Seismic Site Classification and Soil Amplification Assessment of Chiang Rai City, Northern Thailand

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ABSTRACT

One of all the natural disasters that cannot accurately predict is earthquake. There are a lot of histories that show many earthquakes around the world since the past to the present. Each earthquake made many damages, large or small area, related with the intensity of earthquake and the properties of area such as type of soil, rock and building etc, like the biggest earthquake on May 5, 2014 that located in Amphoe Pan, northern of Thailand. This earthquake affects economic, society and lives because it is in big city, Amphoe Pan, which consists of many houses and buildings. Many researches show the soil responds and sensitive with strong earthquakes. Moreover the property of Amphoe Muang, changwat chiangrai area is covered soft soil layers. So soil amplification is one of the most important factors that controlling the damage in areas when was strong earthquakes. This study, soil amplification is analyze forty-six sites in Amphoe Muang, changwat Chiangrai, using geophysical data, shear wave, and geotechnical data, soil profile, to consider with SHAKE 2000 software. The result of study area, the maximum value of amplification is 3.58 g and shear wave velocity of this study is 200 to 562 m/s. Finally, there are accurate soil amplification and average shear wave at 30 depths map of the result.

Key words: Soil amplification, Earthquake hazard, MASW, Changwat Chiang Rai

1. Introduction

Thailand has hypocenters from active faults area in both Thailand and neighbor country. Most faults located in northern and western of Thailand including Maechan fault, Tern fault and Payao fault. Chiang Rai, at the northern of Thailand, locates on active fault and soft soil sediment about 2 - 8 meters depth from surface (Anantaasech and Thanadpipat, 1985). Many researches explained about earthquake which occur and respond to the soft soil layer that relate to the geological data of Chiang Rai area. And Chiang Rai is one of a big city in the northern Thailand that has high population, many buildings and many earthquakes so the earthquake occurred in this area can become immense damages. Moreover, there are high

building and population that can be affected by earthquakes. There are many earthquake researches such as in 2003, Pichai studied about liquefaction resistance of sands in the northern part of Thailand. He used geotechnical data, borehole data and SPT test of Chiang Mai and Chiang Rai city to analyze by using SHAKE2000. The SPT N-value was 5 - 20 times per feet, and then it was used to compute shear wave velocity by formula of engineering. Other soil profile was commuted by borehole data of this area. The results showed that shear wave velocity in hard rock is 900 meters per second and soil amplification was 1.5 to 3 times related with each characteristic of earthquake. At last, the increase or decrease of amplification depended on acceleration value.

In 2010, Palasri and Ruangrassamee studied the probabilistic seismic hazard maps of Thailand that were created from earthquakes data recorded by the Thai Meteorological Department and the US Geological Survey from 1912 to 2006. They used the accelerations to predict a peak of horizontal accelerations at rock site with 2% and 10% probabilities of exceedance in 50 years in Thailand. The maximum accelerations were about 0.4 g in the northern Thailand and 0.04 g in Bangkok with 2% probability of exceedance. And the maximum accelerations were about 0.25 g in the northern Thailand and 0.02 g in Bangkok for 10% probability of exceedance.

Thus, soil amplification of earthquake ground motion in Chiang Rai must be studied and analyst by using geophysical data, shear wave by MASW technic, and geotechnical data, soil profile by borehole data and wave velocity, to process for shear wave velocity and consider with SHAKE 2000 software. Finally this research has objectives including: Study the shear wave velocity, Analyze soil amplification of the earthquake ground motion and Illustrate NEHRP map and soil amplification map of Amphoe Muang, Changwat Chiang Rai.

2. Geologic setting

Data from the department of mineral resources (DMR, 2010) showed that Chiang Rai has an area of 20,107 square meters located in the northern of Thailand with 65% covered by mountain range. There are three types of geology including mountain range that located in the western, eastern and southern area, valley plain and fluvial plain that located in the north, central and east of area. The altitude is about 500-2,000 meters above mean sea level. Many high mountains locate along the northern to southern of Chiang Rai. There are four groups of rock in Changwat Chiang Rai. The first group is clay stone, siltstone, kaolinite located in the eastern of Amphoe Mae Chang. Second group is sandstone such as quartzite-sandstone, feldspar-sandstone, tuff-sandstone, some of clay, siltstone, conglomerate that located from northeastern to southwestern area with mostly mountainous landscape. Third group is shale and the forth is limestone. At the valley plain and fluvial plain, sediments are clay, clayey sand, fine sand, medium sand and some gravel.

Faults in Changwat Chiang Rai are Chiang Saen Fault Zone and Mae Chan Fault which are 150 kilometers length from Laos to Amphoe Chiang San, Mae Chan hot spring, Kok River and Amphoe Fang. Moreover, these faults are active fault because there is evidence shows the uplift in quaternary sediment.

3. Study area

This research is about to study the shear wave velocity, and to analyze soil amplification of earthquake ground motion to create NEHRP map and soil amplification map of Amphoe Muang, Changwat Chiang Rai. There are 46 locations of shear wave velocity survey that including previous (Thitimakorn et al., 2012) and present MASW surveys.

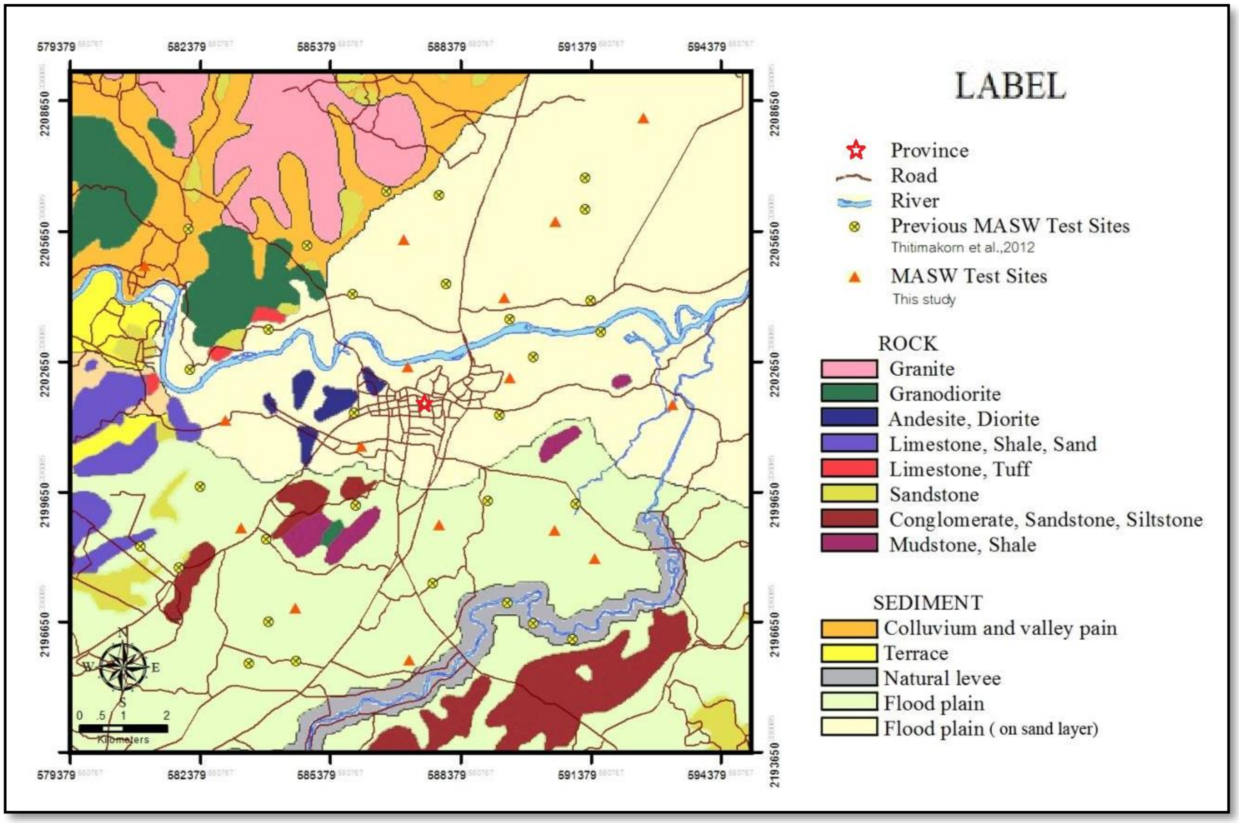

Figure 1. Geological Map of Chiang Rai, at the northern of Thailand, showing the study area where are 46 locations of shear wave velocity survey that including previous and present MASW surveys.

4. Soil amplification

Earthquake is a disaster that cannot accurately predict or calculated when and where it will occur. The earthquakes will suddenly discharge a lot of energy that gather form sub surface. Each time, the energy is transmitted by seismic waves from the epicenter through the intermediary that is rock and soil to the surface. However, the energy will decrease by distance. If the epicenter is far from surface, the energy will be less than the energy from epicenter near surface. The traveling of seismic wave is difference in intermediary according to the properties of each area. So the intermediary is significant to the effects of the occurring earthquake. For example, when wave travels through the bedrock, the wave will be reduced. But when the waves travel through soft soil or sediment layers, the wave will be amplified because these layers' properties response to the earthquake. Besides, if the period of wave is equal to the period of soil, seismic waves would have amplified even more as well.

5. Methodology

The first step is the collecting of geotechnical data, i.e. borehole data of Changwat Chiang Rai received from Department of mineral resources, Thailand. This borehole data is formatted to create standards soil profile of Amphoe Muang, Changwat Chiang Rai. Next, seismic refraction survey is performed to collect P-wave and shear wave velocity. Seismic refraction survey shows

P-wave velocity and surface wave analysis shows shear wave velocity. Then, these data including soil profile, P-wave and shear wave velocity are filled in SHAKE2000 program to analyze for soil amplification.

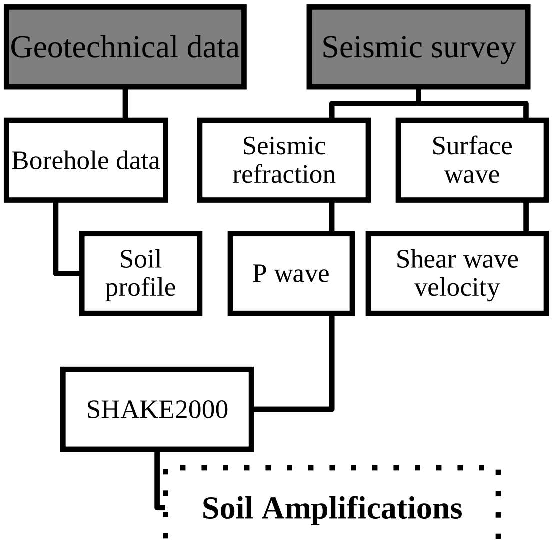

Figure 2. The completed flow chart of methodology in this study.

6. Soil profile

Soil profile used in SHAKE 2000 program is properties of soil such as soil type, thickness at depths, unit weight and shear wave. Soil profile is importance to process in the program so the accurate soil profile has to be determined by geotechnical data like borehole data (Figure3.) and soil properties testing. But this study does not have more borehole data. Therefore, the borehole data form Department of mineral resources was gathered and differentiated. Then these data were divided to group of soil type by shear wave velocity to be a soil profile of each site in this study area.

The ranges of P-wave and shear wave velocity are shown in table 1. All borehole data in Changwat Chiang Rai was combined including seven boreholes from Department of mineral resources at Amphoe Wiang Pa Pao, Amphoe Mae Chan, Amphoe Mae Sai, Amphoe Chiang Khong, Amphoe Muang, Amphoe Mae Lao and Amphoe Pa Daet, and a borehole data from department of water resources at Ban Son Khon School. Finally, the bedrock profiles of this study were characterized and got a constant shear wave velocity about 700 m/s (Borcherdt et al., 1991).

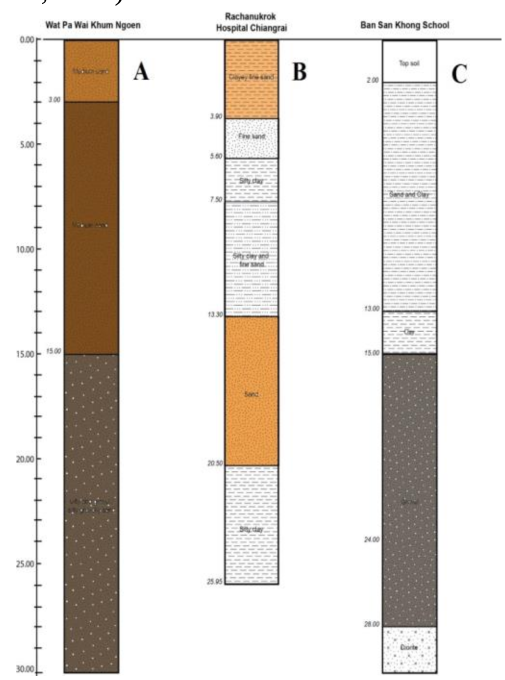

Figure 3. Sample borehole data in Amphoe Muang, Changwat Chiang Rai, A: Wat Pa Wai Khum Ngoen, B: Rachanukrok hospital and C: Ban Son Khon school.

Table 1. P-wave and shear wave velocity of soil profiles.

Soil Profiles	P-wave Velocity (m/s)	Shear Wave Velocity (m/s)
Clay or waste	377 - 558	70 - 138
Sand	559 - 956	139 - 270
Medium sand	957 - 2,673	270 - 520
Silty sand and some gravelly sand	2,674 - 4,000	521 - 699
Bedrock	> 4,000	> 700

7. Data processing

7.1 MASW technique

The highest quality data from seismic survey was chosen from files in seismic controller program. A good quality data set suggests the surface-wave event is the most prominent seismic event as a bad quality data set is normally contaminated by noise.

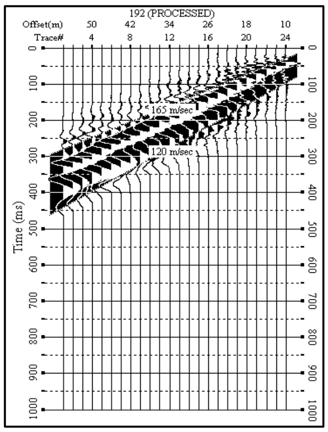

Figure 4. The highest quality data from seismic survey

Then Dispersion between the possessing of frequency and phase velocity domain, and also signal-to-noise ratio curves. This data can be inspected and managed. The color area at the bottom shows the range of amplitude that relates with the frequency.

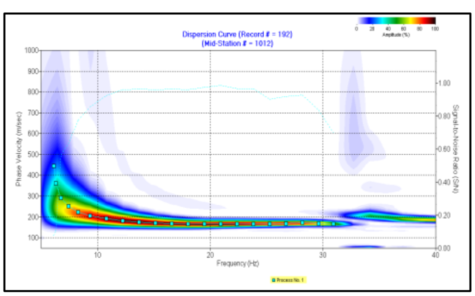

Figure 5. Dispersion curves show between the possessing of frequency and phase velocity domain

Then the Inversion curve shows the relation between velocity and frequency.

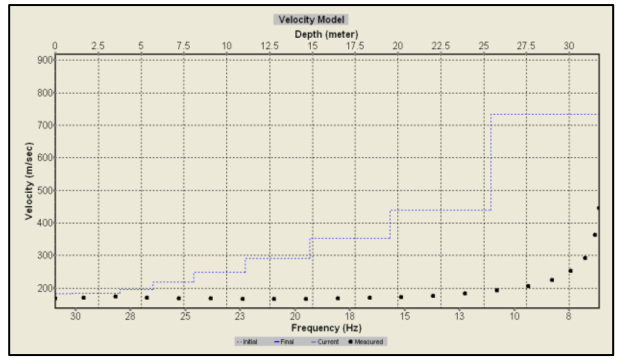

Figure 6. The Inversion curve shows the relation between velocity and frequency

7.2 SHAKE2000

This is a program for site response analysis and will help geotechnical earthquake engineers, geotechnical geologist, seismologist and researchers to analyze site-specific response, soil amplification ratio and the earthquake effects on soil layer. The SHAKE2000 program has important roles for geotechnical earthquake engineering and used as learning tool for student.

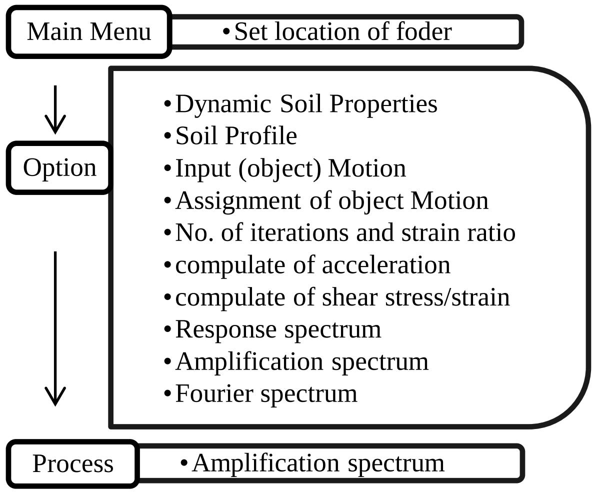

Figure 7. Flowchart of running SHAKE2000 program**.**

There are many earthquake ground motions in this program. It is important to use the similar earthquake occurring in Thailand. The Loma Prieta motion was selected that occurred in Northern California on October 17, 1989 at 5.04 p.m. local time with a moment magnitude of 6.9 and at depth 19 kilometers. In addition, the peak of acceleration is 0.65 g at epicenter that is high.

8. Result

8.1 Amplification

Amplification ratio is an important parameter in earthquake site response study and is a prime result of this research. It is described the ratio of the peak ground acceleration to the peak acceleration at the bedrock. The high value of amplification ratio means the high shaking at the surface that the soil can amplify. The amplification ratio was calculated for all tested locations using SHAKE2000 software. The amplification ratio of the study area ranges from1.77 to 3.58.

Three major zones can be observed namely western zone near the Kok river, north-east and south-west zones. The highest amplification factors are generally observed in soft sediment area (flood pain and some terrace deposits). The lowest amplification ratio is found on the western and eastern parts of the area. The Chiangrai City is situated on the soft soils and has the amplification ratio higher than 2. So, the risk of soil amplification of soils underneath the city is may has to be considered during planning and designing the building or infrastructure in the area.

8.2 shear wave velocity (Vs)

In this study, all 46 shear wave velocity (Vs) data were acquired in the study area using MASW seismic technique. The derived Vs profiles were then weighted average to the depth of 30 meters (Vs30). Then each V (30) was contoured to generate the Vs (30) map which is shown in figure 5.1. The (Vs (30) of the area vary from 200 to 562 m/s. Generally there are 2 zones of Vs (30) distribution observed in the area. The western and eastern part of the study area show high Vs (30) above 500 m/s which correspond to the colluvium, terrace, and some flood plain deposits (see figure 3.2).

The high shear wave velocity may be implied that the soil in this area contain course gained such as gravel and course sand. Conversely the central part including most part of Chiangrai city are characterized by medium to low Vs(30) which are below 380 m/s. Base on geological map it is found that the soil in this part of study area consist of mostly flood plain deposit. From the distribution of Vs(30) of the study area, it is concluded that the City of Chiangrai is situated on the soft and medium to low shear wave velocity soils which will susceptible to some amplification due to earthquake force from surrounding area.

8.3 NEHRP site classification

The Vs (30) data from all MASW test site were used to generate seismic site classification of soils based on recommendation of the National Earthquake Hazards Reduction Program (NEHRP) provisions (BSSC, 2000). Table 2 shows five soil types classified based on the range of Vs(30) values.

There are two class of soils found in this study that are C and D. The soil type C characterizes by very dense soil and soft rock. This soil type is mostly found in the western and eastern part of the study area where the colluviums and river terrace soils are deposited. The soil class D is generally found in central part and consists of mostly stiff to soft soil. Generally the soil class D is considered to be subjected to higher ground shaking than other soil class due to soil

Table 2. Soil type classification for seismic amplification (BSSC, 2003).

Soil Type	General Description	Average Shear Wave Velocity to 30 m (m/s)
A	Hard rock	> 1,500
B	Rock	$760 \leq Vs \leq 1{,}500$
C	Very dense soil and soft rock	$360 \leq Vs \leq 760$
D	Stiff soil 15 ≤ SPT blow count ≤ 50 or 50 kPa Undrained shear strength ≤ 100KPa	$180 \leq Vs \leq 360$
E	Soil or any profile with more than 3 m of soft clay defiled as soil with Plasticity index > 2, water content ≥ 40%, and Undrained shear strength < 25 kPa	≤ 180

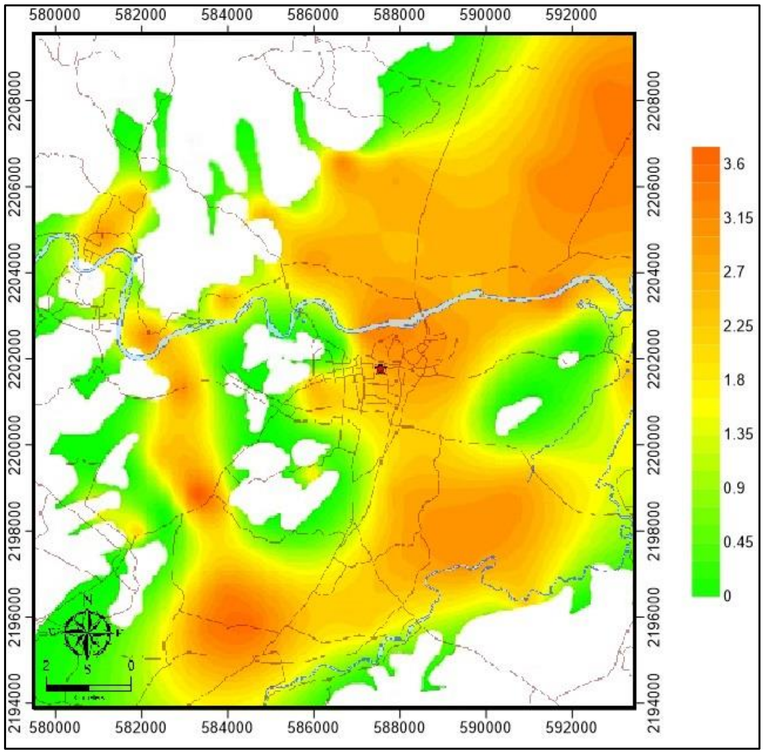

Figure 8. Soil Amplification map of the study area. The highest amplification factors are generally observed in soft sediment area (flood pain and some terrace deposits). The lowest amplification ratio is found on the western and eastern parts of the area.

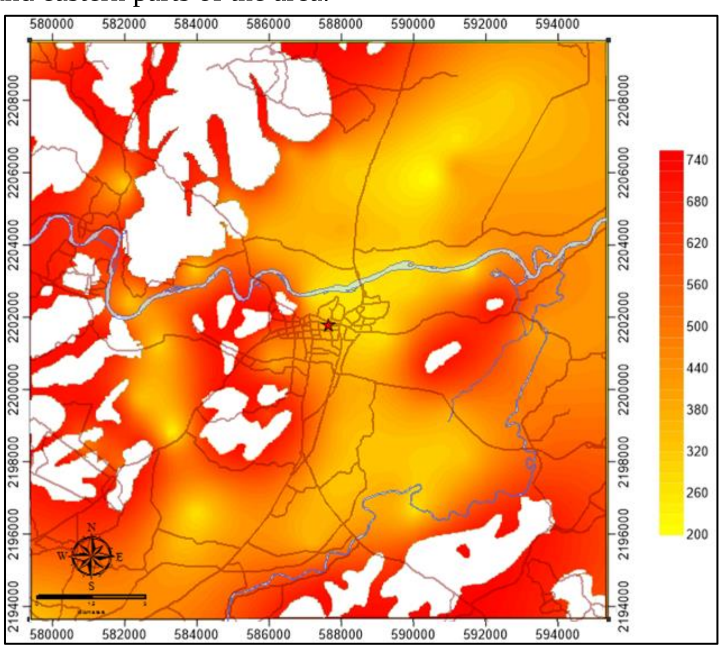

Figure 9. Average Shear wave at 30 meters depth (Vs30) Map. Generally there are 2 zones of Vs (30) in the area. The western and eastern part of the study area show high Vs (30) above 500 m/s which correspond to the colluvium, terrace, and some flood plain deposits

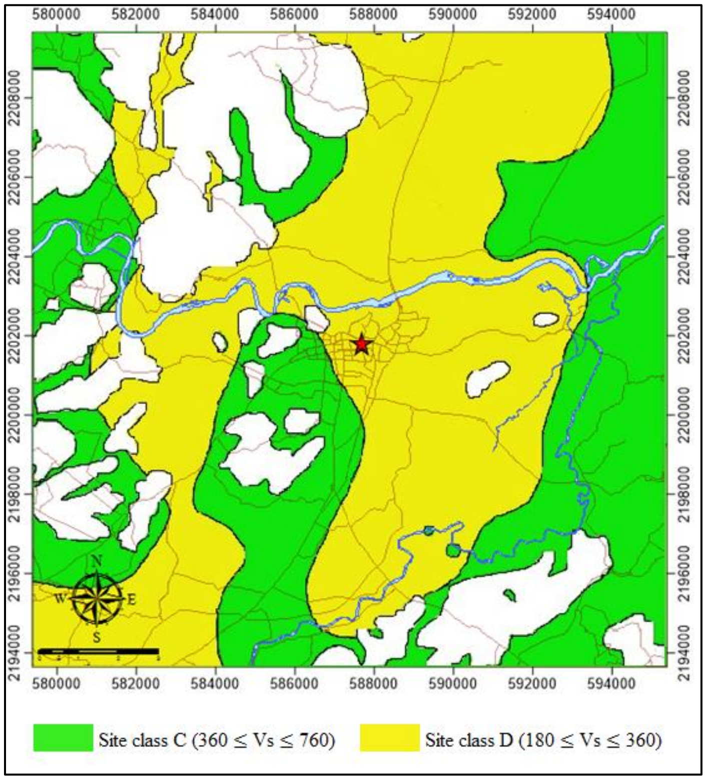

Figure 10. Amplification capability. So, the City of Chiangrai that is situated on soil class D may has some risk from soil amplification.

9. Conclusion and Recommendation

Amplification is defined by SHAKE 2000 program. The result of shear wave velocity is data that were acquired in the study area using MASW seismic technique. The derived Vs profiles were then weighted average to the depth of 30 meters (Vs30).

1. The average shear wave at 30 meters depth (Vs30) is between 200 – 562 m/s. There are two class of soil in this study that are C and D and summary of data obtained from the SHAKE 2000 program.

2. The amplification ratio is between 1.77 – 3.58, is higher in west where near the Kok River that is soil class D . So that soil class D is considered to be subjected to higher ground shaking than other soil class due to soil

This study gathers the borehole data and classifies the group of soil profile in study that may be inaccurate data conversely; the shear wave velocity data were genuinely MASW seismic technique data. Finally the results were combine these data and made the appropriate average shear wave at 30 meters depth (Vs30), NEHRP site classification and Soil Amplification map.

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References

Anantaasech, C., and Thanadpipat, C. 1985. Characteristics and engineering properties of subsoils in intermontane basin. Thailand Engineering Journal 28, 2:101-106.

Borcherdt RD, Wentworth CM, Janssen A, Fumal TE, Gibbs JF (1991) Methodology of predictive GIS mapping for special study zones for strong ground shaking in the San Francisco Bay Region, CA. Proc 4th Inter Conf Seis Zona, 3:545–552.

BSSC, 2000. NEHRP Recommended Provisions for seismic Regulations for New buildings and other Structures, Part1: Provisions, FEMA 368, Federal Emergency Management Agency, Washington, D.C.

BSSC, 2003. NEHRP Recommended Provisions for seismic Regulations for New buildings and other Structures, Part1: Provisions, FEMA 368, Federal Emergency Management Agency, Washington, D.C.

Department of Mineral Resources (DMR), 2010. Geology of Chaingrai, 1st ed. Bangkok, Thailand.

Palasri, C. and Ruangrassamee, A. 2010. Probabilistic seismic hazard maps of Thailand, Journal of Earthquake and Tsunami, Vol. 4, No. 4 (2010): 369–386

Pattararattanakul, P. 2003. Liquefaction Resistance of Sands in the Northern Part of Thailand.Published D.Eng thesis, The Department of Civil Engineering, Faculty of Engineering, Chulalongkorn University.

Srisoros, W., 2003, Seismic Microzonation of Chiang Mai City Using Microtremor Observations, M.Eng. AITThesis, Asian Institute of Technology, Thailand.

Thitimakorn, T. and Channoo, S. 2012. Shear Wave Velocity of Soils and NEHRP Site Classification Map of Chiang Rai City, Northern Thailand. Electronic Journal of Geotechnical Engineering. 17, 2891-2904