria in estimation which is relevant to human lives is 5% in 50 year and 100 year. Moreover, Japan is the advisor in construction of the railways and high speed train lines in the Mainland Southeast Asia.

The results are PGA map for researchers and engineers. There are PGA 5% in 50 year map and PGA 5% in 100 year map of all railway lines in the region, each country's railway lines, Bangkok's railways lines, and Singapore's railways lines, totaling 18 maps.

1) PGA map 5% in 50 Year of all of the railways in the Mainland Southeast Asia. This method estimated the maximum ground acceleration from seismic wave in 50 year. If the construction over 50 year, this method is not recommended as reference.

This is the PGA map 5% in 50 year explaining that the average PGA is 0.17g. The maximum PGA is 0.68g and the minimum PGA is 0g (not affect by seismic vibration). The northern of Laos, the northern and western of Thailand, and Myanmar have high PGA values (PGA greater than 0.4g or 3.92 m/s^2). The PGA values of the western and southern areas are low at less than 0.4g 0r 3.92 m/s^2. Therefore, the railways of area in northern and western parts must be planned for defense seismic hazard in the future. Next, I will explain the PGA 5% in 50 year map by each country and each city.

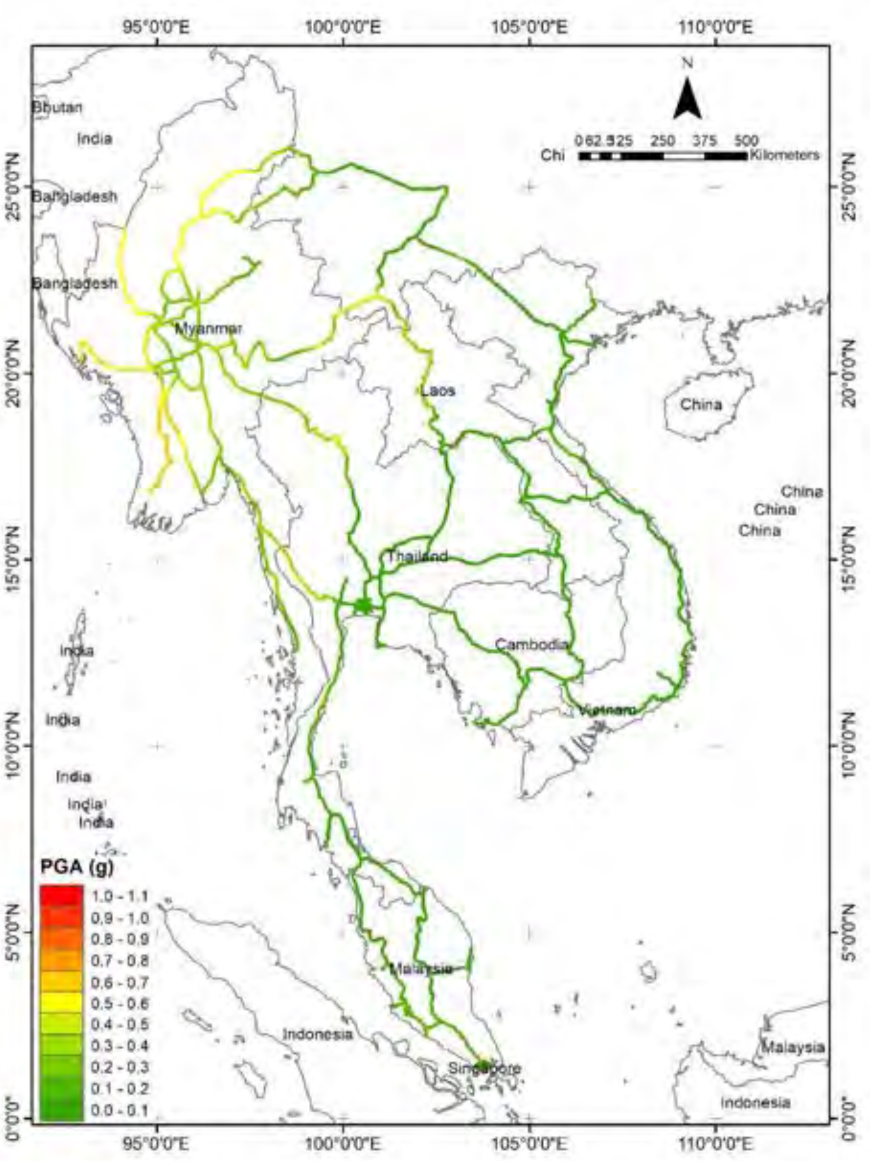


Figure 3.12. Map show PGA 5% in 50 year along the railways in the Mainland Southeast Asia.

2) PGA map 5% in 50 Year of all of the railways in each country. The PGA values in Cambodia are very low. The maximum PGA is 0.007g, the minimum PGA is 0g. The average PGA is 0.002g. PGA value in most of the areas in Cambodia are 0g or near 0g. Thus, Cambodia does not have risk for seismic hazard. In Laos, there are two mainlines. The south line (Vientiane–Champasak) has low PGA than the north line (Vientiane–Kunming). Along the railways, the maximum PGA is 0.39g, and the minimum PGA is 0g. The average of all railways in Laos is 0.12g. PGA values in Laos have difference from maximum and minimum but the maximum values is low from seismic hazard. However, it may be amplified seismic wave from sediment in the area. The construction the north line of Laos should be researched the amplified seismic wave along this line. Malaysia have three mainlines. The PGA values in each line are different. In the south of Malaysia PGA values are higher than the north. The maximum PGA is 0.19g in Padang Besar–Gemas line, and the minimum PGA is 0.015g in Sungai Kolok–Gemas line. The average PGA is 0.09g. PGA values in these lines are too low for seismic hazard but may be the amplified seismic wave from sediment along the railways. Myanmar have many rail lines, and have high PGA values. The maximum value is 0.68g in Pathien–Kalemyo line. This value is considered high risk for seismic hazard. The minimum values is 0.1g in Thein Za Yat–Mergui line. The average PGA in Myanmar is 0.4g. Therefore, Myanmar may have high risk for seismic hazard (PGA greater than 0.4g or 3.92 m/s^2). I recommended that in constructing the railways the earthquake resistance structure should be used or earthquake warning system almost line in the Myanmar should be set up.

Thailand is the important country because it is the center of the Southeast Asia and pathway of logistics in the region. The western and northern parts of the Thailand is the area, where there are high PGA value. The maximum PGA value in the railways along Thailand is 0.49g. The estimated result shows that it has risk for seismic hazard. The minimum PGA value is 0g in Bangkok–Ubon Ratchathani line. The average PGA value is 0.078g. The average value shows that most of PGA values in Thailand is low. Thus, the construction of railways along Thailand should also consider about the amplified seismic wave in the area. Vietnam is the country in the east coast of the Mainland Southeast Asia. There is only one mainline (Hanoi–Ho Chi Minh City). The PGA values in Vietnam are not very much. The maximum PGA value is 0.22g in the northern part of the line, and the minimum PGA value is 0g. The average PGA value is 0.04g. Almost all PGA values in Vietnam are lower than 0.1g, indicating low risk for seismic hazard. However, the amplified of seismic wave should be studied.

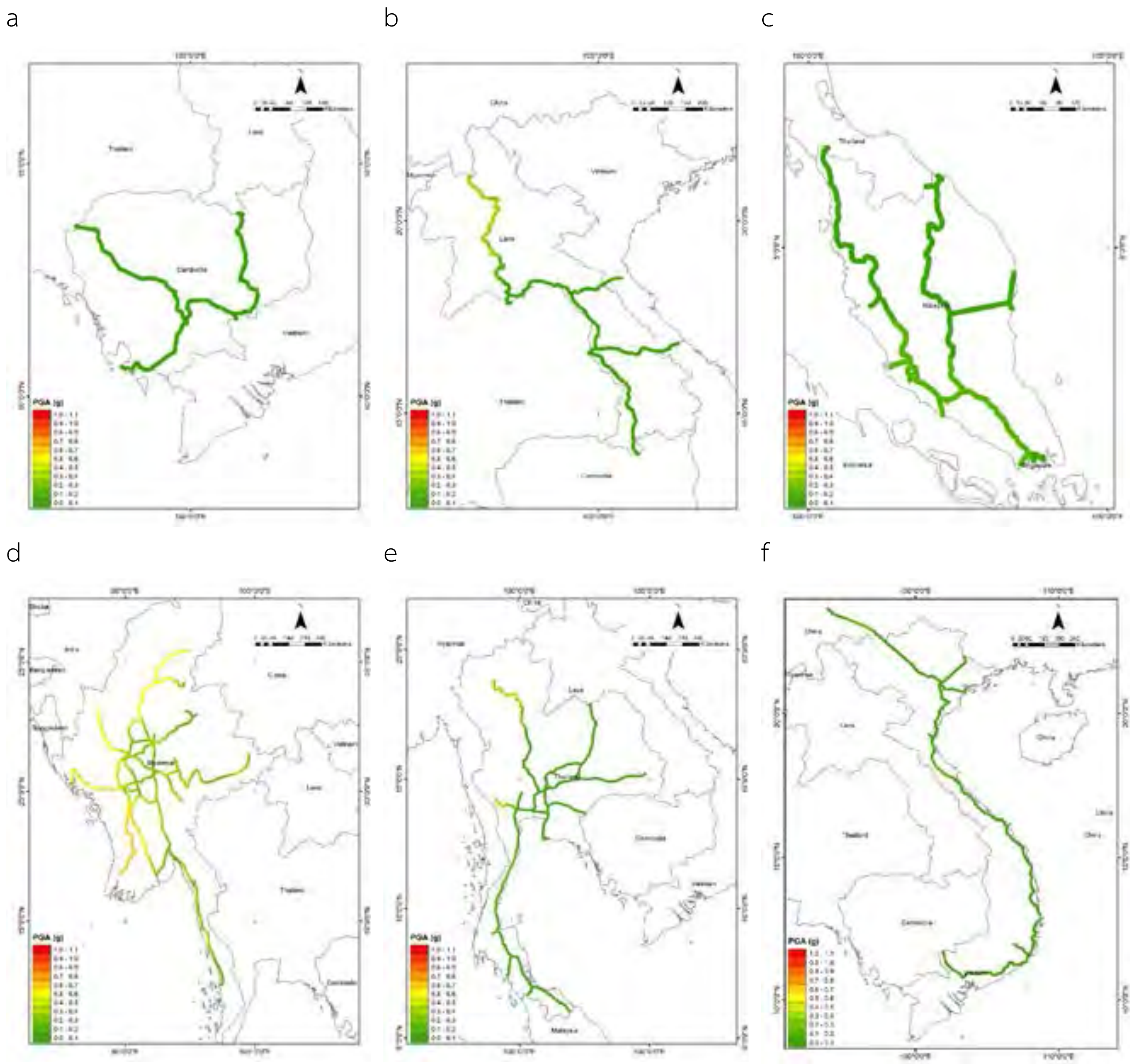


Figure 3.13. Map show PGA 5% in 50 year (a) Cambodia, (b) Laos, (c) Malaysia, (d) Myanmar, (e) Thailand, and (f) Vietnam.

3) PGA map 5% in 50 Year of all of the railways in Bangkok and Singapore. Bangkok is the large city in the Mainland Southeast Asia. It is destination of the railways from north, and the entrance of the south of the region. It is important to estimate the PGV values of this city. The maximum and minimum PGA values are 0.03g and 0.01g, respectively. The average PGA is 0.02g. The PGA values in Bangkok are not vary so much, and they are too low for seismic hazard. However, Bangkok has several more projects for sky trains and metros. In construction of the rail lines should be concerned about the amplified of seismic wave by sediment for defense the collapse the rail lines or tunnel.

Singapore is the small country with one large city. This city is the destination of all railways in the Mainland Southeast Asia. There are pier for transport cargo from the Southeast Asia and Far East Asia (China, Korea, and Japan) to the western countries i.e. Europe and America. The maximum and minimum PGA values are 0.1g and 0.07g, respectively. The average PGA value is 0.87g. PGA values in the western part is not different to the eastern part much. Singapore has seven metro lines. They are more risky for seismic hazard than on ground rail lines. The construction and repair of the railways should be concerned about seismic hazard.

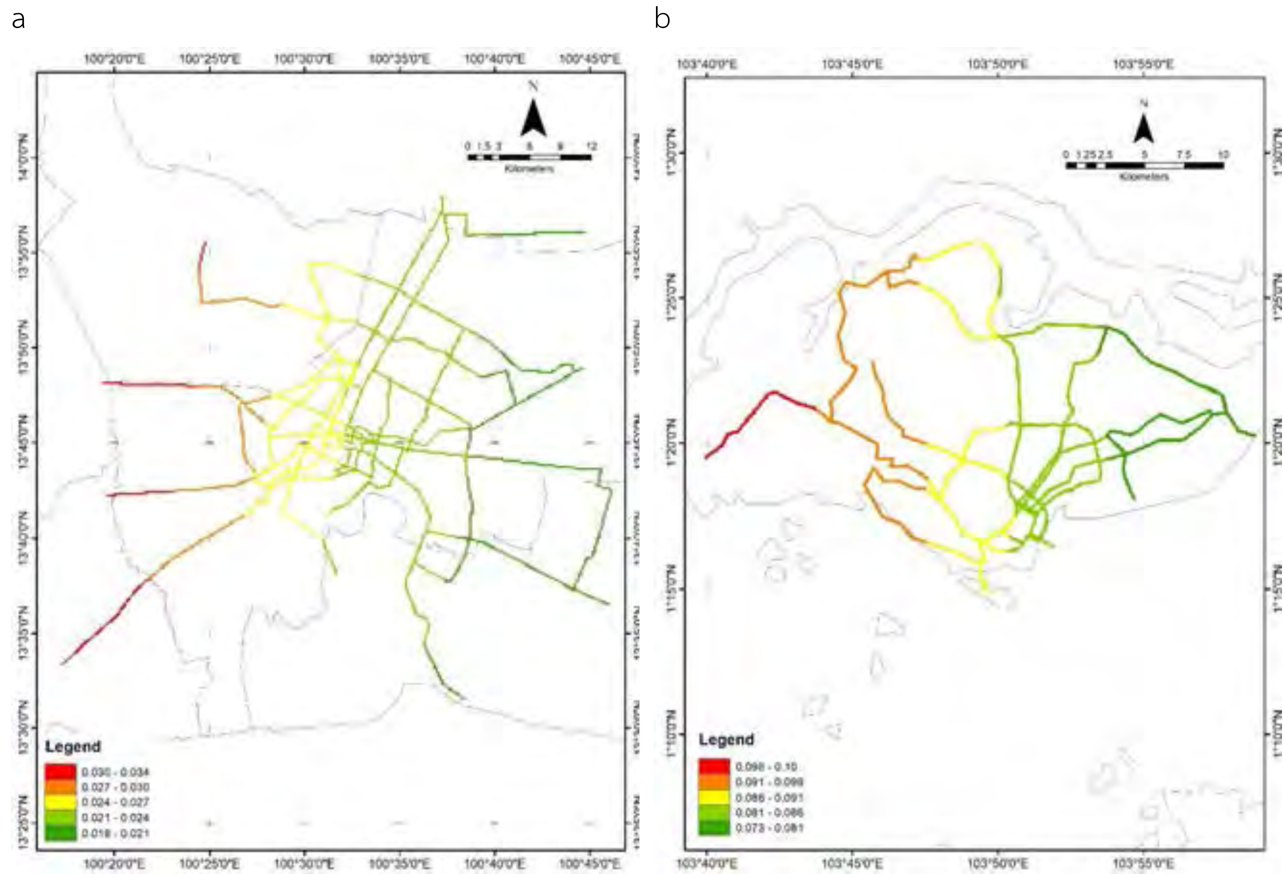


Figure 3.14. Map show PGA 5% in 50 year along the railways in (a) Bangkok and (b) Singapore.

4) PGA map 5% in 100 Year of all of the railways in the Mainland Southeast Asia. This method estimated the maximum ground acceleration from seismic wave in 100 year. If the construction over 100 year, this method are not recommended for reference. If construction of less than 50 year, I recommended to use the PGA 5% in 50 year map, which would save the construction cost. This PGA map 5% in 50 year of all of the railways in the Mainland Southeast Asia explains that the maximum PGA value is 0.85g, and the minimum value is 0g. The average value is 0.2g. Most of the area have low PGA values, but in the western and northern of the area have high PGA values (greater than 0.4g or 3.92 m/s^2). Next, I will show the data of each country and each city.

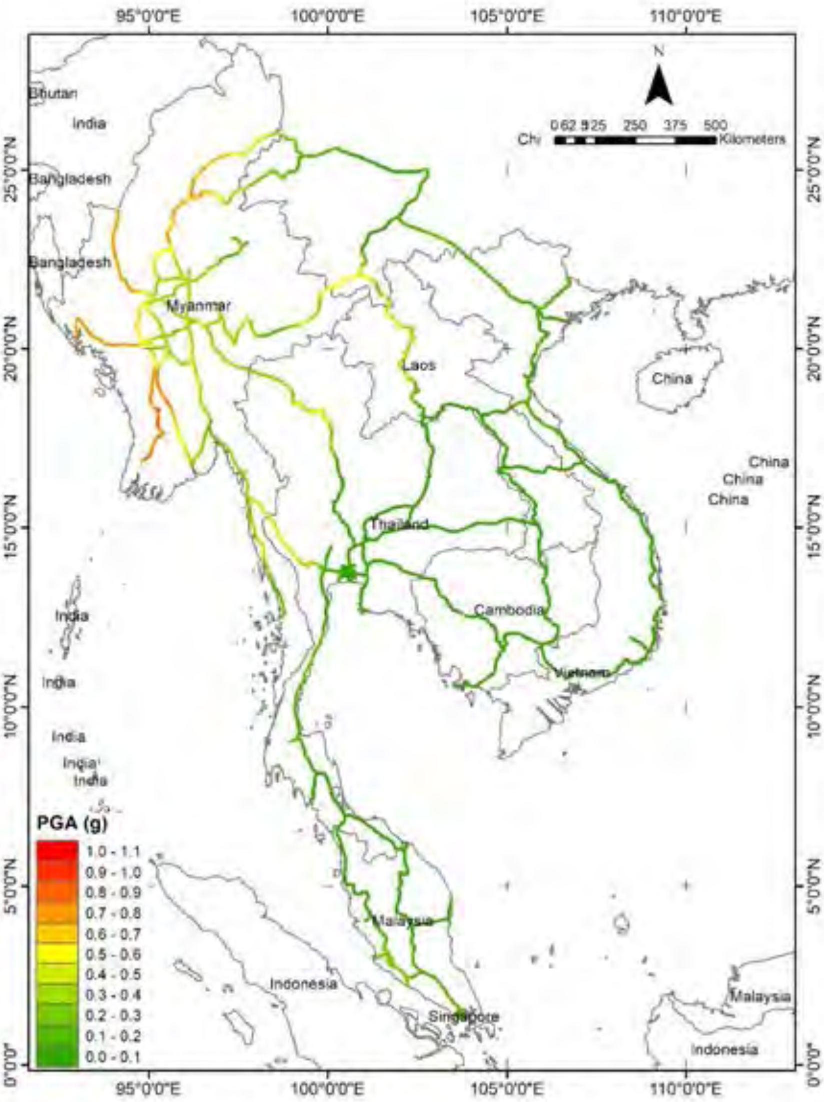


Figure 3.15. Map of the Mainland Southeast Asia show PGA 5% in 100 year along the railways.

5) PGA map 5% in 50 Year of all of the railways in each country. From the Cambodia's PGA map, Cambodia does not have a point where the PGA values over 0.1g. The maximum value is only 0.01g, and minimum value is 0g. The average value is 0.004g. The average value shows that Cambodia does not have a risk for seismic hazard in 100 year. Laos has two mainlines, one in the north (Vientiane–Khunming) and two in the south (Vientiane–Champasak). From the PGA 5% in 100 year, the north line have a risk that damage by seismic hazard. The maximum PGA value is 0.46g in the Vientiane–Kunming line. The minimum value is 0 in the Vientiane–Champasak line. The average value is 0.15g which explains that most of PGA values in rail lines are low. Thus, the north line should be prepared for seismic hazard. This project does not cover the amplified of seismic wave by sediment. From the PGA 5% in 100 year map of Malaysia, the PGA values are not high (less than 0.4g 0r 3.92 m/s^2). The maximum PGA value is 0.24g, and the minimum value is 0.02g. The average value is 0.11g. Although PGA values in the Malaysia is under 0.4g, there are the amplified the seismic wave from sediment. The construction should estimate the amplified of seismic wave. Myanmar's PGA map show that almost PGA values along the railways in Myanmar are high values. The maximum PGA value is 0.845g in Pathien–Kalemyo line. The minimum PGA value is 0.12g in Thein Za Yat–Mergui line. The average PGA value is 0.49g. From average PGA along railways in Myanmar, most of them are high (over 0.4g or 3.92 m/s^2). So, the railways in the Myanmar have high risk for damage caused by seismic hazard. The construction of these lines should use earthquake resistance structure or warning system. The PGA map 5% in 100 year in Thailand show that the north and the west regions of Thailand have high PGA values while the other parts have low PGA. The maximum value is 0.53g in Bangkok – Chiang Mai line. The minimum value is 0.006g in the Bangkok–Ubon Ratchathani line. The average value is 0.093g. The average shows that most of PGA values along railways in Thailand are at low risk from seismic hazard. However, the construction of the railways should use support or alarm where the PGA value over 0.4g. This project does not cover the amplified of seismic wave by sediment. In Vietnam, the PGA map explains that all railways in Vietnam have low PGA values. The maximum PGA value is 0.27g, and the minimum value is 0g. The average PGA value is 0.05g, suggesting that almost all rail lines have low PGA values. From this estimate, Vietnam does not have risk from seismic hazard. However, this project does not cover the amplified the seismic wave. The construction should estimate the seismic wave amplification especially the points which have high PGA value.

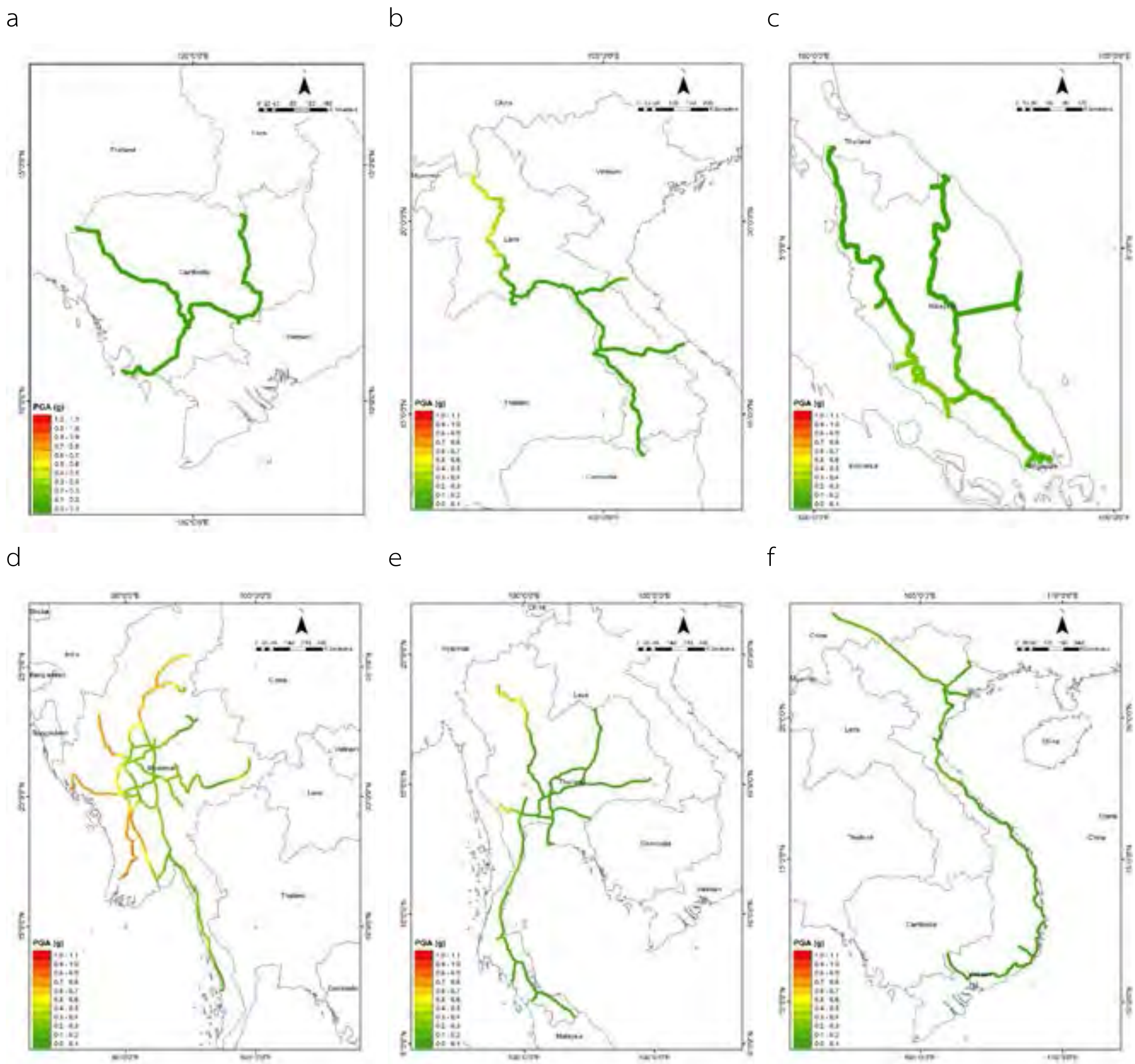


Figure 3.16 Map show PGA 5% in 100 year in (a) Cambodia, (b) Laos, (c) Malaysia, (d) Myanmar, (e) Thailand, and (f) Vietnam.

6) PGA map 5% in 100 Year of all of the railways in Bangkok and Singapore. Bangkok is the center of the Mainland Southeast Asia. It is the destination of northern railways and gate of southern railways. So, Bangkok is the important city for rail system of Southeast Asia. The PGA map 5% in 100 year explain that the PGA values is doesn't difference too much. The maximum is 0.04g. This maximum value is too low for seismic hazard. The minimum PGA is 0.02g. The average PGA is 0.03g. The average show that PGA values in the Bangkok is low, and doesn't have risk for seismic hazard. However, the railways in Bangkok are sky trains and metros. So, the construction should be estimated the seismic wave amplification for defense the collapse of railways and the metro's tunnel. Singapore is the destination of all railways in the East Asia and Southeast Asia. There are 7 metro lines. So, Singapore is important city for transport the cargo from the north to the other side of the world. The PGA map show that the west have PGA values higher than the east. The maximum PGA is 0.14g, and the minimum is 0.10g. The average is 0.11g. The average explain that PGA all of rail lines in Singapore are not difference so much. The overall PGA is too low for seismic hazard, but the rail construction and repair should be concern about the seismic wave amplification.

a b

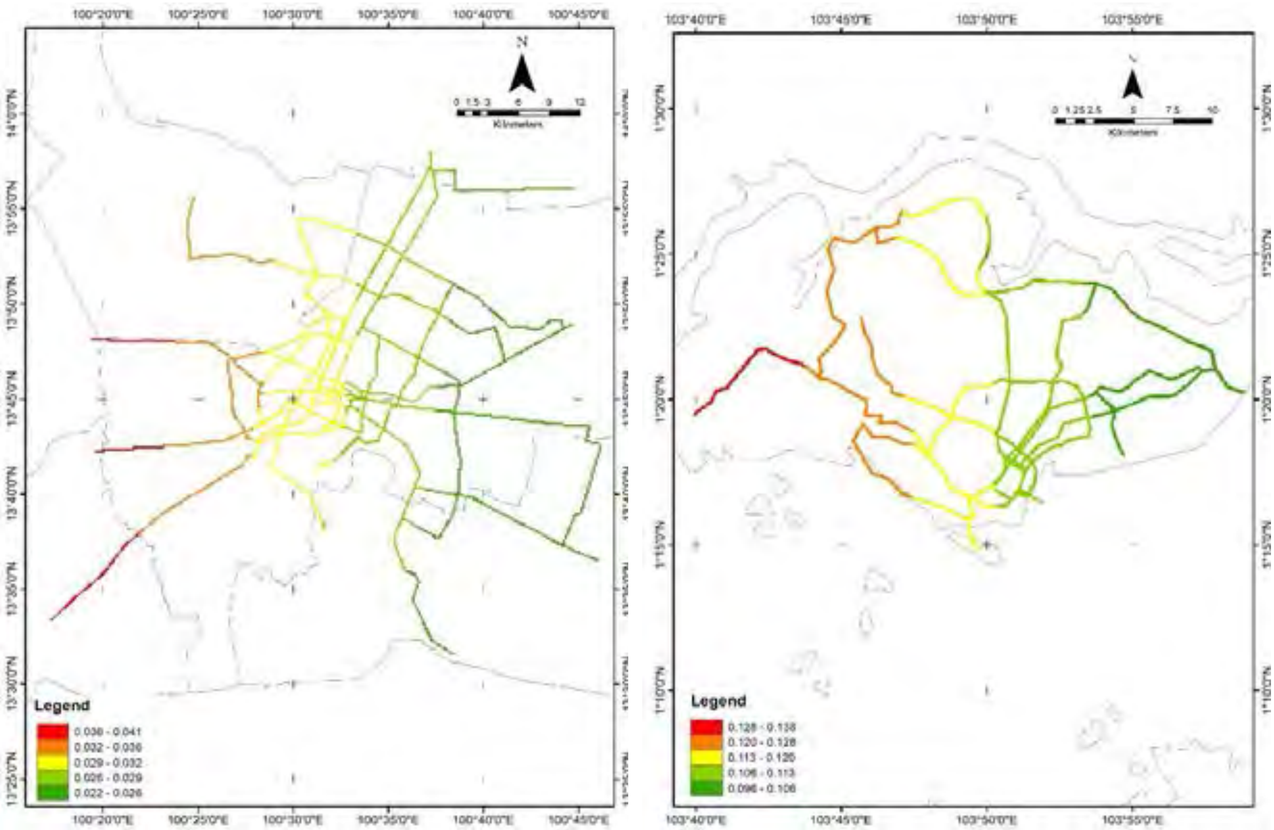


Figure 3.17. Map show PGA 5% in 100 year along the railways in (a) Bangkok and (b) Singapore.

Chapter 4

DISCUSSION AND CONCLUSION

There are 3 points of discussion in this project, i.e. (1) fault zone effect in the railways along the Mainland Southeast Asia, (2) the estimation in the each mainline in details by PGA 5% in 50 year and PGA 5% in 100 year, and (3) the investigation and finding of the warning area by Eurocode 1998-8 standard in double rail lines and high-speed train rail lines.

4.1 The Fault zone that affects the rail lines in the Mainland Southeast Asia

In all of the fault zones that affect the railways in the Mainland Southeast Asia, each fault zone has effects on the rail lines depending on the fault zone's characteristic. I estimate the fault zone by use DSHA map and PSHA 5% in 50 year for invest the fault zone that affects the rail lines and makes the high PGA values.

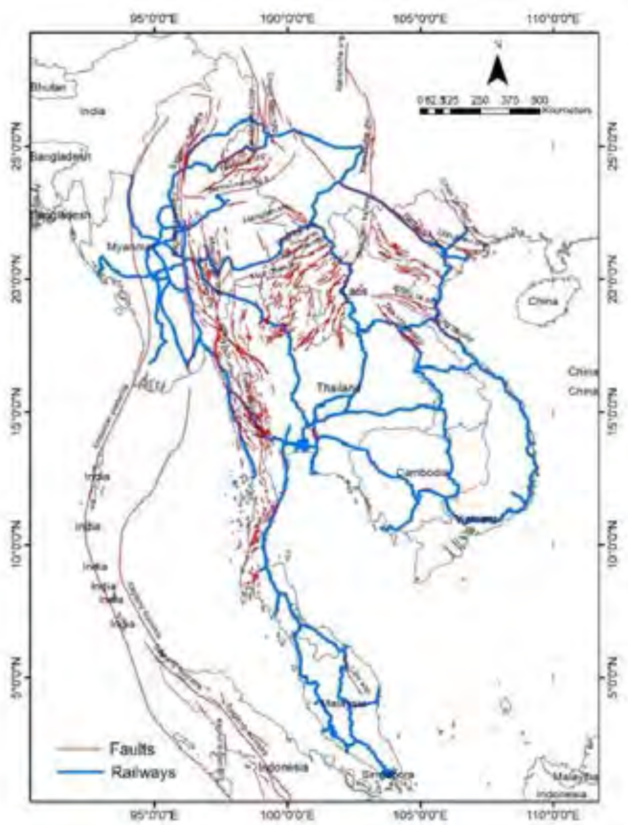


Figure 4.1. Map show fault zone that affects the railways along Mainland Southeast Asia.

4.1.1 DSHA map and fault zones that affect the railways

The map shows that most of fault zones in the Mainland Southeast Asia are in the western and northern parts of the region. In the Myanmar, the high PGA values come from the large active faults which cross the area, e.g. Andaman fault zone, Sagiang fault zone, and Moei fault zone. These faults in the western part of Myanmar cover large area and have high slip rate (see table 3.1), for example Sagiang fault has slip rate of 27 mm p.a. That is the main cause of high PGA in this area. In the northern part, there are many fault zones, e.g. Mae Chan fault zone, Nam Ma fault zone, and Whan Ha fault zone. The slip rate (see table 3.1) of these fault zones in the north are less than those in the west but they can make high PGA in the northern area.

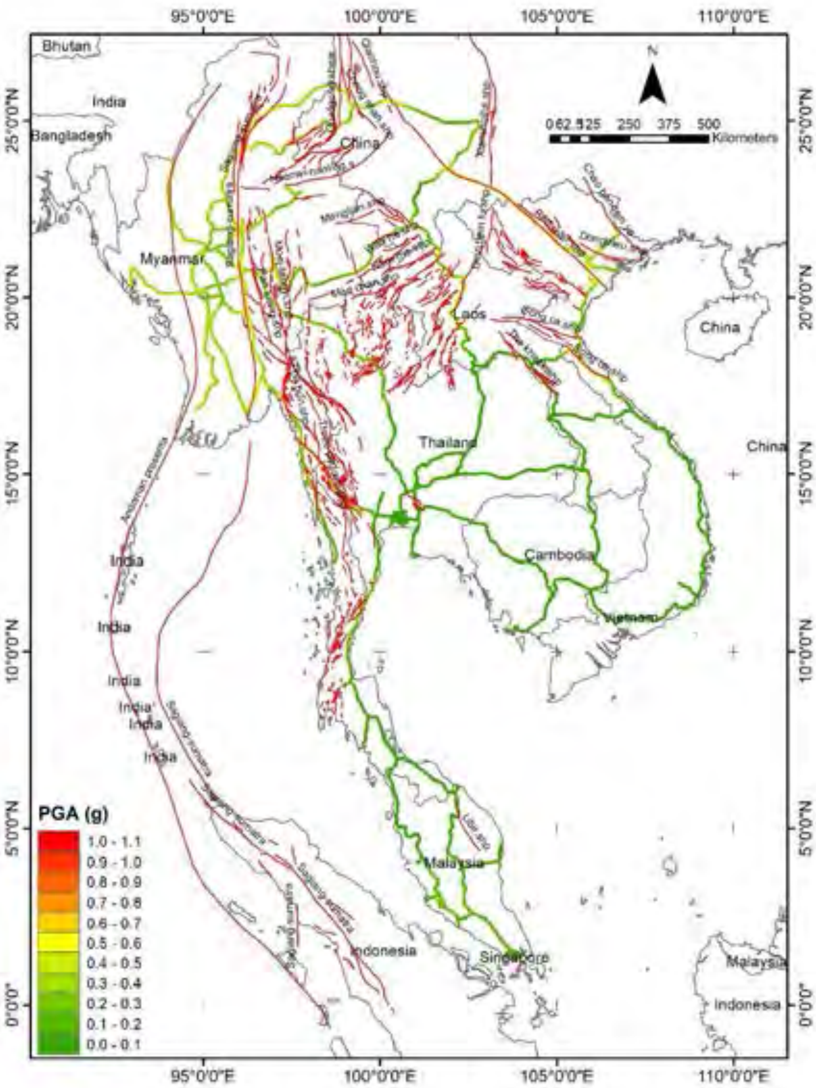


Figure 4.2. Map of Mainland Southeast Asia show DSHA map and fault zone that affect the railways.

4.1.2. PSHA map 5% in 50 year and fault zones that affect the railways

With the same reason as the DSHA map, the western and northern areas of the region have high PGA values than other parts. The fault zones in the western part (Andaman fault zone, Sagiang fault zone, and etc.) have the high slip rate and cover the large area (see table 3.2.1). From the literature review, Andaman fault zone can generate the maximum magnitude of up to 9.2 magnitude. The fault in the northern part of the region (Mae Chan fault zone, Nam Ma fault zone, and etc.) make high PGA values in the railways but the PGA values in the northern part are less than those in the west. These reasons explain why PGA values in northern and western parts of the region have high values.

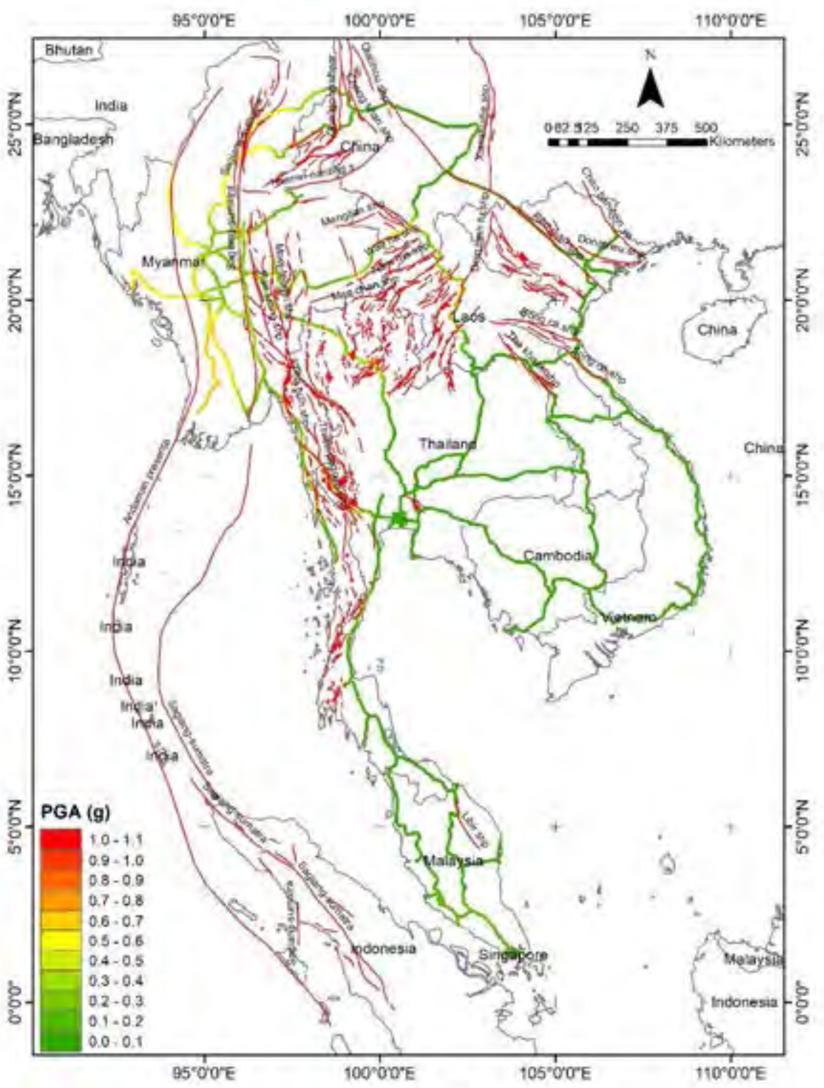


Figure 4.3. Map of Mainland Southeast Asia show PSHA map 5% in 50 year and fault zone that affect the railways.

4.2 Estimating each mainline in details by PSHA 5% in 50 year and 5% in 100 year

There are many main rail lines in the Mainland Southeast Asia. Cambodia has three mainlines, Laos has two, Malaysia has three, Myanmar has five, Thailand has six, and Vietnam has only one mainline. The estimated each mainline uses the JSCE standard for rail structure (PSHA 5% in 50 year and PSHA 5% in 100 year).

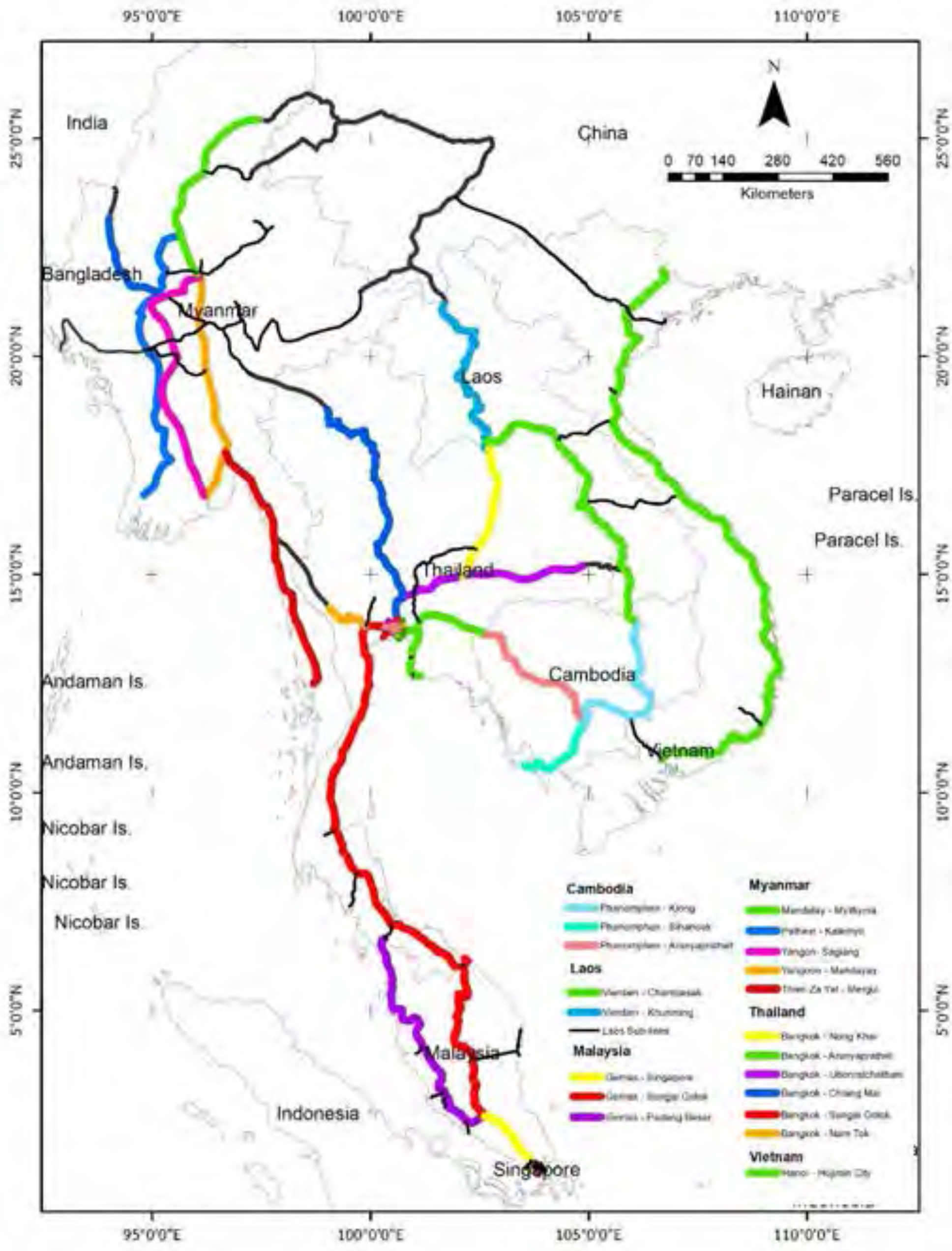


Figure 4.4. Map of the Mainland Southeast Asia show main rail line in each country.

4.2.1. PSHA 5% in 50 year along rail lines in detail

1) Cambodia. There are 3 mainlines in Cambodia (1) Phnom Penh–Klong line (cyan). (2) Phnom Penh–Arunyaprathet line (pink). (3) Phnom Penh–Sihanouk line (green).

Figure 4.5. Map show PGA 5% in 50 year stations along the mainline in Cambodia.

In case of Phnom Penh–Klong line, the PGA values of this line is 0g. It does not have a risk from seismic hazard. In case of Phnom Penh–Arunyaprathet line, the PGA values in this line vary from 0 to 0.007g. The maximum is 0.007g, the minimum is 0g, and the average is 0.002g. The PGA values are too low for seismic hazard. In case of Phnom Penh–Sihanouk line, the PGA value of this line is 0g. It does not have a risk from seismic hazard.

Figure 4.6. The charts show PGA values 5% POE 50 year along each line in Cambodia.

2) Laos. There are 2 mainlines in Laos. (1) Vientiane – Khunming line (blue). (2) Vientiane – Champasak line (green).

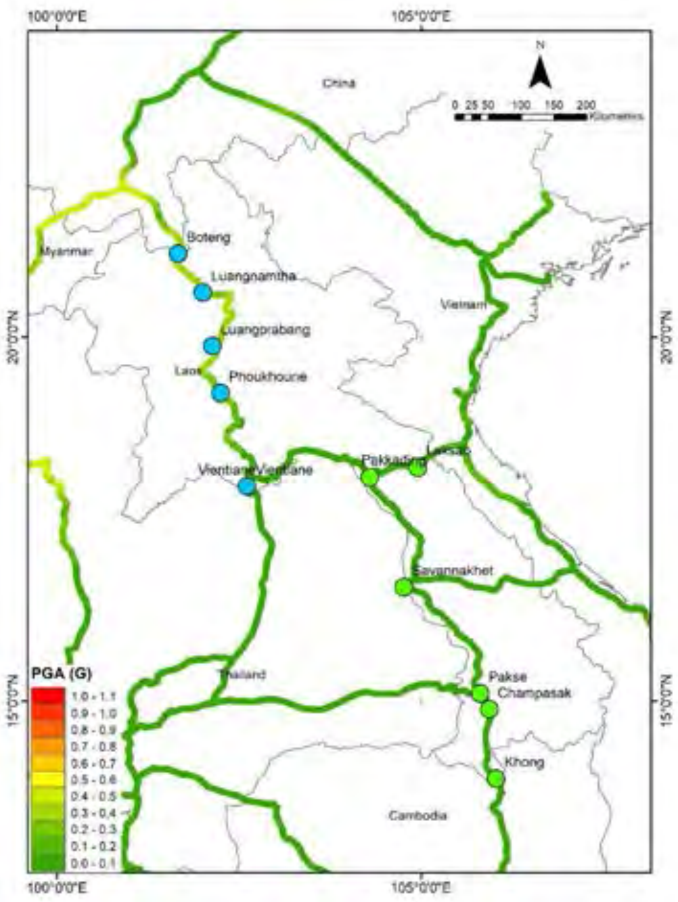


Figure 4.7. Map show PGA 5% in 50 year stations along the mainline in Laos.

In case of Vientiane–Khunming line, this line has the maximum value of 0.39 near Boteng station, and minimum of 0.04 near Vientiane station. The average value is 0.24g. The chart shows that most of the lines have PGA values greater than 0.2g. In case of Vientiane–Champasak line, the maximum PGA value is 0.04g, and minimum is 0g. The average is 0.007g. The PGA of this line declines from 0.04 at Vientiane station to 0 at Savannakhet station. However, the PGA value of this line is too low for seismic hazard.

Figure 4.8. The charts show PGA values 5% POE 50 year along each line in Laos.

3) Malaysia. There are 3 mainlines in Malaysia. (1) Padang Besar–Gemas line (purple). (2) Sungai Golok–Gemas line (red). (3) Gemas–Singapore line (yellow).

Figure 4.9. Map show PGA 5% in 50 year stations along the mainline in Malaysia.

In case of Padang Besar–Gemas line, this line has maximum PGA value of 0.19g, and minimum PGA is 0.02g. The average is 0.09g. From Arua station to Tapah station, there are low PGA. Then, the PGA value increases sharply to 0.19g and stable. However, you should be cautious on the seismic amplification in the high PGA (Tanjang Malim station–Gemas station). In case of Sungai Golok–Gemas line, this line is in the east coast of Malaysia. The maximum PGA value is 0.13 in Bahau, and minimum is 0.01g in Sungai Golok. The average is 0.05g. From the chart, PGA value increases slowly form Sungai Golok station to Teriang station. Then, the PGA value is over than 0.1g and stable. In case of Gemas–Singapore line, the PGA value is relatively stable. The maximum value is 0.13g, and the minimum is 0.08g. The average is 0.11g. Most of PGA values have more than 0.1g. From all rail lines in Malaysia, this line has the highest average PGA value. Thus, it does not include the seismic wave amplification by sediment.

Figure 4.10. The charts show PGA values 5% POE 50 year along each line in Malaysia.

4) Myanmar. There are 5 mainlines in Myanmar. (1) Thein Za Yat – Mergui line (red). (2) Yangon – Mandalay (orange). (3) Yangon – Sagiang (pink). (4) Pathein – Kalemyo (blue). (5) Mandalay – Myitkyina (green).

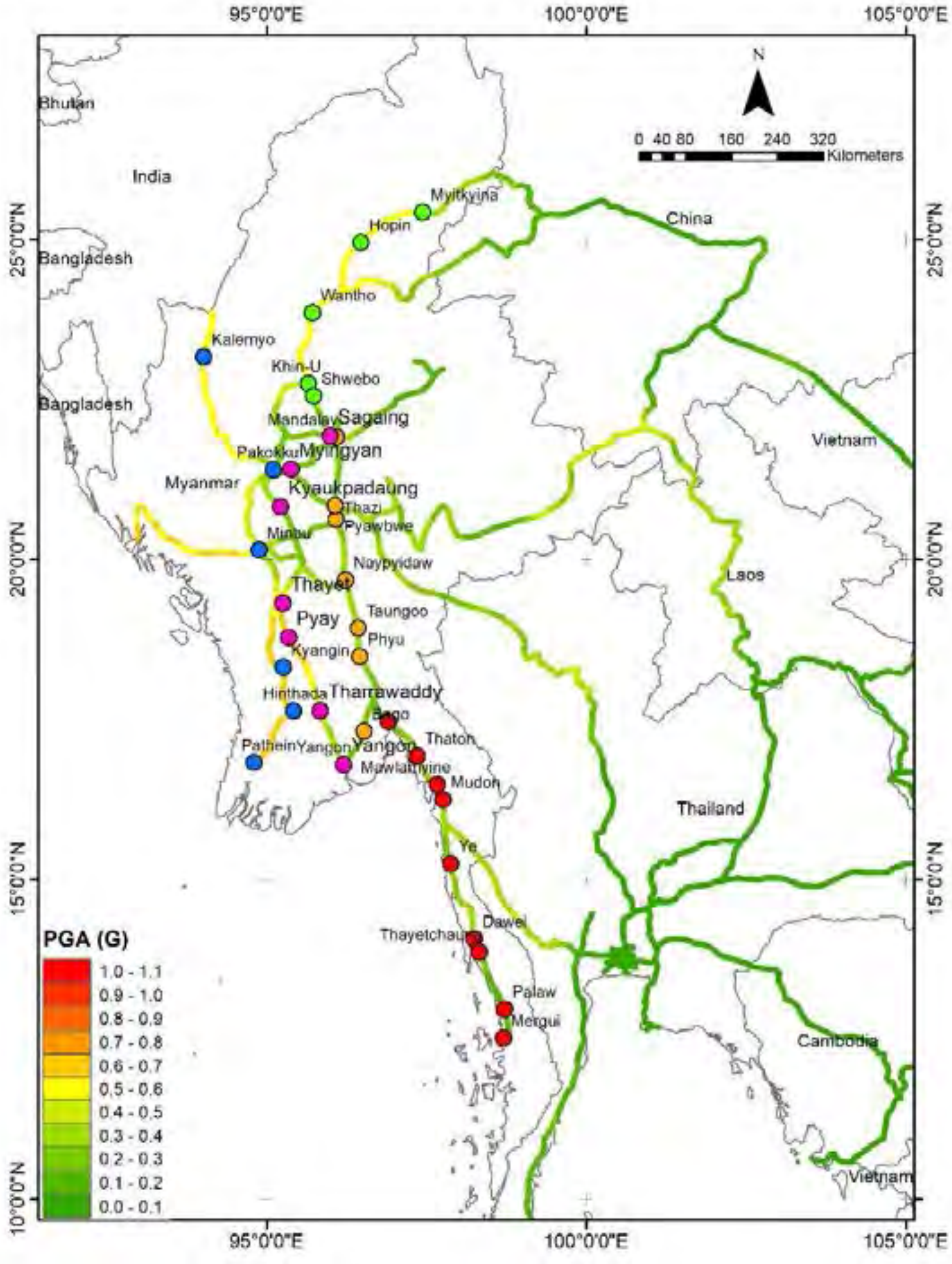


Figure 4.11. Map show PGA 5% in 50 year stations along the mainline in Myanmar.

In case of Thein Za Yat–Mergui line, the PGA values are not stable. There are 4 peaks of high values. The maximum value is 0.35g, and the minimum is 0.1g. The average value is 0.25g, suggesting that most of PGA values in this line are close to the maximum. Thus, the construction of railways along this line may have to be cautious about the seismic wave amplification. In case of Yangon–Mandalay line, there are nearby PGA values along this line. The maximum value is 0.36g in Naypyidaw station, and the minimum is 0.20g near Bago station. The average value is 0.29g, indicating that most PGA values in this area are close to the maximum level. The PGA chart declines slowly from Yangon to Bago, then rises up and stable at above 0.3g, and fall down in km50 to under 0.3g. However, this line has high PGA values. In case of Yangon–Sagiang line, the value increases in the early stage, then fall down. From Yangon station, the PGA values rise up to the maximum level at 0.66g in the Pray station and fall down to 0.23g at Kyaukpadaung station. The average value of PGA in this line is 0.39g, showing that this line has high PGA. In the construction, the earthquake resistant structure should be applied. In case of Pathein–Kalemyo line, this line has the highest PGA value among all lines in Myanmar. The maximum value is 0.68g, and the minimum is 0.3g. The average value is 0.54g, explaining that this line has high PGA and high risk of seismic hazard. In the construction, the earthquake resistance system for railway should be applied. However, the PGA values drop in km 400 to 0.3g, implying that it is not necessary to use the earthquake resistance in all of the way. In case of Mandalay–Myitkyina line, this line is in the northern part of Myanmar. The PGA values increase from the minimum (0.28g) in Mandalay station to the maximum (0.60g) in Khin-U station. The average is 0.50g, which is the 2nd place for the highest PGA of all lines. These PGA values show that this line has high risk from the seismic hazard. It should be use the earthquake resistance. Thus, the PGA value of the early stage of this line is under 0.4g. It is not necessary to use the earthquake resistance at this point.

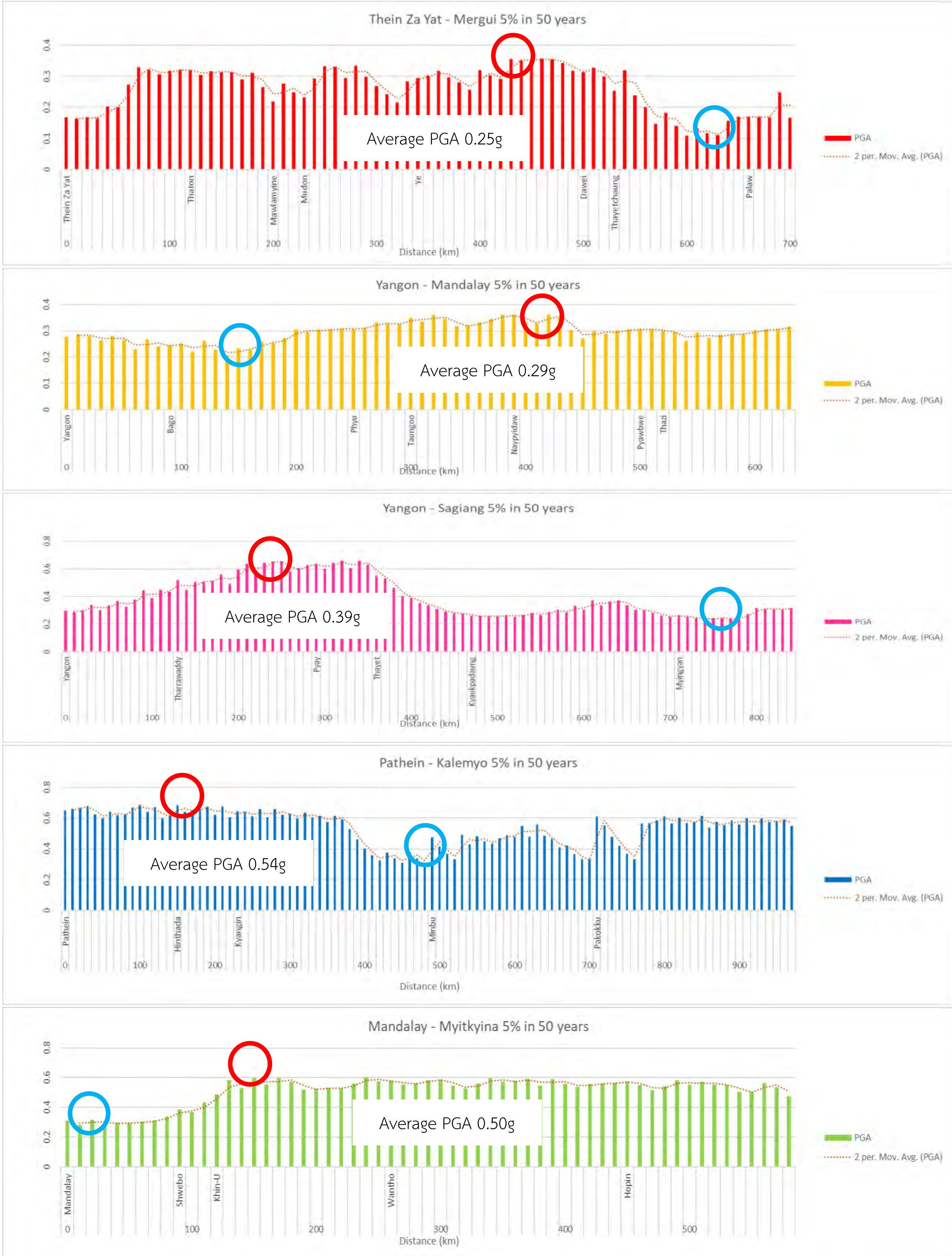


Figure 4.12. The charts show PGA values 5% POE 50 year along each line in Myanmar.

5) Thailand. There are 6 mainlines in Thailand. (1) Chiang Mai – Bangkok line (blue). (2) Bangkok – Sungai Golok line (red). (3) Nong Khai – Bangkok line (yellow). (4) Bangkok – Arunyaprathet line (green). (5) Ubonratchathani – Bangkok line (purple). (6) Bangkok-Namtok line (orange).

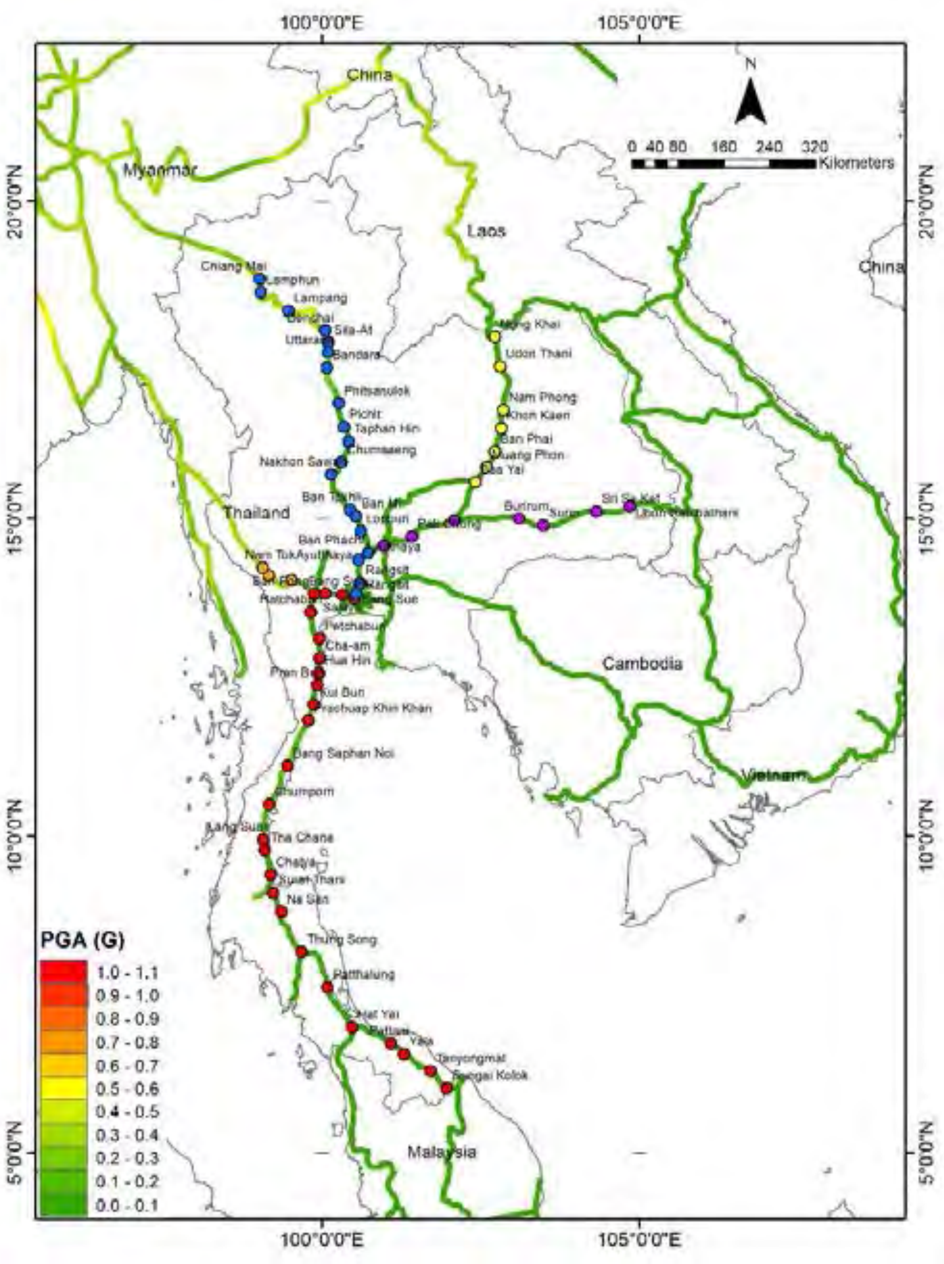


Figure 4.13. Map show PGA 5% in 50 year stations along the mainline in Thailand.

In case of Chiang Mai–Bangkok line, the line is in the northern of Thailand. There are high PGA values in the early stage (the maximum value is 0.45g) and fall down. Then, the values increase at Sila-At station to Uttaradit station and fall down and stable in Taphan Hin station. The minimum value is 0.01g in Lopburi station. The average value is 0.15g, suggesting that most of the PGA values in this line are low. However, the high-value areas should be applied with earthquake resistance. In case of Bangkok–Sungai Golok line, this line has unstable values during the first half of the distance, and stable in the latter half. The maximum value is 0.21g near Bang Saphan Noi station, and minimum is 0.01g near Sungai Golok station. The average is 0.06g, indicating that most area of this line does not have risk for seismic hazard. Nonetheless, in the area between Pranburi station and Surat Thani station the PGA values are high. This suggests that this area should be investigated on the seismic wave amplification by sediment along the line. In case of Nong Khai–Bangkok line, this line is the connection line between Thailand and Laos. The PGA values in this line are low. The maximum is only 0.04g, and minimum is 0.01g. The average is 0.019g. So, the PGA values is too low for seismic hazard. There is no concern about seismic hazard in this line. In case of Bangkok–Arunyaprathet line, this line is the connection line between Thailand and Cambodia. The PGA values decrease from the maximum (0.02g) in Bangkok (Bang Sue station) to minimum (0.01g) in Arunyaprathet station. The average is 0.013g. All PGA values in this line is too low for seismic hazard. In case of Ubonratchathani–Bangkok line, the PGA values in this line are volatile with the uptrend. The maximum is 0.026 value at Rangsit station, and the minimum is 0g near the Surin station and Ubonratchathani station. The average is 0.009g. The PGA values in this line is too low. So, there is no concern about the seismic hazard in this line. In case of Bangkok–Namtok line, this line will be the connection line between Thailand and Myanmar in the future. The PGA increases from the minimum (0.02g) from Bangkok (Bang Sue station) to the maximum (0.39g) in Tum Krasae station. The average is 0.19g. From Ban Phong station to Namtok station, it should be regarded about the seismic wave amplification because that area have high PGA.

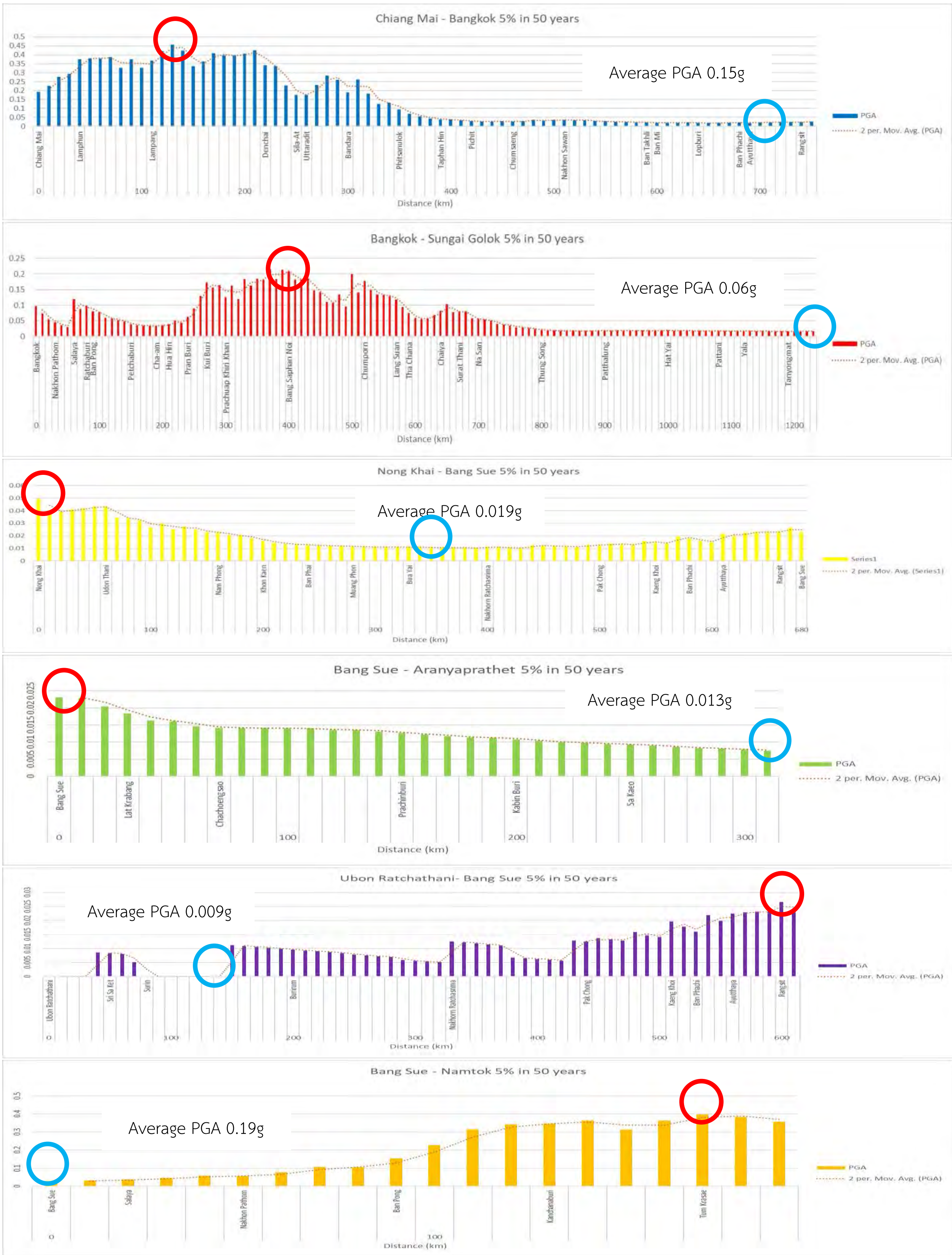


Figure 4.14. The charts show PGA values 5% POE 50 year along each line in Thailand.

6) Vietnam. There is only one mainline in Vietnam that Hanoi – Ho Chi Minh City line.

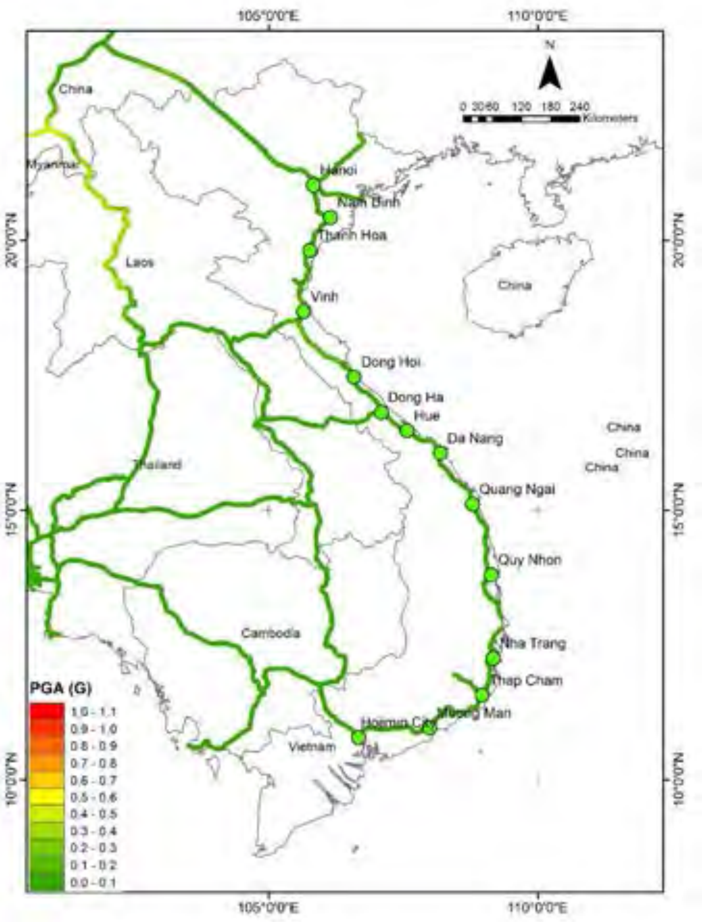


Figure 4.15. Map show PGA 5% in 50 year and stations along the mainline in Vietnam.

Hanoi–Ho Chi Minh City line. This line has maximum PGA value at 0.22 near Hanoi station, and drops continually to 0 in Dong Ha station. The average is 0.04g. Most of the line has low PGA implying no concern about seismic hazard. Thus, the peak near the Hanoi is the area which should be estimated on the seismic amplification by the sediment.

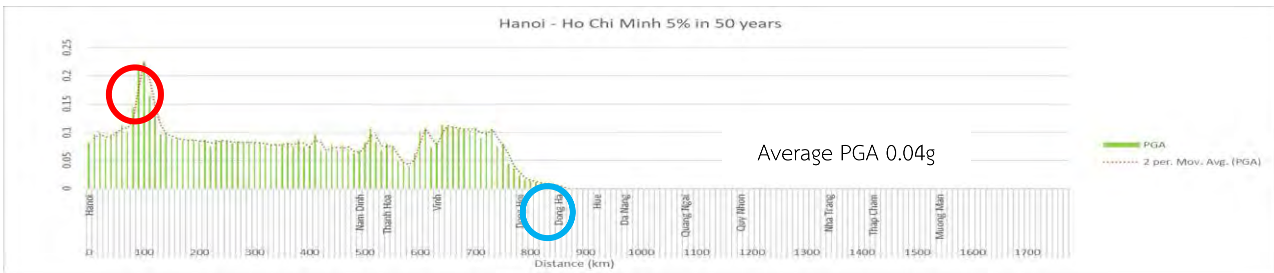


Figure 4.16. The charts show PGA values 5% POE 50 year along each line in Vietnam.

4.2.2. PSHA 5% in 100 year along rail lines in details

1) Cambodia. There are 3 mainlines in Cambodia (1) Phnom Penh–Klong line (cyan). (2) Phnom Penh–Arunyaprathet line (pink). (3)Phnom Penh–Sihanouk line (green).

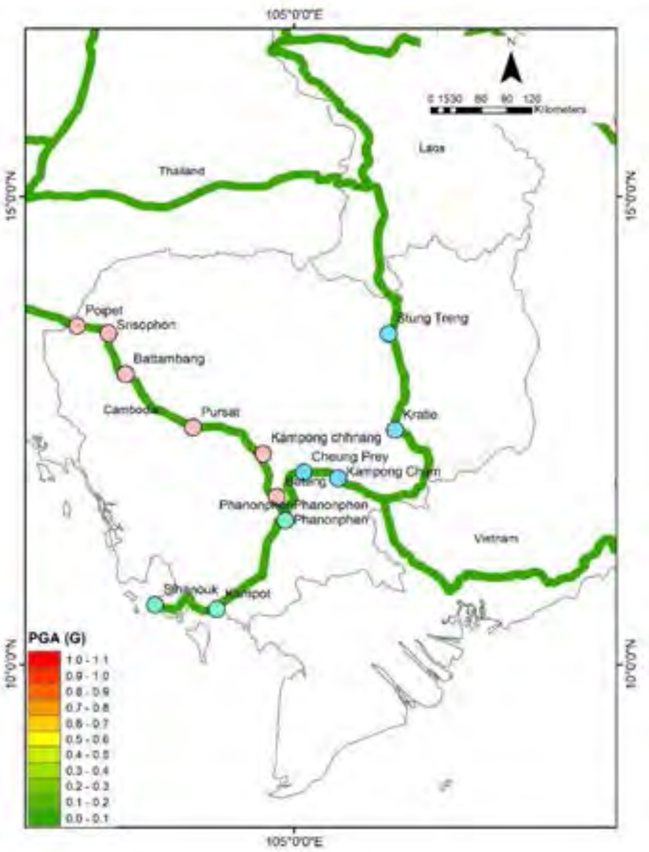


Figure 4.17. Map show PGA 5% in 100 year and stations along the mainline in Cambodia.

In case of Phnom Penh–Klong line, this line is the connection of Cambodia and Laos. In PGA 50% in 100 year, there are very low PGA values. The maximum is 0.005g, and the minimum is 0g. The average is 0.0005g. So, this line does not have impact from seismic hazard. In case of Phnom Penh–Arunyaprathet line, this line has very low PGA values. The maximum PGA is 0.01g, and the minimum PGA is 0.005g. The average value is 0.007g. From the maximum value, this line does not have impact from seismic hazard. In case of Phnom Penh–Sihanouk line, this line has stable PGA values. The maximum is 0.007g, and the minimum is 0.005g. The average is 0.006g. From the maximum value, this line does not have risk of seismic hazard.

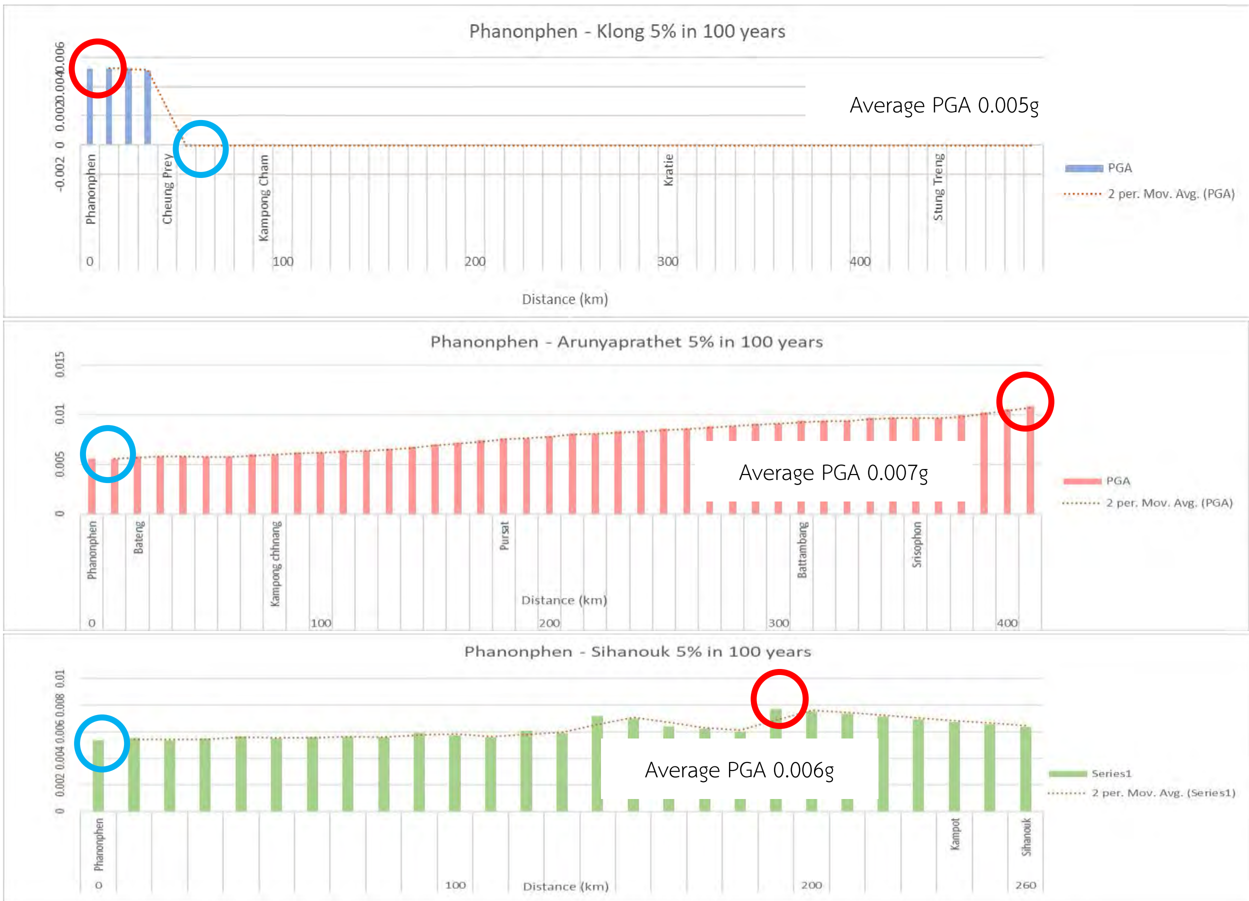


Figure 4.18. The charts show PGA values 5% POE 100 year along each line in Cambodia

2) Laos. There are 2 mainlines in Laos. (1) Vientiane–Khunming line (blue). (2) Vientiane–Champasak line (green).

In case of Vientiane–Khunming line, this line has low PGA in the early stage and high PGA values from km200. The maximum PGA value is 0.46g, and the minimum is 0.05g. The average is 0.29g. From km200 to Luangnamtha station the PGA values are high. The earthquake resistance system should be applied. In case of Vientiane–Champasak line, the PGA in this line falls down from Vientiane station to Champasak station. The maximum is 0.04g, and the minimum is 0g. The average is 0.01g. So, this line does not have risk from seismic hazard.

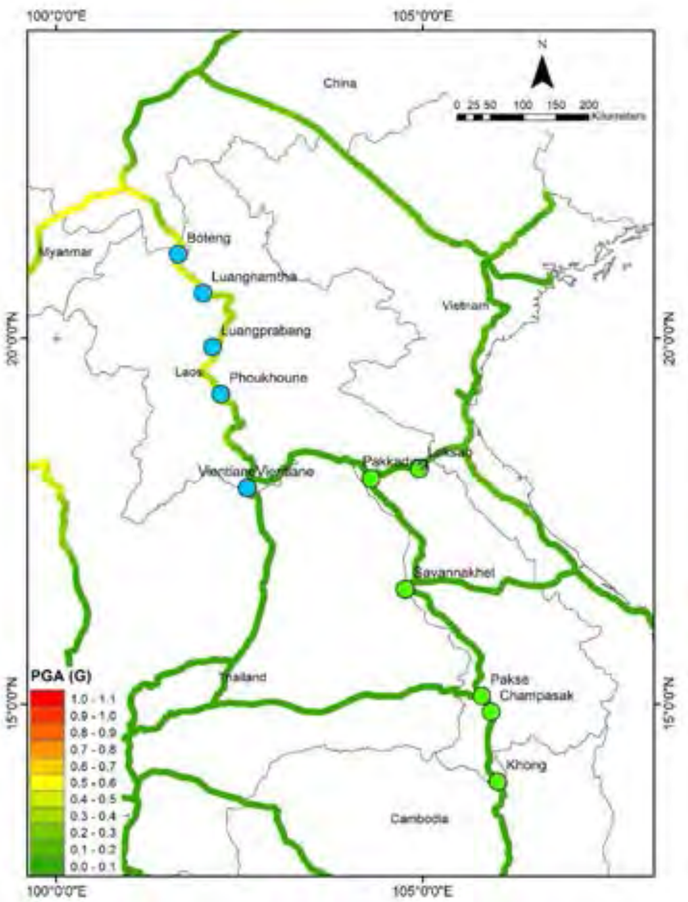
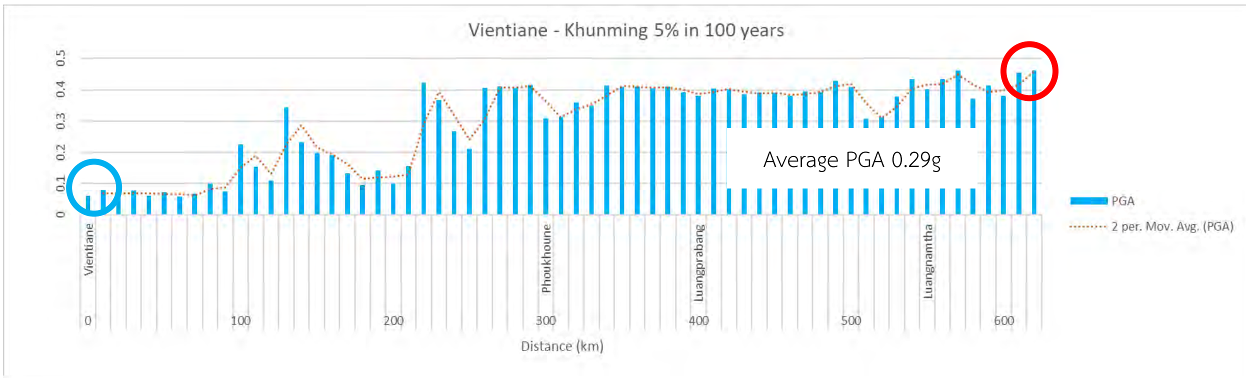


Figure 4.19. Map show PGA 5% in 100 year and stations along the mainline in Laos.



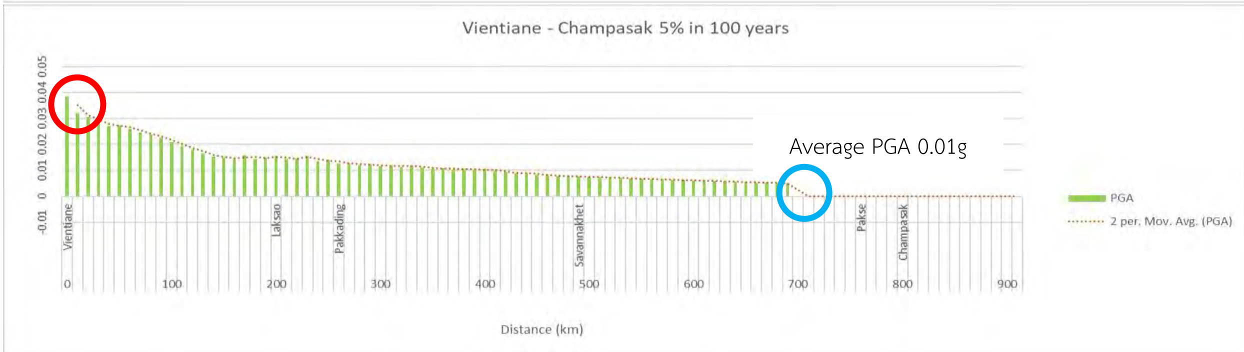


Figure 4.20. The charts show PGA values 5% POE 100 year along each line in Laos.

3) Malaysia. There are 3 mainlines in Malaysia. (1) Padang Besar–Gemas line (purple). (2) Sungai Golok–Gemas line (red). (3) Gemas–Singapore line (yellow).

Figure 4.21. Map show PGA 5% in 100 year and stations along the mainline in Malaysia.

In case of Padang Besar–Gemas line, this line has low PGA in Arau station (minimum is 0.03g). Then, it rises to the maximum (maximum is 0.24g) and stable. The average is 0.12g. The average value shows that most of the line has low PGA values. The area between Tanjang Malim station andgemas station should be investigated on the amplification of the seismic wave. In the case of Sungai Golok–Gemas line, this line has the minimum (0.02g) in Sungai Golok, and increases gradually to the maximum (0.17g) in Kemayan. The average is 0.07, indicating that most of the PGA values of this line are low. However, the Kemayan station togemas station has high PGA. In the case of Gemas–Singapore line, this line has nearby PGA value. The maximum is 0.16g, and the minimum is 0.11g in Singapore. The average is 0.14g. From the chart, this line has low risk of seismic hazard. Thus, the construction should be investigated on the amplification of seismic wave.

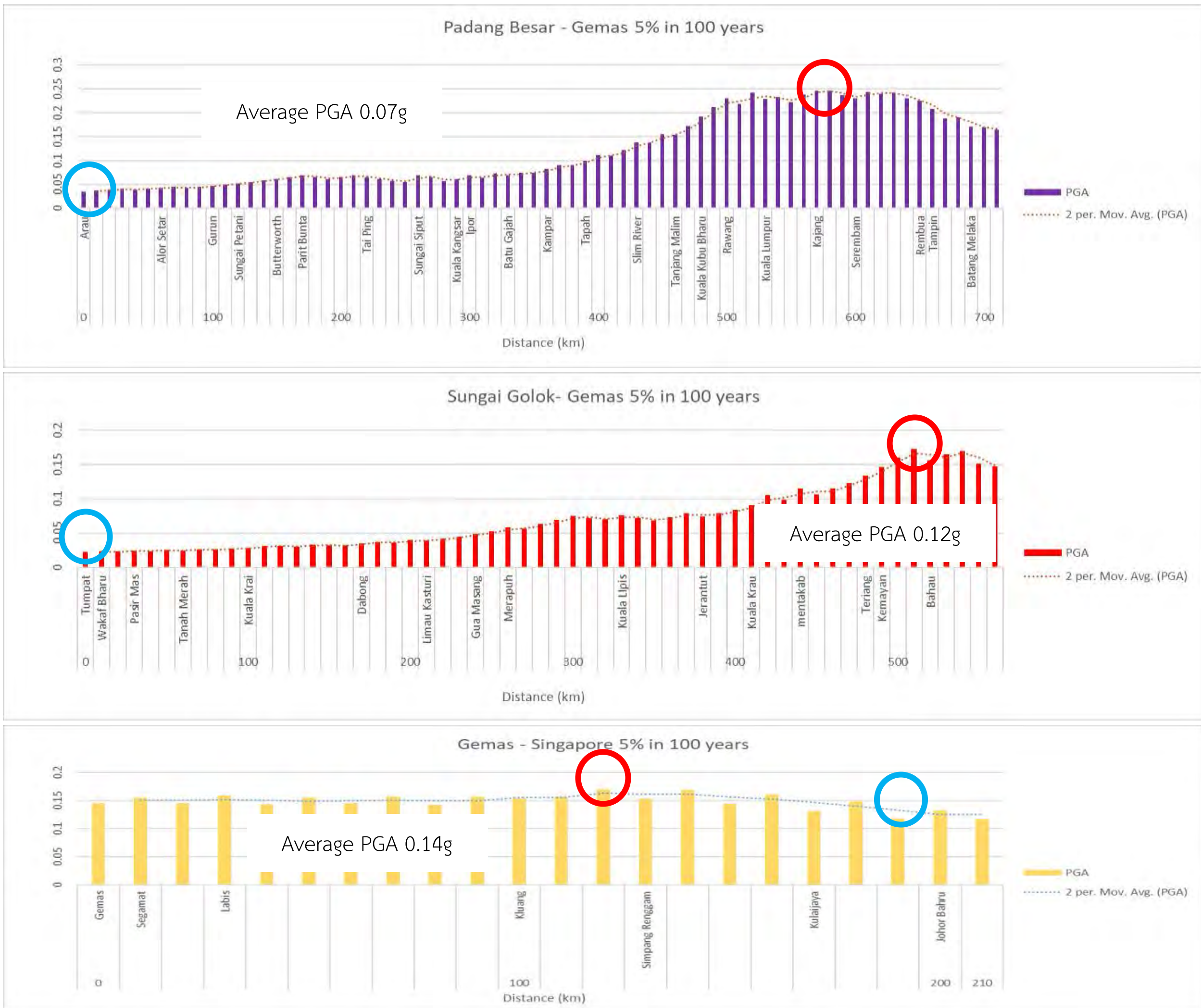


Figure 4.22. The charts show PGA values 5% POE 100 year along each line in Malaysia.

4) Myanmar. There are 5 mainlines in Myanmar. (1) Thein Za Yat–Mergui line (red). (2) Yangon–Mandalay (orange). (3) Yangon–Sagiang (pink). (4) Pathein–Kalemyo (blue). (5) Mandalay–Myitkyina (green).

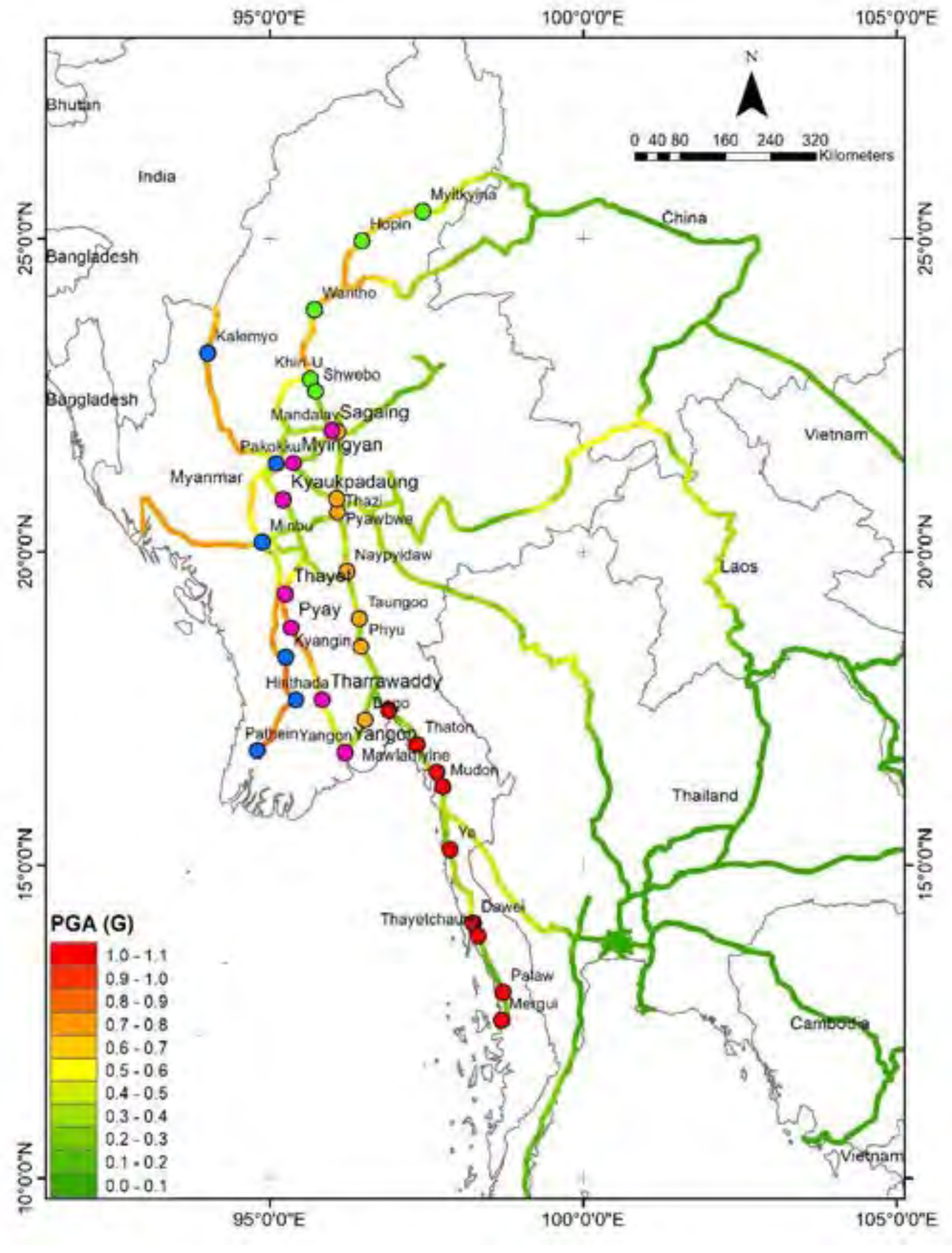


Figure 4.23. Map show PGA 5% in 100 year and stations along the mainline in Myanmar.

In case of Thein Za Yat–Mergui line, Thein Za Yat–Mergui line has fluctuating PGA values. The maximum is 0.41g in km450, minimum is 0.12g near Palaw. The average PGA is 0.3g. From the chart, most of PGA values in this line are high. There should be a risk from seismic hazard. So, it should be estimated on the amplification of seismic wave by sediment. In case of Yangon–Mandalay line, this line has close PGA values. The maximum is 0.42g near Naypyidaw station, and minimum is 0.25g near Bago station. The average is 0.35g. The PGA values in this line are mostly high values. So, this line has risk from seismic hazard. The construction along this line should apply the earthquake resistance system. In case of Yangon–Sagiang line, this line has high PGA values mostly. The maximum is 0.81g near Pyay station, and minimum is 0.29g near Sagiang station. The average value is 0.48g. From the average value, the most of the areas along this line have high risk from seismic hazard. The construction along this line must apply the earthquake structure. In case of Pathein–Kalemyo line, the Pathein – Kalemyo line is in the west of Myanmar. Most of the PGA values in this line are high. The maximum is 0.84g at Hinthada station, and the minimum is 0.39g near Minbu station. The average is 0.67g. The average value in this line is the highest value of all rail lines in the Mainland Southeast Asia. So, this line has high risk for seismic hazard. In case of Mandalay–Myitkyina line, this line has low PGA values initially and the values increasegradually and stable. The maximum is 0.74g, and the minimum is 0.34g. The average value is 0.63g, suggesting that most of the areas along this line have high risk from the seismic hazard. So, the seismic hazard resistance should be used along this line.

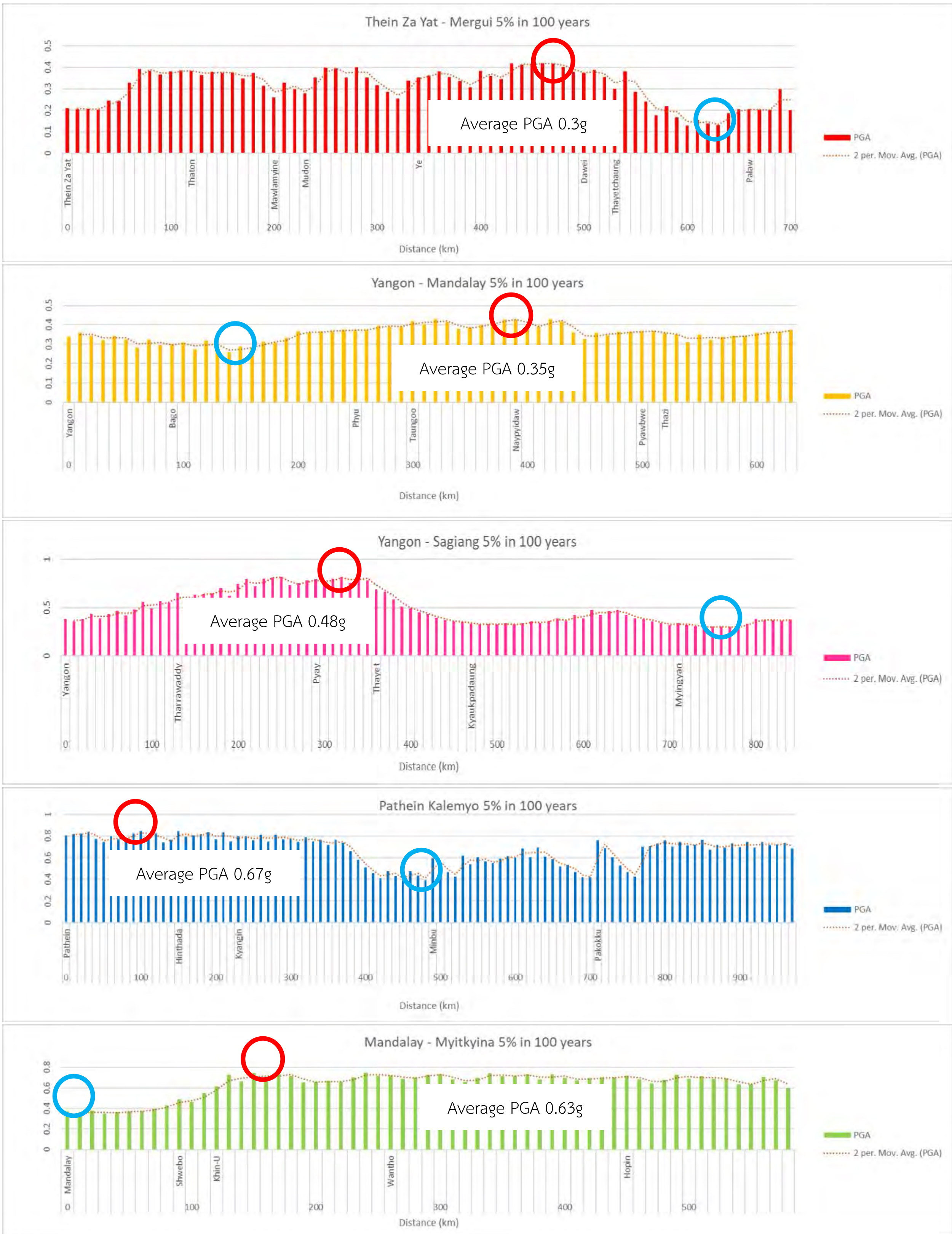


Figure 4.24. The charts show PGA values 5% POE 100 year along each line in Myanmar.

5) Thailand. There are 6 mainlines in Thailand. (1) Chiang Mai–Bangkok line (blue). (2) Bangkok–Sungai Golok line (red). (3) Nong Khai–Bangkok line (yellow). (4) Bangkok–Arunyaprathet line (green). (5) Ubonratchathani–Bangkok line (purple). (6) Bangkok–Namtok line (orange).

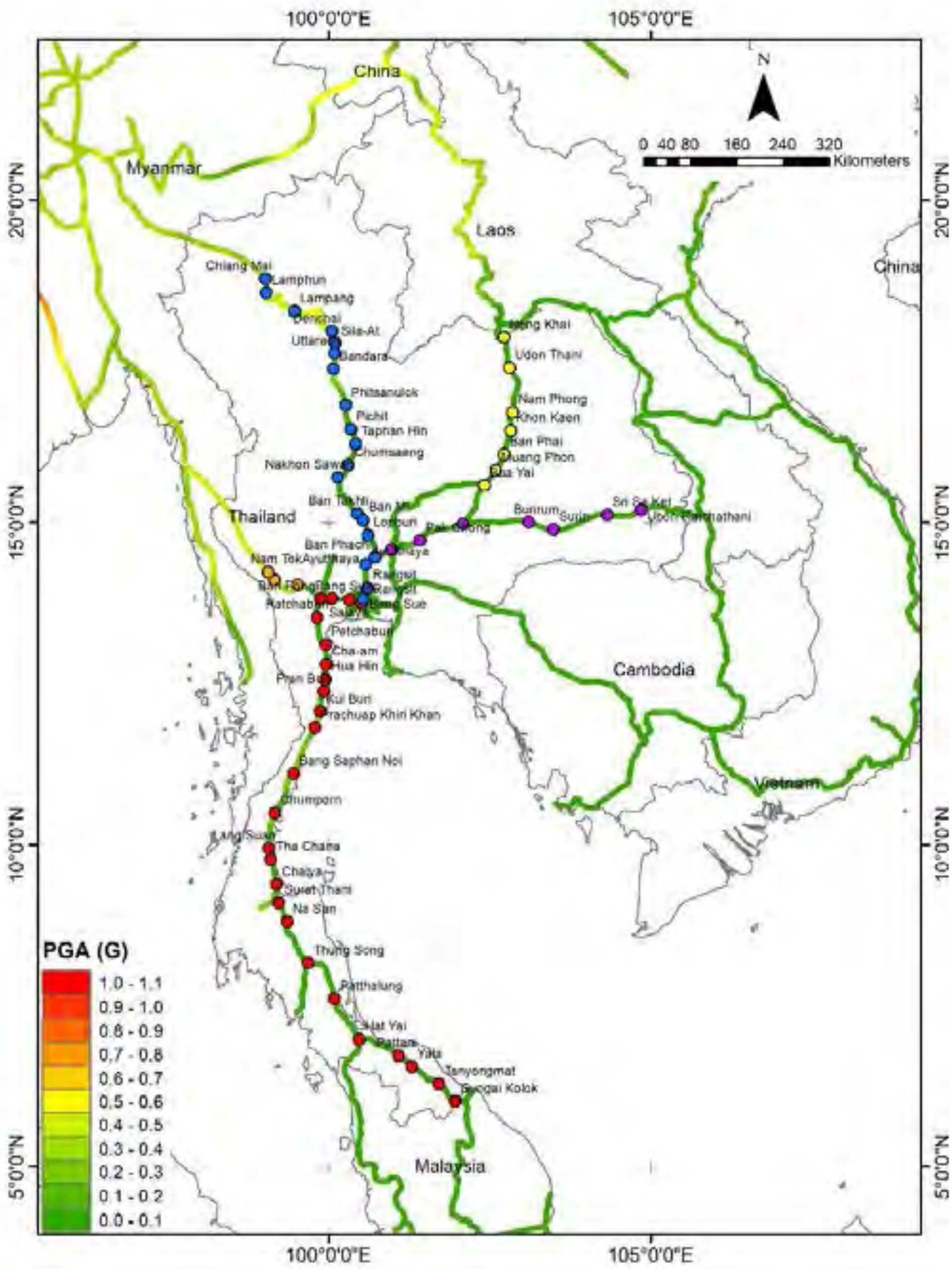


Figure 4.25. Map show PGA 5% in 100 year and stations along the mainline in Thailand.

In case of Chiang Mai–Bangkok line, there are high PGA values from Chiang Mai to Phitsanulok. The maximum is 0.53g at Lampang station, and the minimum is 0.02g. The average is 0.18g. From Chiang Mai to Phitsanulok there is a risk from seismic hazard. In case of Bangkok–Sungai Golok line, this line has unstable PGA value. The maximum is 0.26g in Bang Saphan Noi station, and the minimum is 0.02g in Yala station. The average is 0.08g. From Pran Buri station to Surat Thani station have high PGA value. In this area, it should be estimated on the amplified of seismic wave by sediment. In case of Nong Khai–Bangkok line, this line has low PGA values. The maximum is 0.058g in Nong Khai, and the minimum is 0.013g near Bua Yai station. The average is 0.023g. From the chart, this line does not have a risk from seismic hazard. In case of Bangkok–Arunyaprathet line, the Bangkok–Arunyaprathet line has maximum PGA at 0.03g, and minimum PGA is 0.01g. The average PGA is 0.016g. The PGA values along this line are not meaningful for seismic hazard. In case of Ubonratchathani–Bangkok line, the PGA values of this line are relatively volatile. The maximum is 0.03g near Rangsit station. The minimum PGA is 0.006g near Ubonratchathani station. The average is 0.013g. The PGA values in this line are too low for seismic hazard. Then, there is no concern about seismic hazard along this line. In case of Bangkok–Namtok line, the PGA value rises continually. The minimum is 0.03g. The maximum is 0.46g. The average PGA is 0.23g. From Ban Pong station to Namtok station, the PGA values are high. Then, there are risk from seismic hazard in that area. However, it should be investigated on the amplification of seismic wave.

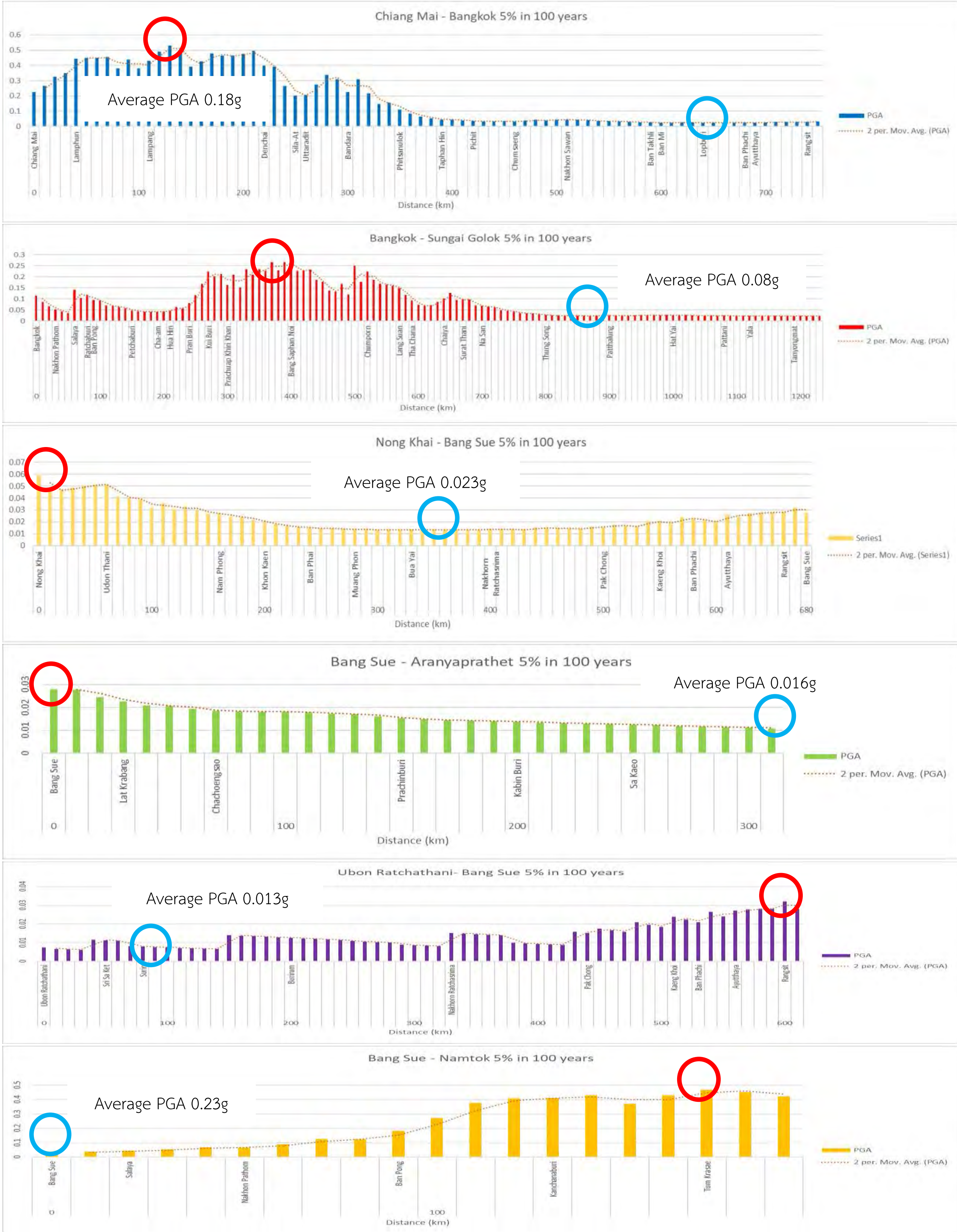


Figure 4.26. The charts show PGA values 5% POE 100 year along each line in Thailand.

6) Vietnam. There is 1 mainline in Vietnam that Hanoi–Ho Chi Minh City line

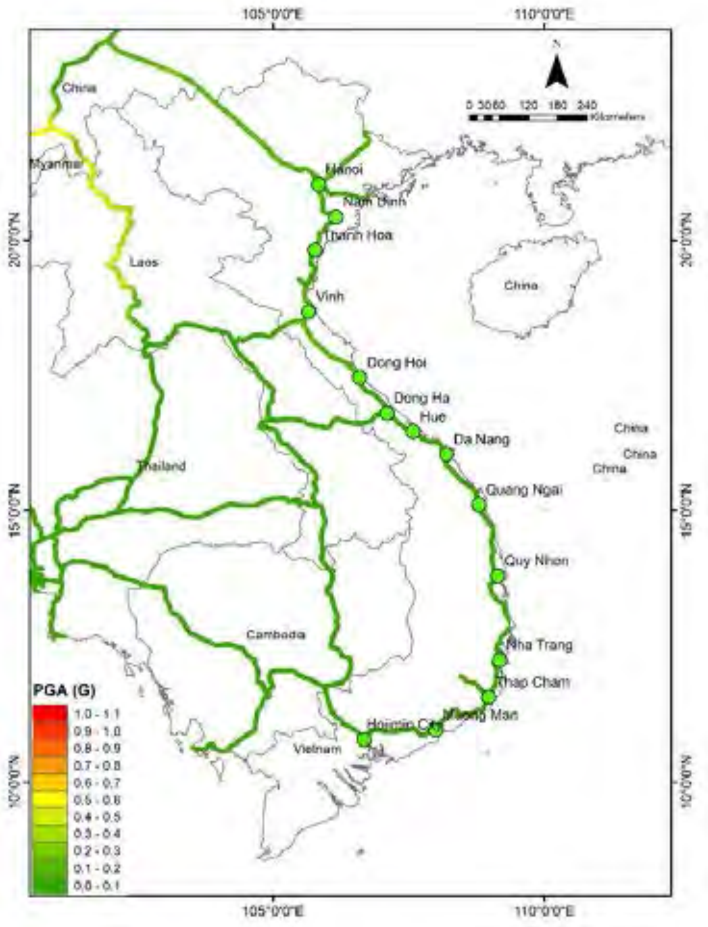


Figure 4.27. Map show PGA 5% in 100 year and stations along the mainline in Vietnam.

Hanoi – Ho Chi Minh line. The Hanoi–Ho Chi Minh line has high PGA values with peak in km100. The maximum is 0.27g in km100, the minimum is 0g, and the average is 0.05g. Most area of Vietnam does not have an effect of seismic hazard. However, it should be estimated on the seismic wave amplification by sediment.

Figure 4.28. The chart show PGA values 5% POE 100 year along each line in Vietnam.

4.3 The investigation and find the warning area by Eurocode1998-8 standard

The Eurocode1998-8 standard is the standard for the design of structure for earthquake resistance that is ruled by the European Union. From the Eurocode-8, the areas that have very low seismicity, the peak ground acceleration on the rock or rock-like is not greater than 0.4g or 3.9 m/s^2.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EN 1998-1 (2004) (English): Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings [Authority: The European Union Per Regulation 305/2011, Directive 98/34/EC, Directive 2004/18/EC]

Figure 4.29. The Eurocode1998-8.

4.3 Eurocode1998-8 for rail line.

In the railways of the Mainland Southeast Asia, the western and the northern parts have the area that the PGA values of more than 0.4g or 3.92 m/s^2. I investigated the seismic hazard and warning point along the railways by using PGA 5% in 100 year map because the Mainland Southeast Asia has the rails that are over 50 year old.

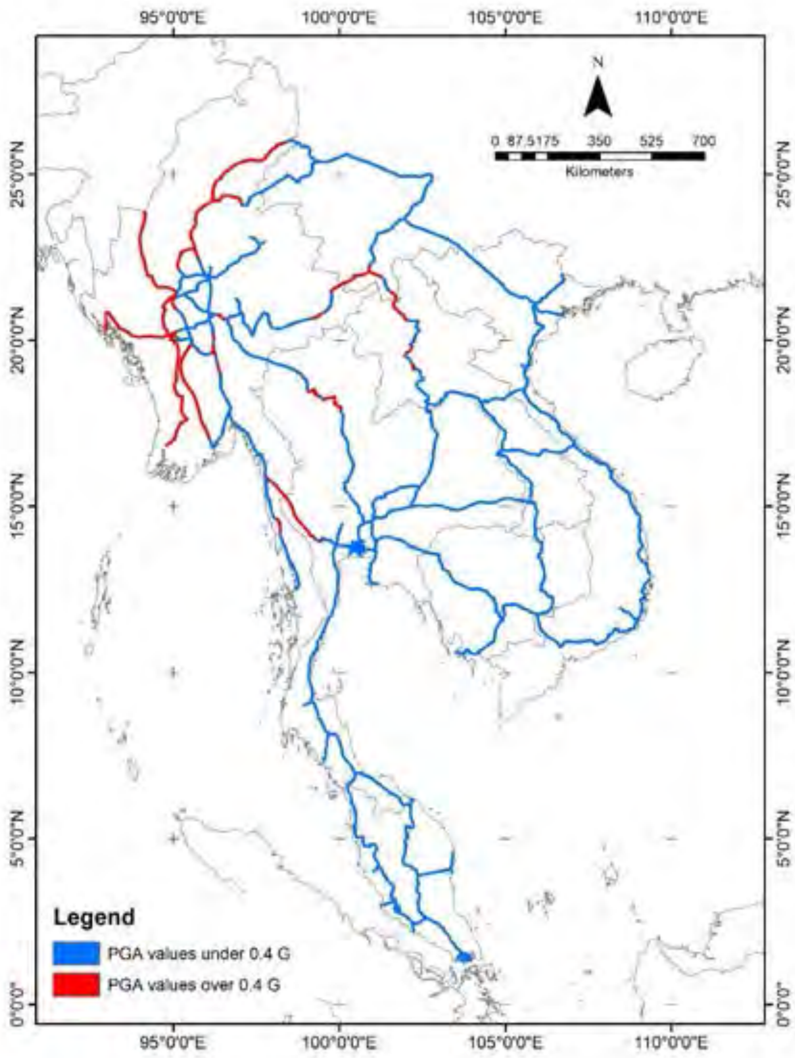

Figure 4.30. Map of Mainland Southeast Asia show PGA 5% in 100 year map for specific the area that have PGA over 0.4g.

From the figure 4.28 and 4.29, the chart shows the area that the PGA values are greater than 0.4g. So, these areas have high risk from seismic hazard. These are Vientiane–Khunming line (km200–km640) in Laos, all lines in Myanmar, and Bangkok–Namtok and Chiang Mai–Bangkok in Thailand (Chiang Mai station–Denchai station). In Laos and Thailand, the areas which have high PGA are not all of the line. In Myanmar, the Thein Za Yat–Mergui line has high PGA in some areas of the line but the other lines have PGA values at greater than 0.4g in nearly all of the line. Thus, this estimate assumes the areas which are the rock or rock-like ground. It does not cover the amplification of seismic wave by the sediment.

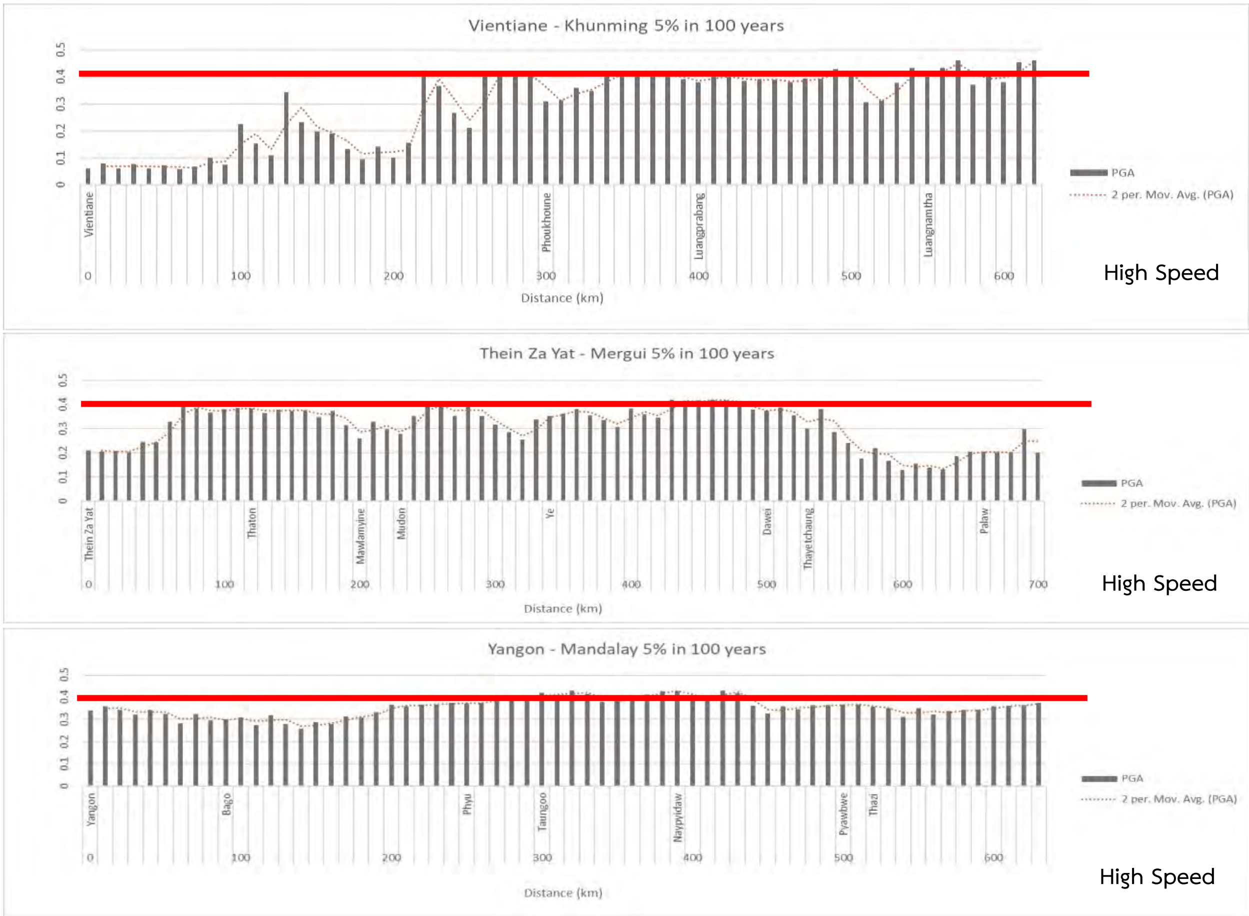

Figure 4.31. The charts show PGA values that over than 0.4g in each line.

Figure 4.31. (Continued) The charts show PGA values that over than 0.4g in each line.

4.3.1. High-Speed Train System

The high-speed railways system is sensible with seismic hazard. It may cause high damages when the earthquake happens because it has high speed (more 200 km/hr.). From the map, there are some areas that have the high PGA values (over 0.4g). These areas should be applied with the earthquake resistance structure or the seismic hazard warning system like in Japan. However, this project assumes the ground is rock or rock-like and does not cover the seismic wave amplification by sediment. Details of each line are shown in figure 4.31.

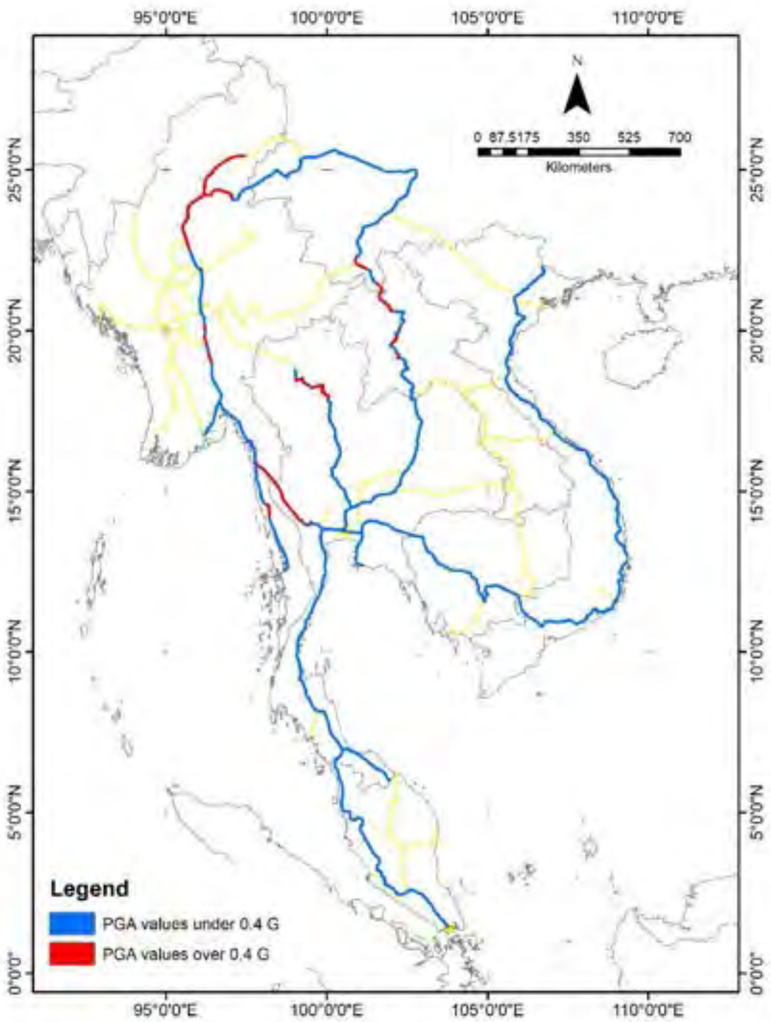

Figure 4.32. Map of Mainland Southeast Asia show PGA 5% in 100 year map for specific the area that have PGA over 0.4g in high speed railways system.

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