CHAPTER 1

Introduction

1.1 Overview

The ground shakes induced by earthquakes, if large enough, can result in huge losses to life, mainly caused from the building collapse. Hence, appropriate building design methods for earthquake resistance have been intensively developed. However, many buildings were constructed before the emergence of the best earthquake knowledge. In other words, the earthquake resistive building design methods have been developed based on what has been learnt from past earthquakes. Especially in the moderate seismicity areas in which earthquake preparedness is at a low level, and there have been many buildings constructed without seismic consideration. The Northern region of Thailand has also long been considered as non-seismic area and therefore many of the buildings in the area are vulnerable to structural damage due to inadequate seismic code enforcement.

As an earthquake is a rapid shaking, there is hence no warning before occurring. It is well recognized that the best way to manage this kind of disaster is to establish preparedness. With the trend of providing preparedness, there has been a number of researchers concerned with earthquake loss estimation. Yeh *et al.* (2006), Molina *et al*. (2007) and Wood *et al*. (2014) developed analysis modules in order to make an early loss estimation system. Hence, the Taiwan city earthquake loss estimation was performed and also a mitigation plan was proposed based on those results. In the work of Nordenson *et al*. (2000), the earthquake loss estimation for New York City was conducted to provide a better understanding of how businesses and agencies to create an effective mitigation plan to reduce potential damage and losses to life from future earthquakes.

Chiang Rai province is one of the most earthquake risk areas consisting of Mae Chan - Chiang Saen fault and Phayao faults that can cause an earthquake of magnitude 6.0 - 6.5 on the Richter scale (Ornthammarath, 2014). The maximum peak ground acceleration area from the earthquake, every 475 year period, is approximately 0.2 g on solid rock (Shedlock, 2000; Palasri, 2010). The recent big Mae Lao earthquake with a magnitude of 6.3 occurred on May 5, 2014 and caused approximately $28 Million in damage (Figure 1.1). The epicenter of the earthquake was about 7.4 kilometers underground in Tambon Dong-Mada south of Mae Lao District and 27 kilometers southwest of Chiang Rai city, Thailand (Wiwekwin and Kosuwan, 2014). The earthquake was recorded as strong, shaking both Northern region of Thailand and neighboring Myanmar. It was the strongest earthquake ever recorded in Thailand, according to the National Disaster Warning Center. Seismically, although the country has long been considered as having low seismicity, the present historical seismicity has proven the city to be classified in a moderate risk zone (Lukkunaprasit, 2006).

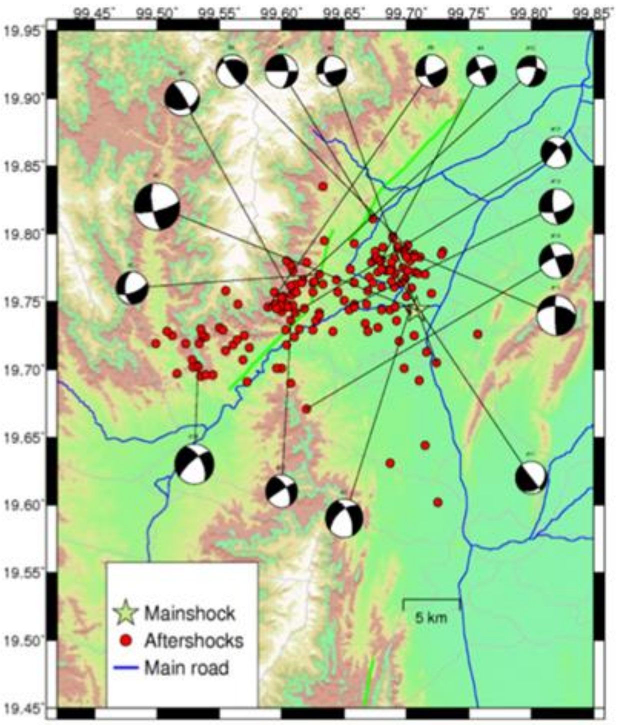

Figure 1.1 Mainshock and aftershock characteristics within 24 hours on May 5th 2014 (Pananont *et al.*, 2014)

Most damage and deaths caused by earthquakes are direct or indirect as a result of ground shaking induced building collapse. This study focuses on a spatial study of the seismic performance of buildings in Chiang Rai Municipality to establish an earthquake scenario with a magnitude of 5.0 that can lead to corresponding seismic scenarios. While the HAZUS (FEMA, 2001) approach is attractive, it is tailored so intimately to the U.S. situations that is difficult to apply it to other environments and geographical regions. In this study, GIS-based software (e.g., ArcGis), using the computational scheme of HAZUS, was used in conjunction with locally provided information, as a tool for this spatial analysis. The results of the study will enable forecasting capabilities which are useful in anticipating the consequences of future earthquakes, and to develop plans and strategies for reducing risk. The collapse of buildings was first estimated and then the number of deaths caused by the building collapse were approximated.

Much research in the past has concluded with the earthquake scenarios, to encourage the building rehabilitation. However, it is economically not feasible to rehabilitate all buildings in the area at the same time. Therefore, it needs for a comprehensive plan to identify critical buildings and their rehabilitation requirements. The prioritize building was to incorporates site seismic hazard, building vulnerability and important building which were treated by a fuzzy rule based and artificial neural network modeling. The buildings with higher risk were selected for the upgrading, and then the amount of losses was re-examined.

1.2 Literature Review

Chen and Scawthorn (2003) suggested the earthquakes are naturally occurring, resulting from a number of causes including tectonic ground motions, volcanism, landslides, and man-made explosions. An earthquake is the perceptible shaking on the surface of the earth, termed seismic hazards, which can cause direct damage to buildings, roads, and human losses. The severity of the seismic hazard depends on the complex combination of the earthquake magnitude, the distance from the epicenter (point at ground level directly above the hypocenter), and the local geological conditions, which may amplify or reduce wave propagation. The tectonic earthquakes are the result from motion between a number of large plates comprising the Earth’ crust or lithosphere. These plates are driven by the convective motion of the material in the

Earth's mantle which in turn is driven by heat generated in the Earth's core. Relative plate motion at the fault interface is constrained by friction and asperities. However, strain energy accumulates in the plates, eventually overcomes any resistance, and causes slip between the two sides of the fault. While the accumulation of strain energy within the plate can cause motion (and consequent release of energy) at faults at any location, earthquakes occur with greater frequency at the boundaries of the tectonic plates. Faults are the physical expression of the boundaries between adjacent tectonic plates and classified according to their sense of motion (Figure 1.2).

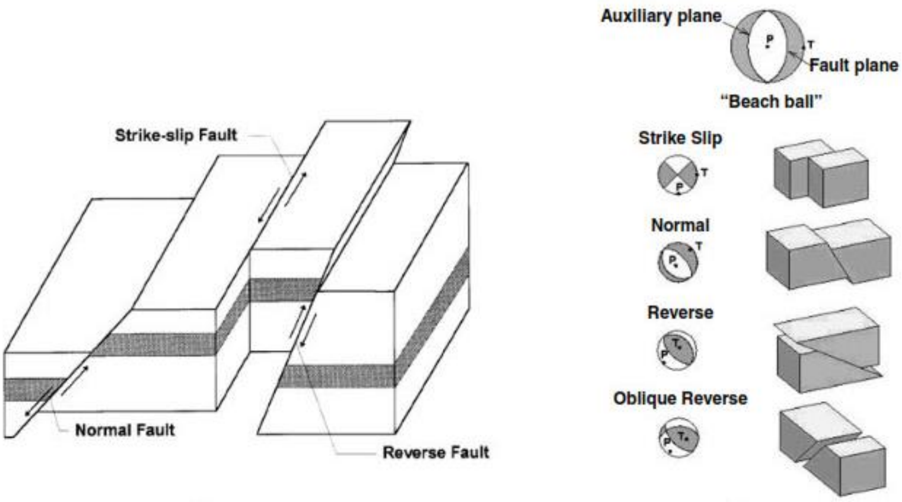

Figure 1.2 Types of faulting and focal mechanisms
(Chen and Scawthorn, 2003)

Basic terms include transform or strike slip (relative fault motion occurs in the horizontal plate, parallel to the strike of the fault), dip-slip (motion at right angles to the strike, up or down-slip), normal (dip-slip motion, two sides in tension move away from each other), reverse (dip-slip, two sides in compression move towards each other), and trust (low-angle reverse faulting). The example types of faulting in Southeast Asia are shown in Figure 1.3.

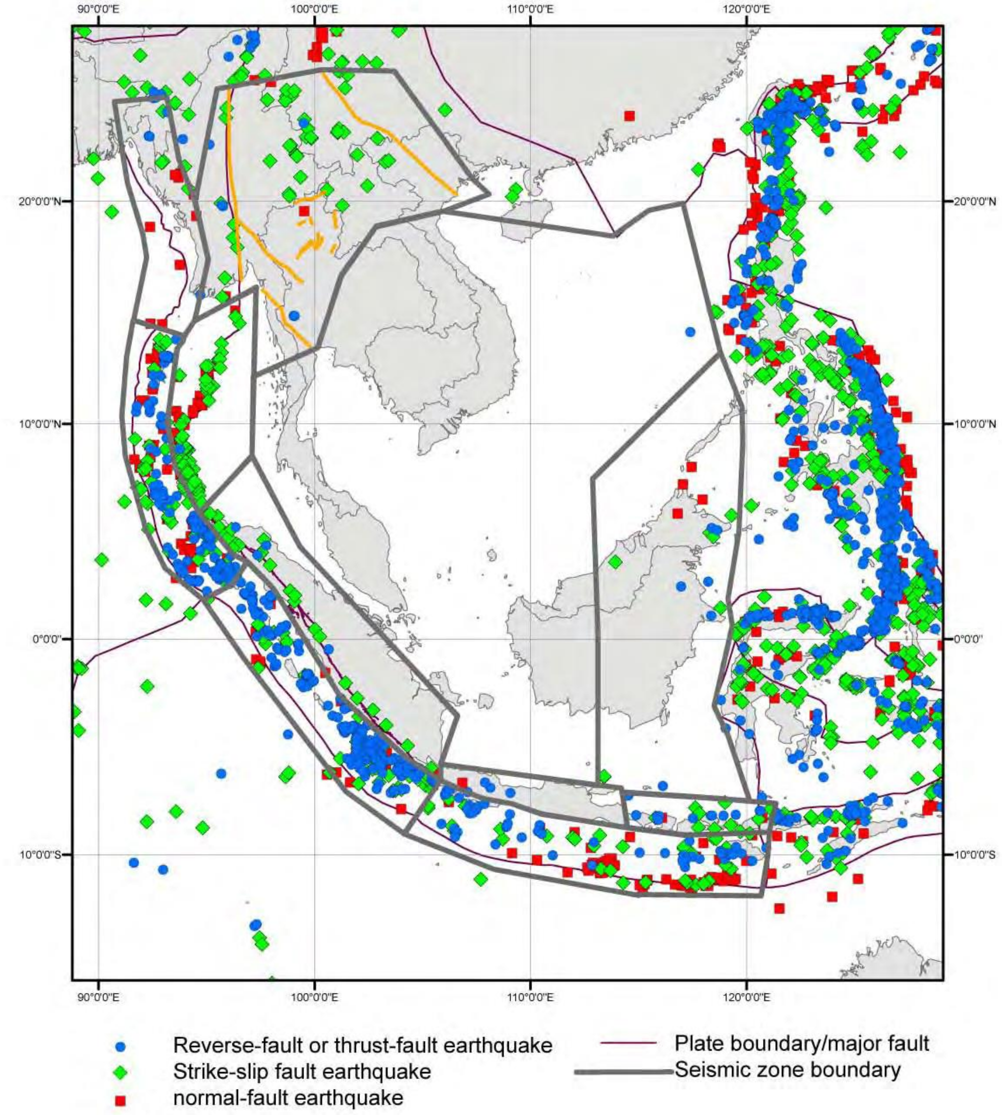

Figure 1.3 Types of faulting in Southeast Asia for the period 1964 – 2005 (Petersen *et al*., 2007)

1.2.1 Tectonic Elements of Thailand and Adjacent Plates

Thailand is located in the stable Sunda Plate, which have moderate rate of earthquake activity. The regions of the Sunda plate adjacent to the Sunda subduction zone have a moderate to high rate of earthquake activity. The Sunda subduction zone can divide into four major sections: the Burma, North Sumatra-Andaman, Southern Sumatra, and Java Zones (Figure 1.4)

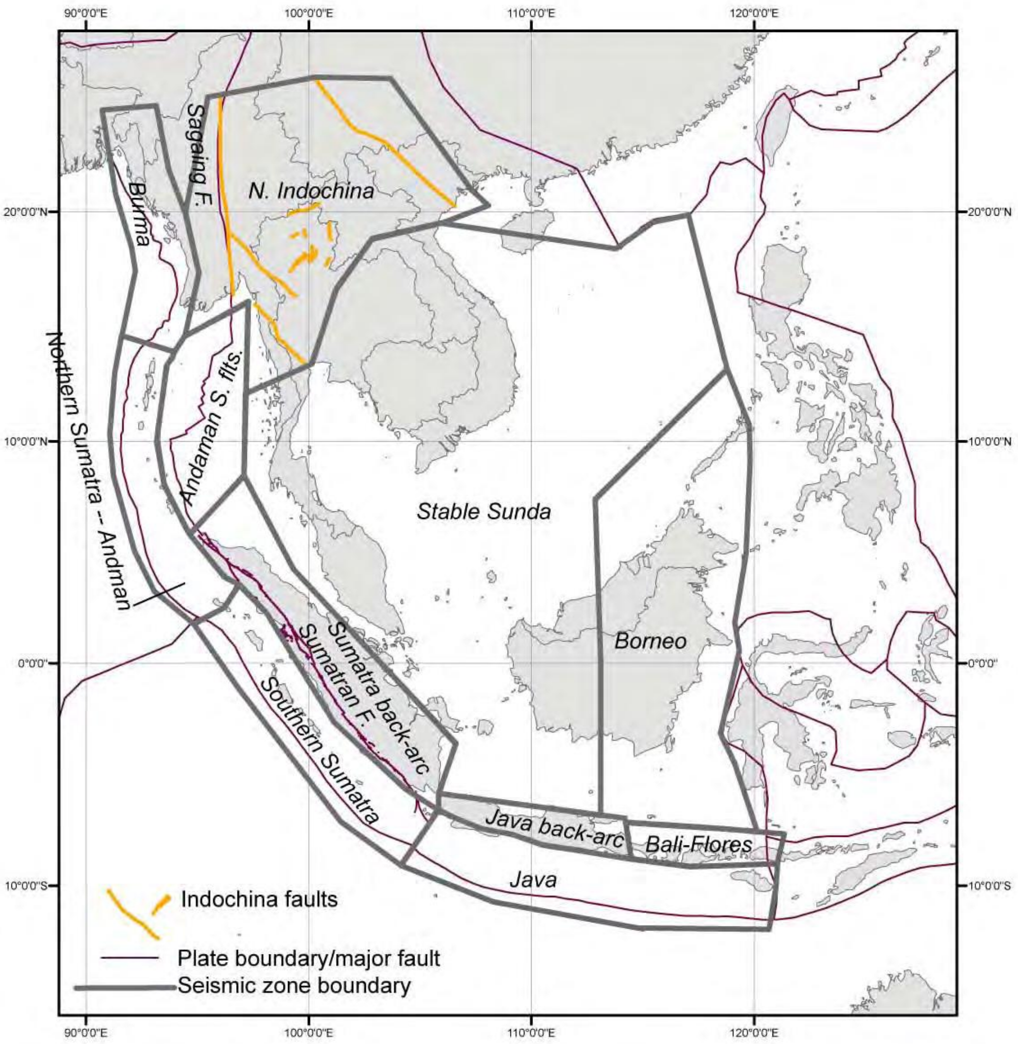

Figure 1.4 Seismic zone boundary with Adjacent plates (Petersen *et al*., 2007)

The Sunda plate includes the South China Sea, the Andaman Sea, southern parts of Vietnam and Thailand along with Malaysia and the islands of Borneo, Sumatra, Java, and part of Celebes in Indonesia, plus the south-western Philippines islands of Palawan and the Sulu Archipelago (Sunda Plate, 2015). The Sunda plate is located at 49.0°N – 94.2°E and exhibit a clockwise rotation rate of 34°/Myr and moves in a general eastward direction at a velocity of 6±1 to 10±1 mm/yr from south to north, respectively (Simons, 2007).

1.2.2 Seismic Hazard in Chiang Rai

1) Active Faults in the Area

Chiang Rai is located in the Northern region of Thailand. The city is in seismic risk regions where many active faults in the area as illustrated in Figures 1.5.

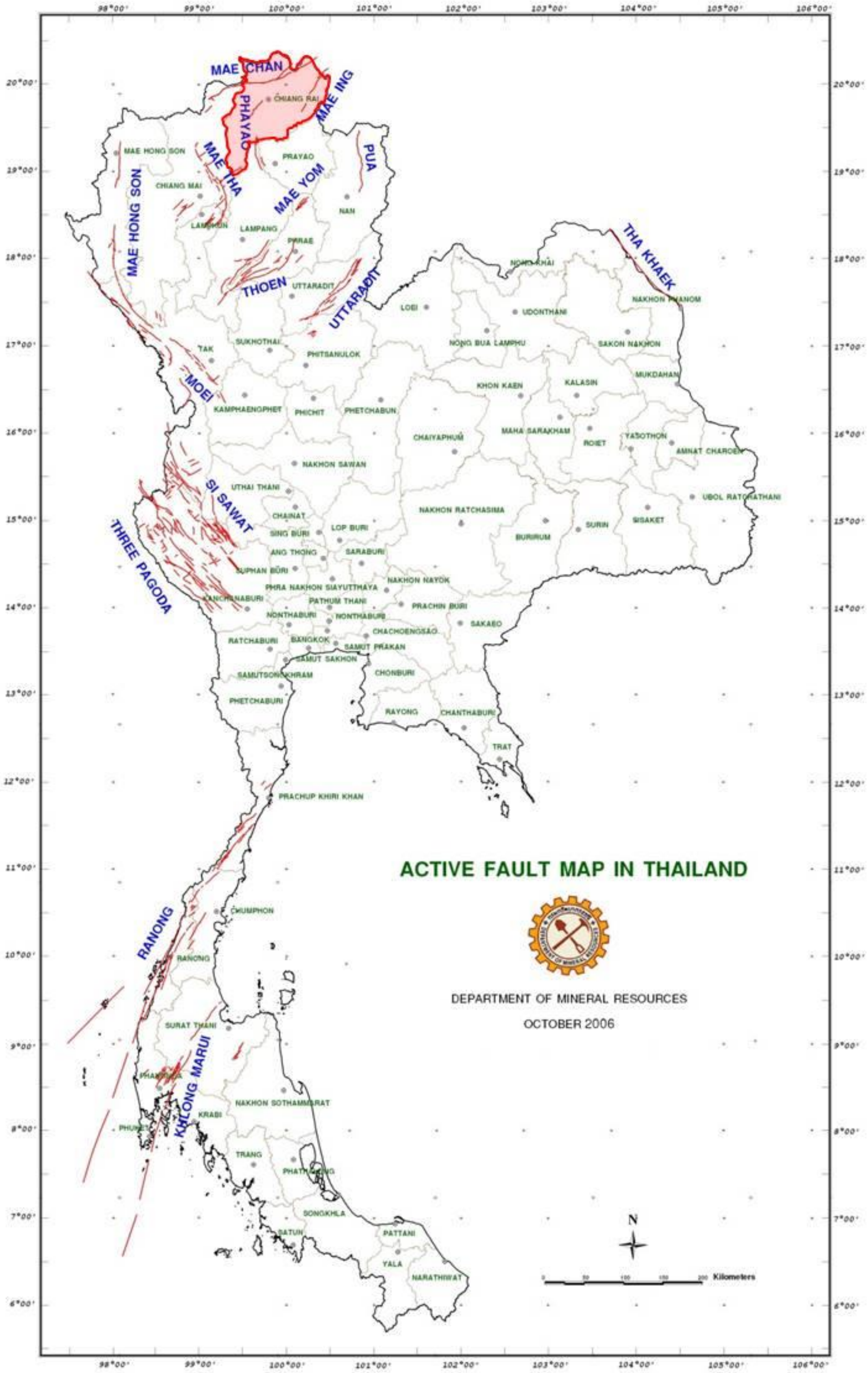

Figure 1.5 Active fault map in Thailand (Active fault zones in Thailand, 2015)

2) Probabilistic Peak Ground Acceleration for Chiang Rai Province

Ornthammarath *et al*. (2011) suggested the PGA hazard map for 10 and 2% probability of exceedance in 50 years, corresponding to 475 and 2,475 years return periods, respectively, as displayed in Figures 1.6 – 1.7.

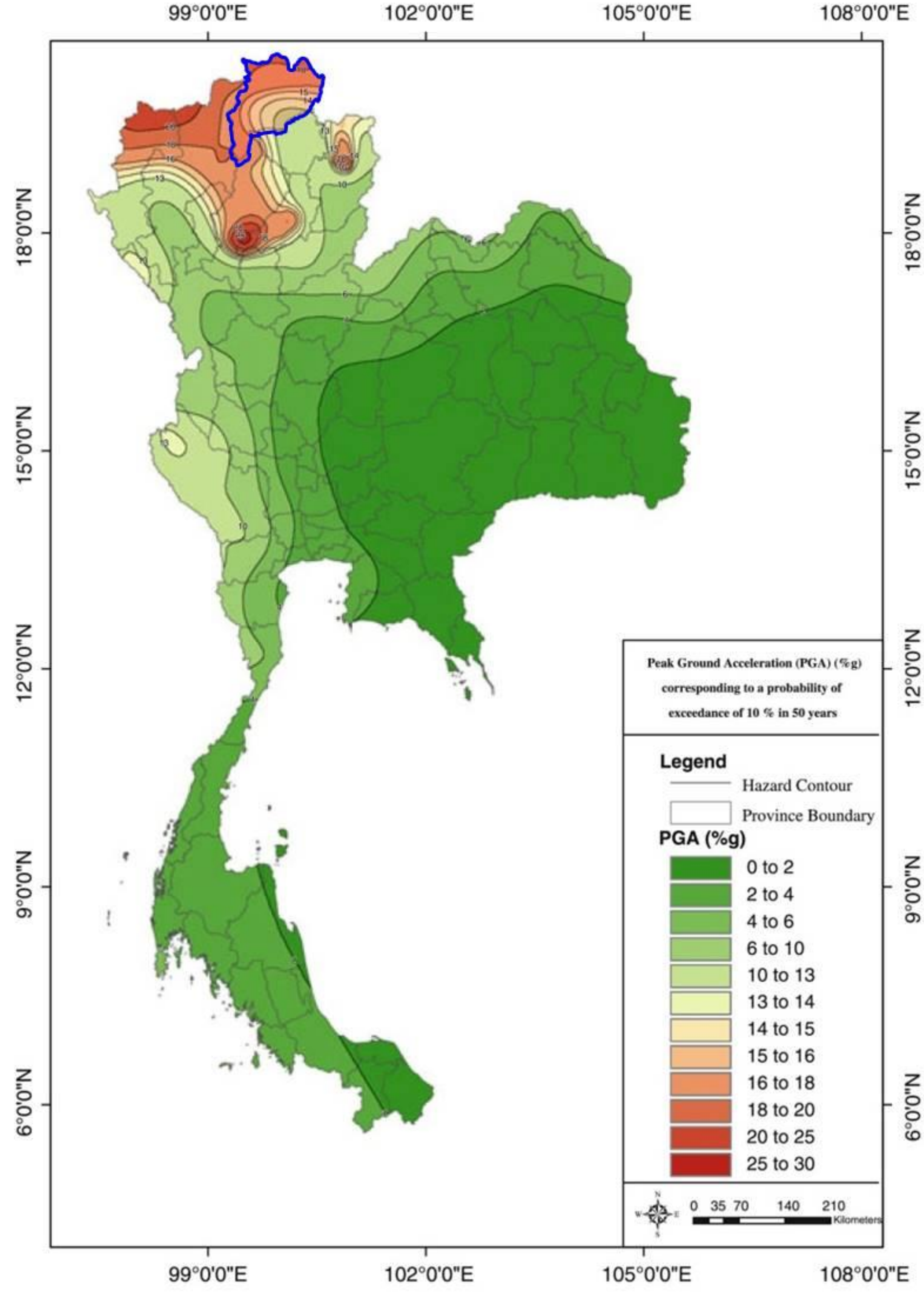

Figure 1.6 Thailand hazard map for PGA corresponding to a probability of exceedance of 10% in 50 years (Ornthammarath *et al*., 2011)

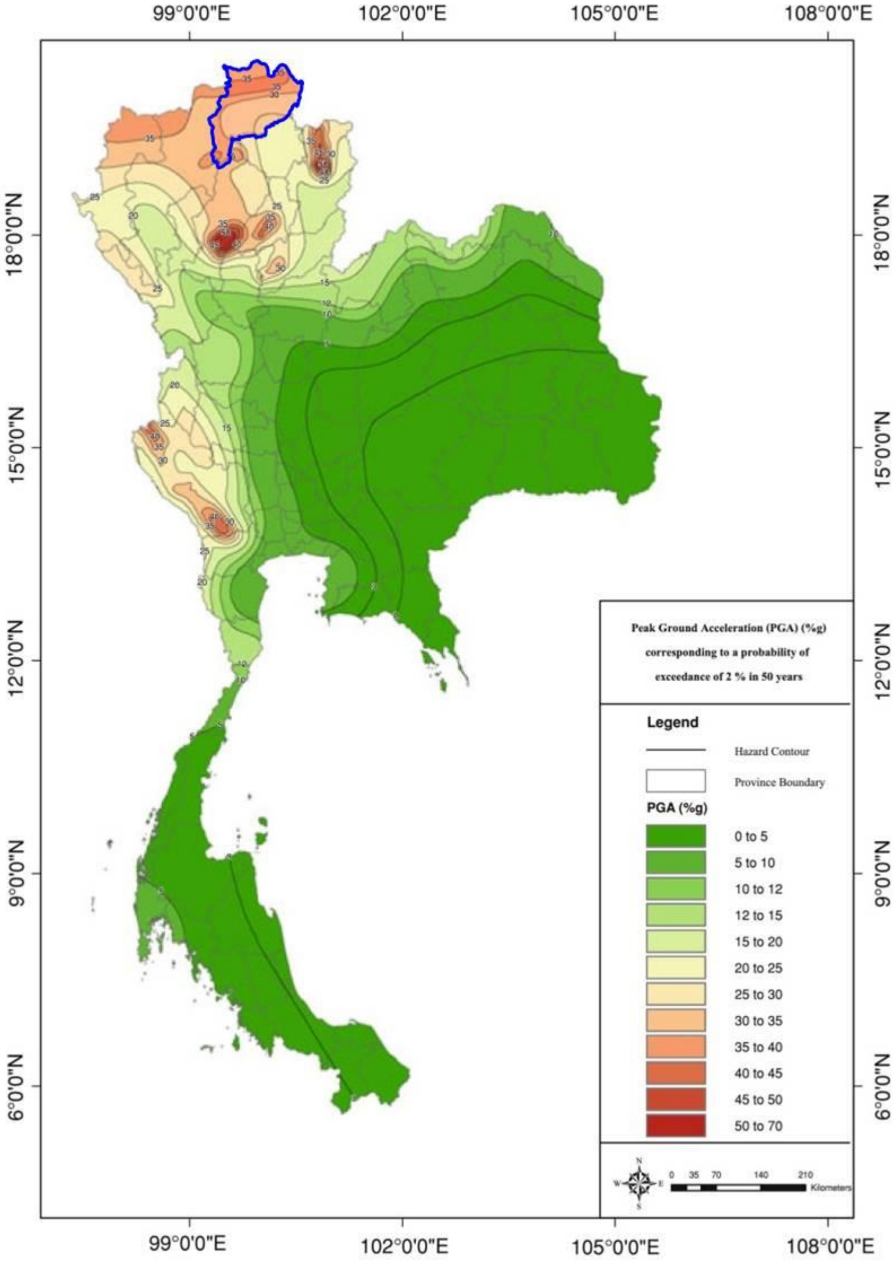

Figure 1.7 Thailand hazard map for PGA corresponding to a probability of exceedance of 2% in 50 years (Ornthammarath *et al*., 2011)

All these seismic hazard maps are based on the reference site condition that is specified to be a boundary between NEHRP classes B and C, with an average shear wave velocity in the upper 30 m of the crust of 760 m/s. Then, the ground motion represented by PGA is in the range of 0.8-28%g, corresponding to the 475 year return period and in the range of 1.3-65%g, corresponding to the 2,475 year return period.

3) Mae Lao Earthquake and Damage Assessment

The recent big Mae Lao earthquake with a magnitude of 6.3 reported on May 5, 2014 with the epicenter at Latitude 19.748 N, Longitude 99.692 E reported by the Seismological Bureau, Thailand Meteorological Department (TMD). The epicenter of the earthquake was about 7.4 kilometers underground in Dong-Mada located at south of Mae Lao District (Weerachat and Suvit, 2014) and 27 kilometers southwest of Chiang Rai Municipality, Thailand (Figure 1.8). The earthquake was recorded as strong vibration shaking both northern of Thailand and neighboring Myanmar. It was the strongest earthquake ever recorded in Thailand, according to the National Disaster Warning Center. That caused approximately $28 Million in direct building damage value. The damage can be summarized according to the buildings damage investigation labeled by green, yellow and red paint-sign ranged from high to low damage as shown in Table 1.1.

Table 1.1 Summary of the buildings damaged level (Ornthammarath, 2014)

District	Red (Heavy damage or collapse)	Yellow (Moderate damage)	Green (Slight damage)
Mae Lao	378	1,631	2,892
Mae Suai	34	39	1,224
Mueang Chaing Rai	34	89	639
Phan	152	578	3,022
Total	598	2,337	7,777

The color labeled during the site investigation after the earthquake was performed suddenly to classify and recommended for the utilization as Figures 1.9 - 1.10. The utilization, according to the damage level can be classified as red paint-sign and yellow paint-sign were unable to use, whereas green paint-sign were useable. It can be seen from Table 1.1 that 2,935 buildings cannot be used and needed to repair (red and yellow).

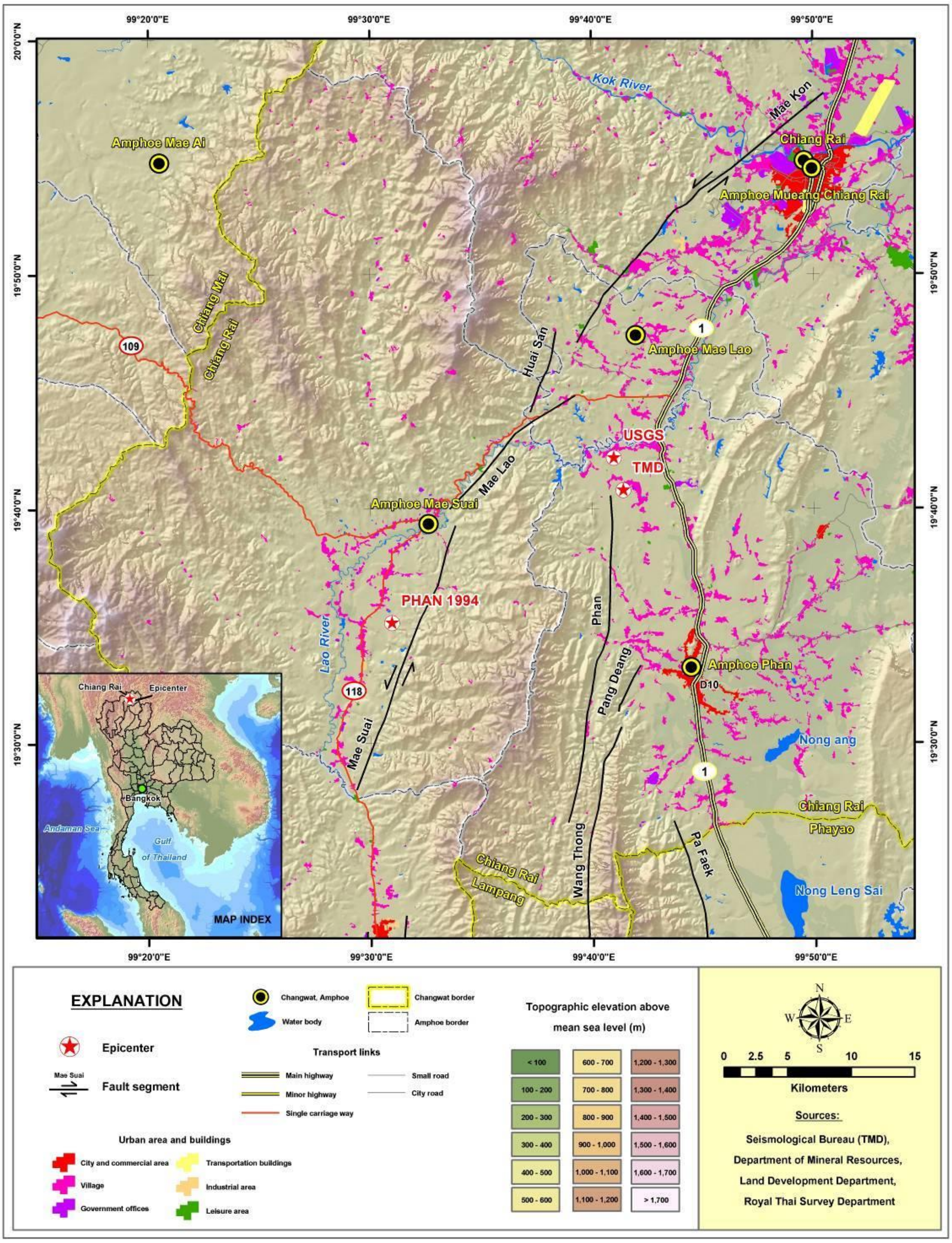

Figure 1.8 Epicenter and surrounding areas (Ruangrassamee *et al*., 2014)

Figure 1.9 Building damage Levels (Green, Yellow, and Red paint-sign)

(a) (b)

Figure 1.10 (a) An elevated one-story reinforced concrete house in Dong-Mada sub-district (b) eccentrically placed Unreinforced Masonry Bearing Walls (URM) fills and failure (Ruangrassamee, 2014)

Figure 1.11 represents typical 3-storey school building in Thailand where the ground floor has a large space, creating a first soft story. Maelaowittayakom school in Mae Lao district has been damaged due to this earthquake event.

Figure 1.11 Maelaowittayakom school in Lae Lao district, Chiang Rai Province

1.2.3 Loss estimation using GIS applications

An earthquake is a natural disaster that can be tremendously destructive in a vast area of massive ground shaking. The GIS application is a suitable tool for assessing the spatial risk to understand the damage characteristic. Hansapinyo and Saicheur (2013), Saicheur *et al*. (2014) presented the spatial earthquake loss estimation in Chiang Mai Municipal and Mae Chan Municipal. The study focuses on a spatial study of the seismic performance of buildings to establish an earthquake scenario with a magnitude of 6.0. The results of the study buildings collapsed was first estimated and then the number of deaths caused by the building collapse was approximated. The number of casualties is due to direct structural damage for any structural type. The estimates are base on loss of life that occurred on probability of collapse given a complete damage state.

The building damage estimation was based on the concept of the capacity-spectrum method. The method combines the ground motion input in terms of the response spectra with the building’ s specific capacity curve varying from building type, construction quality and local building regulations. Figures 1.12-1.13 represent the complete damage (collapse) of the buildings in Chiang Mai Municipal and Mae Chan Municipal, respectively.

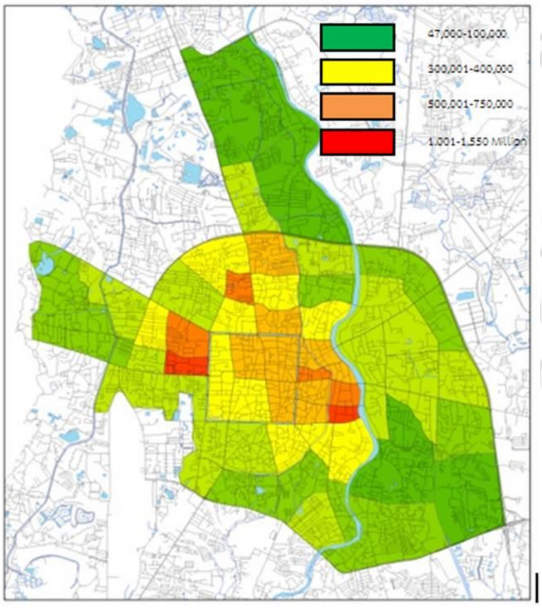

Figure 1.12 Complete damage (collapse) of the buildings in Chiang Mai Municipal (Hansapinyo and Saicheur, 2013)

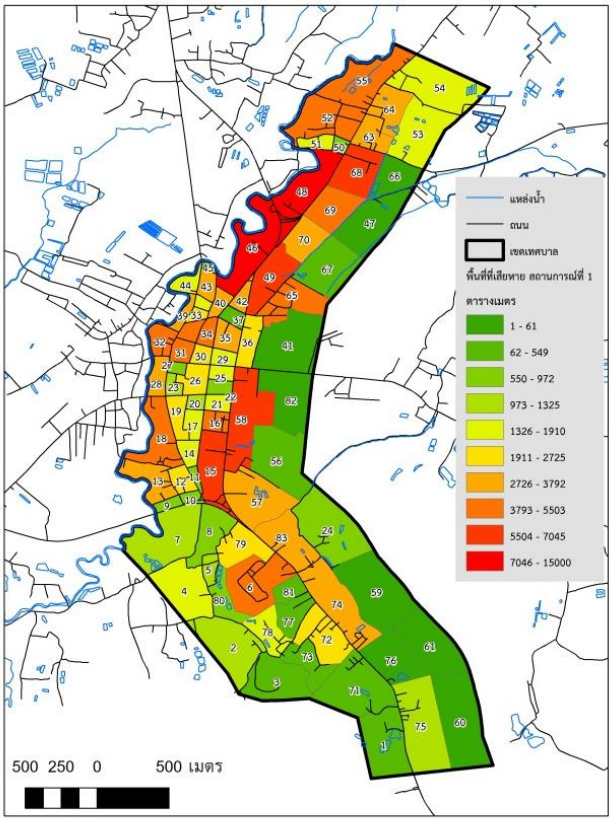

Figure 1.13 Complete damage (collapse) of the buildings in Mae Chan Municipal (Saicheur *et al*., 2014)

1.2.4 Seismic risk assessment by Fuzzy logic model and artificial neural network

Sen (2010) used fuzzy logic for evaluation on existing buildings against possible earthquakes of magnitude 7 or over in Istanbul City municipality. The buildings were classified into five distinctive in terms of fuzzy sets as “without”, “slight”, “moderate”, “heavy” and “complete” hazard categories. This fuzzy logic model was applied for 1249 existing reinforced concrete buildings. The model inputs and outputs were fuzzified with expert views and logical implications were proposed between the input variables and output. Input assessment variables were storey number (S_n), soft story (S_s), cantilever extension (C_e), visible quality (Q_v), weak story (W_s), pounding effect (P_e), Hill-slope effect (H_{se}) and peak ground velocity (PGV), as seen in Figure 1.14.

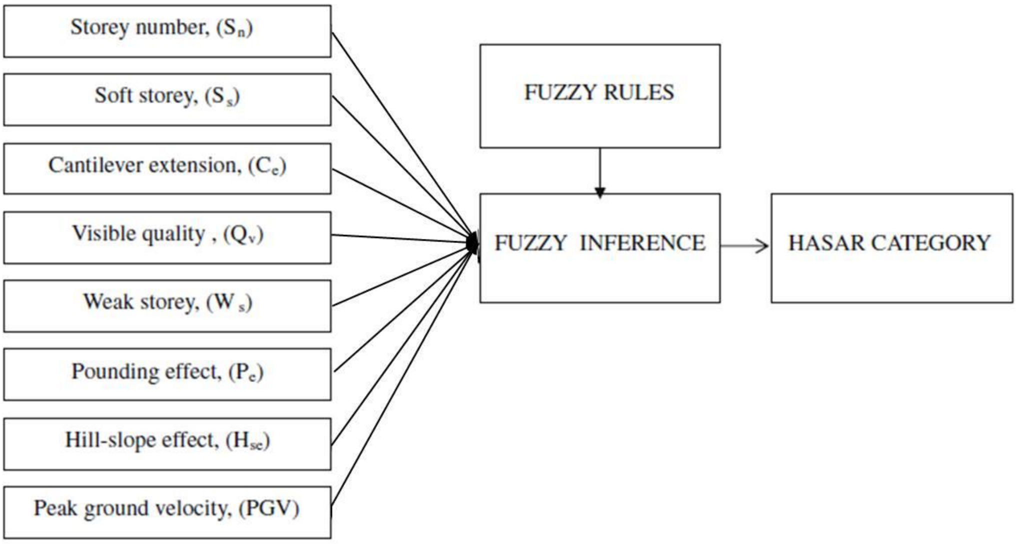

Figure 1.14 Fuzzy logic model components for external inspection (Sen, 2010)

For the input variables, all the factors were converted into fuzzy sets (linguistic variables), fuzzy membership function (MFs) (Figure 1.15), fuzzy-rules and then fuzzy inference system (FIS) was used for the categorization of each building into a few of the five hazard categories.

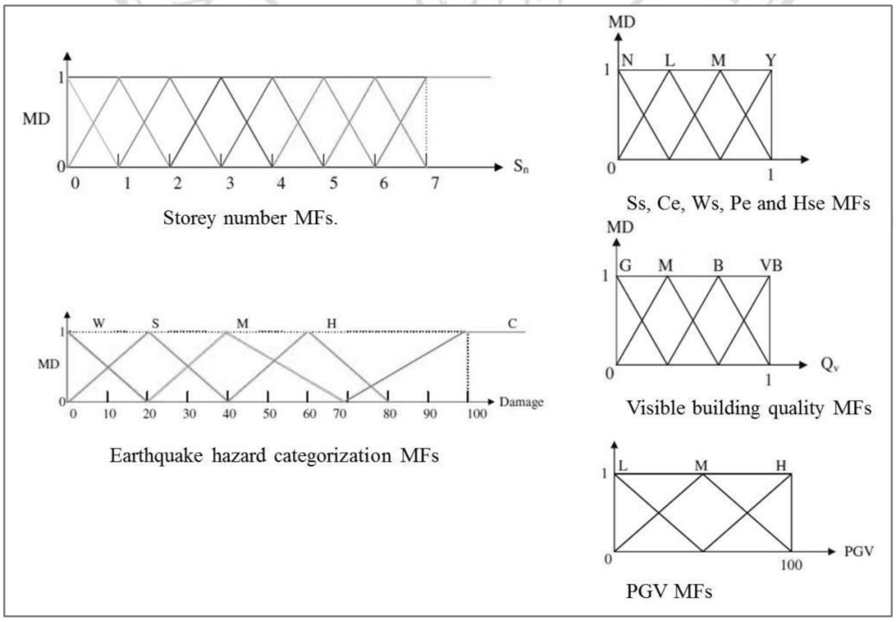

Figure 1.15 Fuzzy membership functions for input and output variables (Sen, 2010)

It was found that 49% of the buildings fall within the “complete” and “heavy” hazard categories. The majority of the buildings falls in the “moderate” hazard category.

Sen (2011) used fuzzy logic for internal evaluation on 747 existing buildings in Zertinburnu quarter of Istanbul City. The interior inspection assessment was considered factors comprising of the story number (building height), storied height ratio, cantilever extension ratio, moment of inertia (stiffness), number of frames, column and shear wall area percentages, as seen in Figure 1.16.

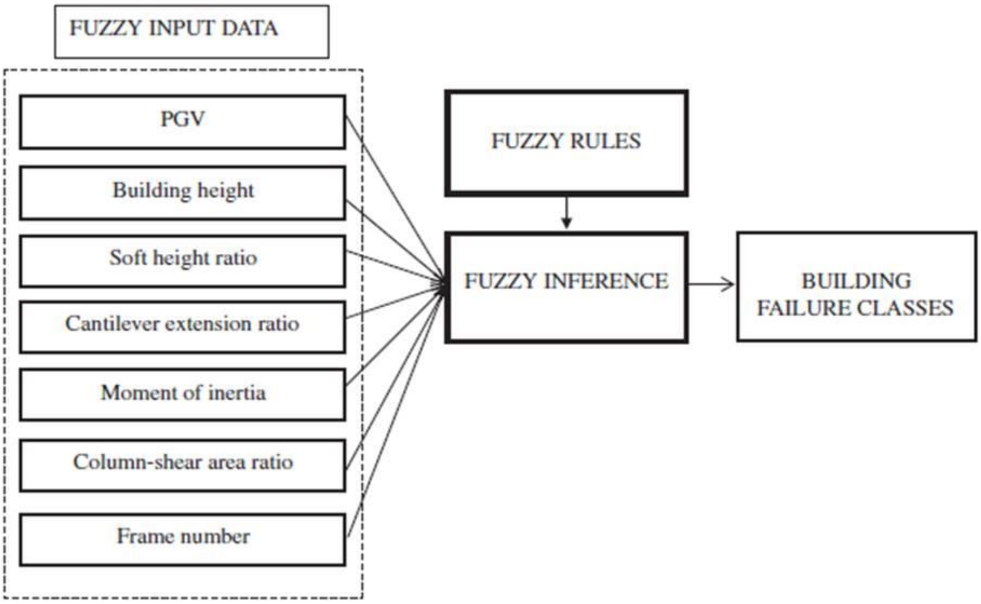

Figure 1.16 Fuzzy logic model components for an interior inspection (Sen, 2011)

It is observed that these buildings are categorized into “none”, “slight”, “moderate”, “extensive”, and “complete” hazard classes with 7.6%, 50.0%, 14.6%, 20.1% and 87.7%, respectively.

Deb and Kumar (2004) presented a method of assessment of seismic damage of reinforced concrete buildings using fuzzy logic. The fuzzy inputs for earthquake ground motion were expressed as predominant frequency of ground motion for different soil conditions, critical damping of soil and strong motion duration. The fuzzy input data in structural parameters were expressed as viscous damping, pre-yielding stiffness ratio, post-yielding stiffness ratio, ductility, cyclic loading coefficient and the materials quality based on ultrasonic pulse velocity. Finally, a damage index corresponding to the damage state of buildings was estimated by applying the defuzzification method, which converts the fuzzy linguistic variable to real number. The damages conditions of buildings were expressed as nonstructural damage, slightly structural damage, moderate structural damage, severe damage and collapse.

Vahdat *et al*. (2014) used fuzzy multi-criteria decision making to assess seismic risk and help decision makers to screen and prioritize multiple regions in seismically prone areas. There are many complex factors to be considered (as seen in Figure 1.17) requiring a form of Multi-Criteria Decision Making (MCDM) system to be adopted.

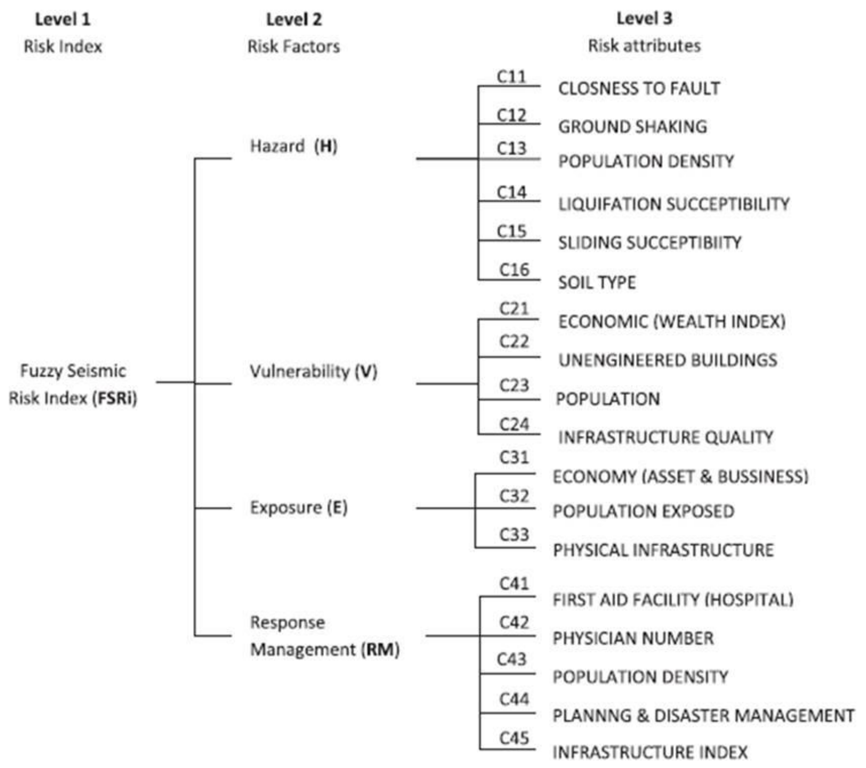

Figure 1.17 The structures for seismic risk system

Level 1 conveys the objective of the problem, which is defined as a “fuzzy seismic risk index” (FSRi). Level 2 represents a set of factors that play a major role in characterizing the seismic risk context. In Level 3, four major factors, including hazard (H), vulnerability (V), exposure (E) and response management (RM), are further broken down into more detailed attributed to reflect precise seismic risk aspects. The risk model was established in four phases, including risk identification, risk analysis, risk aggregation and ranking (rank the results based on relevant indices).

Effati *et al*. (2014) presented a geospatial neuro-fuzzy approach for identification of hazardous zones on regional transportation corridors. To demonstrate the framework, a prototype is developed and tested on Qazvin – Rasht (Iran). Research methodology helps regional roads decision makers to determine which hazard factors are the most important ones, and ultimately to decide where hazard mitigation strategies should be employed. Figure 1.18 shows the overall research design.

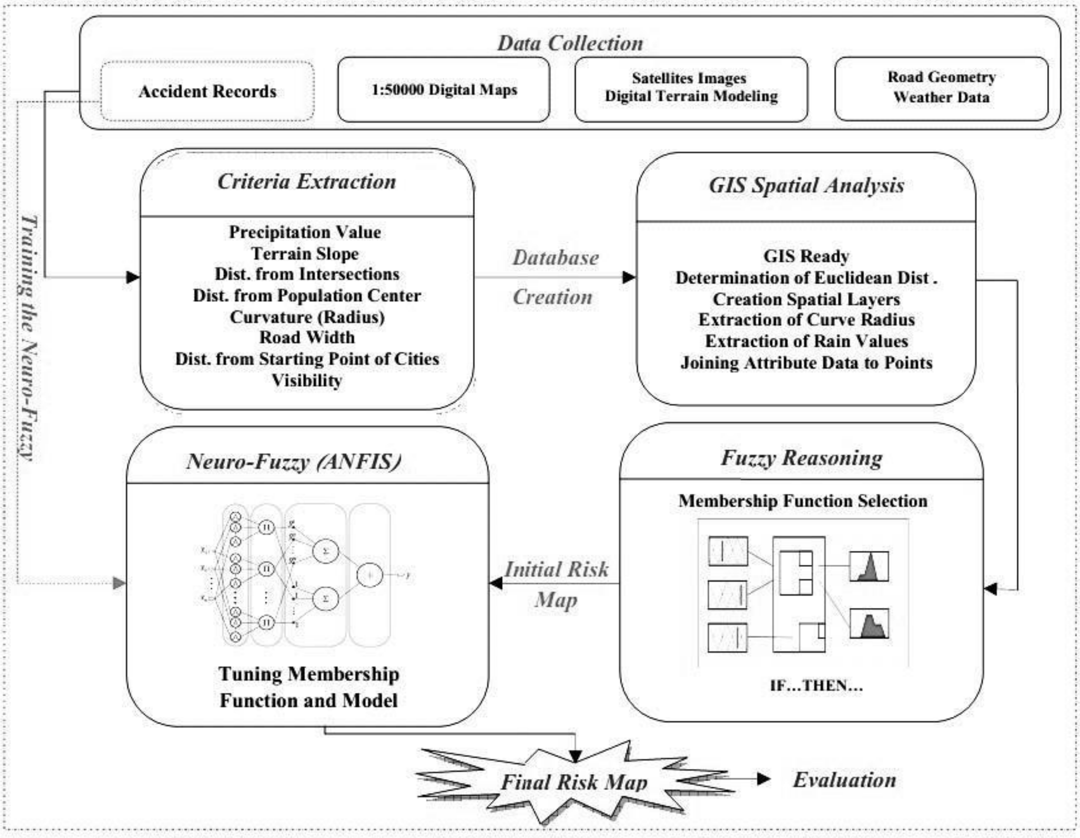

Figure 1.18 Research methodology for identification of road hazardous zones (Effati *et al*., 2014)

Figure 1.19 shows the structure of a fuzzy inference system for identification of road hazardous zones. Although fuzzy logic can encode expert knowledge using linguistic labels, it usually takes a lot of time to turn the membership functions which quantitatively define these linguistic labels. Figure 1.20 shows the architecture of artificial neural networks for the identification hazard zone.

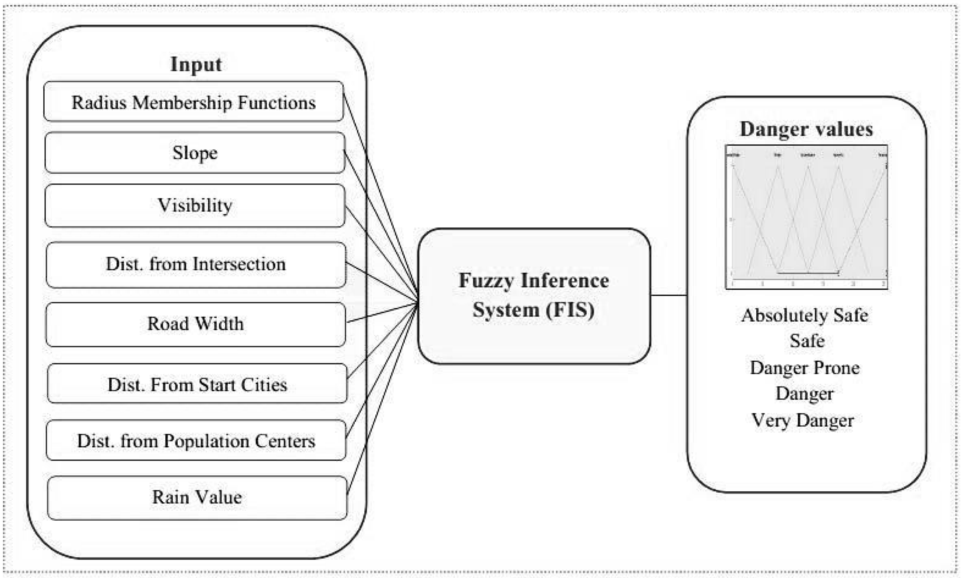

Figure 1.19 Fuzzy inference system for identification of road hazardous zones (Effati *et al*., 2014)

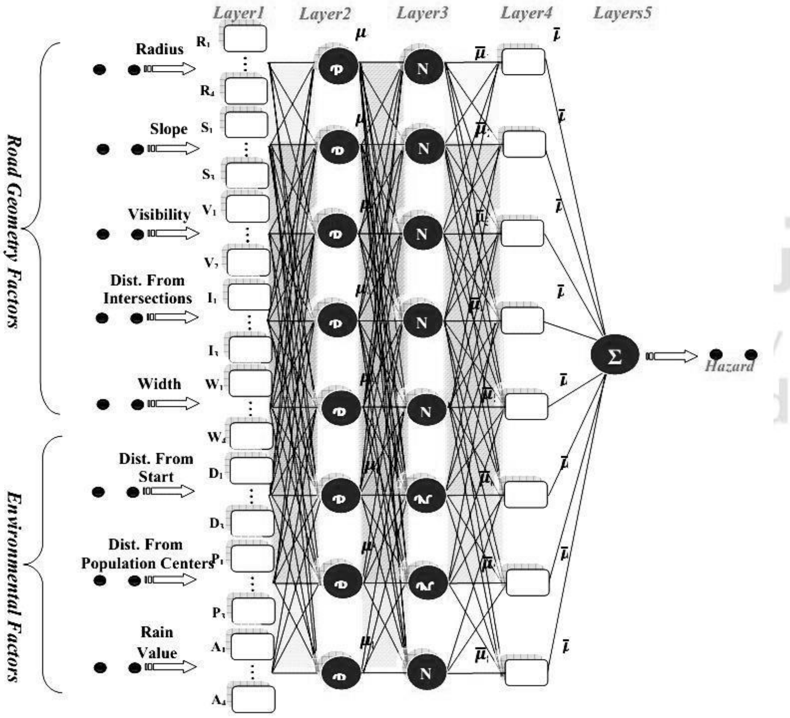

Figure 1.20 Proposed Antificial Neural Fussy Inference System (ANFIS) structure for road hazardous zone identification (Effati *et al*., 2014)

Vahidnia *et al.* (2009) developed an artificial neural network (ANN) for landslide susceptibility assessment in Mazandaran Province, Iran. Controlling factors such as lithology, land use, slope angle, slope, aspect, curvature, distance to fault and distance to drainage were considered as explanatory variables. Data of 151 sample points of observed landslides were used to train and test the approaches. It has been found that ANNs, specifically Multilayer Perceptron (MLP) model, have several advantages for landslide susceptibility mapping, such as the ability to handle imprecise and fuzzy information, fault and failure tolerance, high parallelism, non-linearity, robustness, capability to generalize and tolerance to noise data and thus have the capability to analyze complex data patterns. The number of neurons in the input layer is equal to the number of data sources and the number of neurons in the output layer is constrained by the application and represented by the number of output. The number of hidden layers and the number of neurons in each layer depends on the architecture of the network and usually are determined by trial and error. The network weights are then modified in the training process by a number of learning algorithms based on back propagation learning.

1.3 Research Objectives

1.3.1 To explore and develop an update building information, for seismic disaster management in Chiang Rai Municipality.

1.3.2 To apply Fuzzy and Artificial Neural Networks forecasting models for direct prediction of the spatial distribution to an earthquake scenario.

1.3.3 To enhance the capability of Multi-Criteria Decision Making (MCDM) for building incremental rehabilitation in the regional scale.

1.4 Scope of Research

1.4.1 The Seismic Disaster Management in this study considering only in the Chiang Rai Municipality, Thailand, as show in Figure 1.21.

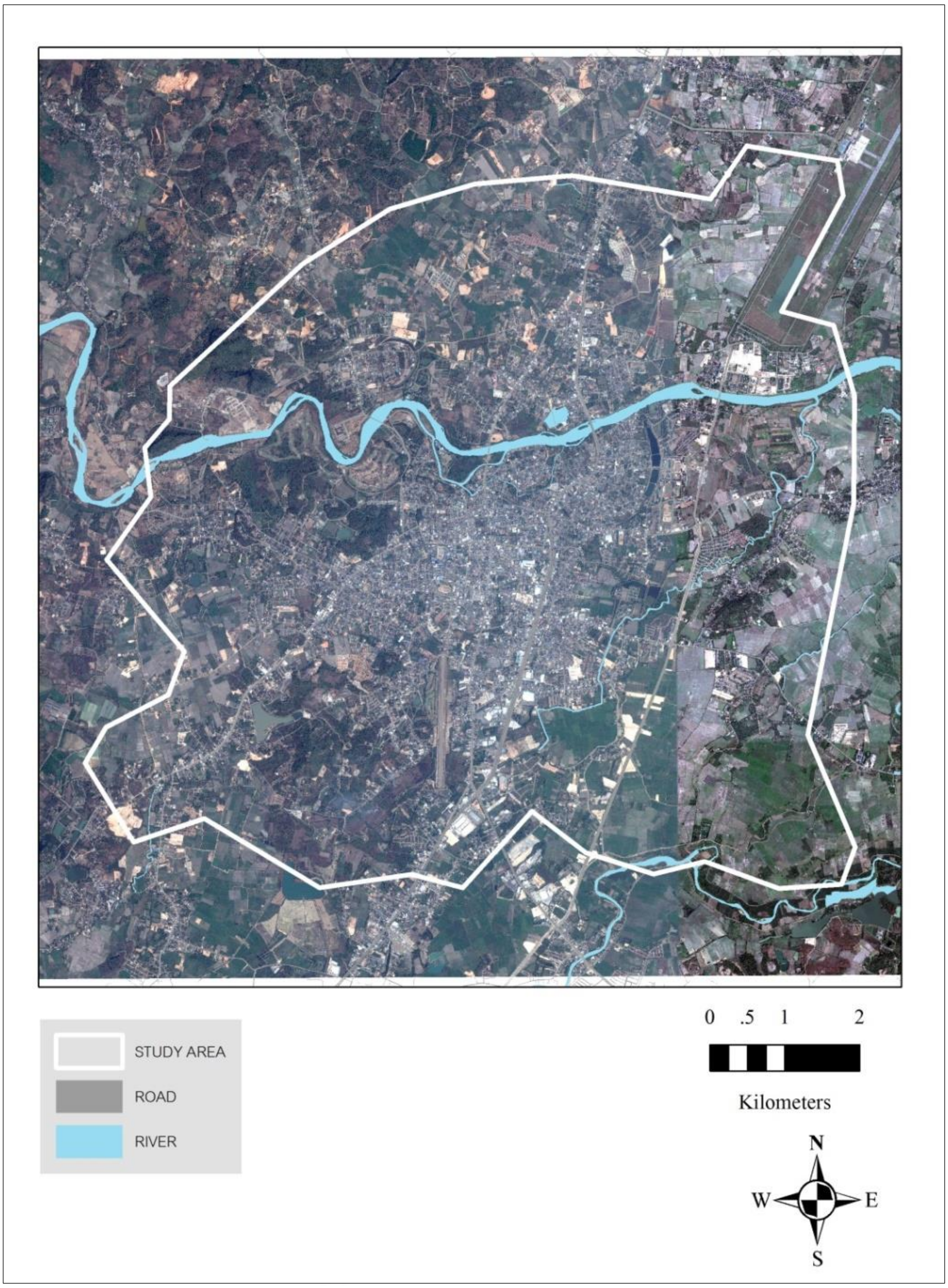

Figure 1.21 Study area, Chiang Rai Municipality

1.4.2 Assessment of the severity of the earthquake risk by GIS-based approach.

1.4.3 The Fuzzy and Artificial Neural network model will be constructed through supervised learning utilizing historical earthquakes and regional geological data (Thailand & adjacent areas) as training sets.

1.5 Research Contribution

1.5.1 The Building information for assessing the severity of an earthquake that may occur in the study area.

1.5.2 Information for the assessment of vibration impact on the study area.

1.5.3 Seismic hazard showing the risk intensity in the Chiang Rai Municipality, Thailand.

1.5.4 General geographic information system (GIS) map to show the impact of the spatial patterns of immigration and to support the appropriate severity level.