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SEISMIC SITE CLASSIFICATION OF NAN CITY, NORTHERN THAILAND

Thanop Thitimakorn[1*], Narongsak Rachukarn[1], and Sasikan Kupongsak[2]

[1]Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok 10330, Thailand

[2]Department of Food Technology, Faculty of Science, Chulalongkorn University, Bangkok 10330, Thailand

*Corresponding author, Email: Thanop.t@chula.ac.th

บทคัดย่อ

เป้าหมายหลักของการศึกษาครั้งนี้คือการจัดทำแผนที่ชนิดของดินจากความเร็วคลื่นเฉือน (Shear-wave velocity) ที่ได้มีการจัดเก็บและวิเคราะห์ด้วยวิธีการวัดคลื่นพื้นผิวแบบหลายช่องรับสัญญาณภายในพื้นที่อำเภอเมือง จังหวัดน่าน ส่วนเป้าหมายรองคือการจัดทำแผนที่ความสามารถในการขยายแรงแผ่นดินไหวเบื้องต้นของพื้นที่ (amplification) ข้อมูลคลื่นพื้นผิวได้ทำเก็บทั้งหมดจำนวน 36 ตำแหน่ง จากการนำค่า $Vs_{(30)}$ ที่ได้มาจัดจำแนกชนิดของดินตามข้อกำหนดของหน่วยงาน NEHRP โดยที่บริเวณอำเภอเมือง จังหวัดน่านพบว่าดินชนิด D ครอบคลุมพื้นที่ส่วนใหญ่ของตัวเมือง ส่วนดินชนิด C นั้นพบบริเวณรอบนอกตัวเมืองน่าน ซึ่งส่วนใหญ่เป็นพื้นที่ใกล้ขอบแอ่งน่านและประกอบด้วยดินตะกอนหยาบเป็นส่วนใหญ่ จากผลการศึกษาค่าความสามารถในการขยายแรงแผ่นดินไหวเบื้องต้นพบว่าพื้นที่ตอนกลางและตะวันออกเฉียงใต้มีค่า amplification สูงกว่าพื้นที่รอบนอก เนื่องจากพื้นที่ส่วนใหญ่เป็นดินตะกอนแม่น้ำซึ่งเป็นดินอ่อนและมีค่า Vs ต่ำ ส่วนพื้นที่รอบนอกตัวเมืองน่านพบว่าดินส่วนใหญ่เป็นดินที่มีขนาดตะกอนหยาบ ทำให้มีค่า Vs ค่อนข้างสูงและมีความสามารถในการขยายแรงแผ่นดินไหวต่ำ ดังนั้นจากผลการศึกษาครั้งนี้สรุปได้ว่าตัวเมืองซึ่งตั้งอยู่บนดินอ่อนที่มีค่าเฉลี่ยความเร็วคลื่นเฉือนต่ำจะมีความเสี่ยงที่จะได้รับผลกระทบต่อการขยายแรงแผ่นดินไหวได้

คำสำคัญ: แผ่นดินไหว, เอ็มเอเอชดับเบิ้ลยู, ความเร็วคลื่นเฉือน, เอ็นอีเอชอาร์พี

ABSTRACT

The primary goal of this study is to generate the NEHRP soil classification map for Nan City using the average shear wave velocity values ($Vs_{(30)}$) derived from the multichannel analysis of surface wave (MASW) data. The secondary goal is to use the $Vs_{(30)}$ data to create the preliminary site amplification map of the area. For this work, MASW data were acquired at 36 preselected sites in the Nan City area. After generating the NEHRP map, it is found that soil class D is present mostly in the central and southeast part of the area, while soil class C is found mainly in the western, eastern, and southern parts. A major part of the city is located on soil class D. The soil amplification map indicates higher amplification in the central and southeast part of the city, where the soil consisted mainly of soft sediments from the alluvial plain and the river terrace. The western, eastern, and southern parts of Nan City had a relatively low amplification, perhaps because the sediment in this part is relatively thin or the bedrock is shallow. The results of the study imply that the major part of Nan city may experience earthquake ground shaking due to amplification of the soft soils.

KEYWORDS: Earthquake, MASW, Shear wave velocity, NEHRP

1. Introduction

Nan city is located in the northern mountain region of Thailand, about 668 km north of Bangkok (Figure 1). The city is a rapidly growing center that occupies a basin with known earthquake sources nearby. Additionally, recent seismic activity has been recorded in the vicinity. Therefore, an up-to-date assessment of the potential seismic hazard is needed. Although several methods can be used to evaluate the seismic hazard for the area, the Building Code can quickly provide recommendations for seismic hazards. The Building Seismic Safety Council (BSSC) established the NEHRP uniform building code for site classification based on the shear wave velocity (Vs) of soil averaged at 30 m depth ($Vs_{(30)}$) [1]. $Vs_{(30)}$ has been reported to be a predictor of earthquake ground-motion amplification in the alluvium-filled basin of California [2], while several other studies have reported that Vs is a key parameter that can be used to quickly and simply assess the ground-motion characteristic parameters of ground-motion, such as the fundamental frequency of the soil profile and the amplification ratio [3-7].

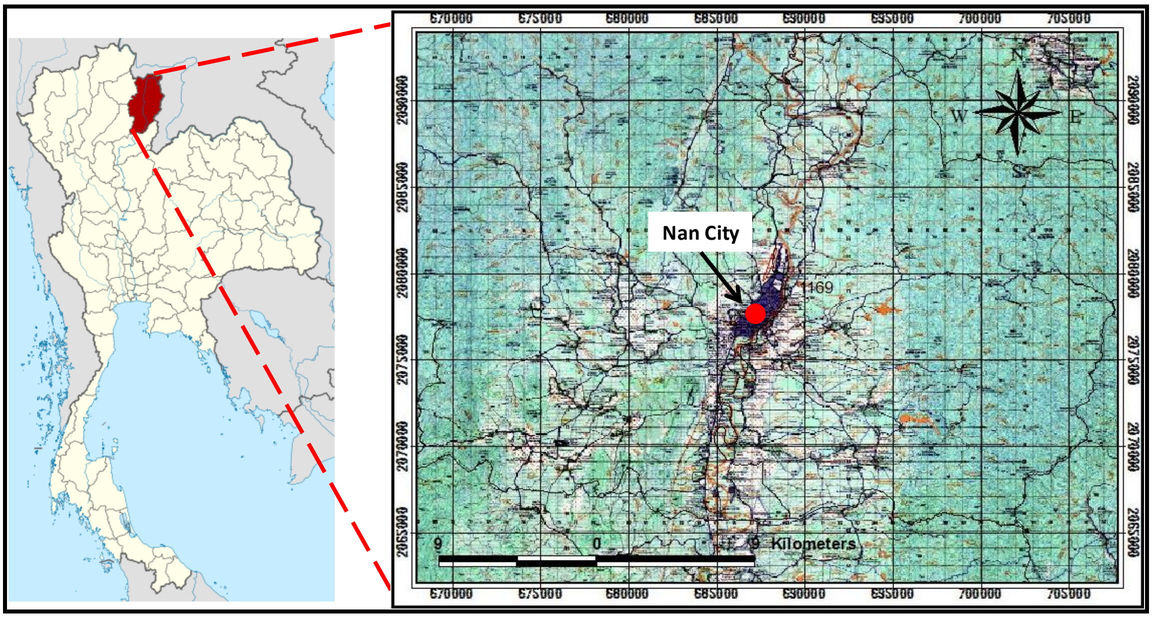

Figure 1 Location of Nan city.

The Vs of soils can normally be determined by borehole measurement, but the cost of this method is quite expensive, and the data acquisition and processing are complicated and time consuming. However, multichannel analysis of surface wave (MASW) is an alternative method that allows a rapid estimation of the soil Vs using the surface wave energy to indirectly determine the Vs profile. Therefore, the objective of this study was to determine the NEHRP site hazard classifications of Nan city using the $Vs_{(30)}$ values derived from the MASW technique. The 36 sets of MASW data were acquired in the city area. All MASW data were then processed and inverted to derive a site-specific Vs profile, and then each Vs profile was averaged to 30 m depth and the NEHRP site class was determined from the derived $Vs_{(30)}$ values.

2. Geology of the study area

Nan city is situated on alluvium sediments of Quaternary age and some colluviums deposited from nearby mountains. Nan River is the major river that runs through the middle of the city and is the major source of sediment in the alluvium plain. Figure 2 shows the geological map of the study area around Nan city. Note that a detailed Quaternary map of the study area was not available at the time of study, and so the sediments were simply called Quaternary sediments (Qa). The thickness of the sediment cannot be estimated accurately due to limited amount of available borehole information. However, some groundwater wells have been drilled in the downtown area with some at a depth of over 100 m that had still not reached the basement. Accordingly, the thickness of the sediment in the basin may be in excess of 100 m in the center and will probably decrease towards the edge of the basin. The northern and eastern mountain range consists of sedimentary rocks and some volcanic rocks of Permo-Triassic age. The western and southern mountain range consists of Jurassic volcanic rocks and sedimentary rocks of Triassic age, whilst the fault systems in the area mostly strike in the N-S direction and are the cause of the intermountain basins found throughout the Northern area of Thailand.

The hazards at Nan city are mostly at a small to moderate level and are due to the ground shaking from the nearby active fault systems, such as the Pua fault zone (No. 6 in Figure 3) which lies from about 30 km to the northeast of the city. The Pua fault is a 68 km long, north-striking, west-dipping normal fault that can generate up to an M7 maximum credible earthquake [8], with a recurrence interval of about 1,700-2,500 years. However, hazards from more distant earthquake sources in Laos in the north east and in China in the north can be substantial due to amplification by the soft soil layers beneath the city.

3. NEHRP site-class and soil amplification

Several methods for classifying soils and rocks based on their site-dependent amplification properties have been proposed [5-6]. For example, the site conditions can be characterized using the average Vs to a depth equal to one quarter of the wavelength of the dominant frequency of interest [6]. However, this method has not been widely used, probably because it is relatively difficult to apply. [5] simplified the method by demonstrating a correlation between the ground motion amplification and the average Vs of the upper 30 m of sediments and/or rocks; this approach has since been incorporated into the NEHRP program. The current NEHRP approach categorizes soils into six classes (A–F) based on their vertical Vs profile, thickness and liquefaction potential.

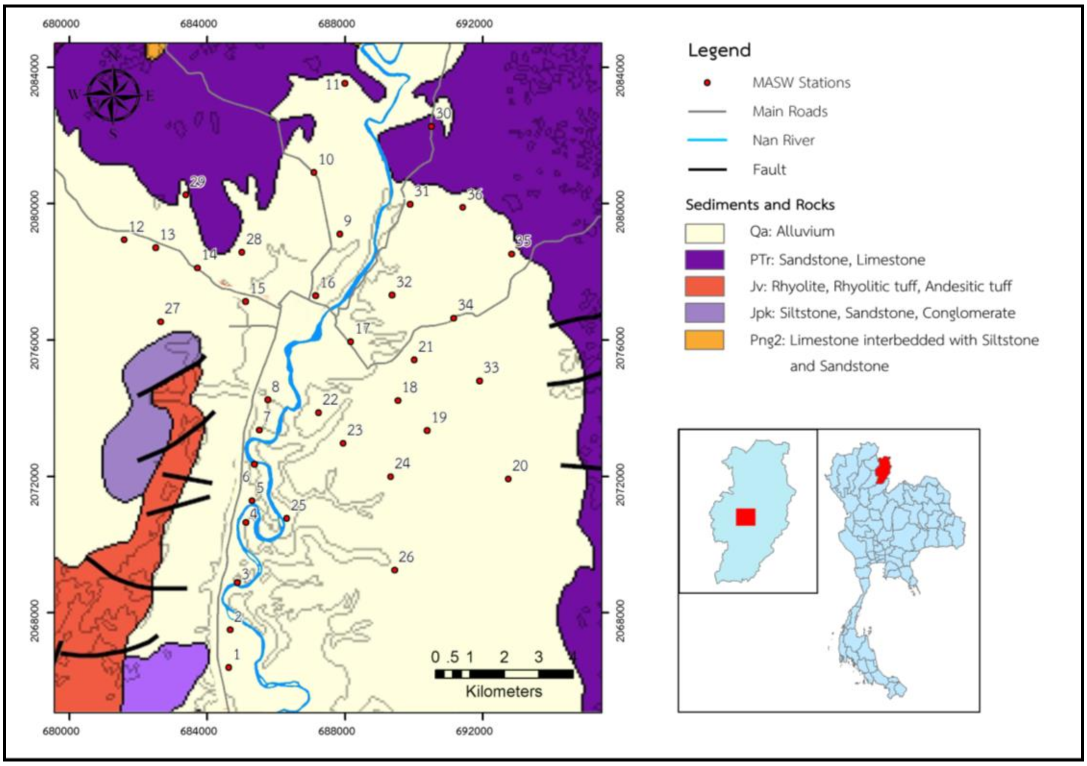

Figure 2 Geological Map of the Study Area.

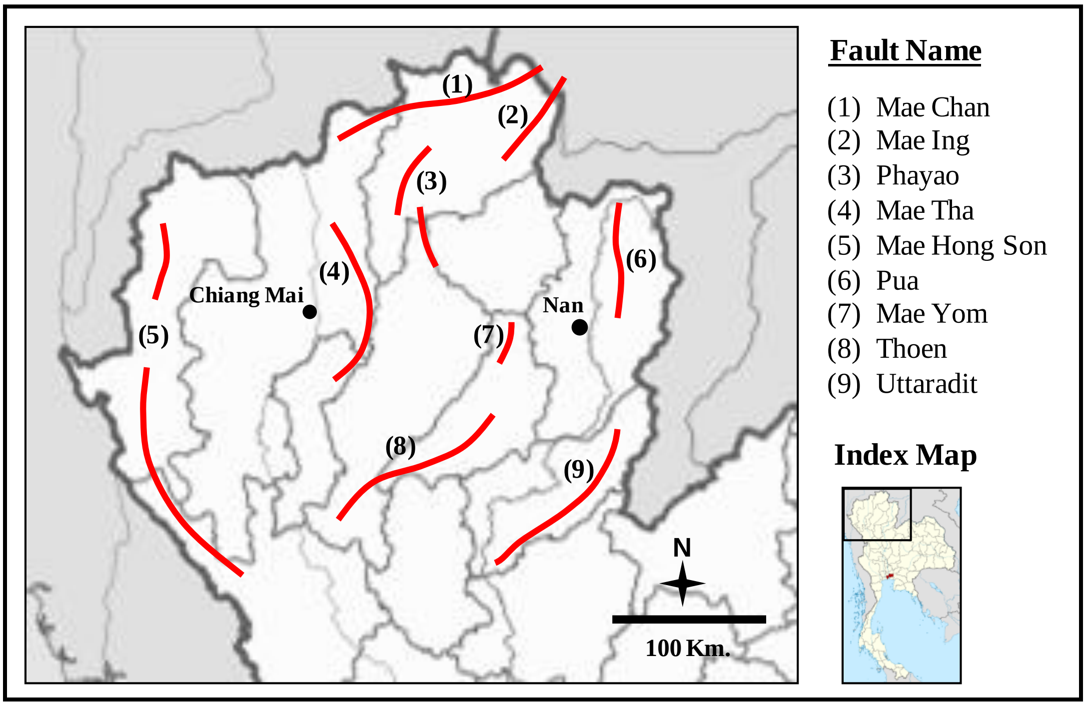

Figure 3 Active fault map of Northern Thailand. The Pua fault is the nearest active fault to Nan city.

For the purpose of earthquake hazard investigations, according to the NEHRP guidelines, the Vs of the soils must be measured or estimated to a depth of 30 m. The $Vs_{(30)}$ at a specific site is calculated using Eq. (1);

$$\overline{Vs} = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{v_{si}}} \tag{1}$$

where $\overline{Vs}$ is the NEHRP $Vs_{(30)}$, v_{si} is the Vs of any layer in m/s, and d_i is the thickness of any layer (between 0 and 30 m).

Table 1 shows the soil profile type classification system used by the NEHRP. [3] evaluated the use of the average values and reported that attenuation affects ground motions as much as the Vs, particularly for deeper geological deposits. Although attenuation is not directly included in current NEHRP provisions, it is accounted for in seismic hazard maps.

Table 1 The NEHRP soil profile type classification for seismic amplification [1].

NEHRP soil type	General description	Average $Vs_{(30)}$ (m/s)
A	Hard rock	> 1500
B	Rock	$760 < Vs \leq 1500$
C	Very dense soil and soft rock	$360 < Vs \leq 760$
D	Stiff soil $15 \leq N \leq 50$ or $50 \text{ kPa} \leq Su \leq 100 \text{ kPa}$	$180 \leq Vs \leq 360$
E	Soil or any profile with more than 3 m of soft clay defined as soil with PI > 20, $w \geq 40\%$ and Su < 25 kPa.	≤ 180
F	Soils requiring site-specific evaluations	

Note: N: SPT blow count, Su: Undrained shear strength, PI: Plasticity index, w: water content

When planning the construction of any type of structure, it is very important to determine the potential soil amplifications caused by earthquakes. Soft soils increase the earthquake energy during an earthquake and are responsible for a large share of earthquake damage. In this study, the Vs data obtained by the MASW approach were used to determine the probable soil amplification of the soils in the Nan City area, since Vs is known to be an index property used to evaluate soil amplifications. The relationships between $Vs_{(30)}$ and soil amplification (A) [7] are given in Eqs. (3) and (4):

$$A = 68\ Vs_{(30)}^{-0.6}\ (Vs_{(30)} < 1100 m/s) \quad (3)$$

$$A = 1\ (Vs_{(30)} > 1100\ m/s) \quad (4)$$

where A is the soil amplification and $Vs_{(30)}$ is the average Vs in the upper 30 m.

In fact, soil amplification is dependent on other soil properties such as profile, types (sand/silt/clay), shear modulus, and damping ratio. Therefore, in this study this relationship was used only to determine the preliminary amplification of the area.

4. Materials and methods

In this study, the MASW method was used to acquire and analyze the data. This method was first introduced to the geotechnical and geophysical community in early 1999 [9] and generates a one-dimensional (1-D) vertical Vs profile by analyzing Rayleigh surface waves on a multichannel record. The method uses the energy that is commonly considered noise on conventional seismic surveys. The acquisition of 1-D MASW data is similar to the acquisition of conventional seismic data (Figure 4). Generally, 24 low-frequency vertical-component geophones, placed at X_2 intervals, are centered on each test location. The source, usually an impact source, is placed at X_1 and is typically either a sledgehammer (as in this study) or an accelerated-weight drop. The seismic signal generated by the source is then detected by the geophones and sent to the seismograph for recording and display.

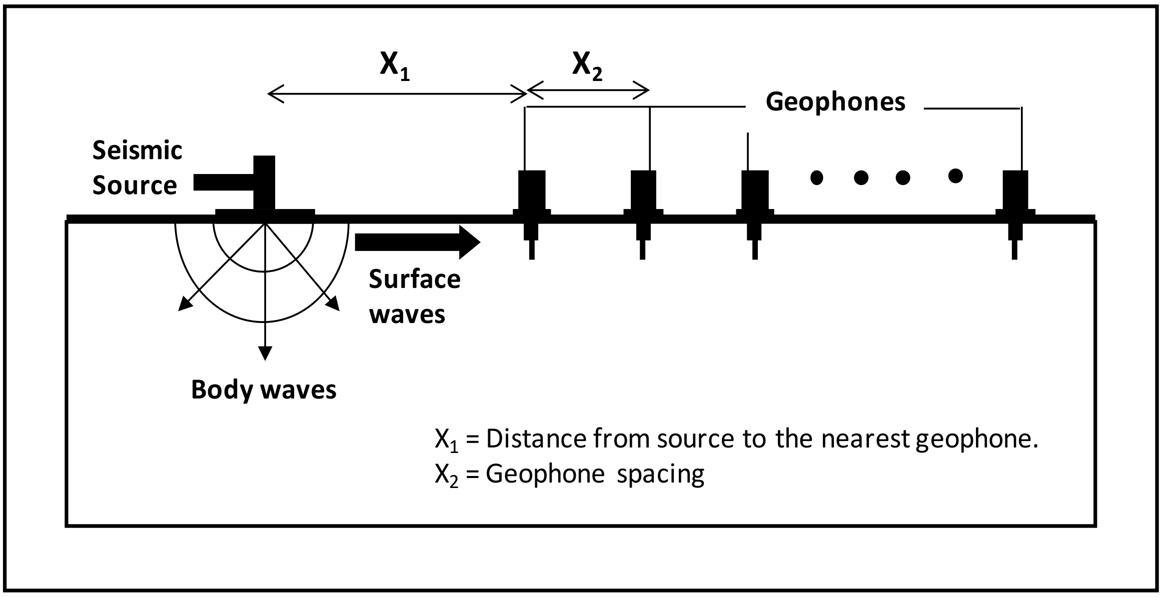

Figure 4 MASW data acquisition field setup.

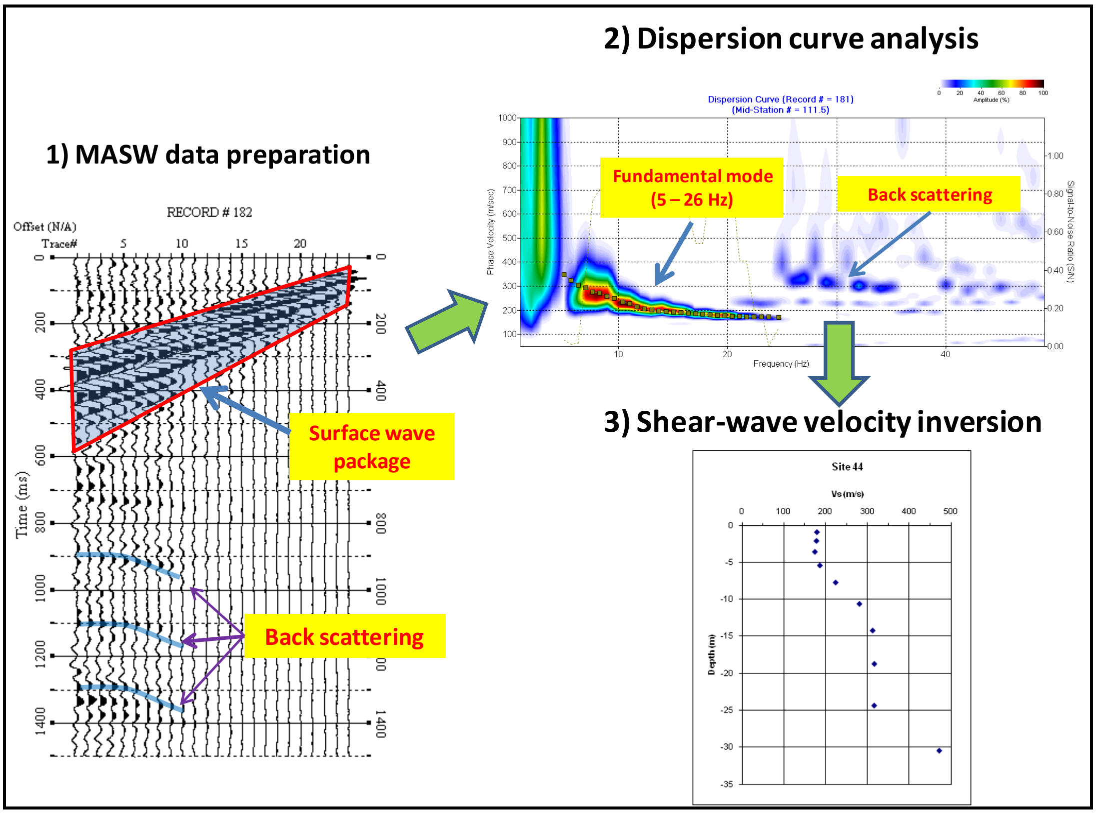

Figure 5 MASW data processing steps: (1) surface wave shot gathering, (2) the corresponding dispersion curve, and (3) the inverted Vs profile.

Figure 5 shows the key processing steps of the MASW data, where the field-based seismic data were used to generate site-specific dispersion curves (phase velocity vs. frequency) for each station location. The site-specific dispersion curves generated from the field-acquired Rayleigh wave data were then transformed into vertical 1-D Vs profiles (MASW Vs profiles) through inversion.

MASW data were collected at 36 sites in the city area (Figure 3). The MASW data was collected with a 24-channel geode engineering seismograph. The 24 of the 4.5 Hz vertical component geophones were placed at a spacing of 2 m apart. A 12-lb sledgehammer was used as the source at a distance of 10 m from the first geophone. The data recording parameters were acquired using a 1000 ms recording length and a 0.5 ms sample interval. No filter was applied to all MASW data. All seismic data were acquired near the main road for ease of accessibility. The acquired MASW data were processed using SURFSEIS, a Kansas Geological Survey software package.

6. Results and Discussion

6.1 $Vs_{(30)}$ and NEHRP site classification map

To create the NEHRP map, the $Vs_{(30)}$ of each test site was calculated using Eq. (1) and the obtained $Vs_{(30)}$ values were also used to classify the soil (class A-F) according to the recommendations of the 1997 National Earthquake Hazards Reduction

Program (NEHRP), as shown in Table 1. The $Vs_{(30)}$ and soil type of each test site are shown in Table 2. Finally, the NEHRP site classification map was generated. The map (Figure 6) revealed that there are only two soil classes (class C and D) in the study area (Figure 7) As seen on the map, the soil class D is present mainly in the central part of the area, where the soil consisted of mainly soft sediments from the alluvial plain and the river terrace. Soil class C was situated mostly in the western, eastern and southern parts because the soils in this area consisted of sand and gravel from the river terrace and some colluvial deposits.

However, a major part of the city is situated on soil class D. According to the NEHRP recommendation, soils with lower Vs values (i.e., toward class F and away from class A) will experience more earthquake ground shaking than bedrocks due to the wave-amplifying properties of the soil. This means that most part of Nan City will more or less experience soil amplification from earthquake ground motion.

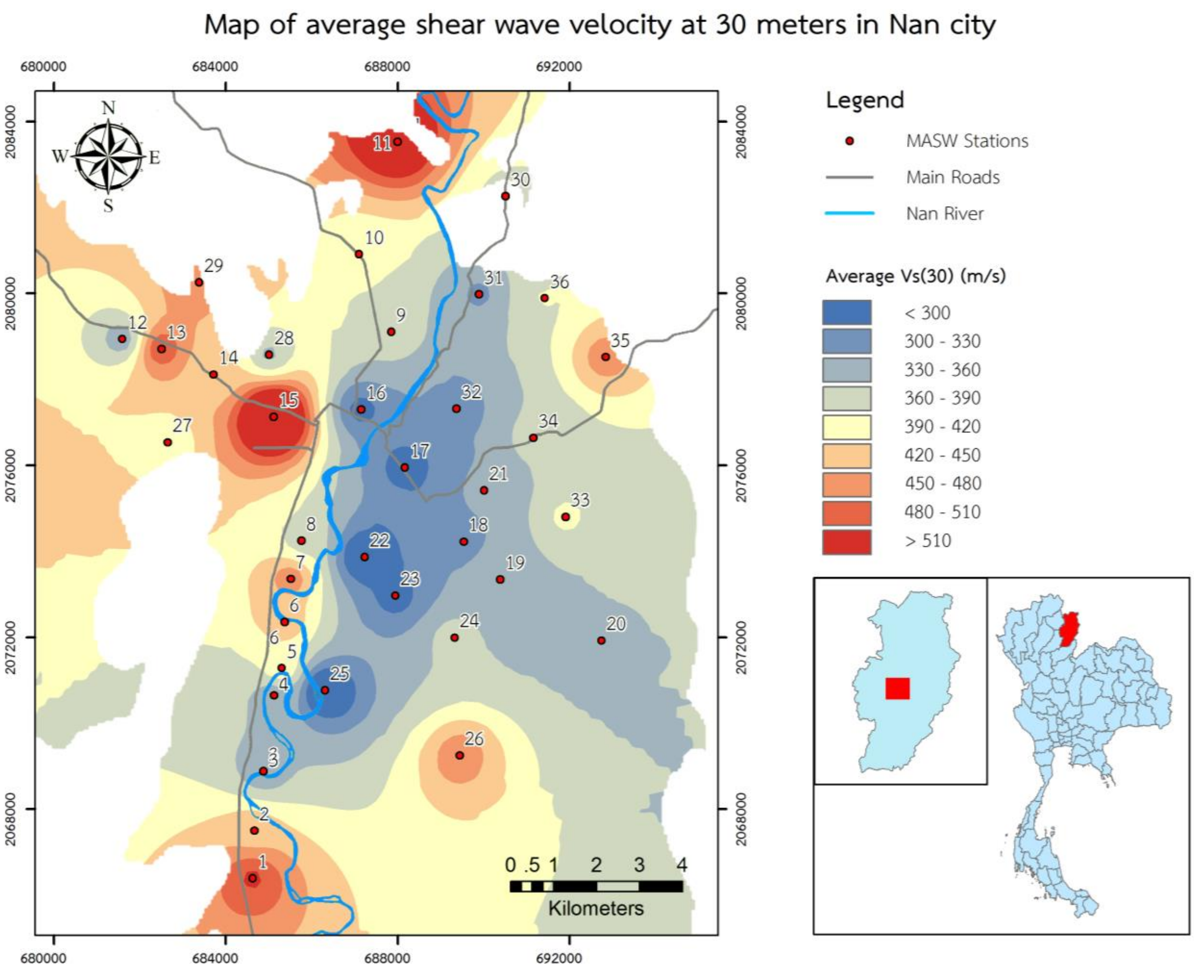

Figure 6 Maps of the $Vs_{(30)}$ of Nan City

Table 2 $Vs_{(30)}$, NEHRP site class and amplification of each test location.

MASW Site	Latitude	Longitude	$Vs_{(30)}$	NEHRP	Amplification
1	684627	2066391	516	C	1.6
2	684661	2067496	440	C	1.8
3	684876	2068882	338	D	2.1
4	685117	2070649	342	D	2.1
5	685300	2071283	423	C	1.8
6	685365	2072359	453	C	1.7
7	685506	2073355	474	C	1.7
8	685754	2074247	379	C	1.9
9	687845	2079106	373	C	1.9
10	687096	2080915	396	C	1.9
11	687990	2083535	583	C	1.5
12	681590	2078936	340	D	2.1
13	682500	2078709	507	C	1.6
14	683713	2078114	418	C	1.8
15	685112	2077130	685	C	1.4
16	687145	2077298	288	D	2.3
17	688166	2075951	283	D	2.3
18	689529	2074225	321	D	2.1
19	690378	2073347	354	D	2.0
20	692735	2071923	356	D	2.0
21	690004	2075420	335	D	2.1
22	687227	2073870	247	D	2.5
23	687939	2072968	285	D	2.3
24	689321	2071988	373	C	1.9
25	686304	2070766	228	D	2.6
26	689435	2069249	471	C	1.7
27	682644	2076535	397	C	1.9
28	685006	2078577	353	D	2.0
29	683376	2080257	477	C	1.7
30	690505	2082261	383	C	1.9
31	689887	2079979	324	D	2.1
32	689362	2077316	311	D	2.2
33	691896	2074803	397	C	1.9
34	691152	2076639	369	C	2.0
35	692827	2078519	468	C	1.7
36	691417	2079887	391	C	1.9

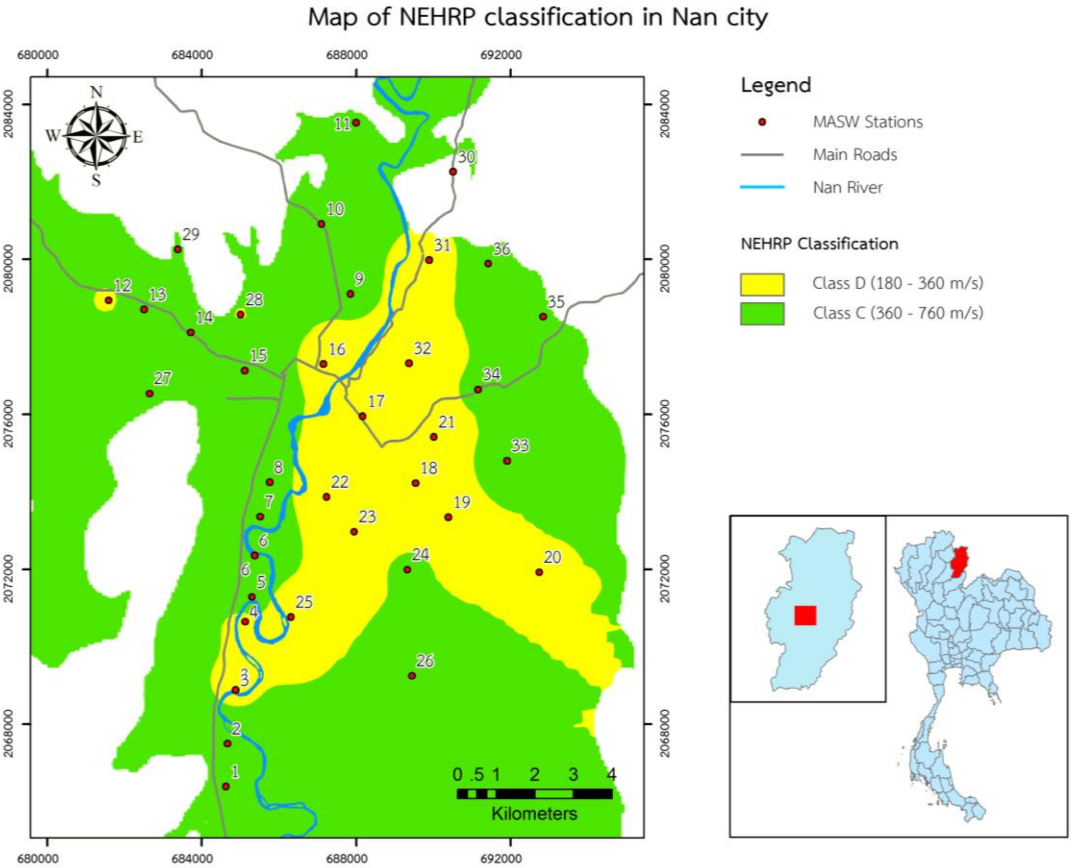

Figure 7 Map of NEHRP site classification of Nan City.

6.2 Preliminary site amplification map

The preliminary site amplification map was also generated based on the $Vs_{(30)}$ values, using the relationship provided by [7] and is shown in Figure 8. Since the average values of the soils in the study area were less than 1100 m/s, Eq. (3) was used to calculate the amplification value for the area. The derived soil amplification value ranged from less than 1.6 to more than 2.8, with higher amplification in the central and south eastern part, where the soils were mainly soft sediments from the alluvial plain and some river terraces (Table 2). In the eastern, western and southern parts of the study area, the amplification was relatively low, presumably because the sediments in this part consisted mainly of sand and gravel from the river terrace and some colluvial deposits. Most parts of Nan City are in a relatively high amplification area (> 2.0), which means that the city will experience some soil amplification from earthquake ground motion.

7. Conclusion and Recommendation

MASW data were acquired from 36 sites in Nan city, northern Thailand. All MASW data were processed, and the Vs profiles were determined by inverting the Rayleigh-wave dispersion curves. All Vs profiles were then average weighted down to

30 m to derive the $Vs_{(30)}$ values. The soils near the margin of the sedimentary basin (Nan basin) and the mountain zone were class C of the NEHRP site. These areas consist of coarse-grained sediments from the old river terrace and colluvial deposits from nearby mountains. However, the downtown part of Nan City and the south eastern part of the study area, which are located around the middle of the Nan Basin, are site class D. Based on the NEHRP site class of each test site in the study area, we conclude that Nan City and the south eastern part of the study area are under some risk of soil amplification due to ground motion from nearby active faults and distance seismic sources from surrounding countries.

Due to the limited information from the boreholes in the area, the thickness of the sediments and the detailed stratigraphy cannot be determined. This limitation may lead to a misunderstanding of the cause of the low and high Vs values at each test location. Additional wells may be drilled to obtain the shallow stratigraphy of sediments in the city, while gravity or seismic reflection geophysical surveys may help to clearly image the shape of the basin and thus allow an understanding of the basin effect due to ground shaking. Additionally, more MASW data should be acquired throughout the region to create a more comprehensive site-class map of the area.

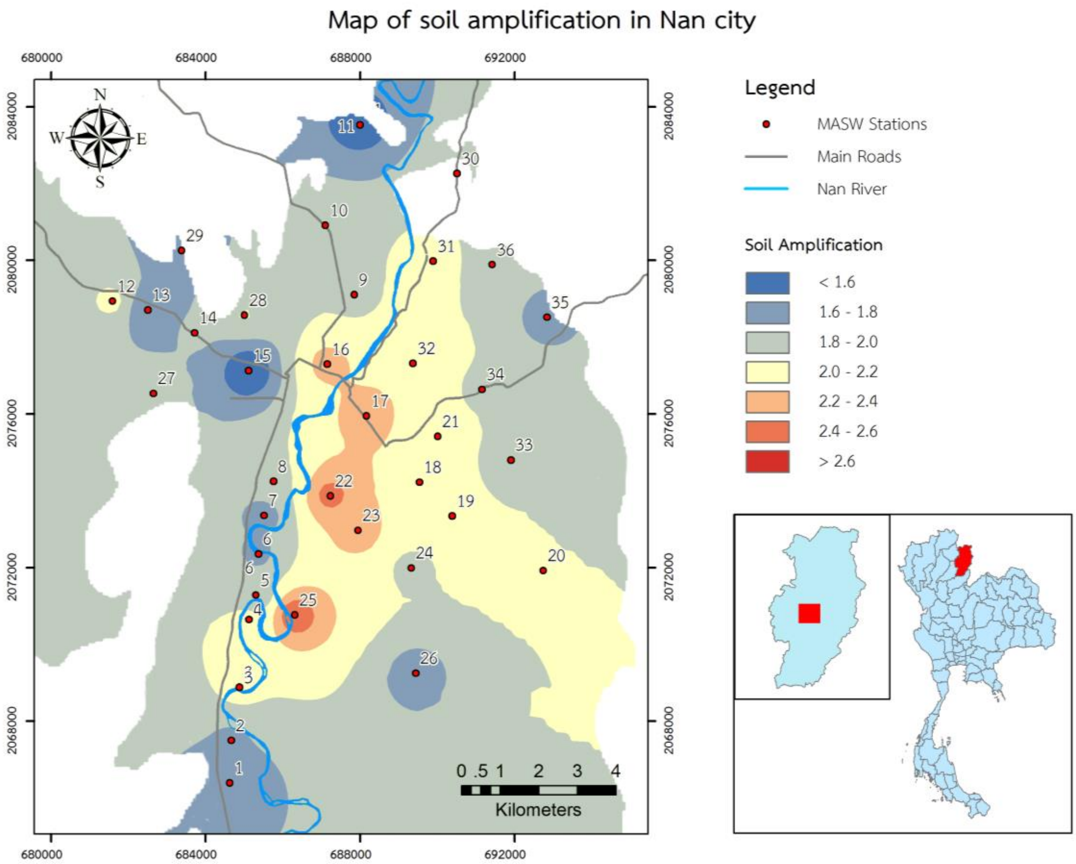

Figure 8 Preliminary soil amplification map of Nan city

Conflict of interest

The authors declared that this article has no conflict of interest.

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