การประเมินการขยายแรงแผ่นดินไหวของชั้นดินโดยใช้ข้อมูลธรณีฟิสิกส์และธรณีเทคนิค ในอำเภอเมือง จังหวัดเชียงราย

นางสาวรัชดาภรณ์ จินตประสาท

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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SOIL AMPLIFICATION ASSESSMENT OF EARTHQUAKE GROUND MOTION USING GEOPHYSICAL AND GEOTECHNICAL DATA IN AMPHOE MUANG, CHANGWAT CHIANG RAI

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A Thesis Submitted in Partial Fulfillment of the Requirements
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รัชดาภรณ์ จินตประสาท : การประเมินการขยายแรงแผ่นดินไหวของชั้นดินโดยใช้ข้อมูลธรณีฟิสิกส์และธรณีเทคนิคในอำเภอเมือง จังหวัดเชียงราย (SOIL AMPLIFICATION ASSESSMENT OF EARTHQUAKE GROUND MOTIONUSING GEOPHYSICAL AND GEOTECHNICAL DATA IN AMPHOE MUANG, CHANGWAT CHIANG RAI) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. ดร.ฐานบ ธิติมากร, 96 หน้า.

แผ่นดินไหวเป็นภัยพิบัติทางธรรมชาติอย่างหนึ่งที่ไม่อาจคาดเดาการเกิดได้อย่างถูกต้องและแม่นยำ จากบันทึกประวัติศาสตร์ของโลกตั้งแต่อดีตจนถึงปัจจุบันพบว่าแผ่นดินไหวเกิดขึ้นตลอดเวลา การเกิดแผ่นดินไหวในแต่ละครั้งสร้างความเสียหายให้กับพื้นที่นั้นมากน้อยขึ้นอยู่ลักษณะการเกิด ความรุนแรงของแผ่นดินไหวและลักษณะของพื้นที่ในการเกิดแผ่นดินไหวเช่นชนิดของดิน ชนิดหินและโครงสร้างอาคาร เป็นต้น เช่นเดียวกับการเกิดแผ่นดินไหวขนาดใหญ่เมื่อวันที่ 5 พฤษภาคม 2557 ที่อำเภอพาน จังหวัดเชียงราย ซึ่งถือได้ว่าเป็นเหตุการณ์แผ่นดินไหวที่รุนแรงส่งผลกระทบโดยจรงต่อเศรษฐกิจ สังคมและการดำรงชีวิตของประชาชนในพื้นที่ เพราะบริเวณที่เกิดแผ่นดินไหวเป็นแหล่งชุมชนขนาดใหญ่ จากการศึกษาของงานวิจัยที่หลากหลายพบว่าการเกิดแผ่นดินไหวจะเกิดและมีการตอบสนองต่อบริเวณที่ประกอบไปด้วยชั้นดินได้ดี อีกทั้งพื้นที่อำเภอเมืองจังหวัดเชียงรายก็วางตัวอยู่บนชั้นดินอ่อนเช่นเดียวกัน ดังนั้นการขยายตัวของชั้นดินเป็นหนึ่งในปัจจัยสำคัญที่จะควบคุมความเสียหายอันเกิดจากแผ่นดินไหวใหญ่ได้ การศึกษานี้วิเคราะห์จุดสำรวจทั้งหมด 46 จุดในพื้นที่อำเภอเมือง จังหวัดเชียงราย และใช้ข้อมูลทางธรณีฟิสิกส์โดยวิธีการหาความเร็วคลื่นเฉือนและข้อมูลธรณีเทคนิคคือ ชั้นดินในพื้นที่ เพื่อวิเคราะห์ในโปรแกรม SHAKE2000 อีกทั้งมีจุดสำรวจพิเศษคือจุดที่ 34 ซึ่งมีข้อมูลชั้นดินจากการสำรวจหลุมเจาะ โดยผลของการศึกษาในพื้นที่ศึกษาทั้งหมดนั้นพบว่า ค่าการขยายแรงในชั้นดินสูงสุดคือ 3.58 และค่าความเร็วคลื่นเฉือนเฉลี่ยที่ 30 เมตรคือ 200-562 เมตรต่อวินาที และสุดท้ายสามารถนำข้อมูลเพื่อนำไปจัดทำแผนที่แสดงความเสี่ยงของการขยายแรงแผ่นดินไหวของชั้นดินได้และแผนที่ความเร็วคลื่นเฉือนเฉลี่ยที่ระดับ 30 เมตรได้อย่างถูกต้อง

ภาควิชา ธรณีวิทยา ลายมือชื่อนิสิต ....

สาขาวิชา ธรณีวิทยา ลายมือชื่อ อ.ที่ปรึกษาหลัก ....

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RATCHADAPORN JINTAPRASAT: SOIL AMPLIFICATION ASSESSMENT OF EARTHQUAKE GROUND MOTIONUSING GEOPHYSICAL AND GEOTECHNICAL DATA IN AMPHOE MUANG, CHANGWAT CHIANG RAI. ADVISOR: ASST. PROF. THANOP THITIMAKORN, Ph.D., 96 pp.

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, relate with the intensity of earthquake and the properties of area such as type of soil, rock and building etc. Like the biggest earthquake is on May 5, 2014 that located in Amphoe Pan, northern part of Thailand. This Earthquake affects economic, society and a life because it is in big city, Amphoe Pan, where is many houses and buildings. Many researches show about the soil respond and sensitive with strong earthquakes. Moreover the property of Amphoe Muang, changwat Chiang Rai 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 Chiang Rai, using geophysical data, shear wave, and geotechnical data, soil profile, to consider with SHAKE2000 software. The special site is No.34 where has borehole data. The result of study area, the maximum value of amplification is 3.58 g and shear wave velocity of this study is 200 – 562 m/s. Finally, there are accurate soil amplification and average shear wave at 30 depths map of the result.

Department: Geology
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Student's Signature ....
Advisor's Signature ....

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CHAPTER 1
INTRODUCTION

1.1 Background

One of the natural disasters that cannot accurately predict is an earthquake. Many histories around the world indicated the occurrence of earthquakes from the past to present day. Each time, the earthquake made damages at large or small area depends on the intensity of earthquake and the properties of area such as type of soil, rock characteristic, building, etc. One of the biggest earthquakes in northern Thailand was on May 5, 2014 at Amphoe Pan, Changwat Chiang Rai. The hypocenter was in Tambon Dongmada, Amphoe Maelao, Changwat Chiang Rai. The magnitude in Richter scale was about 6.3. This earthquake affected to lives and economics because it occurred in big city, Amphoe Pan, which has many residents and buildings. Many researches explained that soft soil layers can response to the force from earthquake. The area of Amphoe Muang, Changwat Chiang Rai is covered by soft soil layers so soil amplification could be analyzed after the earthquakes occurrence. By using geophysical survey, seismic acquisition provided geophysical data to indicate shear wave. Furthermore, geotechnical data and borehole data were compared with the local area data. Then, the final result would be shown as NEHRP map.

1.2 Objective

This research has 3 objectives including:

1. Study the shear wave velocity.
2. Analyze soil amplification of the earthquake ground motion.
3. Illustrate NEHRP map and soil amplification map of Amphoe Muang, Changwat Chiang Rai.

1.3 Scope of the Study

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. The final results were expected to use for management to save the damages from the earthquake in the study area.

1.4 Expect Results

1. The map of an average shear wave velocity at depth 30 meters Vs(30) in Amphoe Muang, Changwat Chiang Rai.
2. The map of soil amplification in Amphoe Muang, Changwat Chiang Rai.
3. The frequency map in Amphoe Muang, Changwat Chiang Rai.
4. The map of peak ground acceleration in Amphoe Muang, Changwat Chiang Rai.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The research (Palasri and Ruangrassamee 2010) showed that the earthquakes affected to Thailand have hypocenters from active faults area in both Thailand and neighbor country such as Myanmar and Indonesia. Most faults located in northern part and western part of Thailand including Maechan fault, Tern fault and Payao fault. The magnitude of each earthquake had a relationship with the lengths of fault. The probabilistic seismic hazard maps of Thailand 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 0.40 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.

Then, after the earthquake on May 5, 2014 at Amphoe Pan, Changwat Chiang Rai, northern part of Thailand. It was the strongest earthquake that recorded by National Disaster Warning Center, in the Thailand. This earthquake damages many buildings in many zones such Changwat Chiang Rai, Changwat Chiang Mai, Changwat Tak, Changwat Nan, Changwat Phayao, Changwat Phrae, Changwat Lampang, Changwat Lamphun and Changwat Mae Hong Son

Many researches (Poovarodom and Pitakwong 2010) explained about earthquake which occur and respond to the soft soil layers that relate to the geological data of Changwat Chiang Rai area. Changwat Chiang Rai is one of a big city in the northern part of Thailand that has high population, many buildings and many earthquakes so the earthquake occurred in this area can become immense damages. Thus, soil amplification of earthquake ground motion in Changwat Chiang Rai must be studied and analyst by using geological data and geophysics survey to process for shear wave velocity.

Microtremor technique was studied about a seismic microzonation map of Changwat Chiang Mai (Srisoros 2003) The study area had 102 sites covered 7 Amphoes in Changwat Chiang Mai. He compared with the shear wave velocity model processed by SHAKE91 software and identified 4 predominant period groups. The first group is 0 - 0.40 second (Zone I), the second is 0.40 - 0.60 second (Zone II), the third is 0.60 - 0.80 second (Zone III) and the last is more than 0.80 second (Zone IV). The southern of Amphoe Sonsai, the western of Amphoe Muang, and the northern of Amphoe Sarapee, Changwat Chiang Mai, have 0.40 - 1.60 second (Zone II-IV) that risk to several damages.

The researchers (Yilmaz 2007) made an active fault map and analyzed soil profiles model by using seismic refraction survey to analyze the probability of earthquake. They analyzed the involvement of shear wave velocity and acceleration for computing saturated ground water in soil profile model. They separated their study into 3 cases in Izmit, the eastern of Istanbul. At first, seismic microzonation was determined for the liquefaction and soil amplification. The next was a site characterization survey to determine S-wave and P-wave velocities. The last case was a large-offset seismic survey to image complex structures in thrust belts.

Seismic microzonation map and shear wave velocity map were generated by shear wave and P-wave (Mahajan, Slob et al. 2007). The velocity of shear wave and P-wave were analyzed as the main factors to make the soil response model by using SHAKE2000 software. There were 5 sites in the Dehradun City, India, located in the Doon valley within the Siwalik foreland basin of Garhwal Himalaya. The result was shown that the estimated shear wave velocity was higher in the northern part of study area than the south and southwestern parts. The response spectra were three to eight times higher than peak ground acceleration at bedrock. The analyses of peak amplification were 3 – 4 Hz in the northern, 2.00 - 2.50 Hz in the central, and 1.00 - 1.50 Hz in the south to southwestern parts of the city.

Seismic model was generated by the soil profile and soft soil amplification that using geophysical data such as shear wave velocity, P-wave velocity and borehole data (Yilmaz, Eser et al. 2009). There were 20 sites in Istanbul, Turkey, which were categorized to three zones including the eastern, central and western. The maximum soil amplification ratio, maximum surface-bedrock acceleration ratio, depth interval of significant acceleration, maximum soil-rock response ratio, and design spectrum periods TA–TB were estimated. This study proved that soil model relates with the characteristic of earthquake in study area.

First introduced in geophysics, the multichannel analysis of surface waves (MASW) method is one of the seismic survey methods that evaluating the elastic condition of the ground for geotechnical engineering. The surface wave that normally filtered during data processing is a needless signal in conventional seismic surveys. The surface wave are commonly characterize with high amplitude low velocity and frequency (Sheriff and Geldart 1995). The MASW method was beginning about the geotechnical and geophysical community (Park, Miller et al. 1999).

SHAKE2000 software was used to studied and analyze ground response of Lalitpur, Nepal where is a very high seismic hazard area. Then a response spectrum was compared with three scenario earthquakes (Destegul, Westen et al. 2007). For the scenario with 8 of magnitude and 48 km hypocentral depth, the maximum is 0.48 g, the maximum value of PGA is 1.54 g, and SA is 2.80 g for frequency at 3 Hz. For 6.7 of magnitude and 6.4 km epicentral depth, the maximum is 0.50 g, the maximum value of PGA is 3.44 g, and SA is 8.64 g for frequency at 2 Hz. This study demonstrated that the results from SHAKE2000 software decreased when used with stiff soils and records with maximum of 0.48 g or more.

Finally, Changwat Chiang Rai, at the northern part of Thailand, locates on active fault and soft soil sediment about 2 – 8 meters depth from surface (Anantaasech 1985). 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 Changwat Chiang Mai and Changwat Chiang Rai to analyze by using SHAKE2000 software. 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 3.0 times related with each characteristic of earthquake. At last, the increase or decrease of amplification depended on acceleration value (Pattararattanakul 2003)

2.2 Basic Geological Data

2.2.1 Geology

Data from the department of mineral resources showed that Changwat Chiang Rai has an area of 20,107 square kilometers located in the northern part 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 northern, central and eastern area. The altitude is about 500 - 2,000 meters above mean sea level. Many high mountains locate along the northern to southern of Changwat 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 Chan. 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 ((DMR) 2010).

2.2.2 Sructural Geology

Regional structural geology of Changwat Chiang Rai is anticline fold located at the western part of area with north-south alignment and the eastern area with northeast-southwest alignment. The geography is mountain located around Kok River at the southern area.

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.

2.3 Earthquake Characteristics

2.3.1 Earthquake

Earthquake is a disaster that shaking of the ground caused by suddenly movement of two plates of the earth. The slipping surface is called the fault or fault plane. The hypocenter is the location that earthquake starts below the surface, and the epicenter is the location that earthquake starts above the surface (United States Geological Survey: USGS) All earthquakes make the fault lines on the surface. Earthquake can be occurred by natural and human action. Nowadays, the earthquake cannot be accurately predicted or calculated about times and location, it will happen.

2.3.2 Earthquake in of Changwat Chiang Rai

There are earthquakes happened at both urban and countryside area in Chiang Rai. The record of Thai Methodological Department showed the earthquakes in Thailand always occur especially in Chiang Rai and Chiang Mai. The important earthquake in Chiang Rai is Mae Lao earthquake occurred at 11.08 on May 5 with the magnitude about 6.3 M_W. The hypocenter was located at depth 9 kilometers in Tambon Dongmada, Amphoe Mae Lao, Changwat Chiang Rai.

2.3.3 The Earthquake Magnitude Scale

Vibrations of seismic waves from each earthquake are recorded on an instrument called seismographs. Seismographs record the varying amplitude and ground motions. Sensitive seismographs can detect strong earthquakes from the sources anywhere in the world. The location, time and magnitude of the earthquake can be determined from the data recorded by seismograph stations. There are many types of earthquake scale including;

- ML is an indication of a small earthquake, local earthquake or nearly earthquake (a distance of less than 1,000 km) calculated from the height of the wave detected by seismogram. In 1935, the Richter magnitude scale was developed by Charles F. Richter. So, ML is also called "Richter" that use wave height of the tallest waves, i.e. S waves, with a range between 0.1 to 1.0 seconds to calculate.

- MB or mb is an indication of both nearly and far earthquake (a distance of more than 1,000 km) calculated from the height of the wave detected by seismogram. It is also called “Body-wave magnitude”. P-waves with a range between 1.0 to 5.0 seconds are used to calculate.
- Ms is an indication of a regional earthquake called “Surface Magnitude”. Surface waves with a range between 18 to 22 seconds are used to calculate.
- Mw or “Moment magnitude” is an indication of the energy of earthquake that analyzes from Seismic Moment (Mo). The seismic moment is a result of fault displacement analysis.
-

Table 2.1 Types of earthquake scale

Scale	Equation	Seismic wave	Wavelength (s)	Detector
ML	$LogA - LogA_0$	S	0.1 - 1.0	displacement
MB, mb	Log(A/T) + Q (h,D)	p	1.0 - 5.0	velocity
Ms	LogA + 1.66 LogD + 2.0	Surface	20	velocity
Mw	$(2/3logM_0) - 10.7$	Surface	> 200	velocity

*where A = the amplitude of ground motion (in microns)

T = the corresponding period (in seconds)

Q(D,h) = a correction factor that is a function of distance

D (in degrees), between epicenter and station and focal depth

h (in kilometers), of the earthquake.(Spence 1989)

2.3.4 Earthquake Intensity Scale

USGS said that the intensity has an effect to an earthquake on the Earth's surface. The intensity scale consists of a series of apparent responses such as people awakening, movement of furniture of destruction of building, etc. Although the numbers of intensity scales have been developed several hundred years ago, the Modified Mercalli Intensity Scale (MMI) was currently used in the United States, which developed in 1931 by two American seismologists, Harry Wood and Frank Neumann.

The lower numbers of the intensity scale depended on human feeling. The higher numbers of the intensity scale depended on observed structural damage **(USGS 1989).**

Table 2.2 An abbreviated description of the levels of Modified Mercalli intensity

Intensity	Shaking	Description/Damage
I	Not felt	Not felt except by a very few under especially favorable conditions.
II	Weak	Felt only by a few persons at rest, especially on upper floors of buildings.
III	Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly.
IV	Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building.
V	Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.

Intensity	Shaking	Description/Damage
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, monuments, walls. Heavy furniture overturned.
XI		Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.
XII		Damage total. Lines of sight and level are distorted. Objects thrown into the air.

2.4 Seismic Waves

The vibration of the ground is in three dimensions that can be measured the motion in horizontal plane (northern, southern, eastern and western) and vertical plane. The seismic waves can be detected by measuring the vibration which have two types of seismic wave including;

- Body wave is the main wave moving under the surface, i.e. P-wave and S-wave. P-wave moves along force plane but S-wave moves along the north-south and east-west plane and wavelength of s-wave is between 0.01 to 50 seconds.

- Surface wave is including Love wave and Rayleigh wave. Love wave moves along a horizontal plane, like the movements of the snake. Rayleigh wave moves like a combination of P-waves and S-waves. Wavelength of surface wave is about 10 - 350 seconds.

Surface waves Body waves

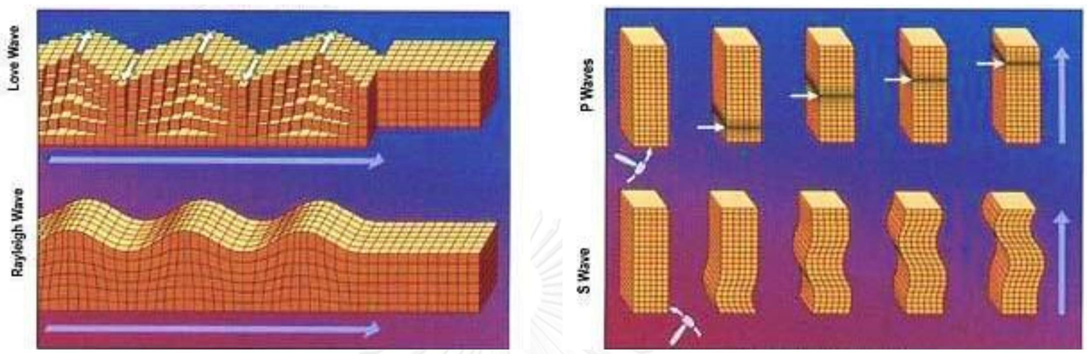

Figure 2.1 Seismic waves (USGS).

2.5 Peak Ground Acceleration

The acceleration of the ground or Peak Ground Acceleration (PGA) is a priority factor in the engineering design of building about a risk from earthquake. The second of Newtonian's theory that the force is direct variation to the mass and acceleration support this concept about acceleration.

Most of the large earthquakes affect a maximum acceleration but sometimes larger earthquake does not show maximum acceleration.

2.6 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.

CHAPTER 3
METHODOLOGY

3.1 Introduction

This study is about determining soil amplification and there are four steps for analyzing including the raw data, technical survey, software for analysis and the result data. 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 software to analyze for soil amplification.

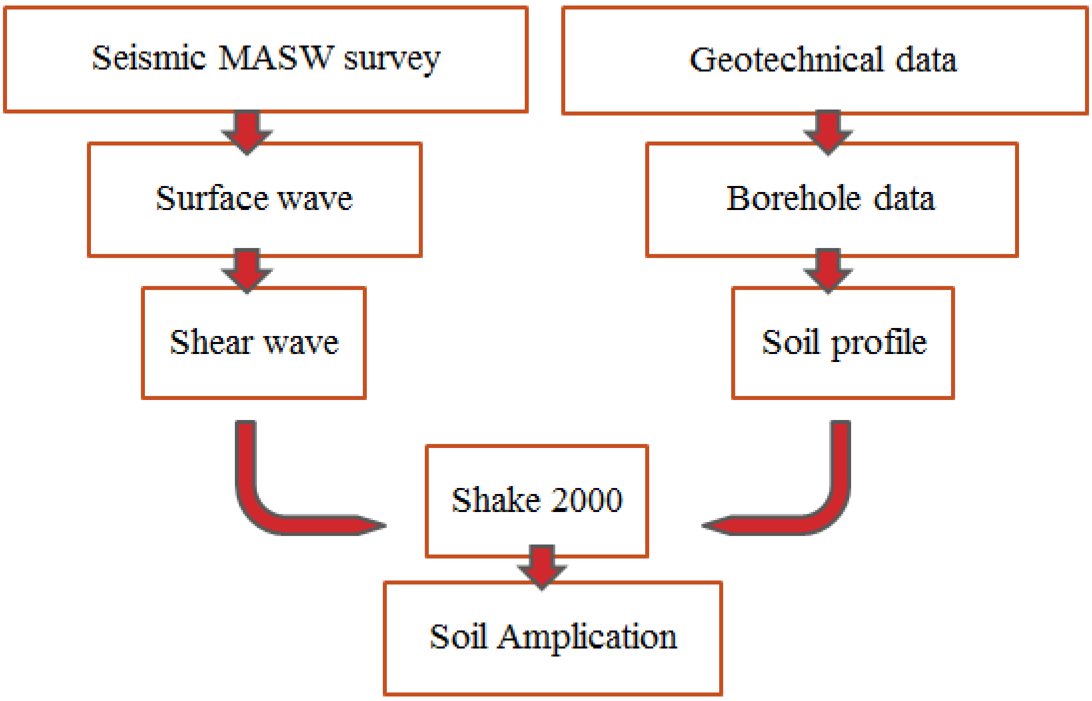

Figure 3.1 The completed flow chart of methodology in this study.

3.1 Study Area

The study areas have 46 test sites that cover rock and sediment unit in Amphoe Muang, Changwat Chiang Rai. The first to thirtieth sites are previous MASW test sites (Thitimakorn and Channoo 2012). The thirty first to forty sixth are tested in this study using MASW technique. At the northwestern of study area, rock units are granite, limestone, sandstone and mudstone. Rock units at the western area are limestone and sandstone. At the central are conglomerate, sandstone and siltstone. Furthermore, there are sediments such as colluvium and valley pain, terrace, natural levee and flood plain. The thirty forth site located in Wat Pa Wai Khum Ngoen, near Chiang Rai international airport, is a specific site because there is a borehole data form Department of Mineral Resources.

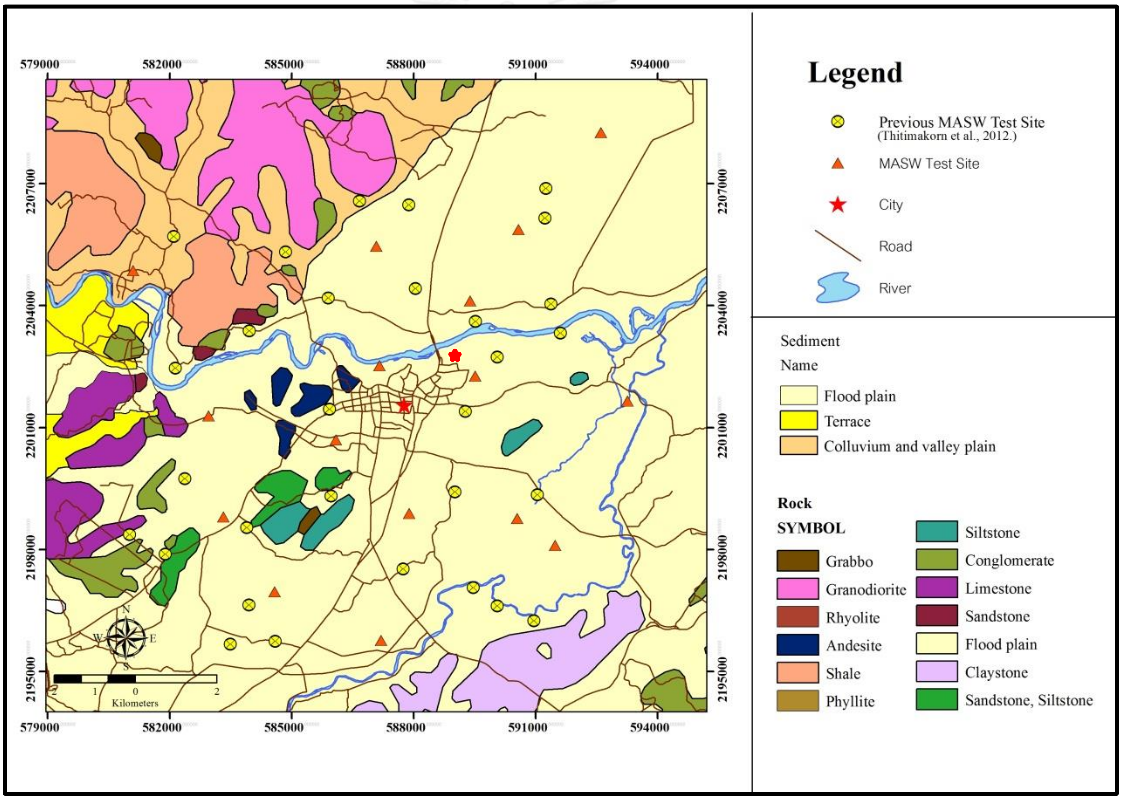

Figure 3.2 Geologic map of the study area with locations of 46 test sites in Amphoe Muang, Chang Wat Chiang Rai. (Modify after, ((DMR) 2010))

3.2 Soil Profile

Soil profile used in SHAKE 2000software is properties of soil such as soil type, thickness at depths, unit weight and shear wave. Soil profile is importance to process in the software so the accurate soil profile has to be determined by geotechnical data like borehole data and soil properties testing. But this study does not have borehole data of any sites except the site No.34. Therefore, the borehole data form Department of mineral resources was gathered and differentiated to be a soil profile of each site in this study area.

The site No.34, Wat Pa Wai Khum Ngoen, located in the eastern north of study area was chosen to be a specific site because there is a borehole testing that consists of soil type, thickness, depth and shear wave data. But another site does not have any data except shear wave velocity that received from seismic surveying. Thus the standard of soil profile has to be created by all borehole data in Amphoe Muang, Changwat Chiang Rai, to compare the type of soil in borehole data with shear wave velocity from seismic survey.

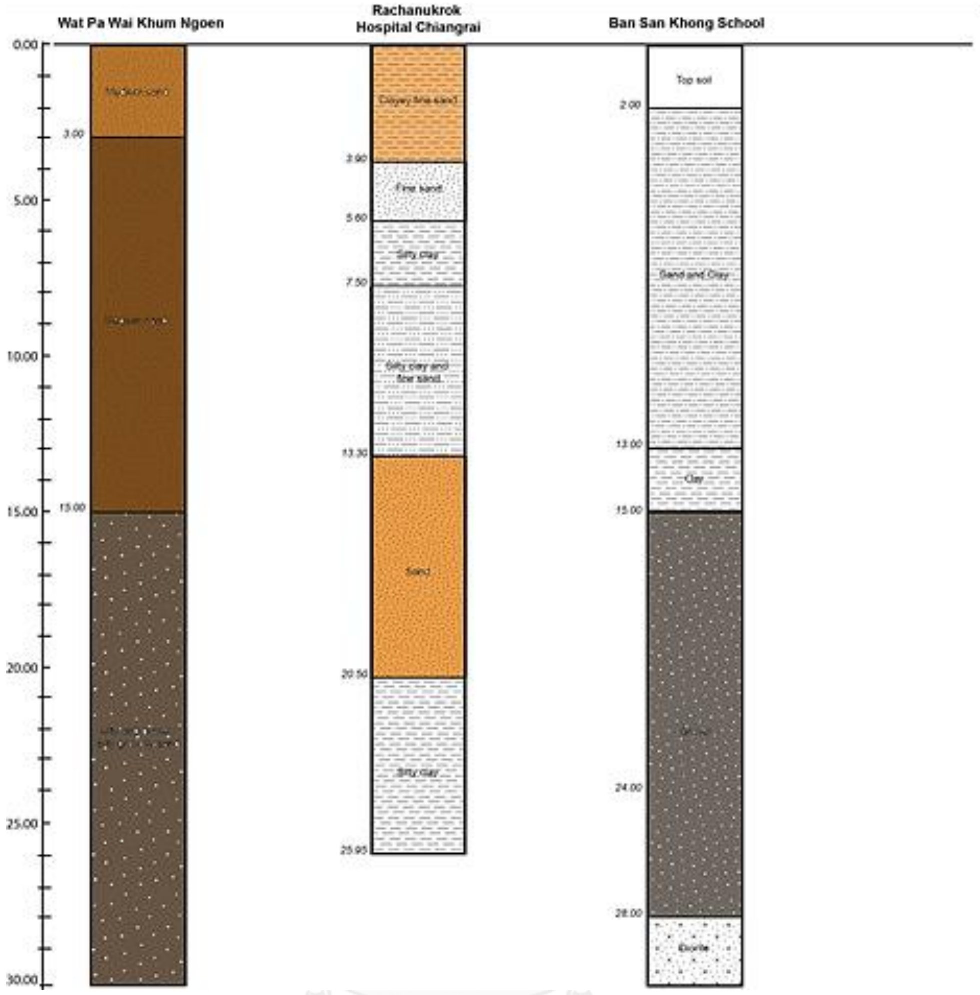

Figure 3.3 Borehole data in Amphoe Muang, Changwat Chiang Rai, Thailand. A: The specific site is No.34, Wat Pa Wai Khum Ngoen. B and C are parts of all samples that were gathered and created soil profile; B: Rachanukrok hospital and C: Ban Son Khon school.

The ranges of P-wave and shear wave velocity are shown in table 3.1. 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).

Table 3.1 P-wave and shear wave velocity of soil profiles.

Soil Profiles	P-wave Velocity (m/s)	Shear Wave Velocity (m/s)
Clay	377 - 558	70 - 138
Clayey Sand	559 - 956	139 - 270
sand	957 - 1,673	270 - 520
gravelly sand and gravel	1,674 - 2,000	521 - 699
Bedrock	> 2,000	> 700

The shear wave velocity to 30 m (Vs30) from seismic survey can be compared with the study area and then identify the soil type to make NEHRP (National Earthquake Hazards Reduction Program) map. It showed the zone of soil type as groups of A, B, C, D and E, as shown in table 3.2. Most of study area is soil type C, very dense soil and soft rock, and D, stiff soil.

Table 3.2 Soil type classification for seismic amplification (Building Seismic Safety Council 2003).

Soil Type	General Description	Average Shear Wave Velocity to 30 m (m/s)
A	Hard rock	> 1,500
B	Rock	760 ≤ Vs ≤ 1,500
C	Very dense soil and soft rock	360 ≤ Vs ≤ 760
D	Stiff soil 15 ≤ SPT blow count ≤ 50 or 50 kPa Undrained shear strength ≤ 100KPa	180 ≤ Vs ≤ 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

3.3 Software

3.3.1 SurfSeis

The Surfseis is a software that has been immensely used as basic software. The Kansas Geological Survey developed SurfSeis software to process seismic data from the multichannel analysis of surface waves (MASW) survey method and to estimate shear-wave velocity (Vs) and depth (z).

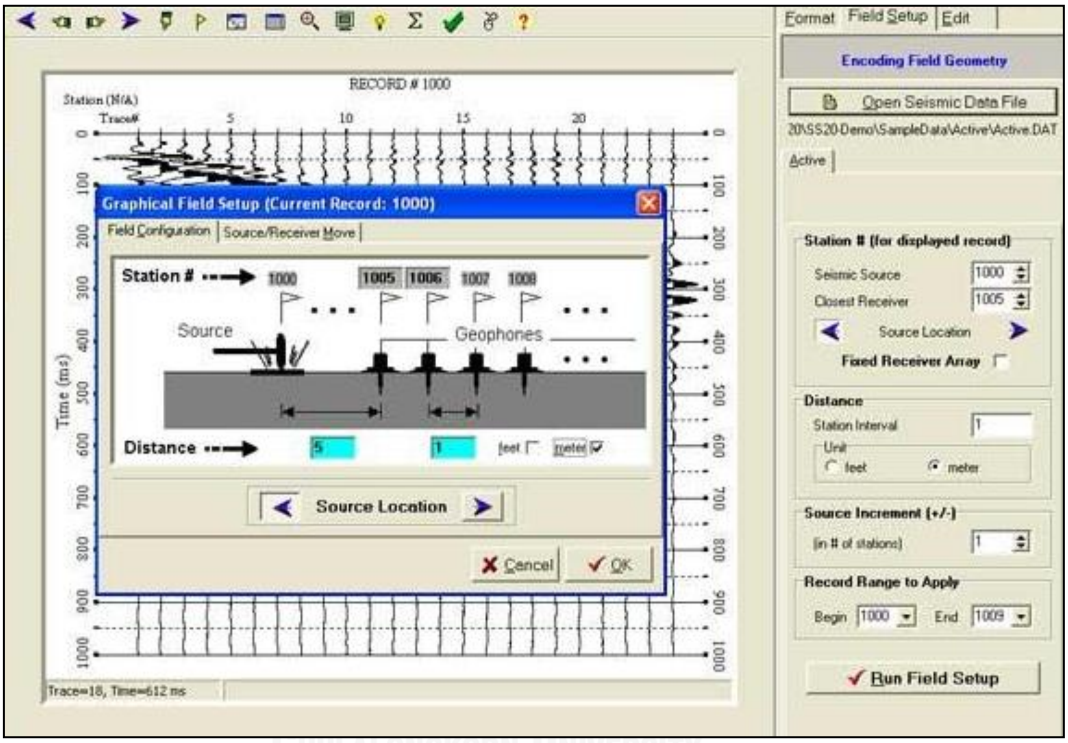

Figure 3.4 The interface of the Surfseis software.

3.3.1.1 Data

The highest quality data from seismic survey was chosen from three data files in seismic controller software. Data quality such as signal-to-noise is the influence factors for analyzing. 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.

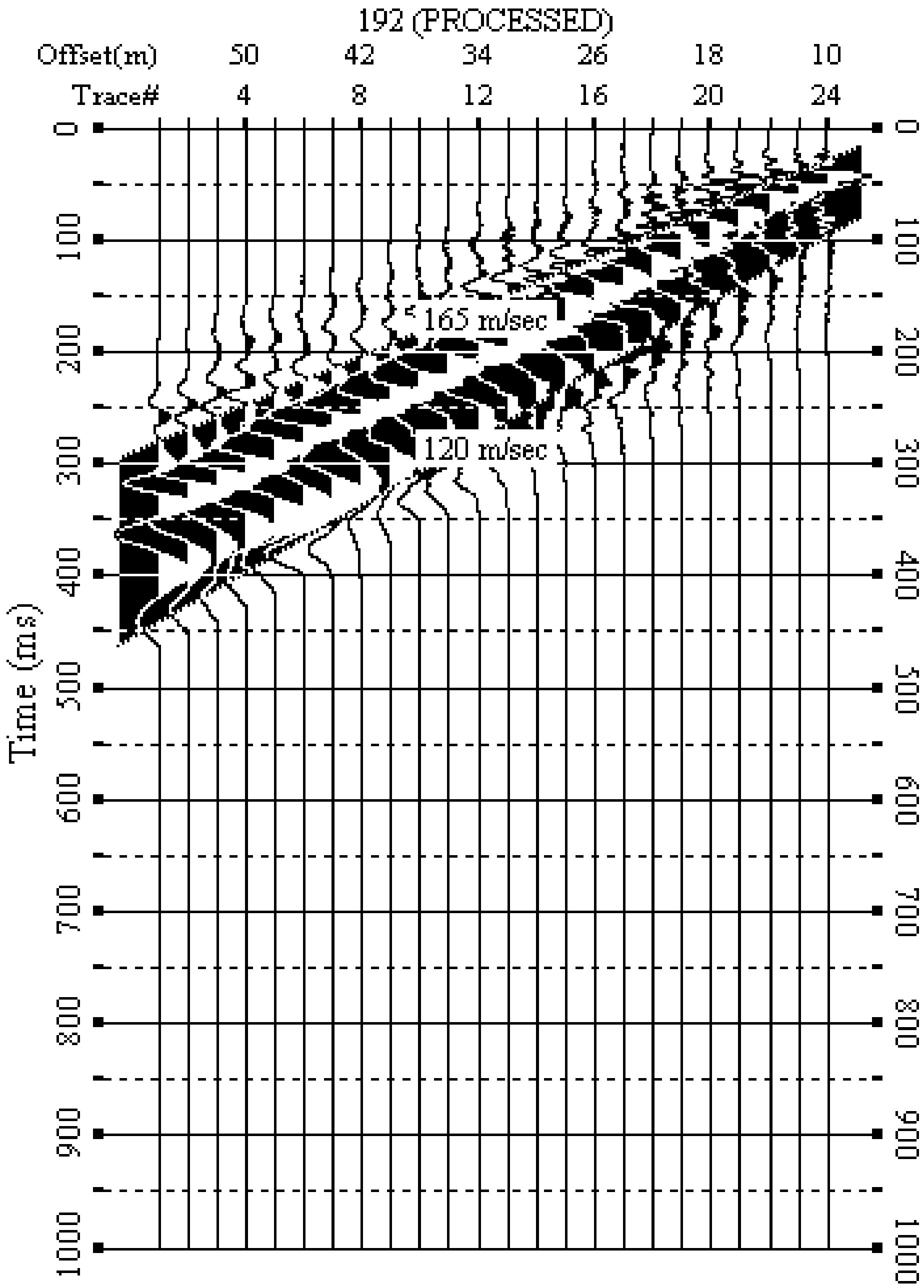

Figure 3.5 Data from seismic survey at site No.34.

3.3.1.2 Dispersion Curve

Dispersion curves show 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 of figure 3.6 shows the range of amplitude that relates with the frequency.

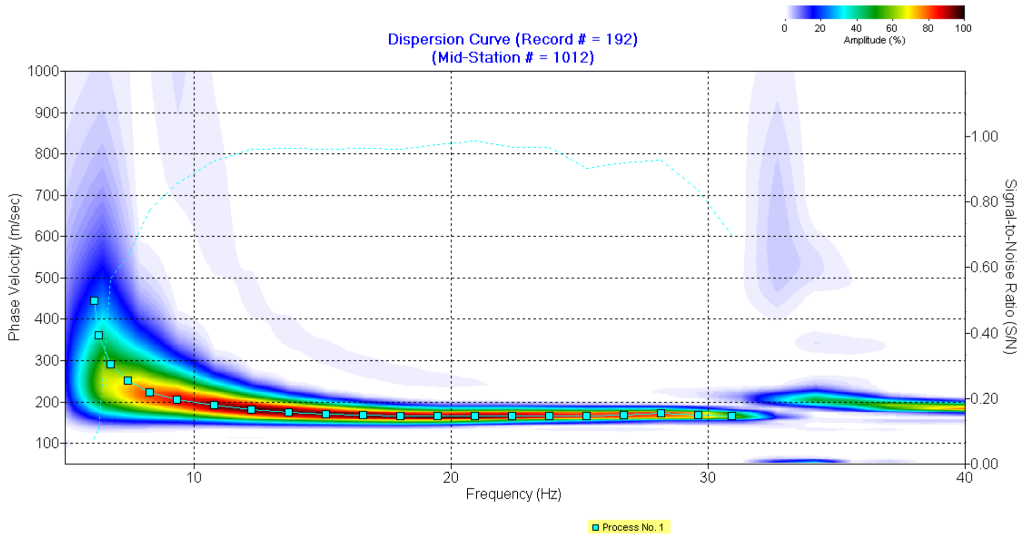

Figure 3.6 Dispersion curve at site No.34.

3.3.1.3 Inversion

The dispersion curve was selected and saved as a *.DC file. Then the software would proceed to either Inversion analysis for the saved curve or Dispersion analysis to move on to the next seismic record (depend on the input of seismic data which contains only one or multiple records). For Dispersion analysis, the analysis for each record would be similar to the previously described procedure. The Inversion curve shows the relation between velocity and frequency.

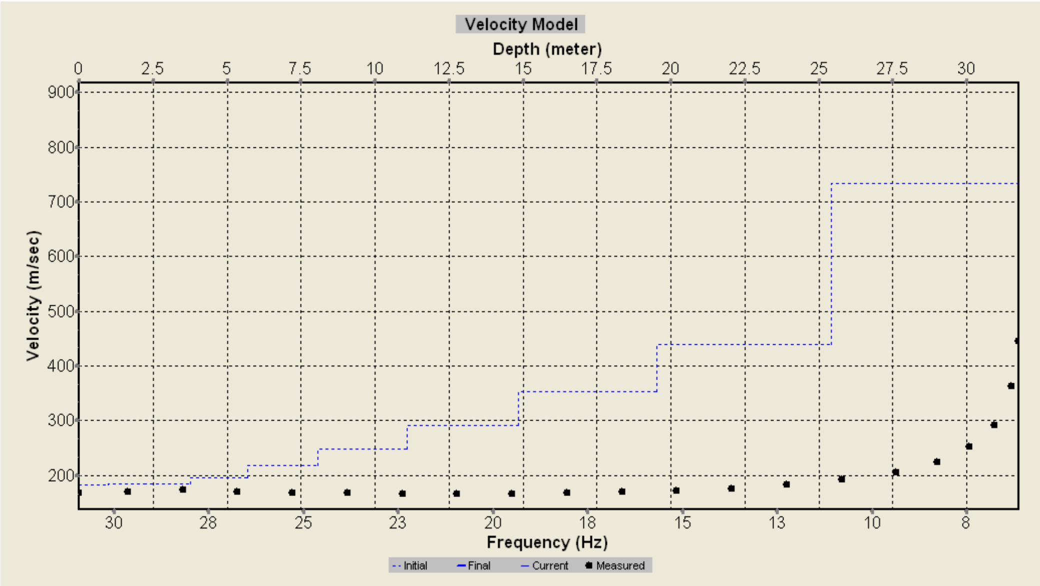

Figure 3.7 Inversion curve (velocity model) at site No.34.

3.3.2 SHAKE2000

SHAKE2000 software is a program for equivalent-linear site response analysis. This program 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 software has important roles for geotechnical earthquake engineering and used as learning tool for student.

SHAKE2000 software is a graphical interface for SHAKE. It was originally a user aid to the creation of the input file, and was the graphical display of the program's numeric output. It accomplished the first step by incorporating user-friendly screens to assist in entering the input data for the different SHAKE options. The second step was routines for the processing and checking about error of output data, and for display the output. SHAKE2000 software was developed by H. Bolton Seed, John Lysmer and Per B. Schnabel, the University of California, Berkeley. The program can compute the response soil layer in a system of homogeneous, viscous-elastic layers of infinite horizontal extent subjected to vertically traveling shear wave's velocity. The program is based on the continuous solution to the wave-equation for using with ground motions. The parameters that required for using SHAKE2000 software are soil profiles (rock type with thickness at depth, shear wave velocity and unit weight), damping and Input motion. The flowchart of running SHAKE2000 software is shown as Figure 3.8.

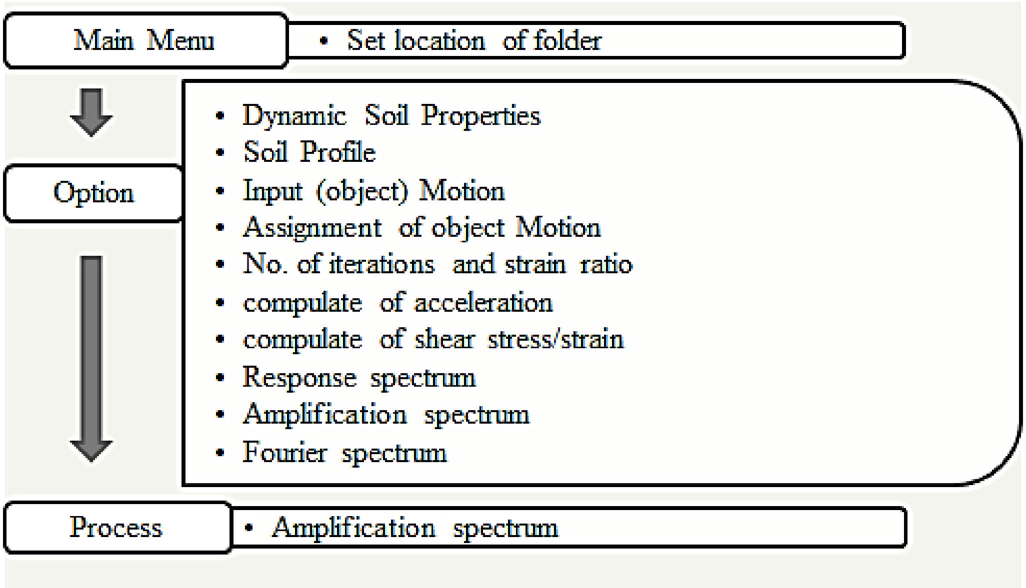

Figure 3.8 Flowchart of running SHAKE2000 software

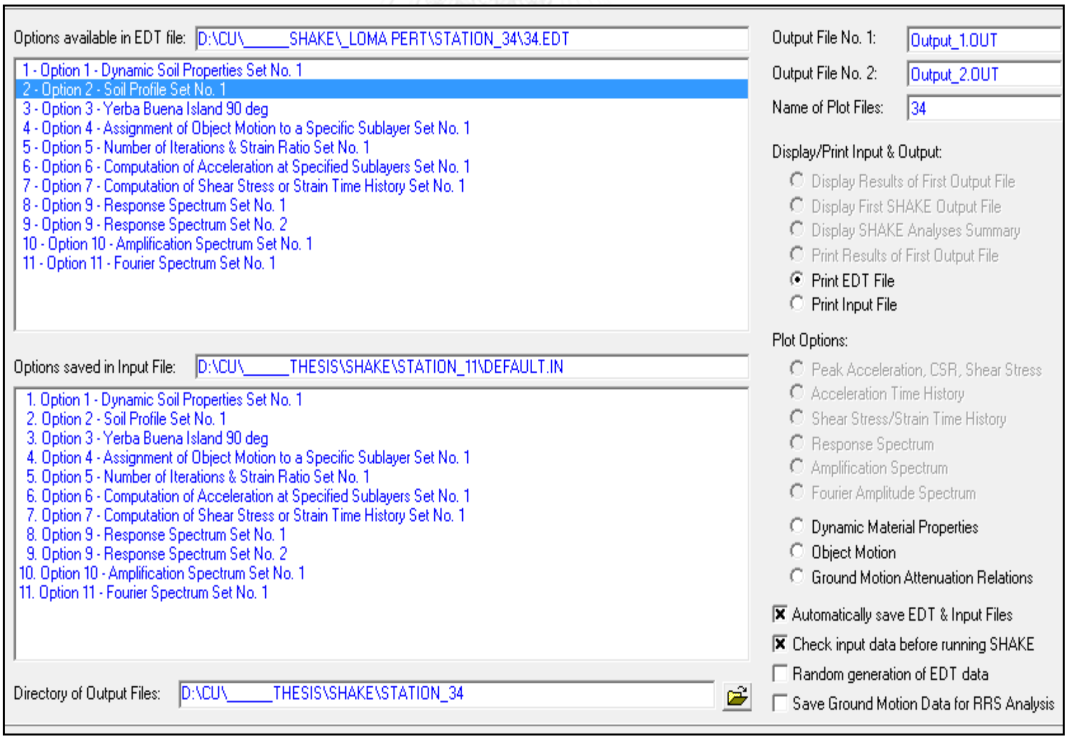

Figure 3.9 There are eleven options to run SHAKE2000 software**.**

The option No. 2 is soil profile. There are five parameters that have to set in this option including soil type, thickness, damping, unit weight and shear wave velocity.

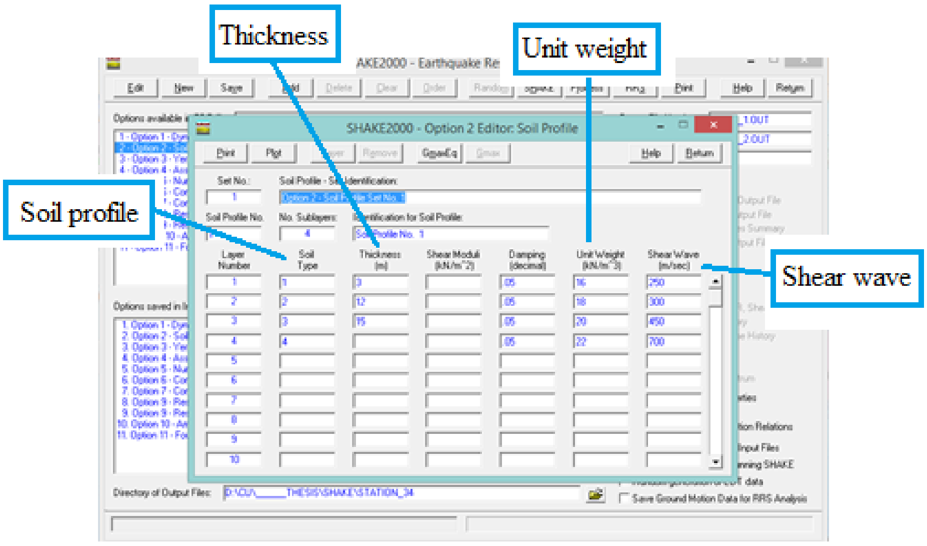

Figure 3.10 Soil parameters from soil profile.

Option No.3 is an earthquake ground motion. There are more ground motions in SHAKE2000 software.

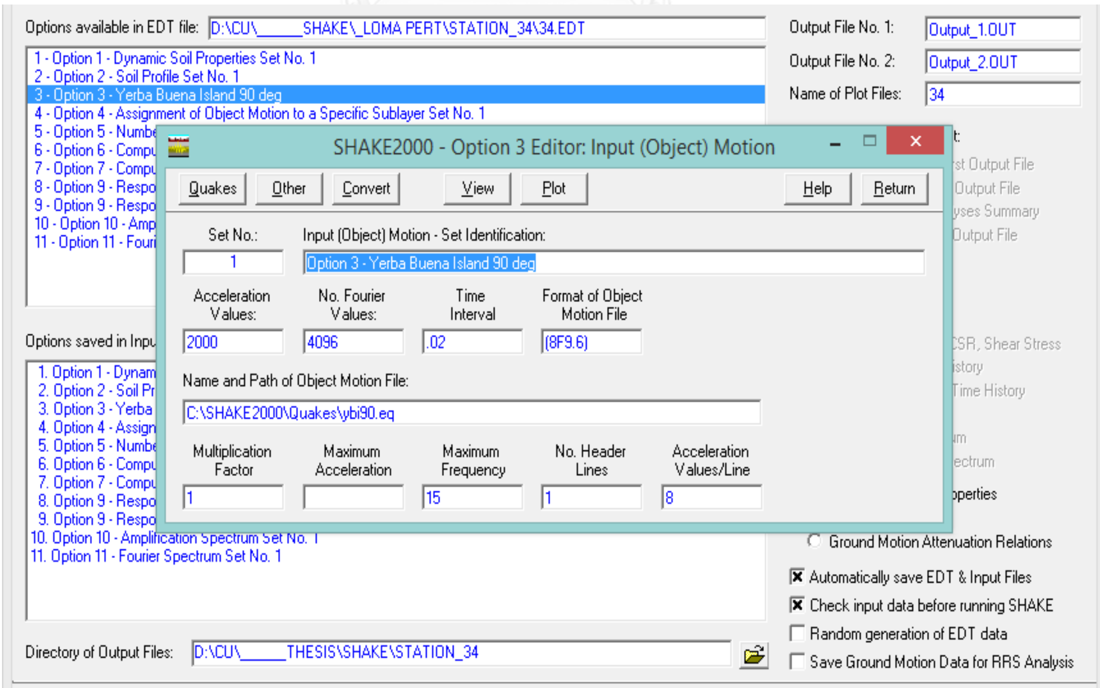

Figure 3.11 Option No.3 in SHAKE2000 software is used for selecting the ground motion earthquake.

3.4 Seismic Survey

3.4.1 Seismic Refraction

Seismic refraction is a geophysical survey ruled by Snell's Law, i.e. law of wave refraction. The seismic refraction method utilizes the refraction of seismic waves on geologic layers and rock/soil units in order to characterize the subsurface geologic structure and conditions.

The method depends on the fact that seismic waves have different velocities in different types of soil or rock. The waves are refracted when they cross the boundary between different types or properties of soil or rock. This method is able to determine the general soil types and the approximate depth to strata boundaries, or to bedrock.

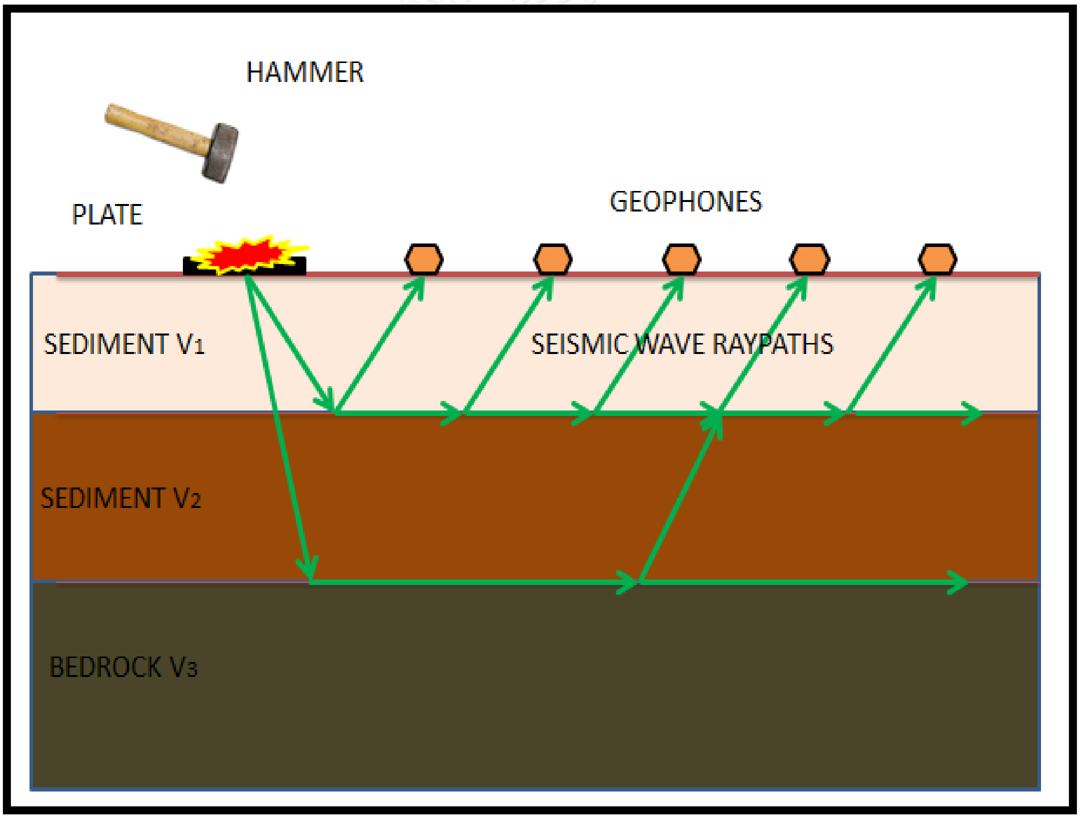

Figure 3.12 seismic refraction surveys.

3.4.2 MASW

Mmultichannel analysis of surface waves (MASW) method is seismic method generates a one-dimensional (1-D) vertical shear-wave velocity (Vs) profile which analyzing surface waves on a multi-channel record. The method considered to be a noise on conventional seismic surveys. The conventional seismic data acquisition is the acquisition of the 1-D MASW data in figure 3.5.2. Normally, the source likes hammer, Drop Weight or impacting mass is X1 intervals and we use 24 of geophones, low-frequency and vertical-component, is dx intervals on each test site. The signal of seismic was detected by the geophones and sent the signal to seismograph for recording and display on the computer.

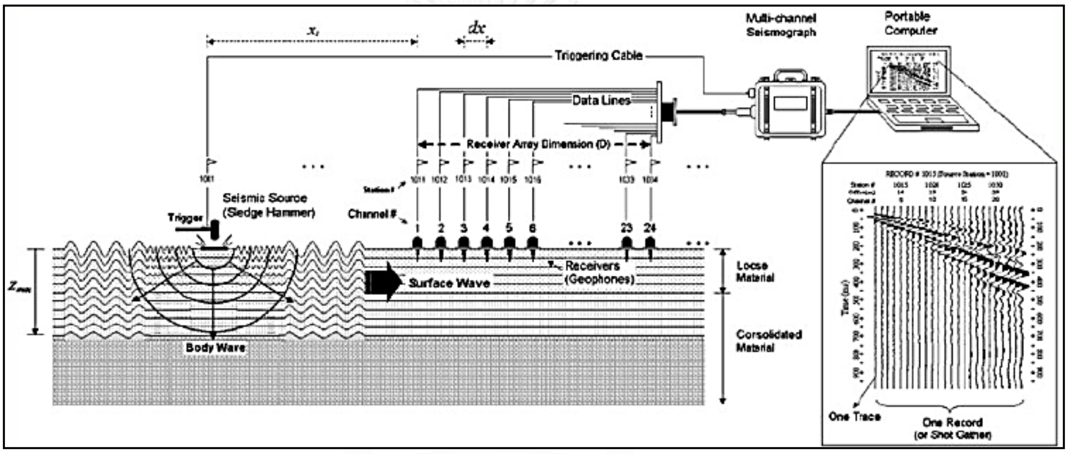

Figure 3.13 MASW method (Park, Miller et al. 1999).

3.5 Input Motion for Analysis

There are many earthquake ground motions in this SHAKE2000 software. 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.

CHAPTER 4
COMPARATION OF SOIL AMPLIFICATION FROM DIFFERENT METHODS

4.1 Introduction

Site respond of soil deposit is one of important characteristics of soil that affect the building structure. In this study site response analysis was performed by the SHAKE2000 software. Site response analysis was calculated by using shear wave velocity city derived from downhole seismic and MASW methods. The aim is to verify the effectiveness and correctness of shear wave velocity derived from MASW technique when comparing to downhole shear wave velocity.

4.2 Parameter used for site response analyses

4.2.1 Borehole data

The input data for analyze consist of two parts which are borehole data and shear wave velocity. First, borehole data in this study are from department of mineral resources. There are 7 boreholes from different sites namely Wat San Mana, Wat don mawan, Wat Nong O, Wat Pa Wai Khum Ngoen, Wat Thung Hong, Wat Si Bun Koet, Wat Fueai Hai (figure 4.1) in changwat chiangrai. They consist of soil type, depths and shear wave velocity. These data were divided to group of soil type by shear wave velocity. Each soil types are difference rages of shear wave velocity from downhole data that are a standard parameter to classify soil type of forty-six sites in study area. The soil types are five groups that are below.

- First group is Clay or waste (Vs = 70 – 138 m/s)
- Second group is sand (Vs = 139-270m/s)
- Third group is Medium sand (Vs = 270- 520 m/s)
- Forth group is Silty sand some gravelly sand (Vs = 521 -699 m/s)
- Fifth group is Bedrock (Vs >700 m/s)

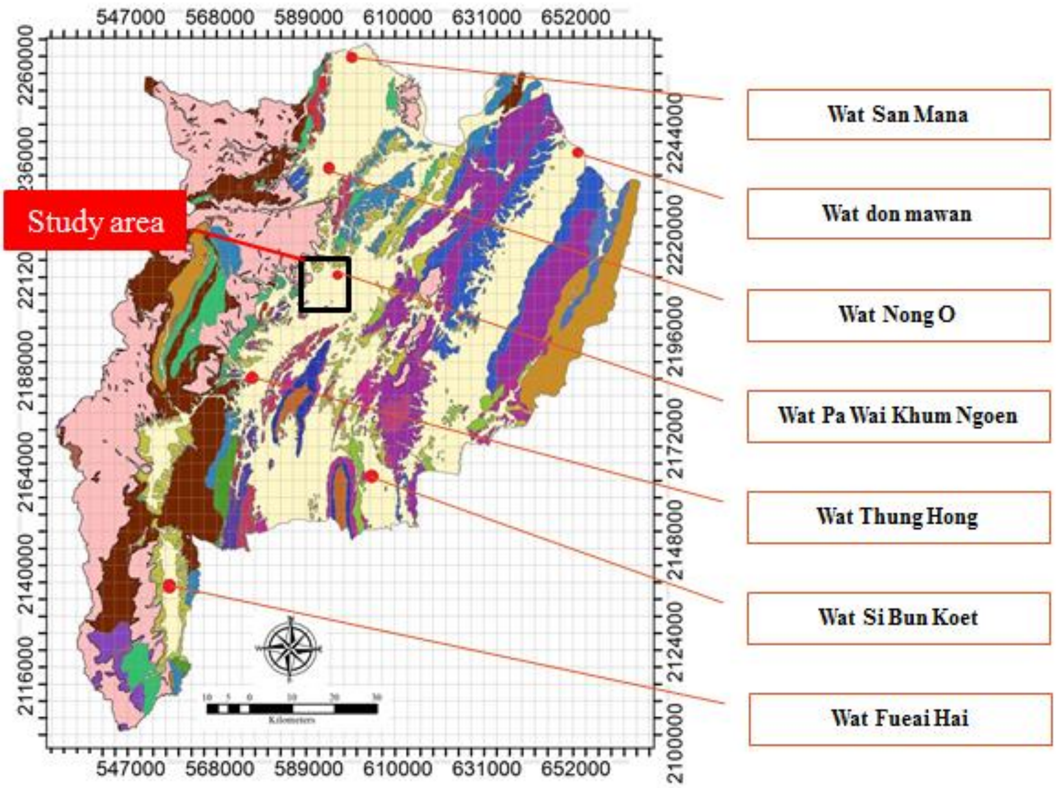

Figure 4.1 Location of borehole data in Changwat Chiang Rai.

4.2.2 Shear wave velocity data

Second, the shear wave velocity of this study was acquired from MASW seismic technique. The result of shear wave at each depth was analyzed by surfseis software. After analyzed, mainly all site of study area was divided to 10 layer of soil. Then the Vs(30) of each site were calculated by using equation

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

where:

$\overline{Vs}$= the shear wave velocity, The Vs(30)

v_{si} = the shear wave velocity of any layer in m/s,

d_i = the thickness of any layer (between 0 and 30 m)

So the shear wave at each layer that results from surfseis software was compared with downhole data and form soil classification of the study area. Therefore the study area has less borehole data, the refer soil classification is imperative data for using. Then the shear wave velocity at 30 meter depth of study area is about 200 – 562 m/s.

While the all borehole data and the shear wave velocity data cannot indicate the accurate depth of bedrock. This study should evaluate the bedrock at 700 m/s that refer the research. And Wat Pa Wai Khum Ngoen site is especially site because there is a borehole data with downhole and present MASW surveys for calculate soil amplification ratio in Changwat Chiang Rai.

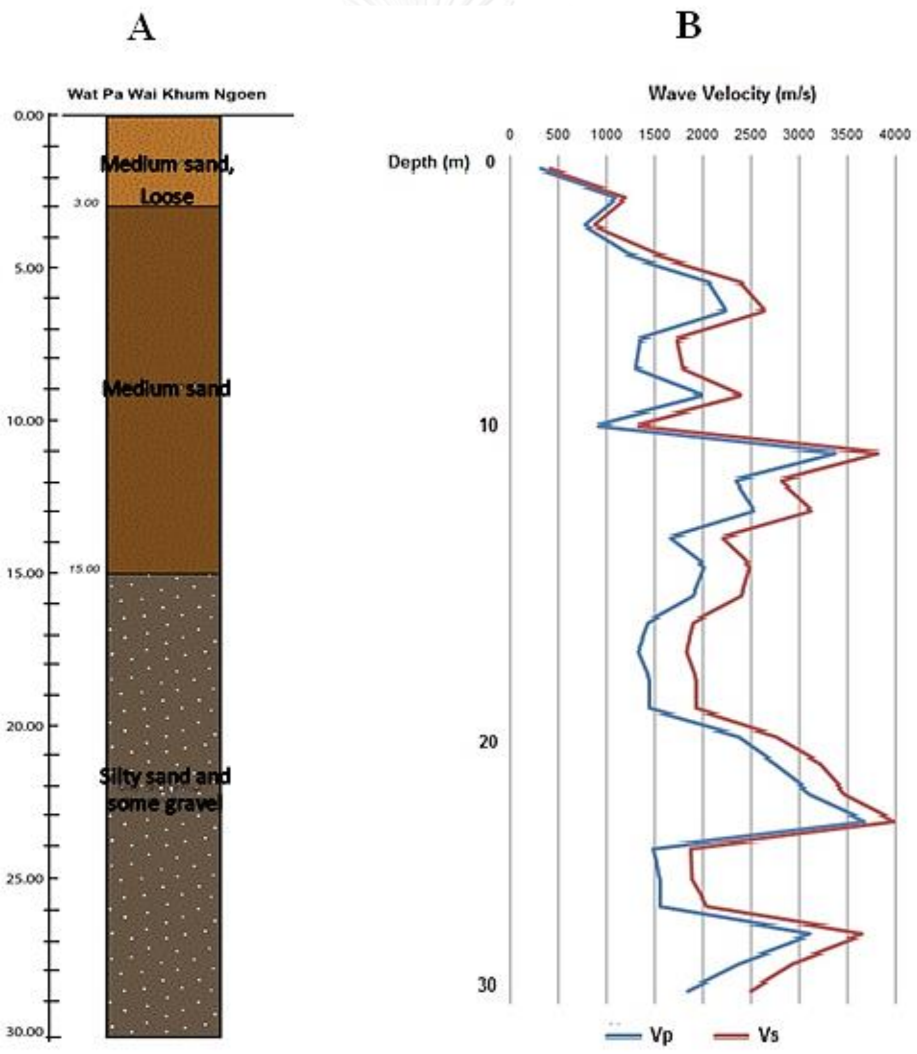

Figure 4.2 The borehole data of site No.34, Wat Pa Wai Khum Ngoen

A: soil profile, B: Wave velocity (m/s) from downhole data

4.3 Computer software (SHAKE2000 software)

The soil profiles and ground motions are used to set for the site response analyses using SHAKE2000 software. The input ground motions are determined in the input motion's option of the program. As well it is ability to peak ground acceleration for each motion to use in amplification ratio which analyses.

Table 4.1 The PGA of Strong ground motion in the SHAKE2000 software

Earthquake motion	Location	Year	Magnitude (M_w)	Depth (km)	PGA (g)
San Francisco	Northern California, United States	1957	5.7	9.3	0.15682
Imperial Valley	Imperial Valley-06, El Centro	1979	6.5	12.5	0.29698
Loma Prieta	Loma Prieta, Saratoga–Aloha Ave	1989	6.9	8.5	0.82584
Kobe, Japan	Kobe, Japan, Takarazuka	1995	6.9	0.3	0.37442

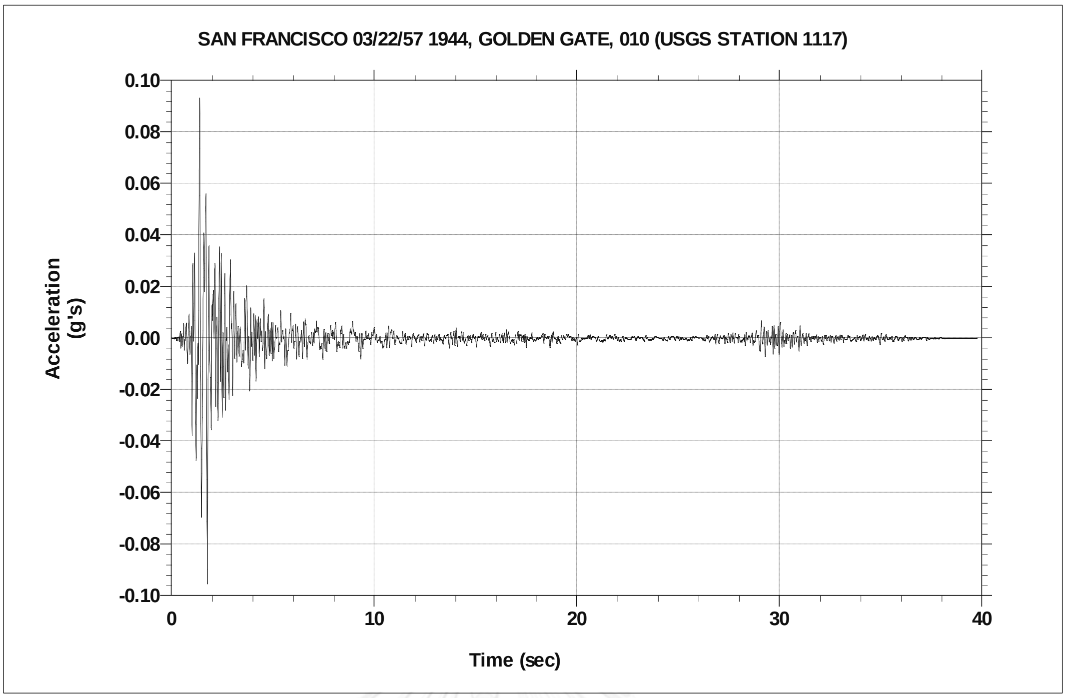

Figure 4.3 Time history of San Francisco ground motion (Amplitude of Acceleration = g's rms. or peak)

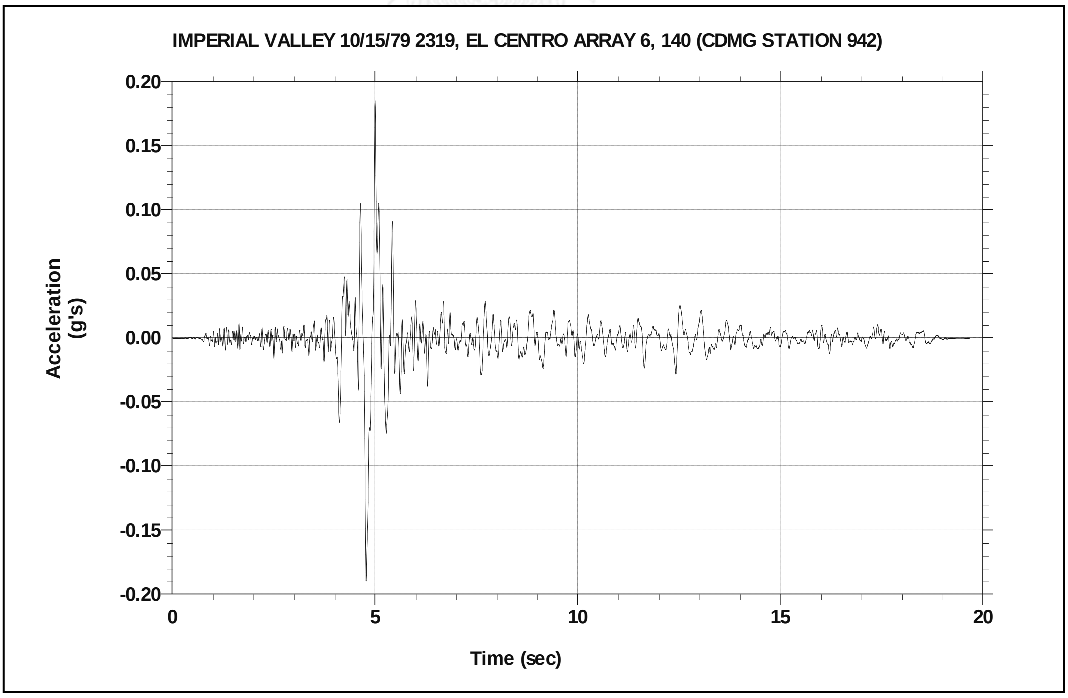

Figure 4.4 Time history of Imperial Valley Figure ground motion (Amplitude of Acceleration = g's rms. or peak)

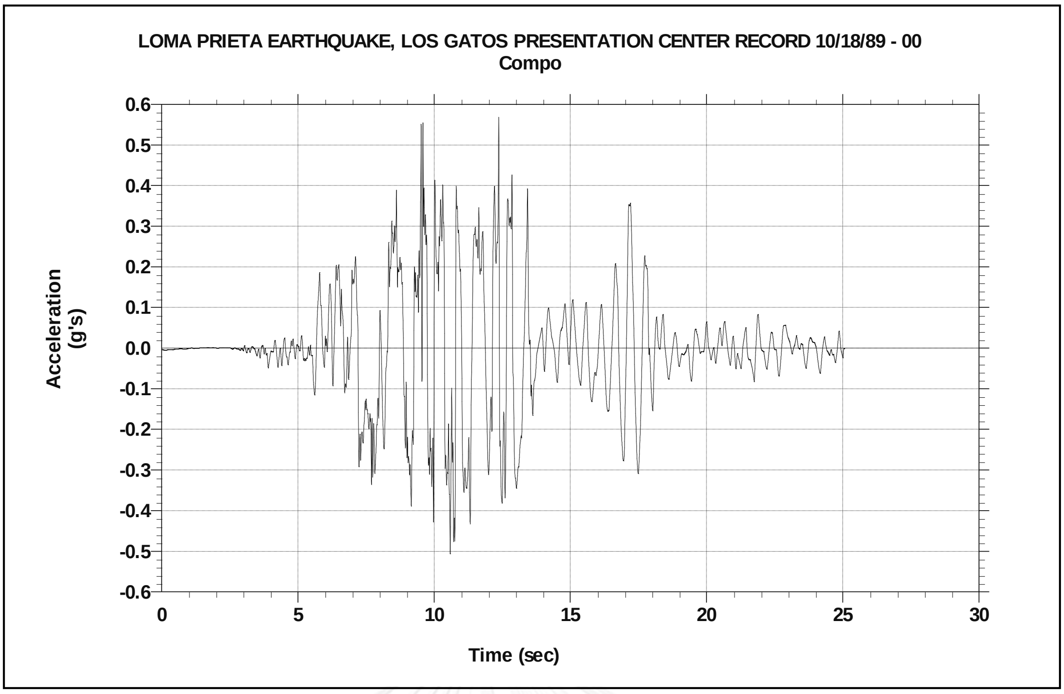

Figure 4.5 Time history of Loma Prieta ground motion (Amplitude of Acceleration = g's rms. or peak)

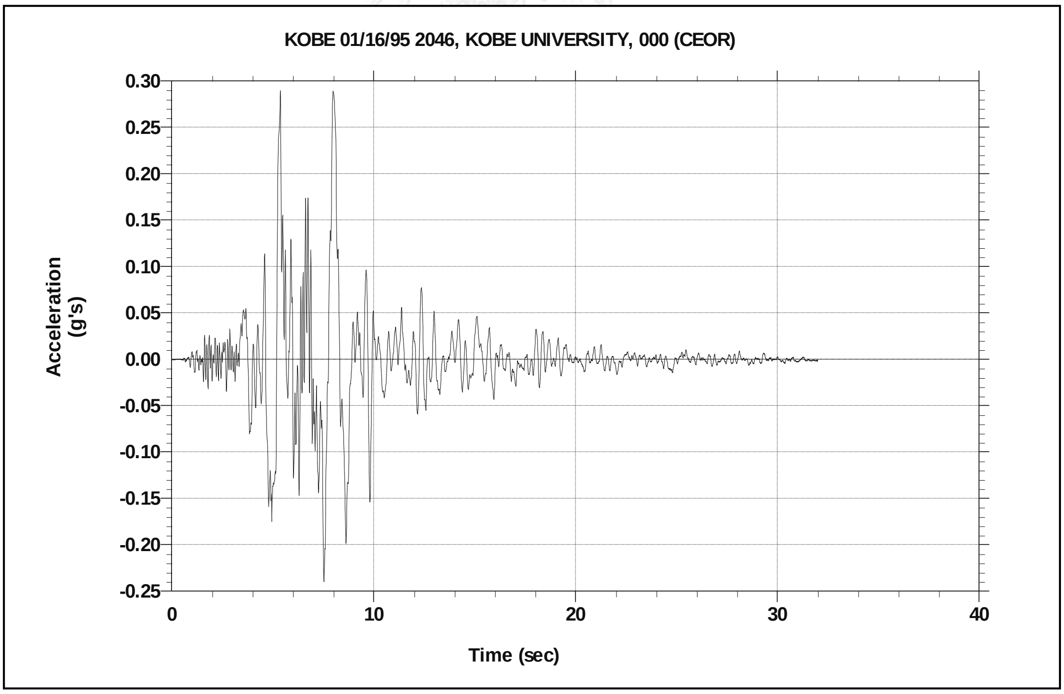

Figure 4.6 Time history of Kobe, Japan ground motion (Amplitude of Acceleration = g's rms. or peak)

Peak acceleration (at each depth), spectra displacement and amplification ratio of this result show by the text in the folder of result and graph which show when choose the option in SHAKE 2000 software.

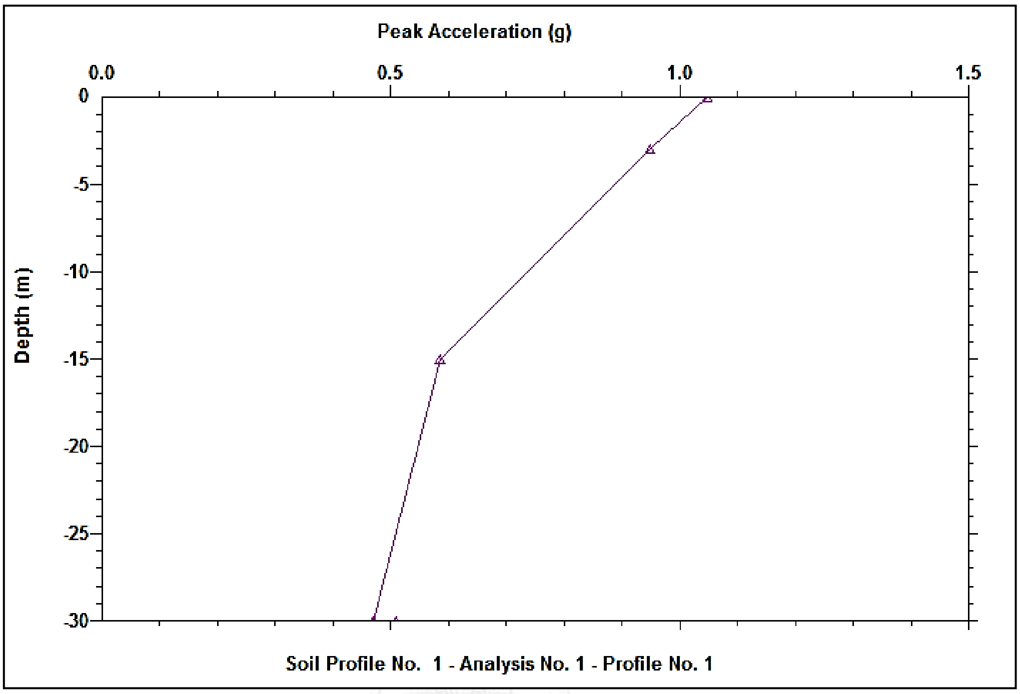

Figure 4.7 Peak Acceleration (g) at site No.34

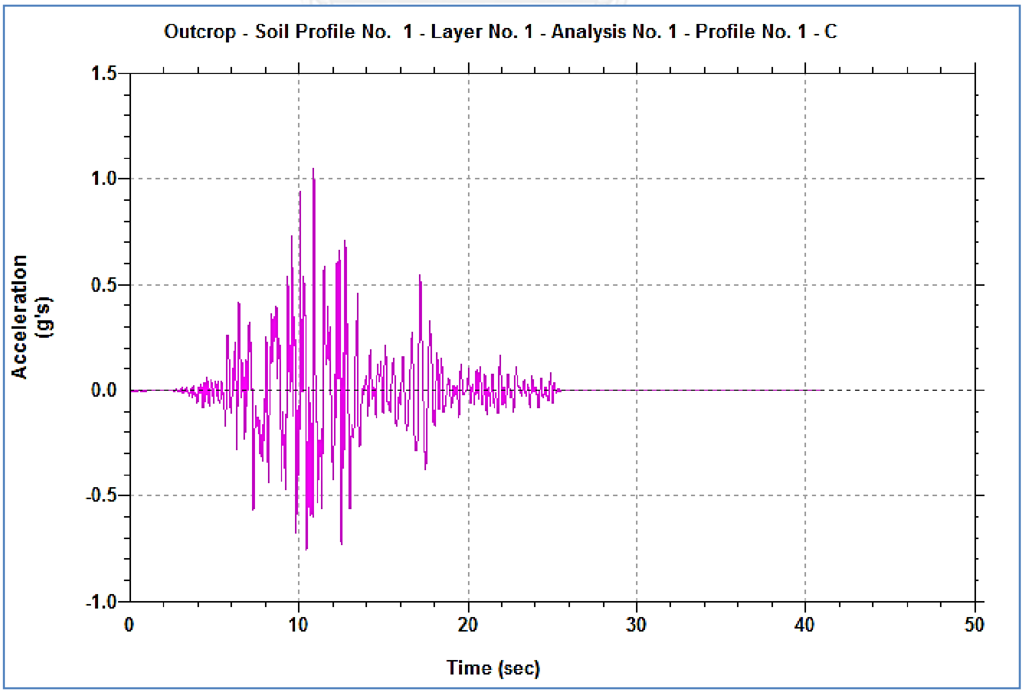

Figure 4.8 Acceleration (g's) at site No.34

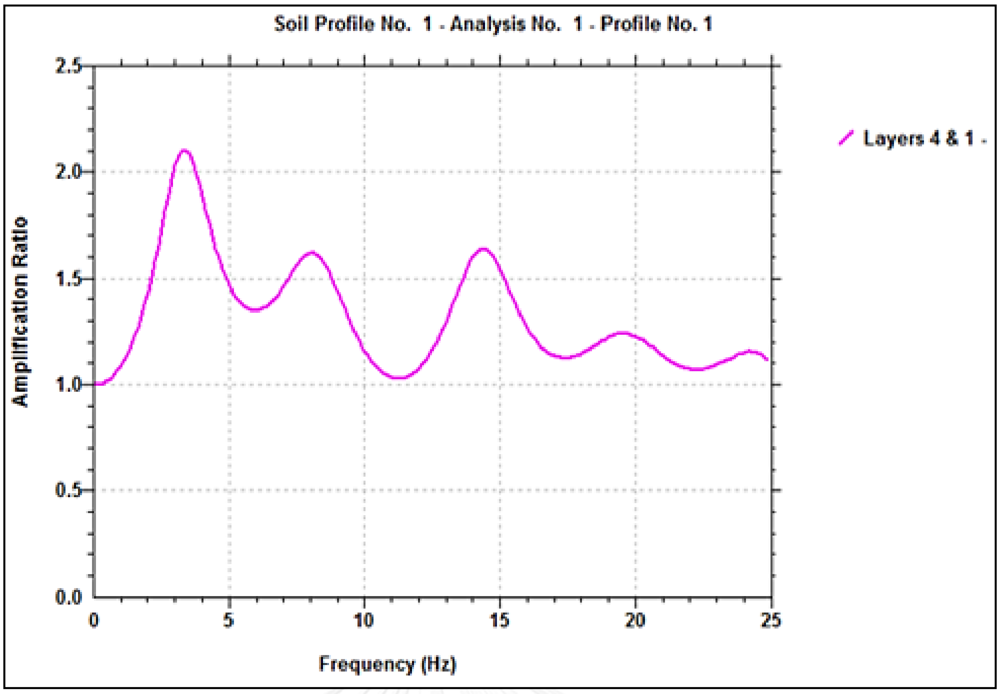

Figure 4.9 Amplification Ratio at site No.34

4.3 From downhole

The specific site is number 34 where is Wat Pa Wai Khum Ngoen. The soil types can be classifies into 3 layers as first layer is medium sand (loose) , next is medium sand and medium dense, last is silty sand some gravelly sand (table 4.2).

Table 4.2 Borehole data at site No.34: Wat Pa Wai Khum

Description	**P Wave Velocity (m/s)**	**S Wave Velocity (m/s)**
Medium sand	377-957	70 - 138
Medium dense sand	957-1673	139 - 420
Silty sand some gravelly sand	1674 - 2000	421 -700
Bedrock	>2000	>700

4.4 Comparative analysis at specific site : Wat Pa Wai Khum

The aim of this chapter is to compare site response of soil by using data from downhole and surface seismic methods. The results are not much different. Meanwhile, shear wave velocity at 30 meter (Vs30) of Borehole data is 315 and Seismic survey data is 299 which is similar. Table 4.3 shows the comparison of different parameters from both methods. The results of both methods were quite similar. The result confirmed that the soil amplification calculated using shear wave from MASW method is very reliable.

Table 4.2 The result of comparison at site No.34: Wat Pa Wai Khum

Parameters	Borehole data	Seismic survey data
Vs30 (m/s)	315	299
PGA (g)	1.25691	0.96270
Amplification ratio	2.58	2.92
Frequency (Hz)	3.88	4.5
Natural Period ($\frac{1}{f}$)	0.26	0.22

4.5 Comparison of difference ground motions

There are four different ground motions selected for comparison. The objective is to compare the response of soil with different ground motions. The high PGA that explains the peak ground acceleration that may affect the ground when the earthquake occurs. The different Magnitude (M_w), depth and PGA of motion make vary result after processing the SHAKE2000 software. Most PGA that process the software of motions is higher. Finally the result of amplification ratio that is using the difference ground motions is coincident.

Table 4.3 The results of site response analysis from difference ground motions at site No.34: Wat Pa Wai Khum

Earthquake	Location	Year	Magnitude M_w	Depth (km)	PGA (g)	PGA(g) After software	Amplification Ratio
San Francisco	Northern California, United States	1957	5.7	9.3	0.18	0.16	2.20
Imperial Valley	Imperial Valley-06, El Centro	1979	6.5	12.5	0.26	0.30	2.25
Loma Prieta	Loma Prieta, Saratoga – Aloha Ave	1989	6.9	8.5	0.65	0.83	2.92
Kobe, Japan	Kobe, Japan, Takarazuka	1995	6.9	0.3	0.71	0.37442	2.11

CHAPTER 5
RESULTS AND DISCUSSION

In this chapter, all results of study were summarized in the forms of map and discussed. The Vs (30) and NEHRP maps is derived from previous and present MASW surveys. The soil amplification ratio, the PGA, and the natural frequency map are calculated from SHAKE2000 software using Vs from the MASW method incorporated with the geotechnical soil properties from borehole available in the study area.

5.1 Average Shear wave at 30 meters depth (Vs30) Map

In this study, all 46 shear wave velocity (Vs) data were acquired in the study area using MASW seismic survey. The derived Vs profiles were then weighted average to the depth of 30 meters (Vs30). Then each Vs (30) were 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 northern west 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 Changwat Chiang Rai 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 Changwat Chiang Rai 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.

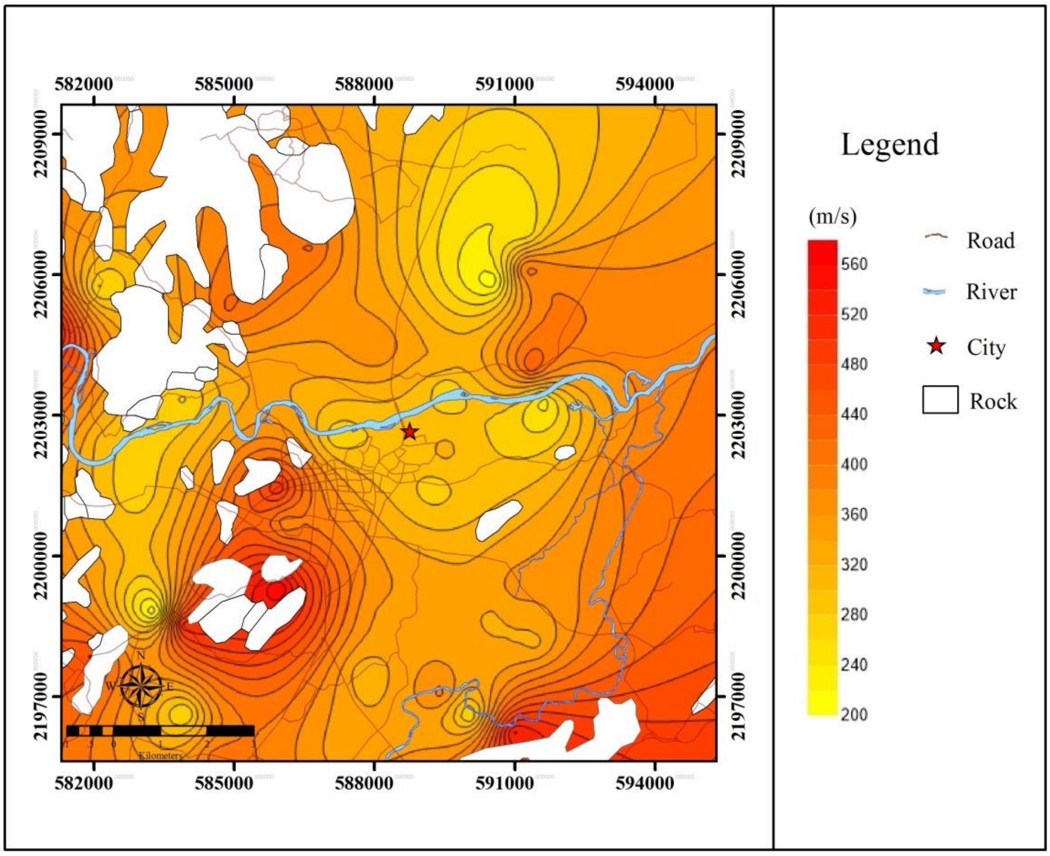

Figure 5.1 Average Shear wave at 30 meters depth (Vs30) Map

5.2 NEHRP Map Site Classification Map

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 3.2 shows five soil types classified based on the range of Vs (30) values. Figure 5.2 shows the NEHRP site class map of the study area. 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 which has average Vs (30) greater than or equal 360 m/s but less than or equal 760 m/s. 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 amplification capability. So, the City of Chiangrai that is situated on soil class D may has some risk from soil amplification.

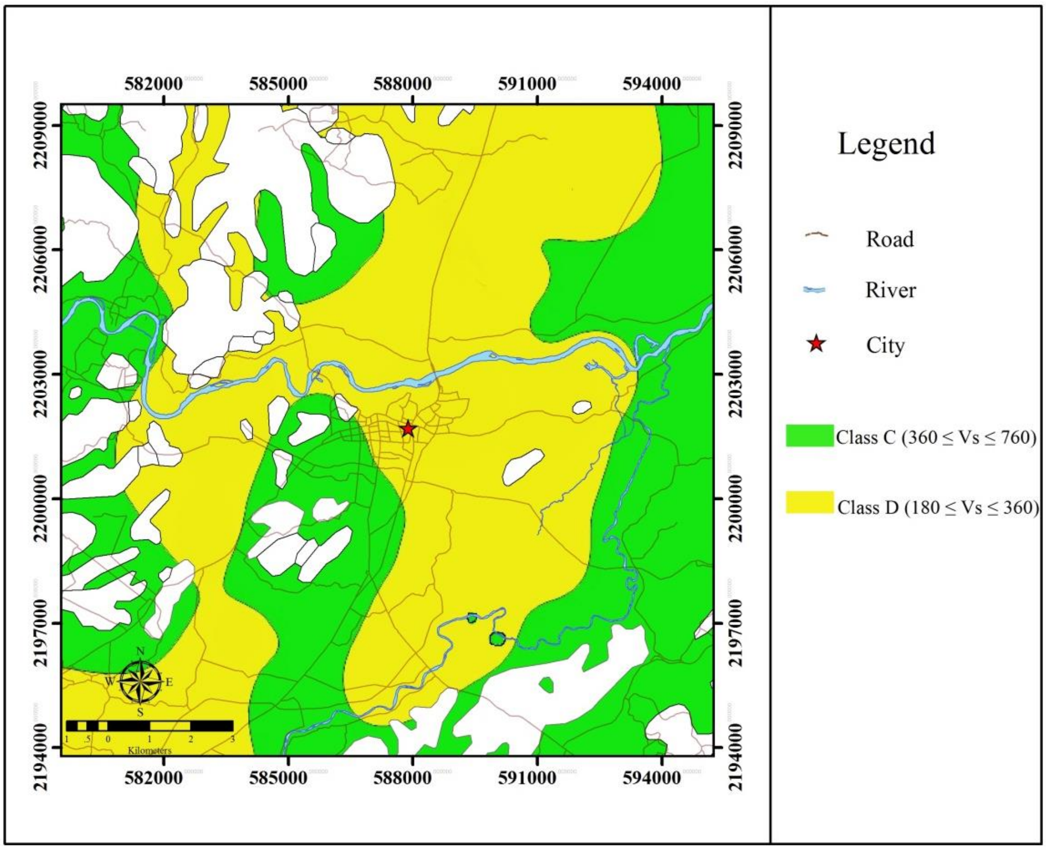

Figure 5.2 NEHPR map of the study area

5.3 Soil Amplification map

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 Figure 5.3 shows the amplification map of the study area. The amplification ratio of the study area ranges from 1.77 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. Changwat Chiang Rai is situated on the soft soils and has the amplification ratio higher than 2.0.

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.

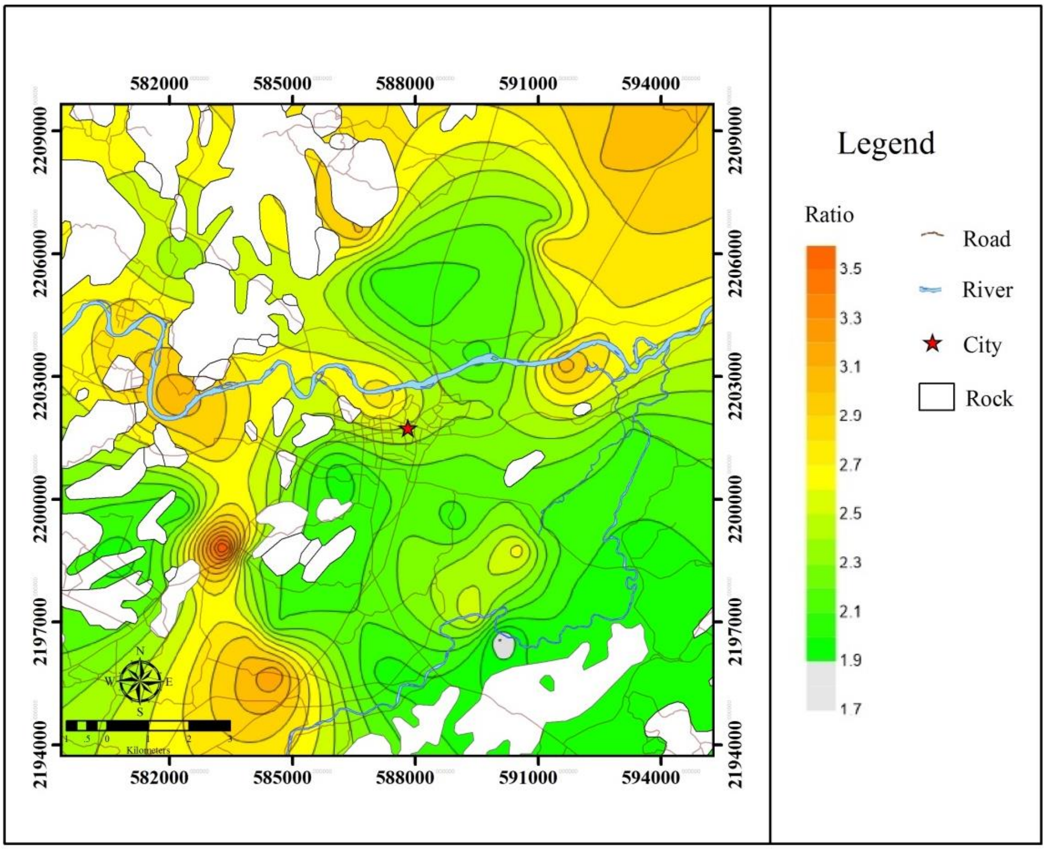

Figure 5.3 Soil Amplification map of the study area

5.4 Peak Ground Acceleration (PGA)

The PGA at the surface of all test location which is derived from SHAKE2000 software is contoured and present in the form of map (figure 5.4). The surface peak ground acceleration varies from 0.30 to 1.40. The highest PGA is generally observed in soft soils (flood pain and some terrace deposits) and can be found in the central and northern east and southern west direction. The lowest PGA is found at the southern part of this study which may result from the shallow bedrock or course gain sediments. The PGA is relate with the earthquake when occurs in this area. The study area has surface PGA higher than 1 which is probably due to the soft sediments underneath the city. Generally ground motions with high PGA will cause more damage than motions with low PGA. So, the city may have to be caution with the amplification potential of the soil soils.

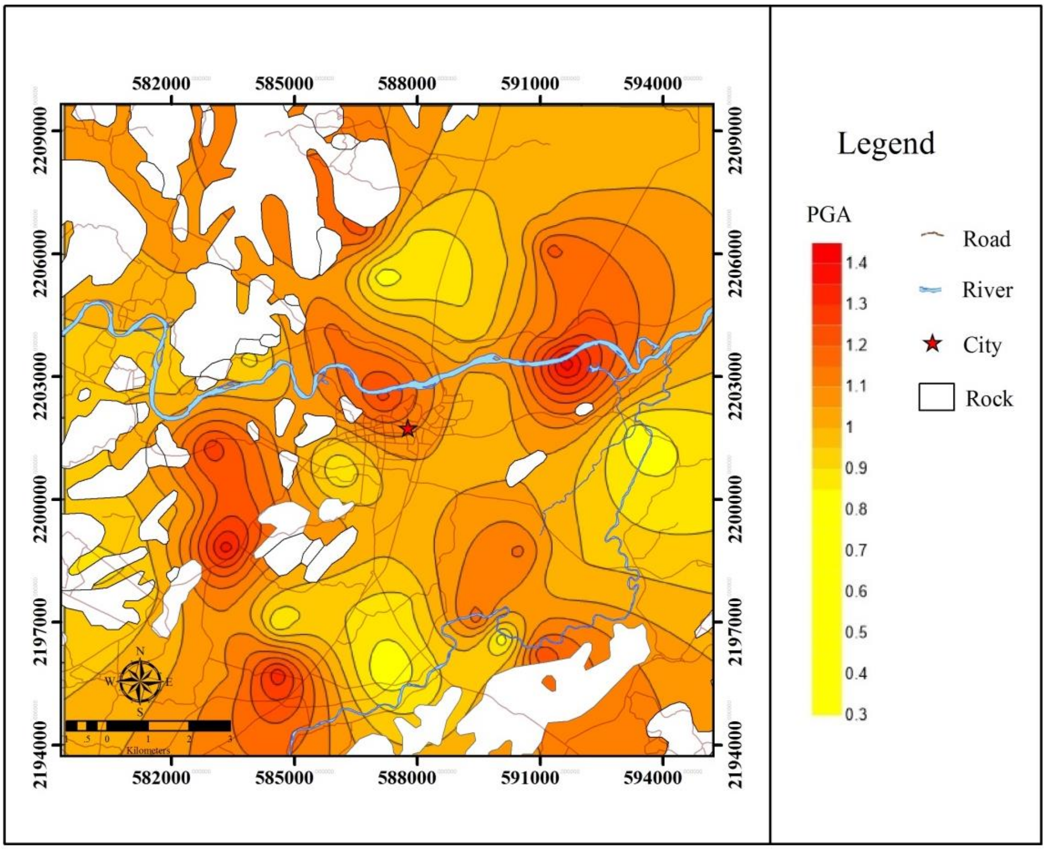

Figure 5.4 PGA map of the study area

5.5 Natural Frequency Map of the Study Area

One of the important parameter that describes the characteristic of earthquake is the period or inversely frequency. These parameters are also very important to evaluate the effect of building structure that constructed or will be constructed in the future. All buildings and other infrastructures has their own natural period and frequency. This means that when the seismic wave propagates to the site, the building will tend to shake back and forth at its natural period or frequency. One story building has natural period about 0.10 second (10 Hz) while the 4 story building will shake at about 0.50 second (2 Hz).

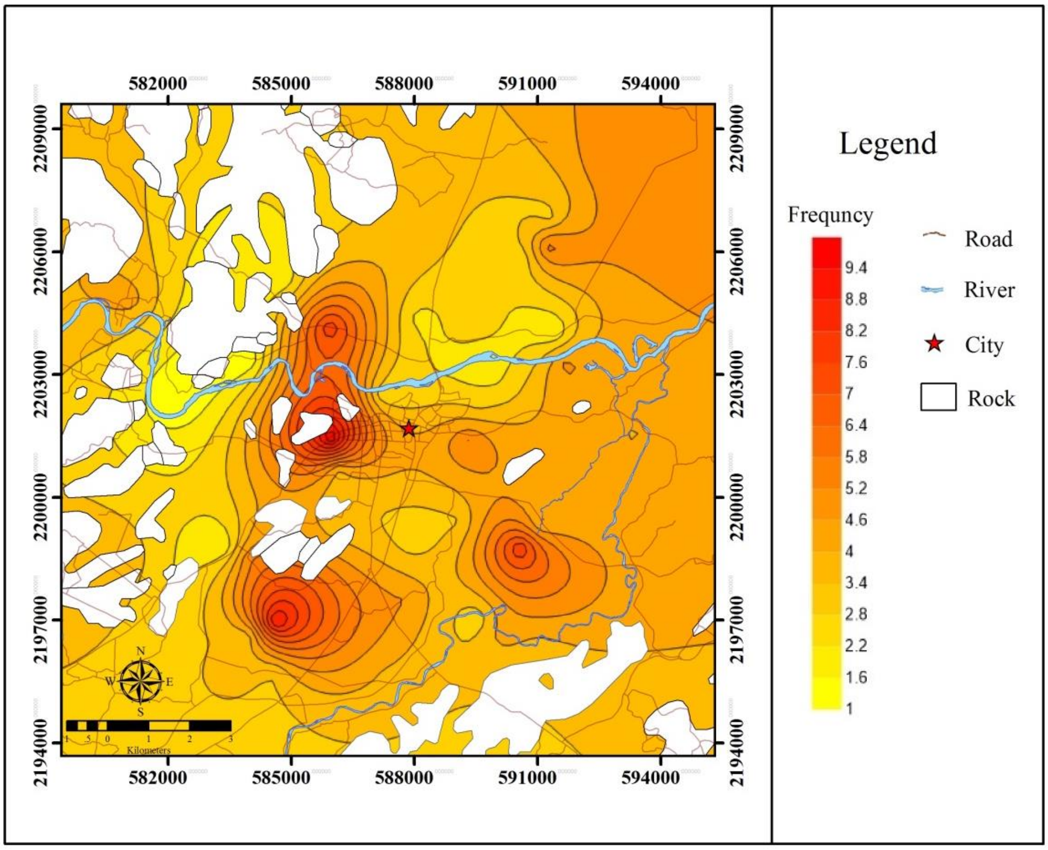

Figure 5.5 Natural frequency map of the study area.

In this study, the natural frequency of all 46 test site that derived from SHAKE2000 software is display in figure 5.5. The natural frequency of the area varies from 0.20 to 9.50 Hz. The western part of the study area show quite low frequency about 1 to 2.20 Hz. However the central part and most part of study area present higher natural frequency (> 6 Hz). It is implied that the short building structure such 1 or 2 stories will be subjected to higher ground shaking that tall building.

CHAPTER 6
CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Soil amplification assessment of earthquake ground motion in Amphoe Muang, Changwat Chiang Rai was determined by using MASW surveys data and SHAKE2000 software. All the results of study were summarized in the form of map. The Vs(30) and NEHRP map were derived from previous and present MASW data. The soil amplification ratio, the PGA and the natural frequency were calculated from SHAKE 2000 software.

6.1.1 The average shear wave velocity from surface to at 30 meter depth of this study is 200 – 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 and the central part of the study are characterized by medium to low Vs(30) which is about 200-380 m/s.

6.1.2 The result of Vs(30) from MASW surveys were used to generate seismic siteclassification of soils based on recommendation of the National Earthquake Hazards Reduction Program (NEHRP) provisions (BSSC, 2000). So site class of study area is 2 types which are C and D. The soil type C is dense soil and soft rock, ($360 \leq Vs \leq 760$) and the soil type D is stiff to soft soil, ($180 \leq Vs \leq 360$). Finally, changwat Chiang Rai is situated on soil class D may has some risk from soil amplification.

6.1.3 Amplification ratio is calculated from SHAKE2000 software that is 1.77 – 3.58. It is described the ratio of the peak ground acceleration to the peak acceleration at the bedrock. The highest amplification ratio is 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. Finally, Changwat Chiang Rai is situated on the soft soils and has the amplification ratio higher than 2 that has risk of soil amplification.

6.1.4 The PGA at the surface of all test sites is derived from SHAKE2000 software that range from 0.30 to 1.40 g in study area. The highest PGA is generally observed in soft soils (flood pain and some terrace deposits) that related with the low average shear wave velocity at 30 meter depth and highest amplification ratio and the PGA is relate with the earthquake when occurs in this area. Generally ground motions with high PGA will cause more damage than motions with low PGA. So, the city may have to be caution with the amplification potential of the soft soils.

6.1.5 Natural frequency map was calculated from SHAKE2000 software that range from 1.0 to 9.5 H_Z and 0.11 to 2.5 second respectively. The western and eastern part of the study area show low frequency. However the central part and most part of City present higher natural frequency (> 6 Hz). It is implied that the short building structure such 1 or 2 stories will be subjected to higher ground shaking than tall building.

6.2 Discussion

Pattarattanahul (Pattararattanakul 2003) reported that the soils in this study area have ability to amplify ground motion on the order of 1.5 to 3 times. The result of this study show similarly result that is 1.77 – 3.58 times. The result is slightly different and may cause by the different method of data collection used in SHAKE2000 software such as shear wave velocity data (Pattararattanakul 2003) used SPT data to estimate the shear wave velocity whereas in this study, the shear wave velocity was derived from in situ testing that is MASW seismic survey

However, in this study at each MASW test site, the soil profile was estimated from Vs value. The relationship between soil type and Vs value was established based on several downhole shear-wave velocity data available in Changwat Chiang Rai..

6.3 Recommendation

In this study there were a few boreholes available in the study area. So, additional borehole drilling may help researcher in site specific soil profile development and more downhole seismic testing may be very helpful in MASW data verification.

In this study the ground motion used as an input in SHAKE2000 software was selected from the database available in the software. So, for the future work ground motion should be generated based on geological and tectonic data of the area. This synthetic ground motion will be well represented of an earthquake that actually happened in the area.

The series of maps that were generated from this study may be only used as a guideline and recommendation for engineer and city planner. Detailed study may still be needed when dealing with the design and planning any critical structures that will be constructed in the city area in the future.

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APPENDIX

Table A-1 The result of study area

Station	UTM		Vs30	PGA	Amplification	Frequency	Natural Period
1	584597	2195740	392	0.29401	3.09	2.88	0.35
2	583501	2195672	330	1.05424	2.87	3.13	0.32
3	583954	2196638	251	1.05912	2.81	3.25	0.31
4	582001	2197897	443	0.97115	2.31	2.13	0.47
5	580893	2198465	412	0.89914	2.05	3.38	0.3
6	582379	2199746	316	1.00631	2.09	2.38	0.42
7	583905	2198543	493	1.12611	2.36	4.38	0.23
8	585973	2199315	562	1.02937	2.11	3.00	0.33
9	585940	2201453	481	0.94172	2.31	9.50	0.11
10	589280	2201400	268	0.96157	2.32	4.63	0.22
11	590064	2202737	284	0.97463	2.33	2.25	0.44
12	591379	2204041	422	1.11665	2.42	1.63	0.62
13	589526	2203610	263	1.02290	2.11	1.75	0.57
14	587746	2197519	305	0.88775	2.31	4.00	2.50
15	589468	2197066	369	1.12950	2.57	2.38	0.45
16	590061	2196610	250	0.80142	1.77	3.63	0.28
17	590964	2196246	524	1.18499	2.08	3.00	0.33
18	591048	2199347	351	1.00482	2.19	3.38	0.30
19	589018	2199421	337	1.01950	2.15	2.75	0.36
20	591616	2203323	228	1.39513	2.99	4.13	0.24
21	591237	2206153	391	1.17258	2.82	4.88	0.21
22	591258	2206879	245	1.00859	2.36	2.63	0.38
23	587884	2206477	328	0.89113	2.36	3.38	0.3
24	586672	2206572	402	1.17625	2.93	2.88	0.35

Table A- 2The result of study area

Station	UTM		Vs30	PGA	Amplification	Frequency	Natural Period
25	588047	2204418	362	0.95753	2.16	2.00	0.50
26	585904	2204183	326	1.11623	2.57	6.88	0.15
27	584856	2205318	406	1.03312	2.51	1.88	0.53
28	583965	2203380	256	0.88312	2.65	1.13	0.89
29	582143	2202459	293	0.95403	3.00	1.00	1.00
30	582108	2205698	254	1.00617	2.44	2.38	0.42
31	581104	2204865	544	0.96717	2.71	3.63	0.28
32	587084	2205463	343	0.81572	2.12	3.5	0.29
33	590579	2205872	204	0.97755	2.24	2.38	0.42
34	592607	2208258	299	0.09627	2.92	4.5	0.22
35	589392	2204119	318	0.90267	2.29	2.75	0.36
36	593265	2201655	381	0.81483	2.18	3.38	0.30
37	591485	2198102	314	0.95001	2.14	4.88	0.21
38	590533	2198762	318	1.11156	2.66	7.00	0.14
39	589520	2202267	309	0.94974	2.43	2.63	0.38
40	587165	2202524	265	1.22333	2.81	2.38	0.42
41	587894	2198890	344	0.97635	2.34	2.50	0.40
42	587203	2195768	331	0.79888	2.04	3.38	0.30
43	584581	2196959	367	0.84748	2.20	8.38	0.12
44	583327	2198806	200	1.33995	3.58	1.63	0.62
45	582965	2201288	265	1.23630	2.81	2.25	0.44
46	586093	2200700	362	0.84236	2.04	3.38	0.30

Station No. 1

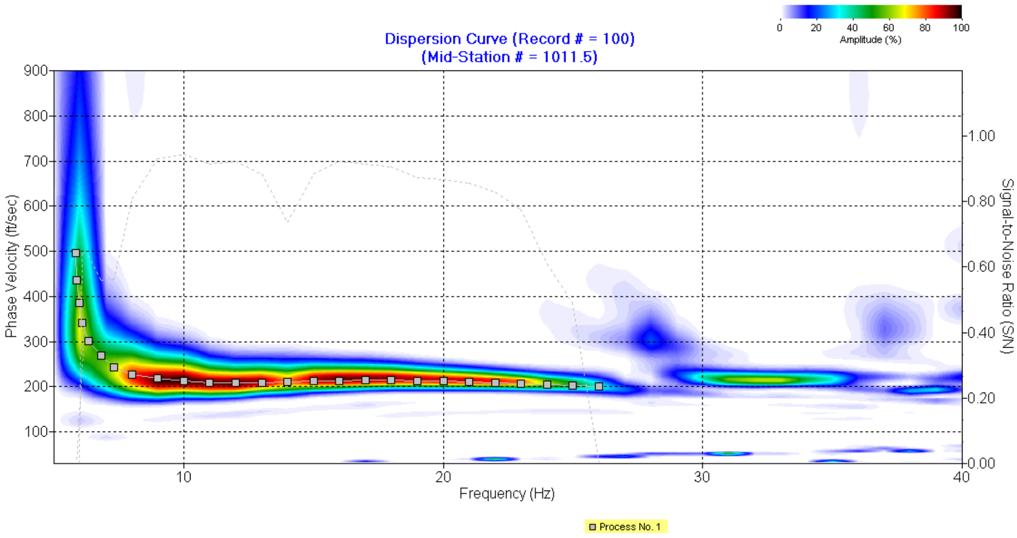


Figure A-1 Dispersion curve of Station No.1

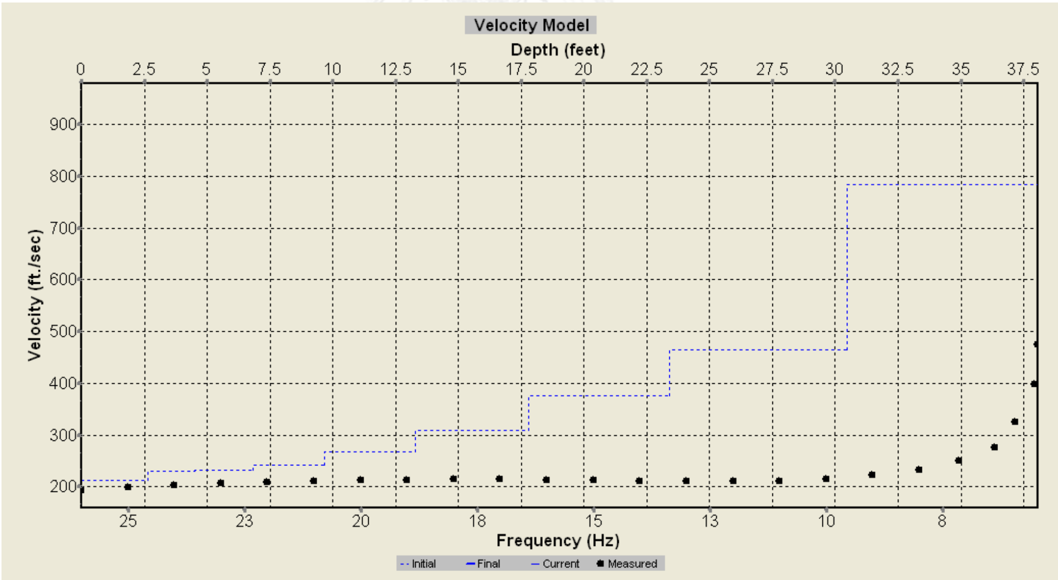


Figure A-2 Inversion of Station No.1

Station No. 2

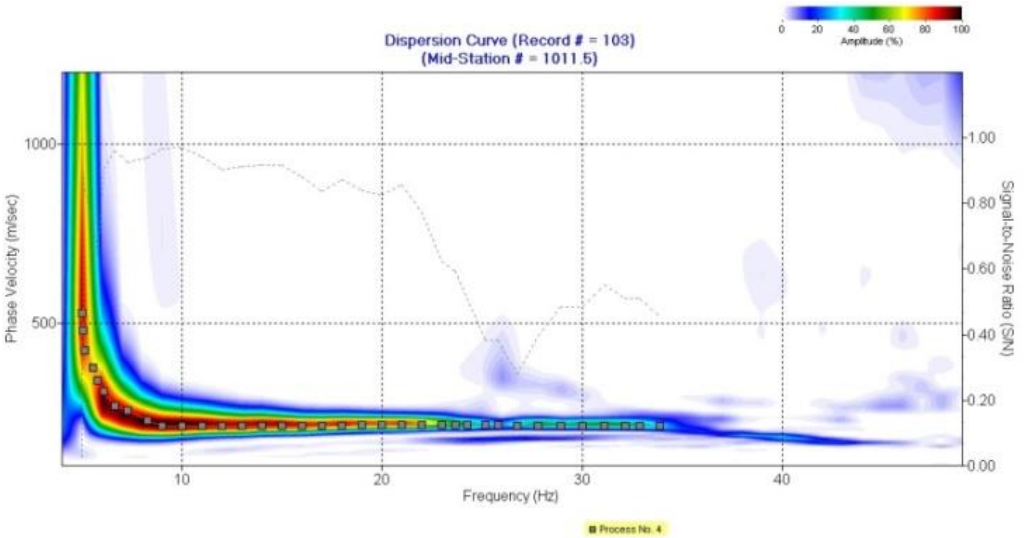


Figure A-3 Dispersion curve of Station No.2

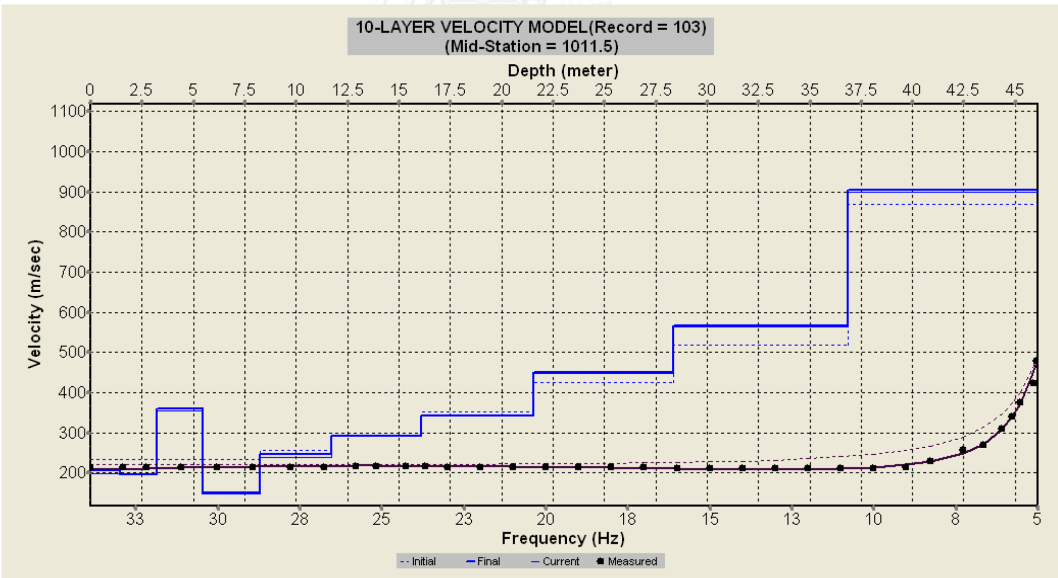


Figure A-4 Inversion of Station No.2

Station No. 3

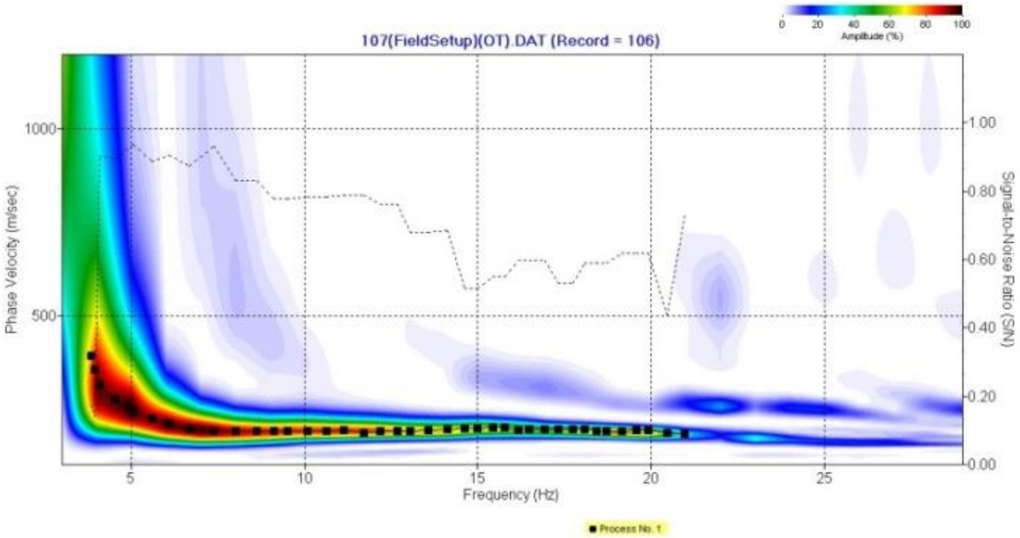


Figure A-5 Dispersion curve of Station No.3

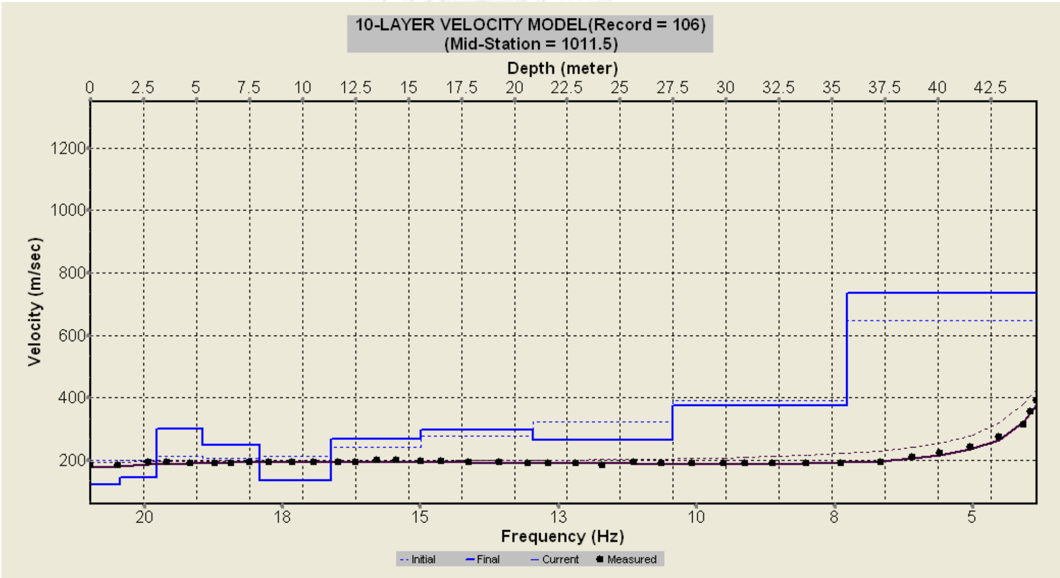


Figure A-6 Inversion of Station No.3

Station No. 4

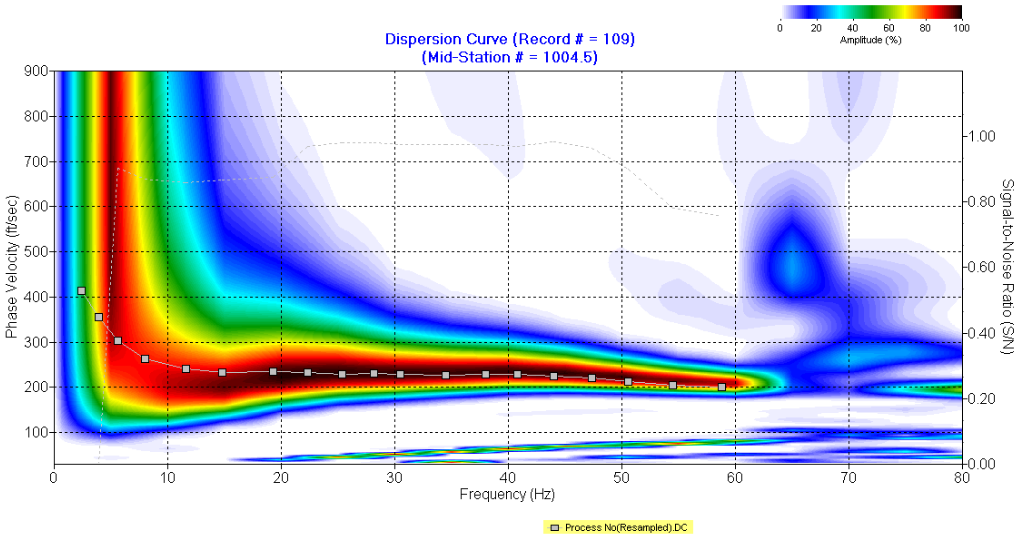


Figure A-7 Dispersion curve of Station No.4

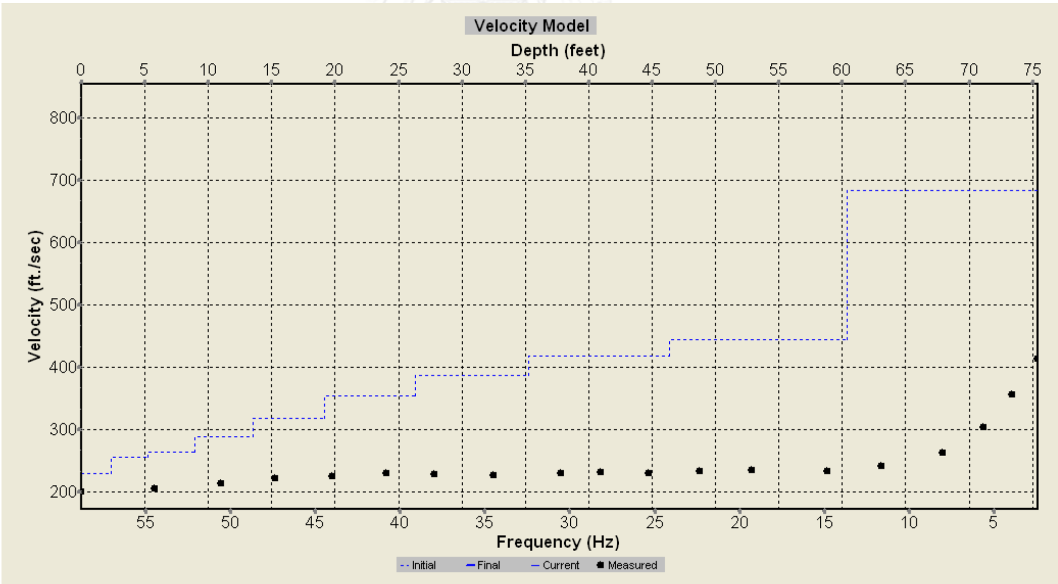


Figure A-8 Inversion of Station No.4

Station No. 5

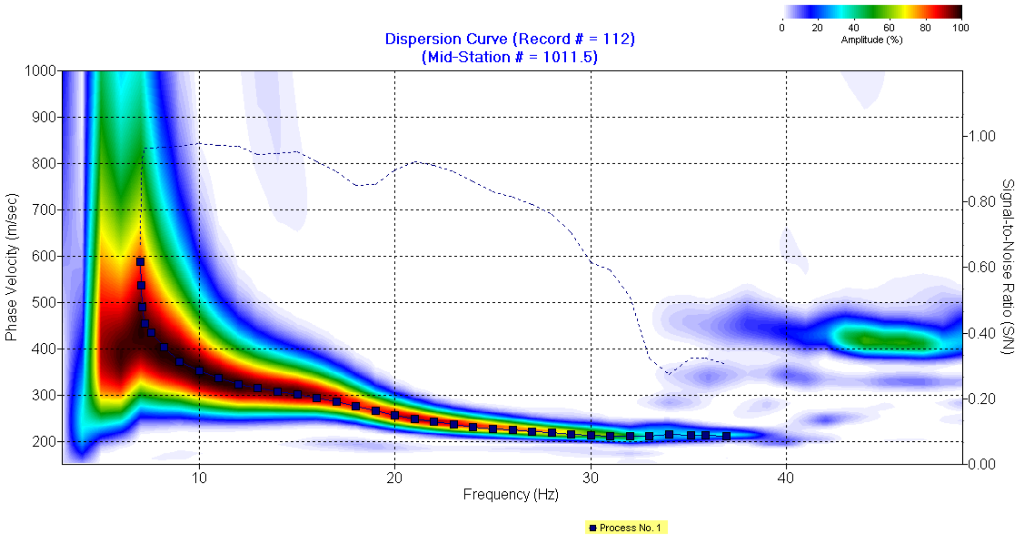


Figure A- 9 Dispersion curve of Station No.5

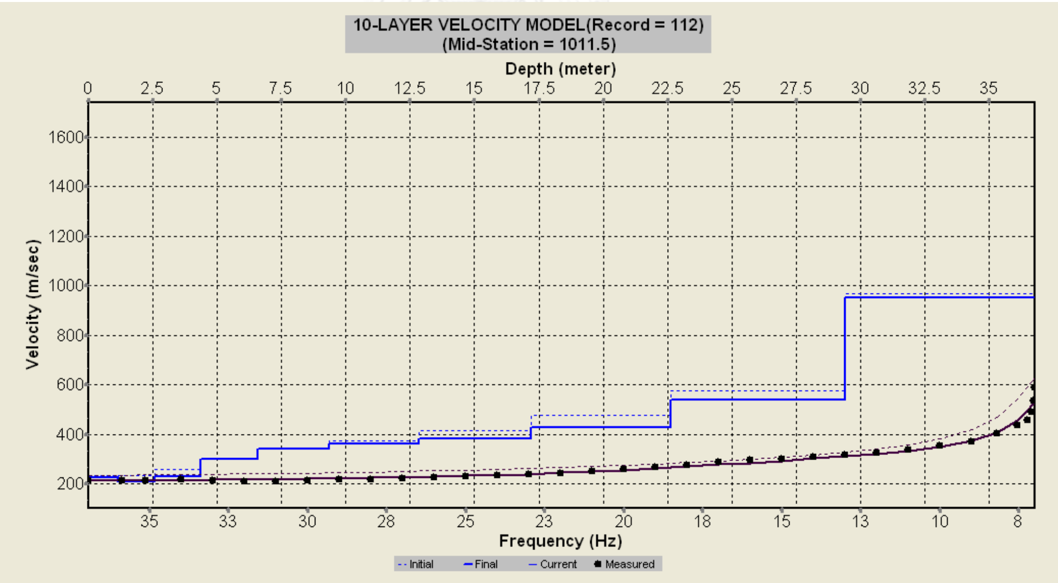
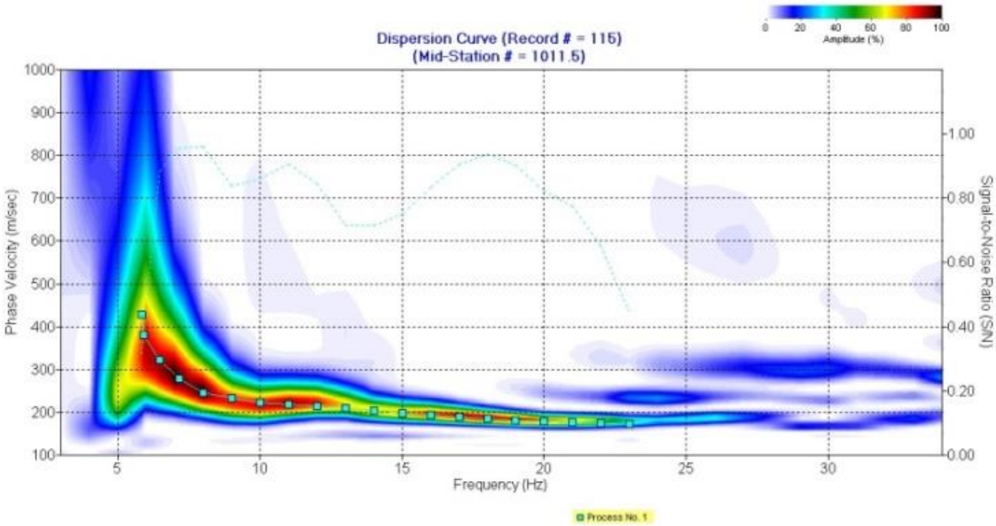


Figure A-10 Inversion of Station No.5

Station No. 6



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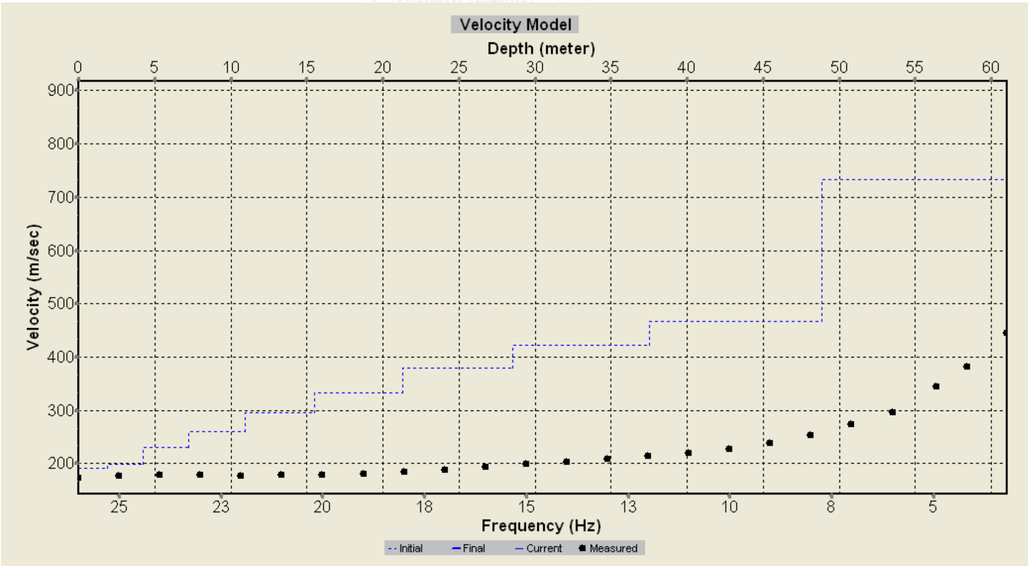

Figure A-12 Inversion of Station No.6

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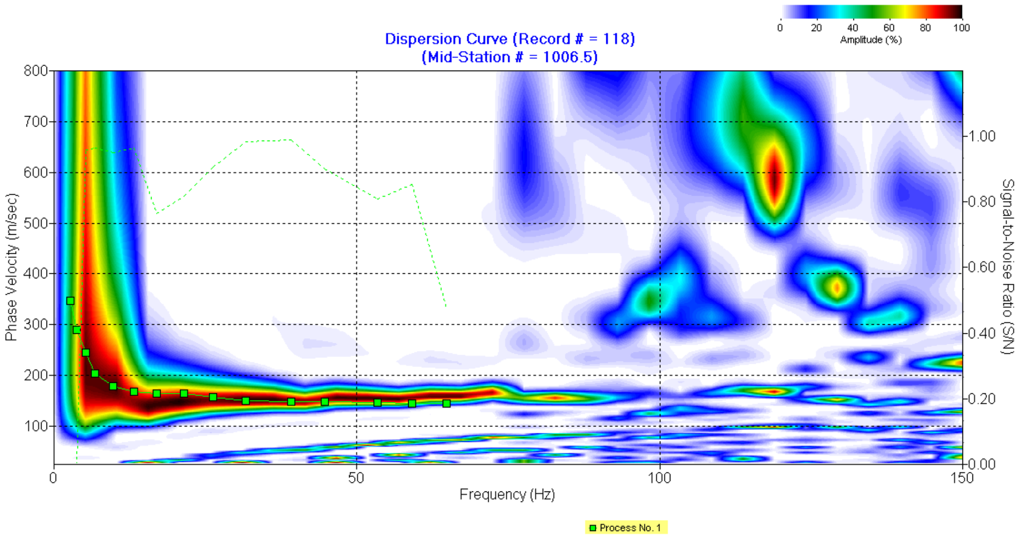


Figure A- 13 Dispersion curve of Station No.7

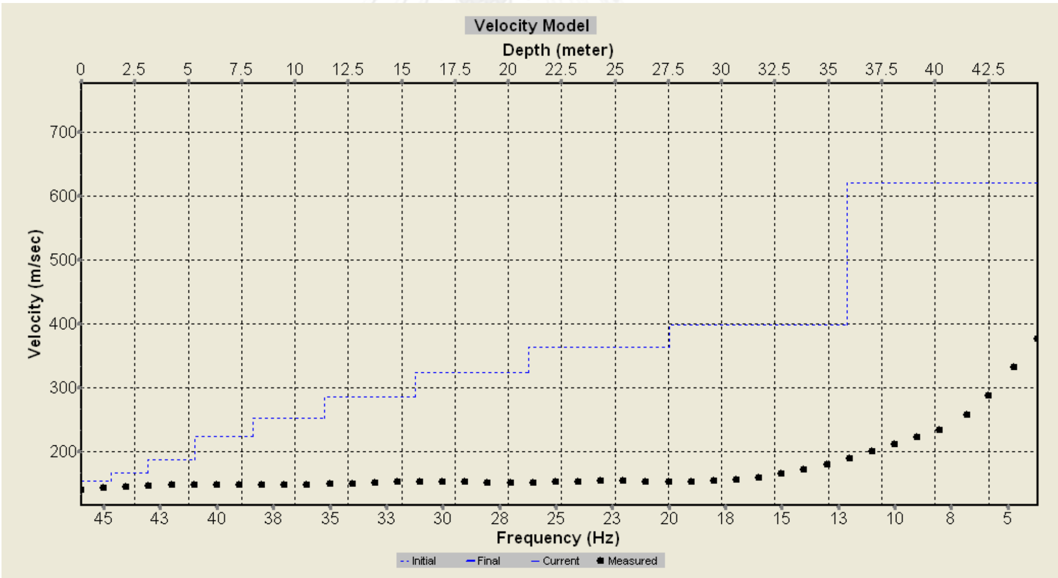
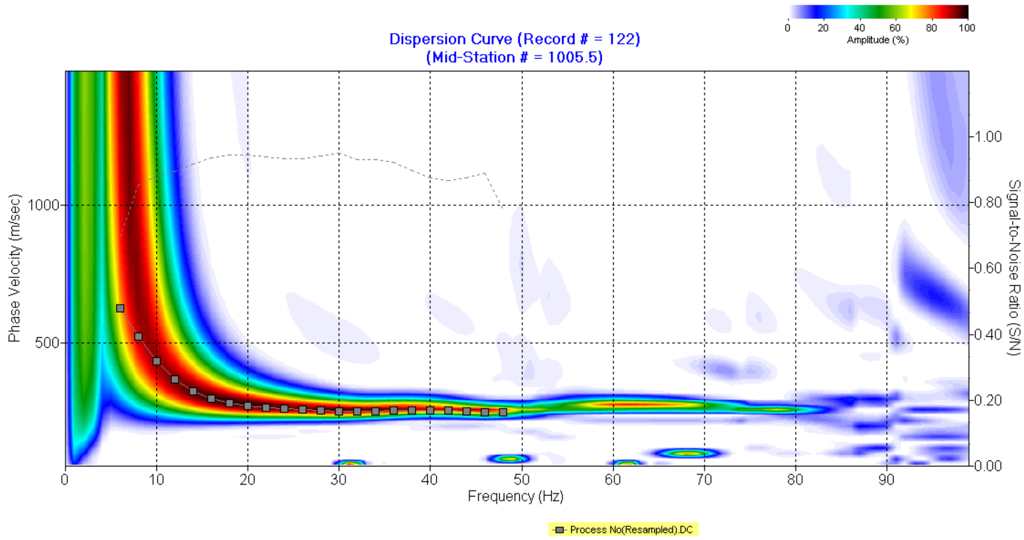


Figure A-14 Inversion of Station No.7

Station No. 8



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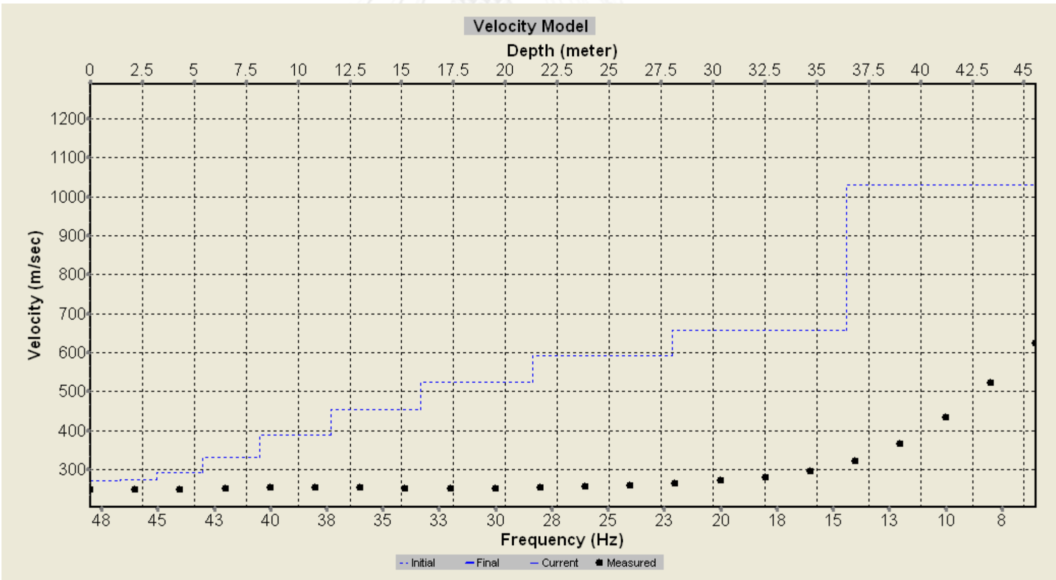


Figure A- 16 Inversion of Station No.8

Station No. 9

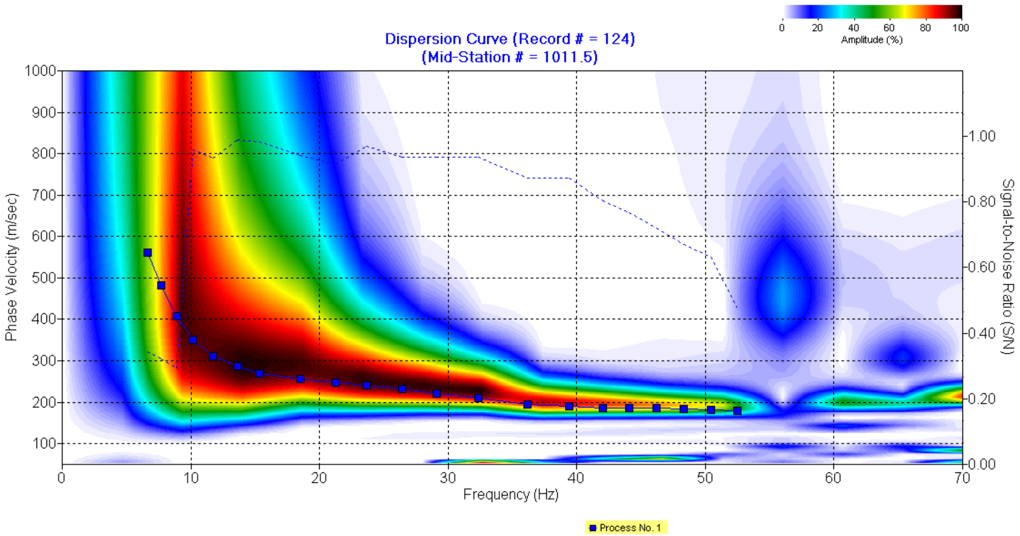


Figure A-17 Dispersion curve of Station No.9

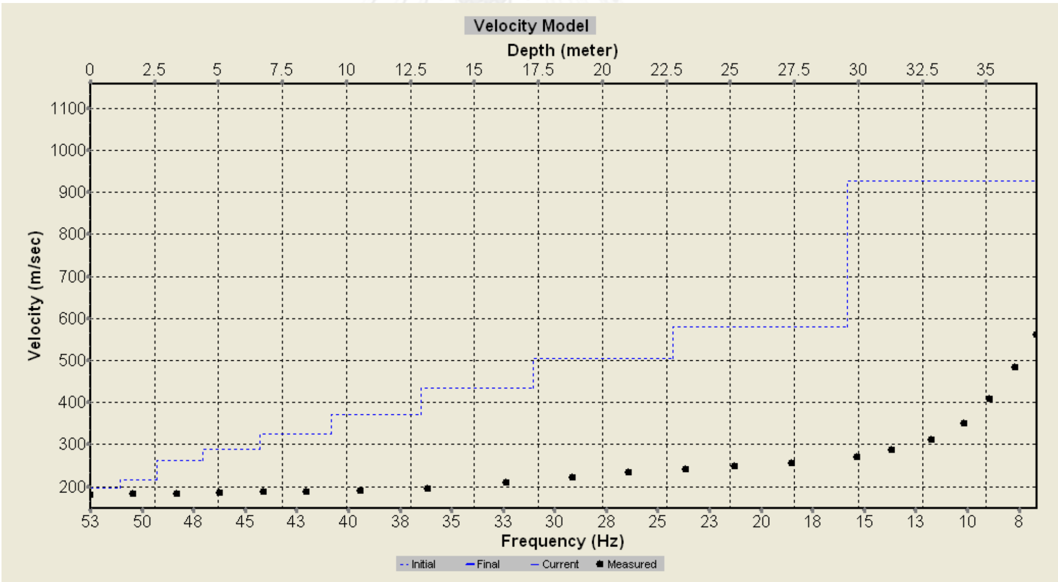
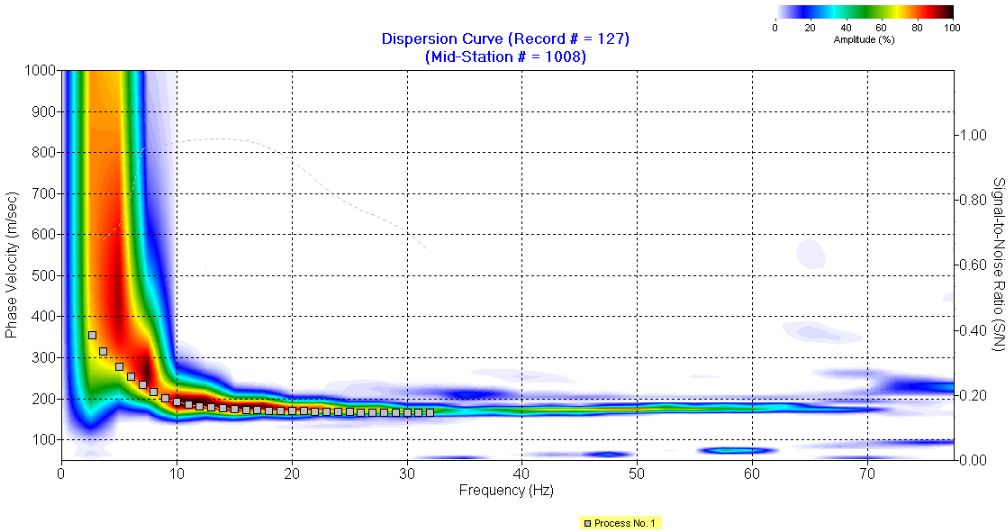


Figure A-18 Inversion of Station No.9

Station No. 10



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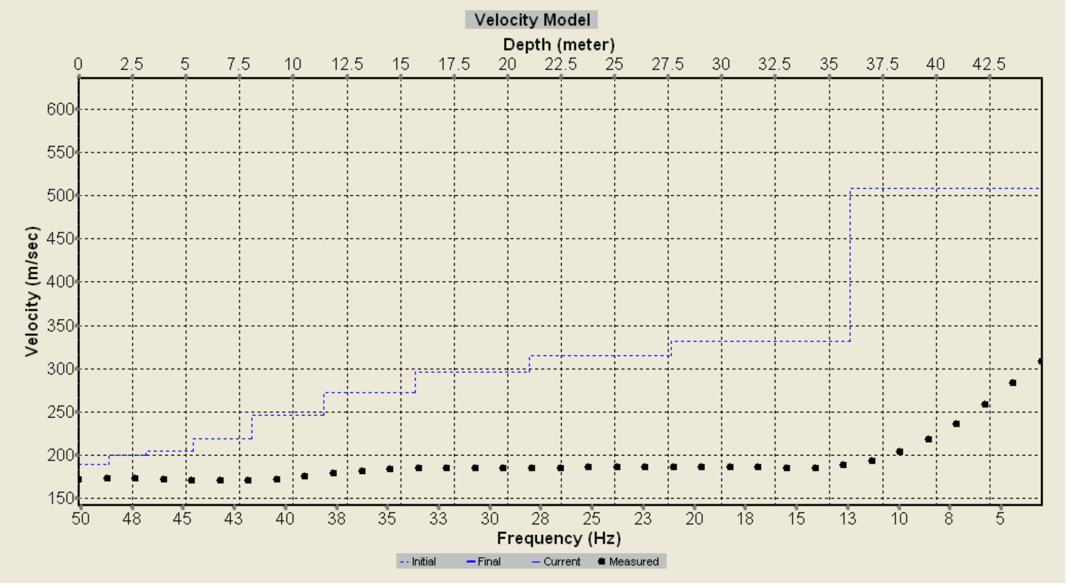
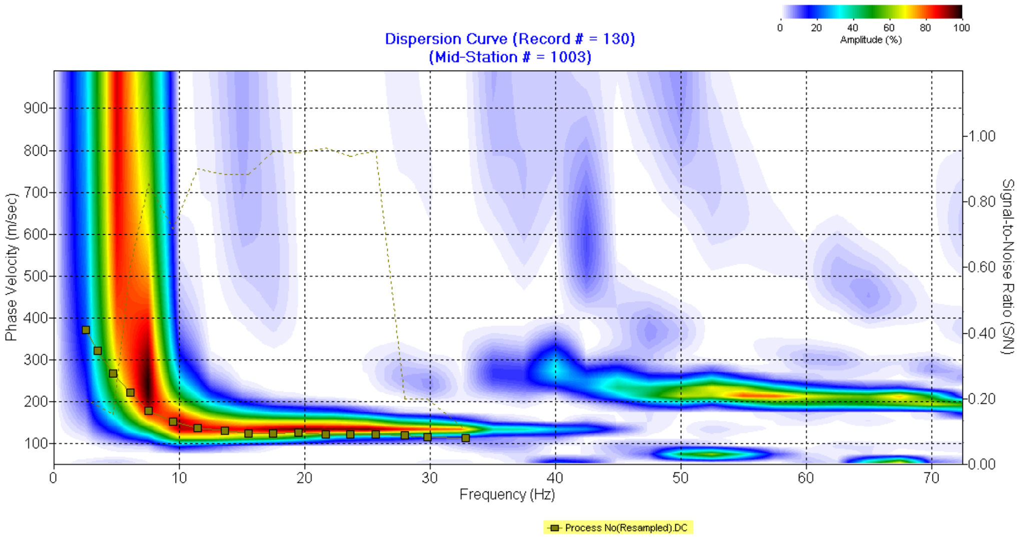


Figure A-20 Inversion of Station No.10

Station No. 11



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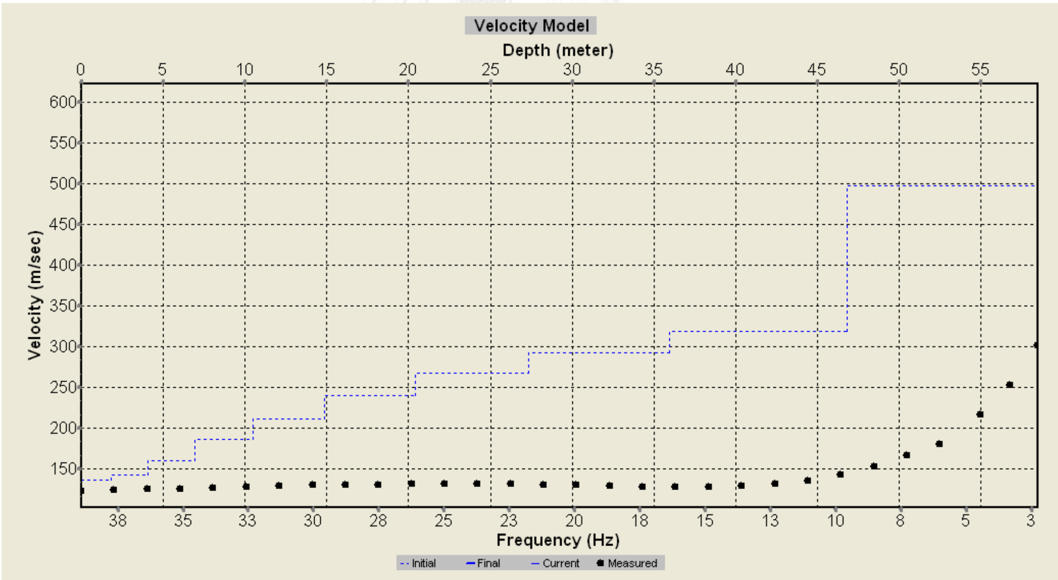

Figure A-22 Inversion of Station No.11

Station No. 12

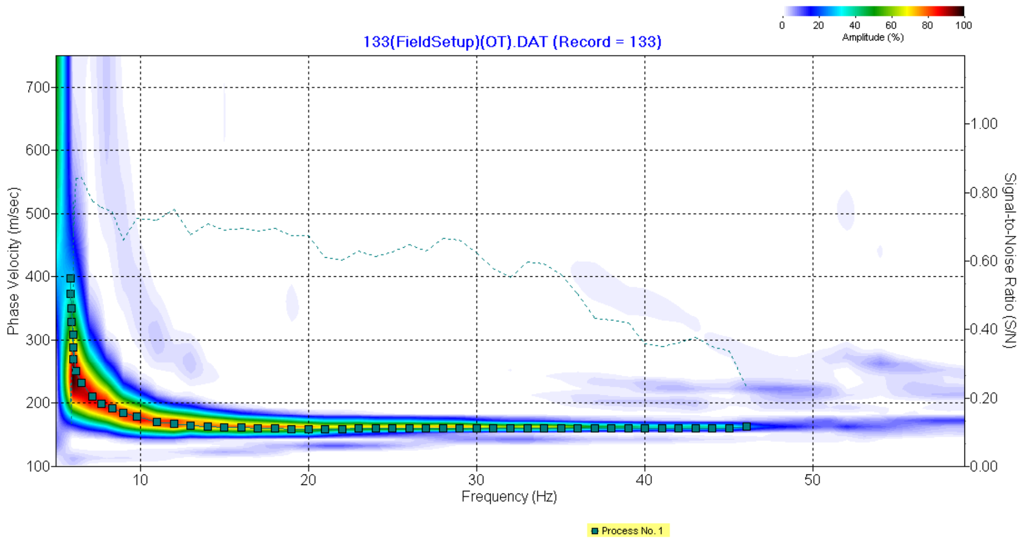

Figure A-23 Dispersion curve of Station No.12

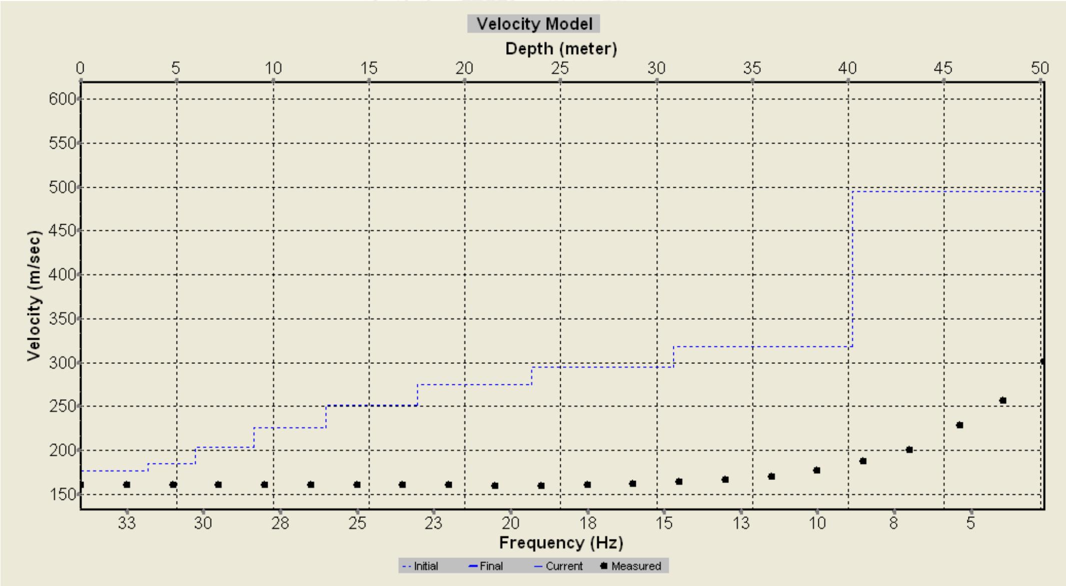

Figure A-24 Inversion of Station No.12

Station No. 13

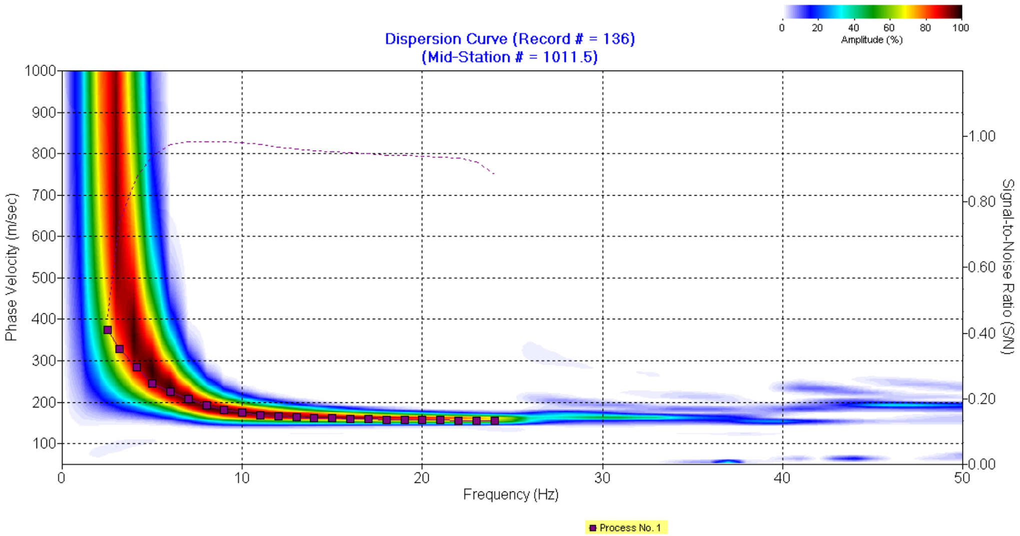

Figure A-25 Dispersion curve of Station No.13

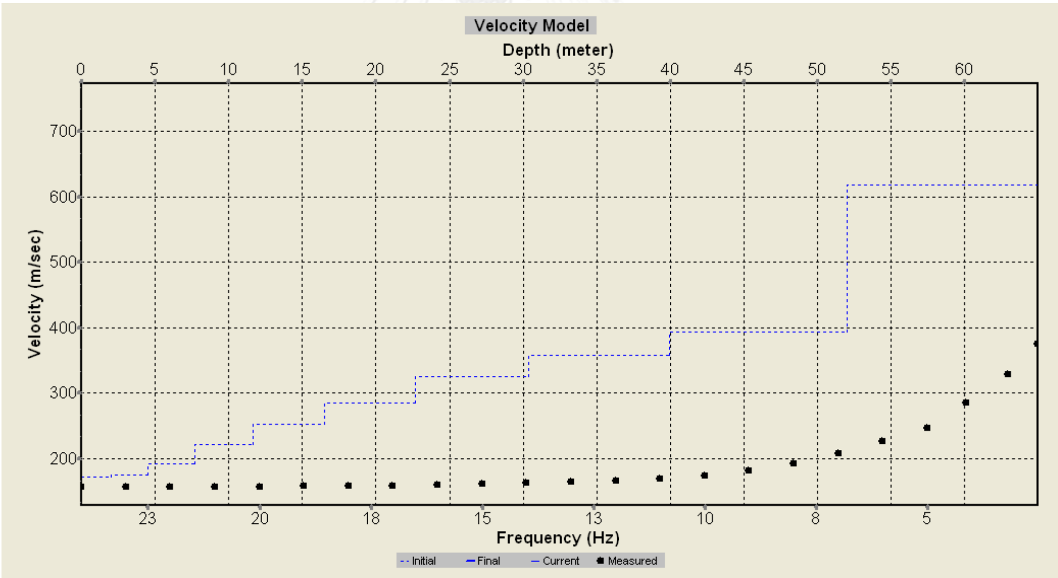

Figure A-26 Inversion of Station No.13

Station No. 14

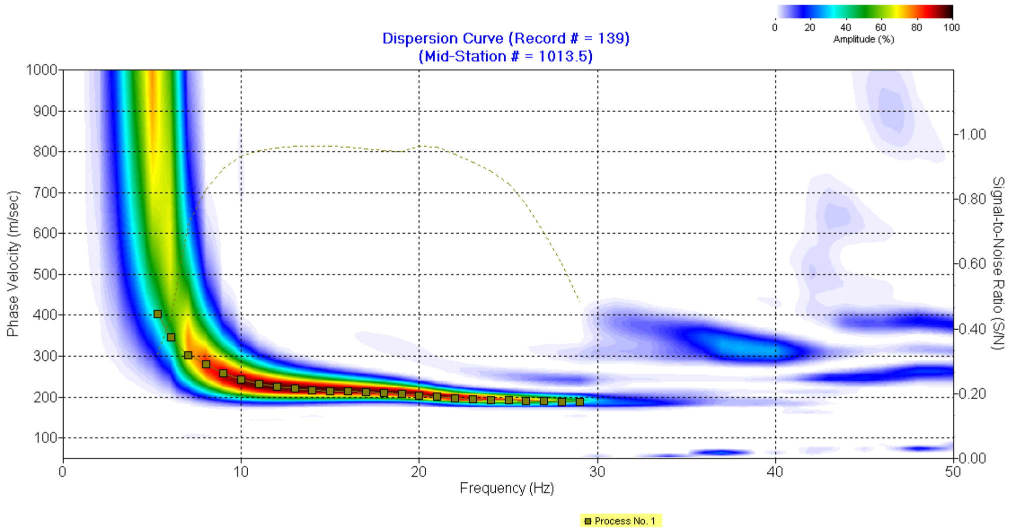

Figure A-27 Dispersion curve of Station No.14

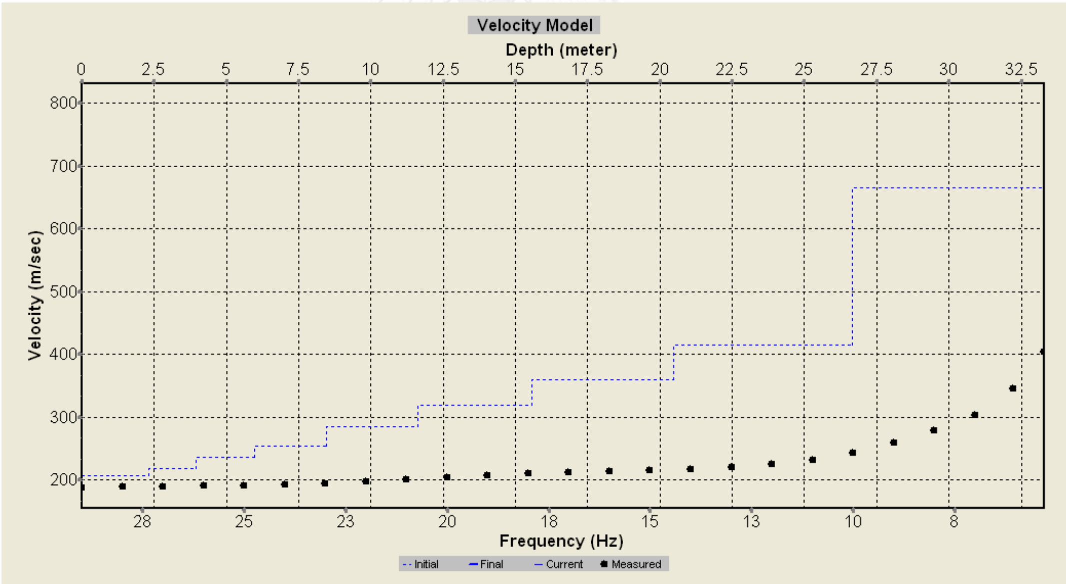

Figure A-28 Inversion of Station No.14

Station No. 15

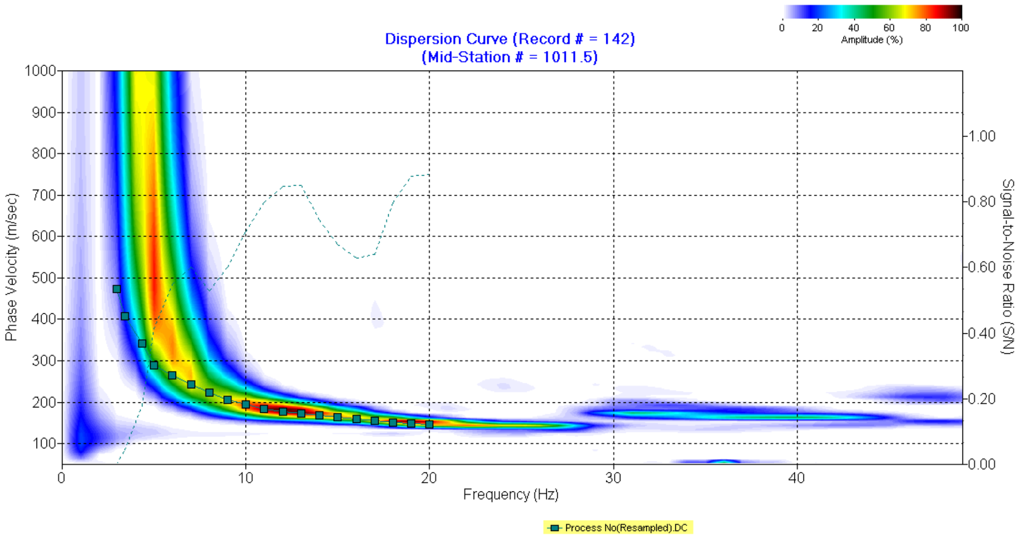

Figure A-29 Dispersion curve of Station No.15

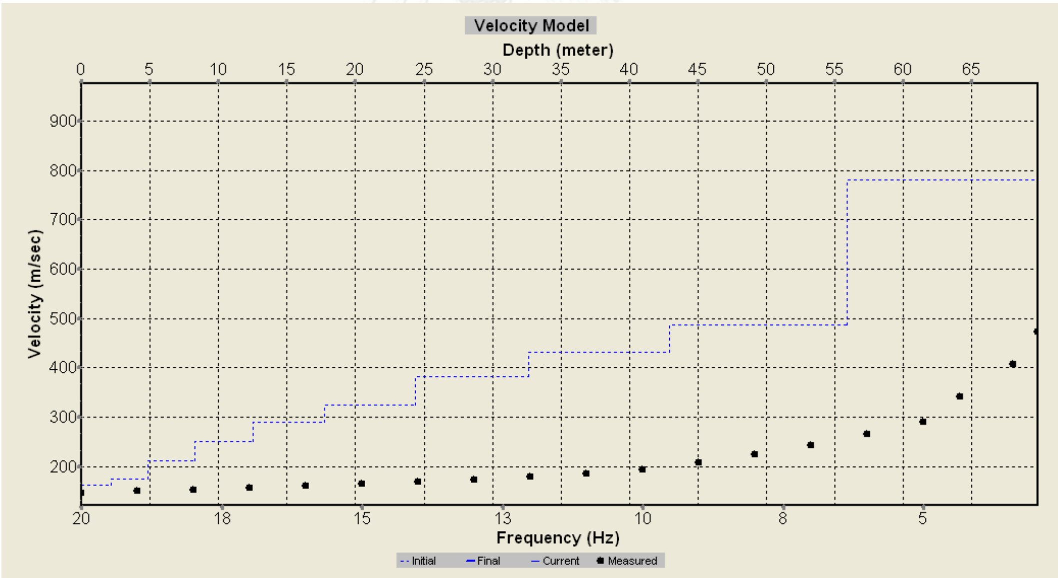

Figure A-30 Inversion of Station No.15

Station No. 16

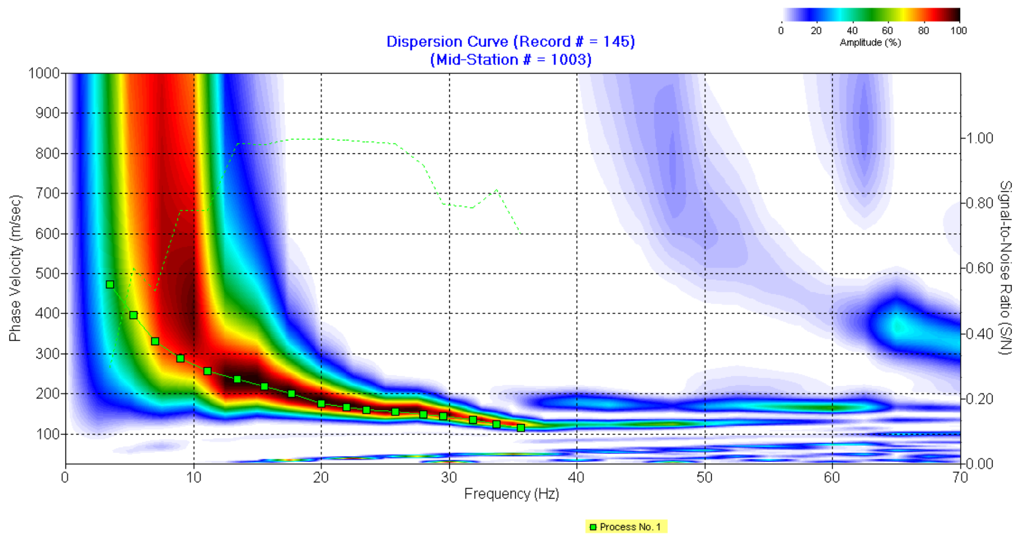

Figure A-31 Dispersion curve of Station No.16

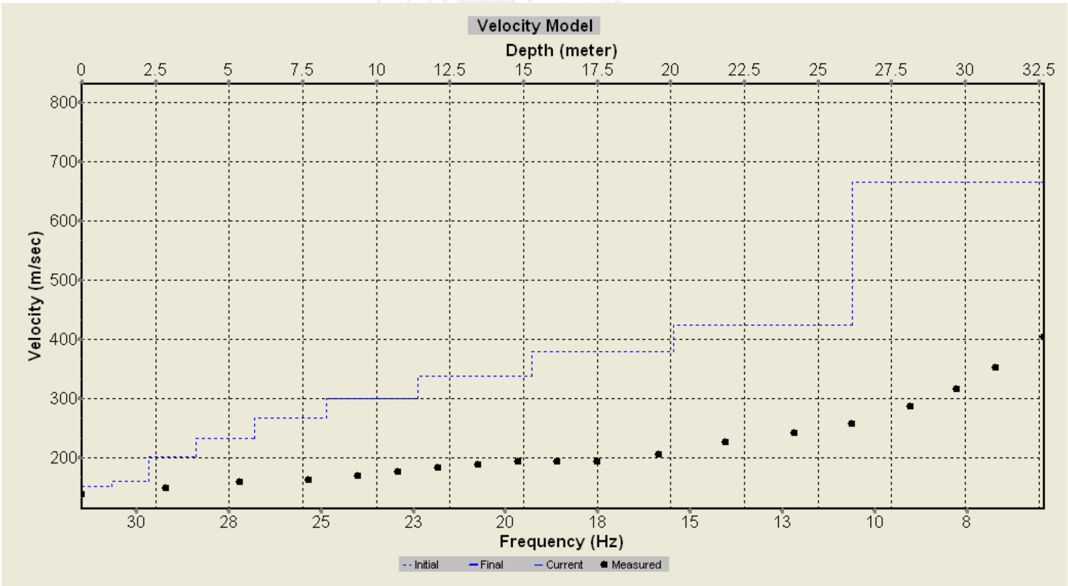

Figure A-32 Inversion of Station No.16

Station No. 17

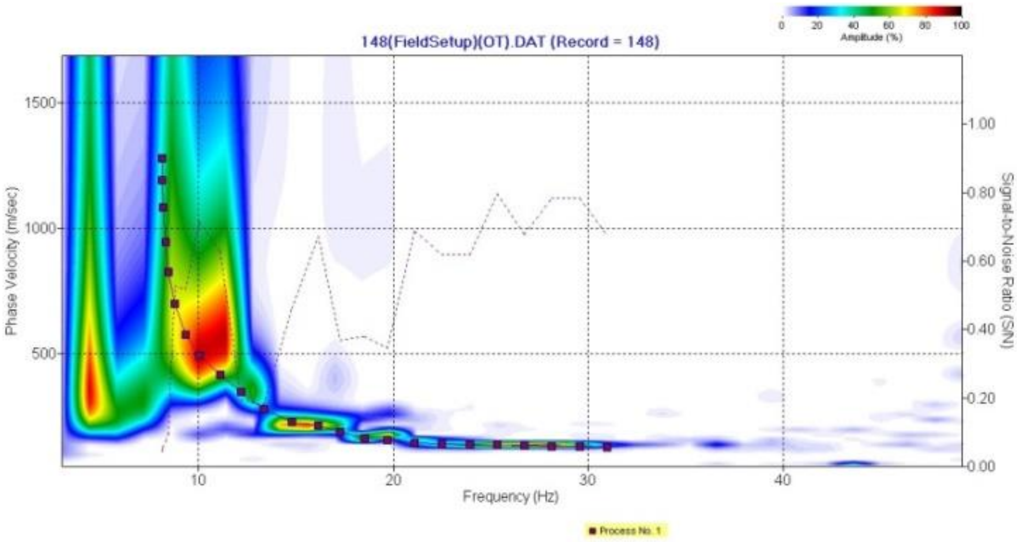

Figure A-33 Dispersion curve of Station No.17

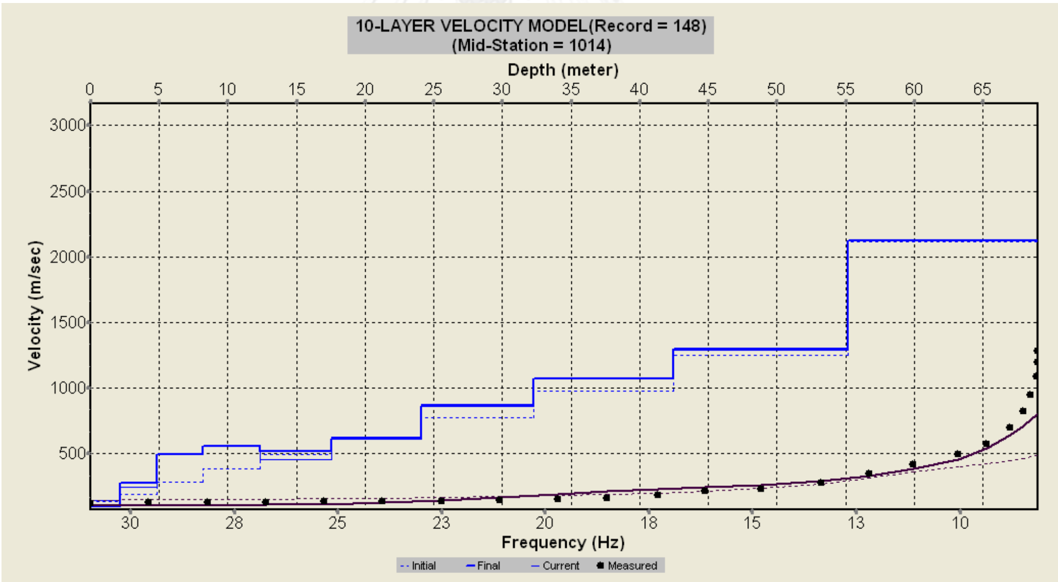

Figure A-34 Inversion of Station No.17

Station No. 18

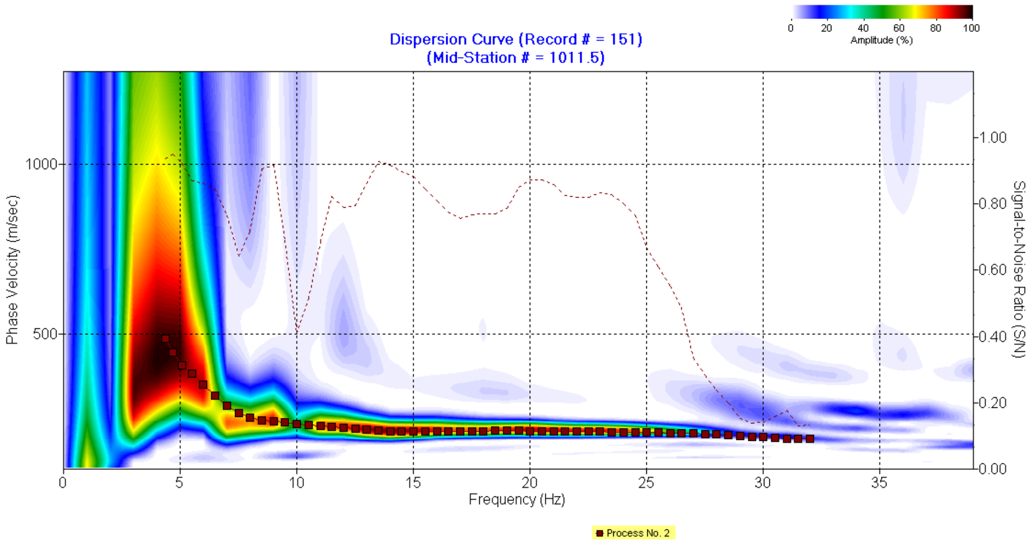

Figure A-35 Dispersion curve of Station No.18

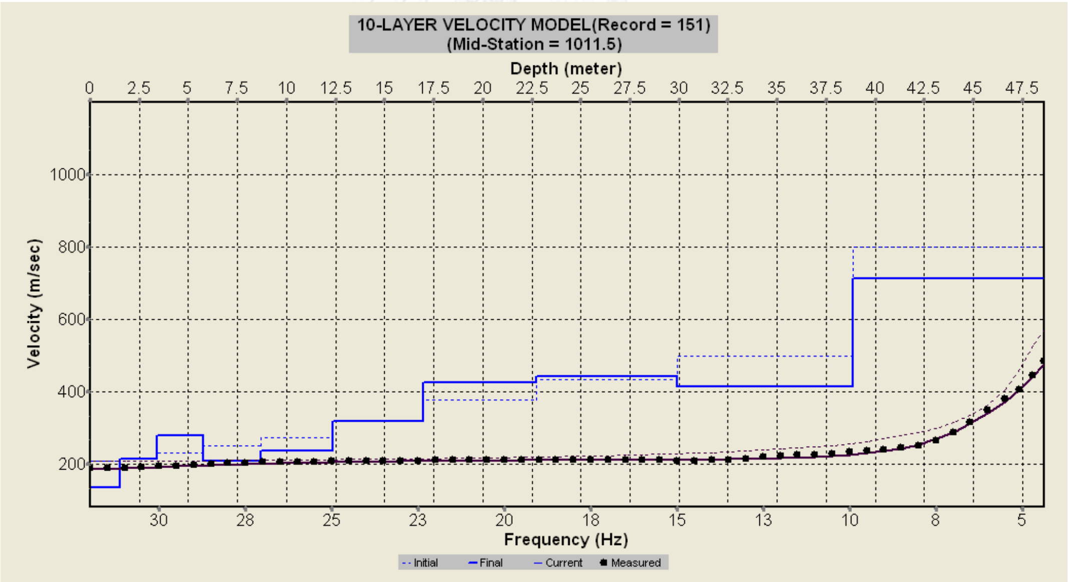

Figure A-36 Inversion of Station No.18

Station No. 19

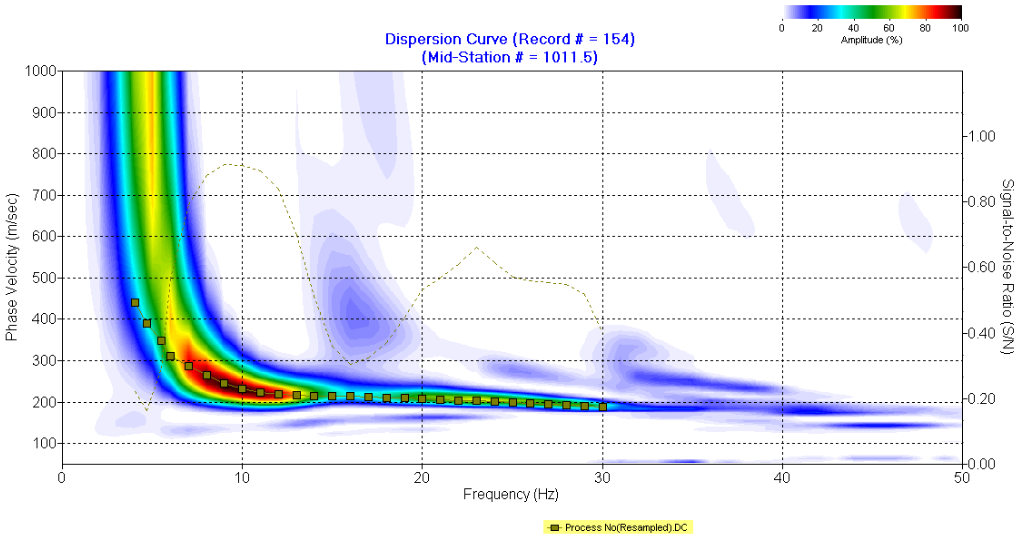

Figure A-37 Dispersion curve of Station No.19

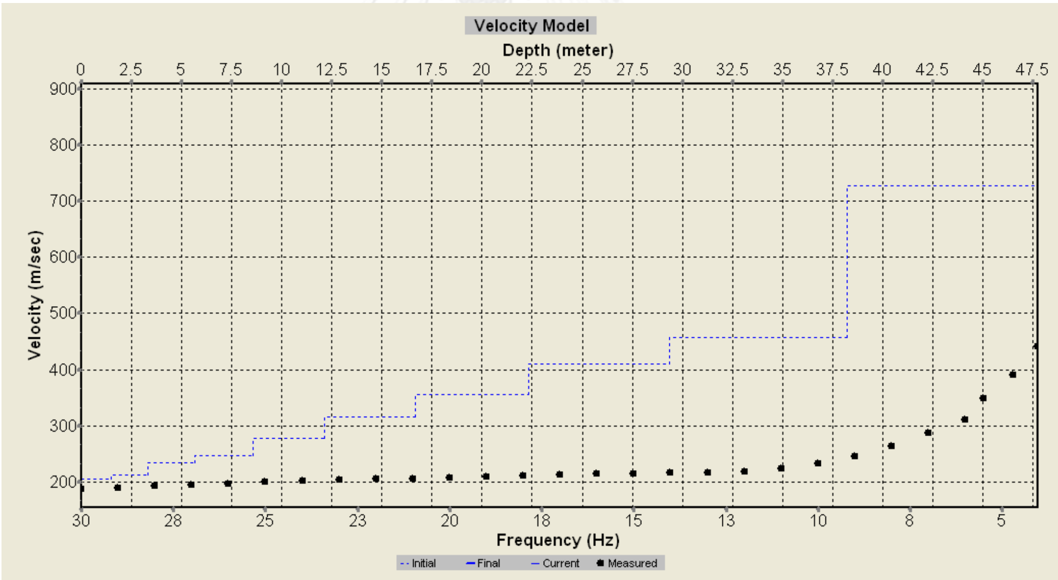

Figure A-38 Inversion of Station No.19

Station No. 20

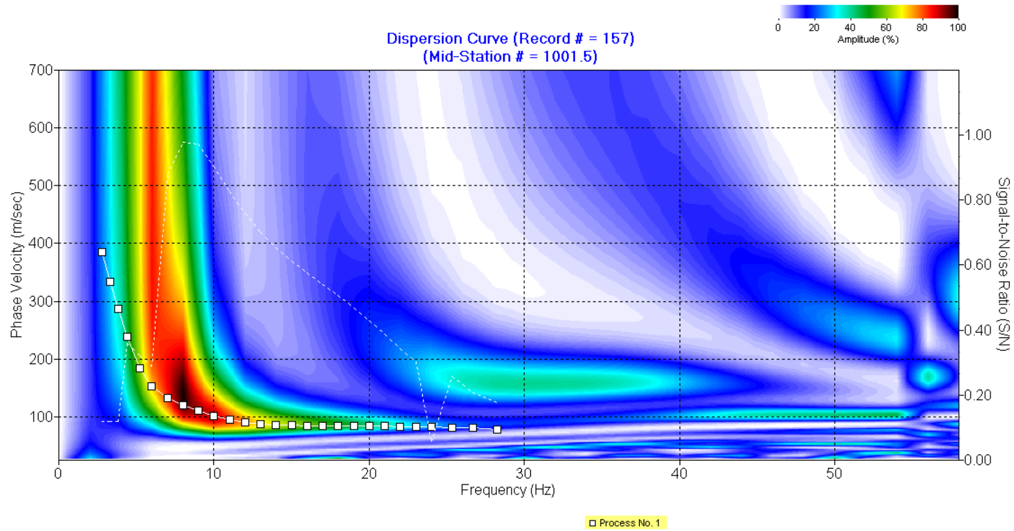

Figure A-39 Dispersion curve of Station No.20

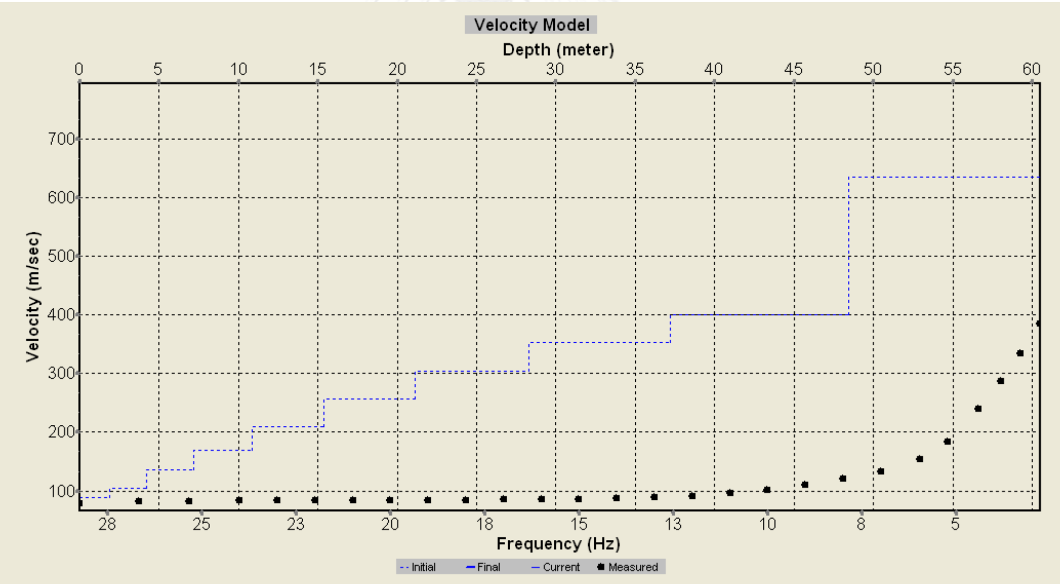

Figure A-40 Inversion of Station No.20

Station No. 21

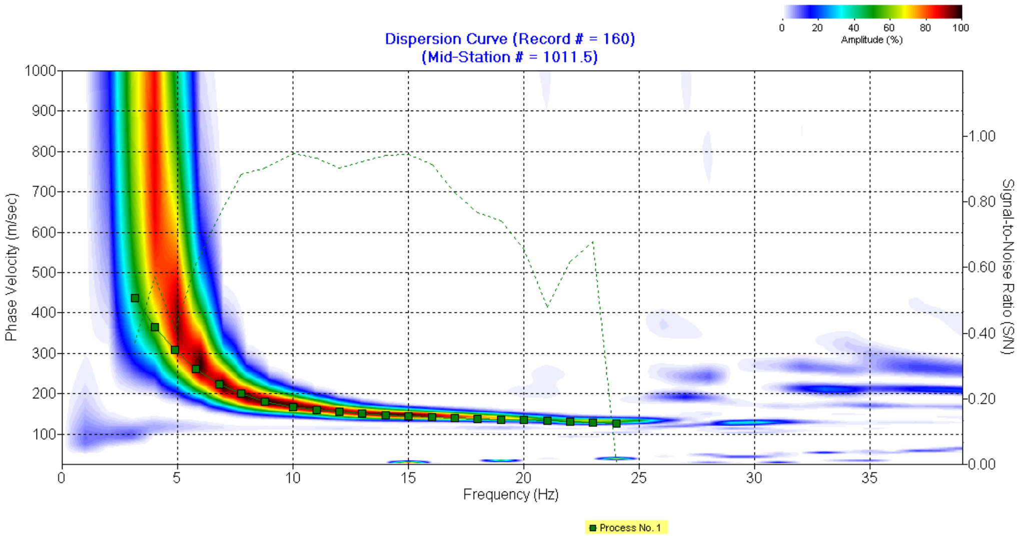

Figure A-41 Dispersion curve of Station No.21

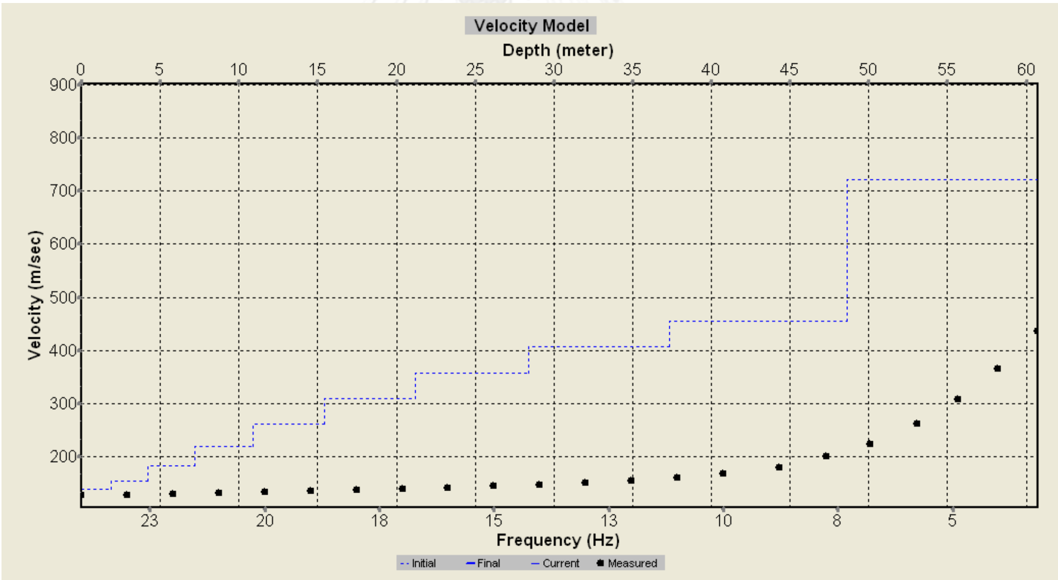

Figure A-42 Inversion of Station No.21

Station No. 22

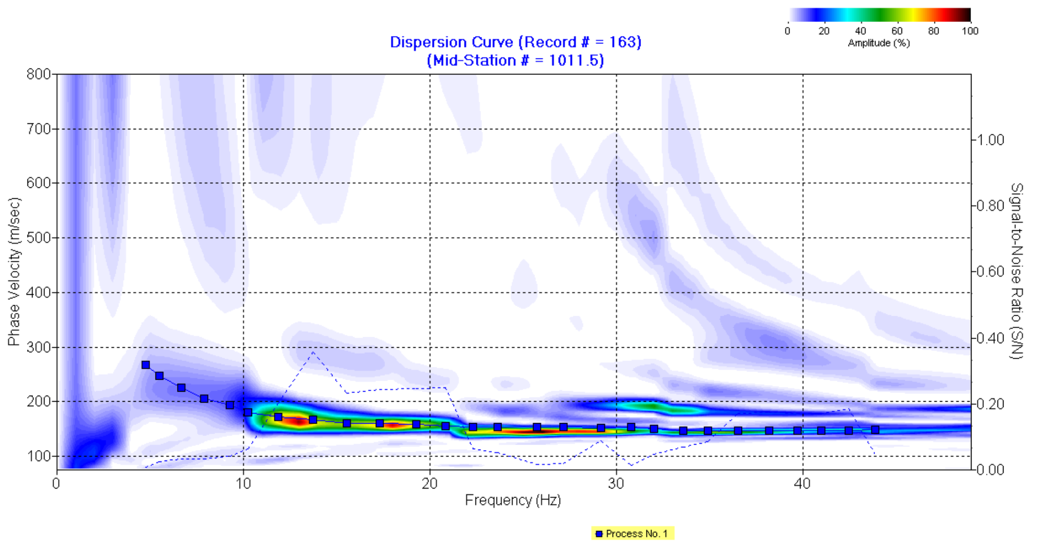

Figure A-43 Dispersion curve of Station No.22

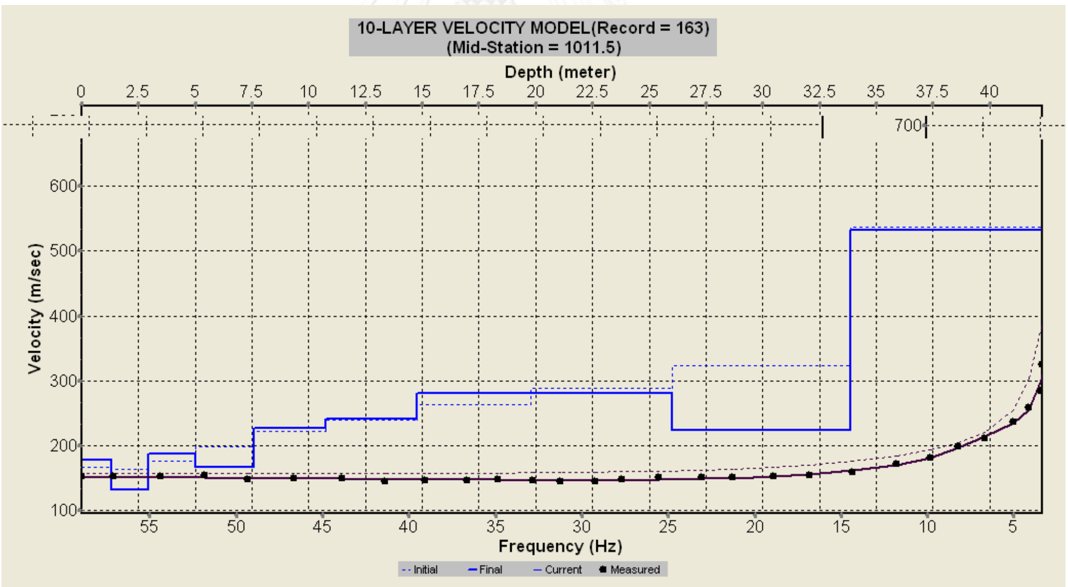

Figure A-44 Inversion of Station No.22

Station No. 23

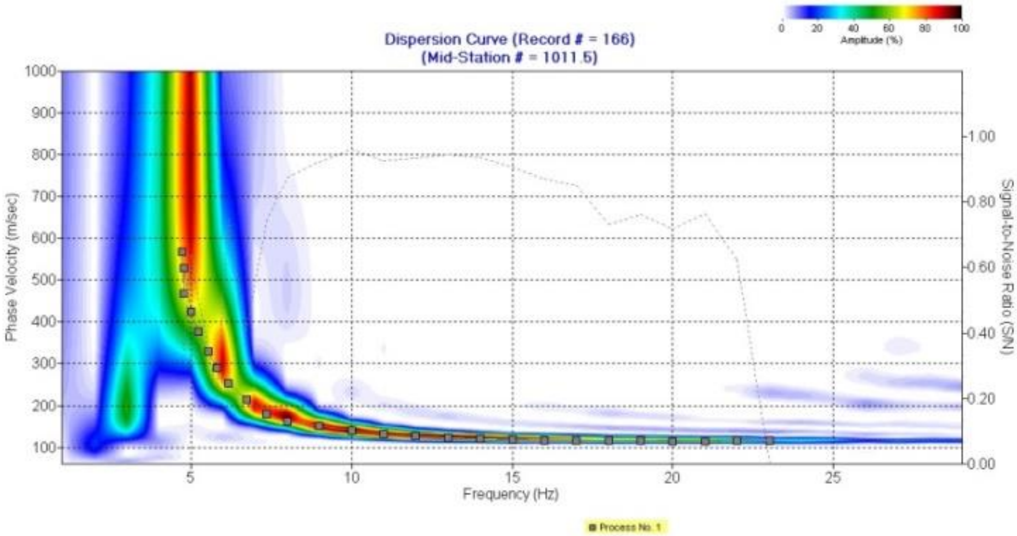

Figure A-45 Dispersion curve of Station No.23

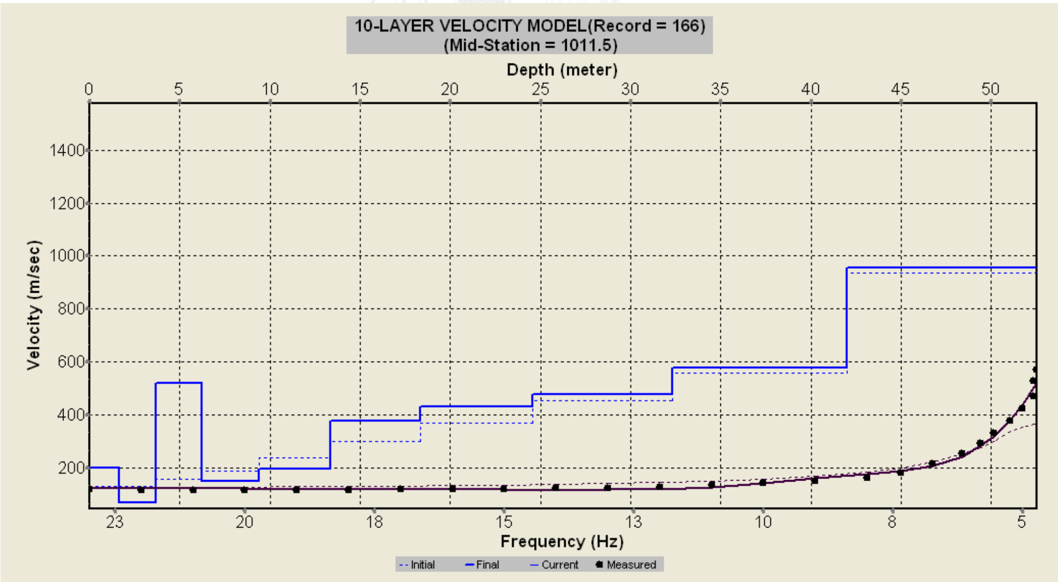

Figure A-46 Inversion of Station No.23

Station No. 24

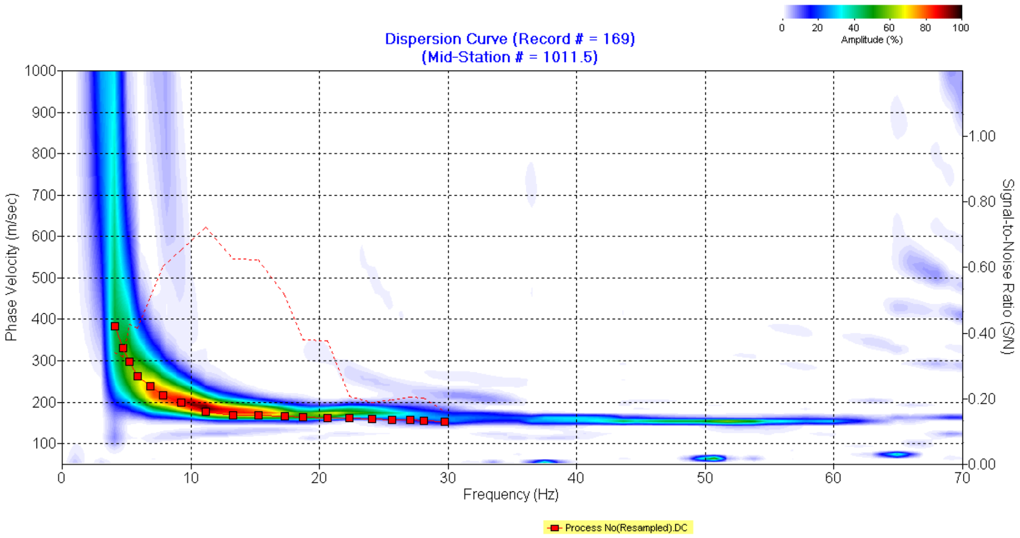

Figure A-47 Dispersion curve of Station No.24

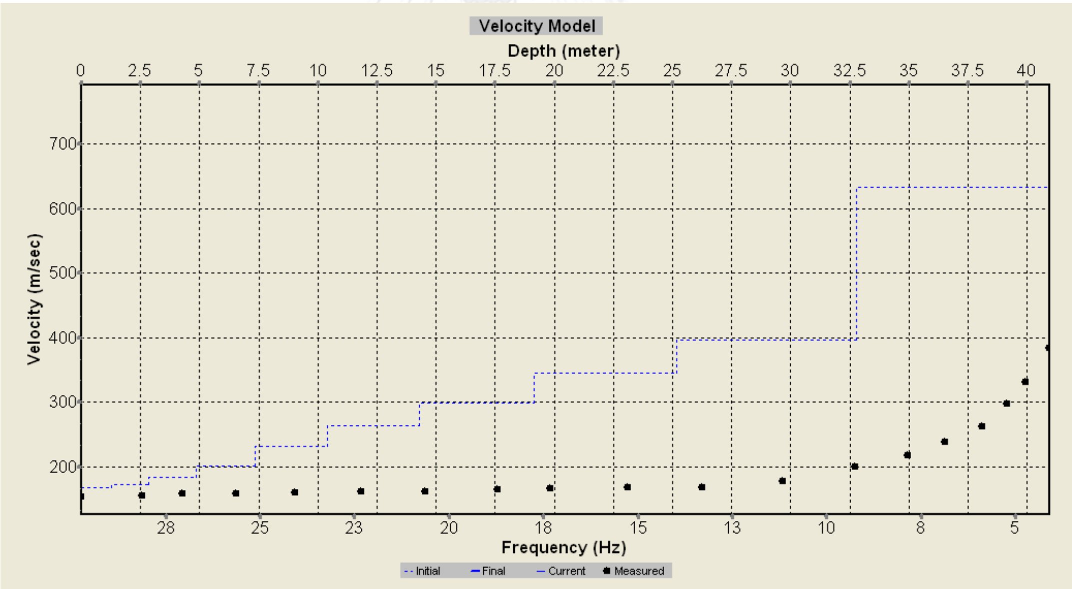

Figure A-48 Inversion of Station No.2

Station No. 25

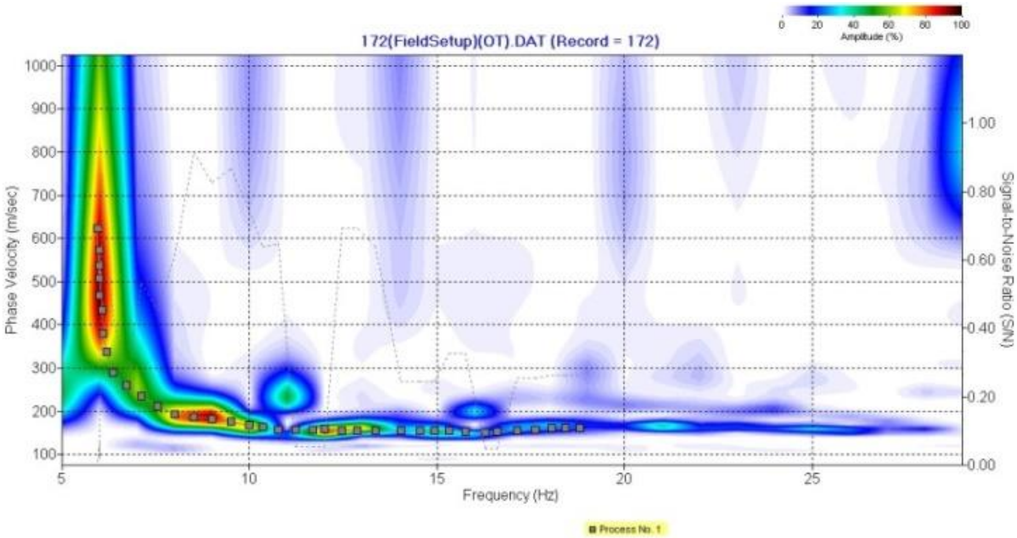

Figure A-49 Dispersion curve of Station No.25

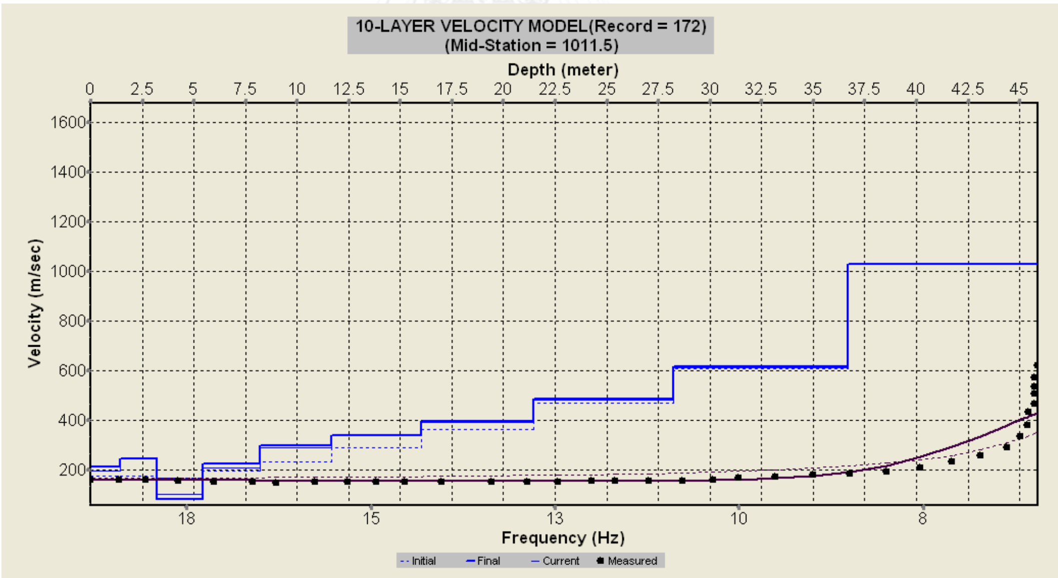

Figure A-50 Inversion of Station No.25

Station No. 26

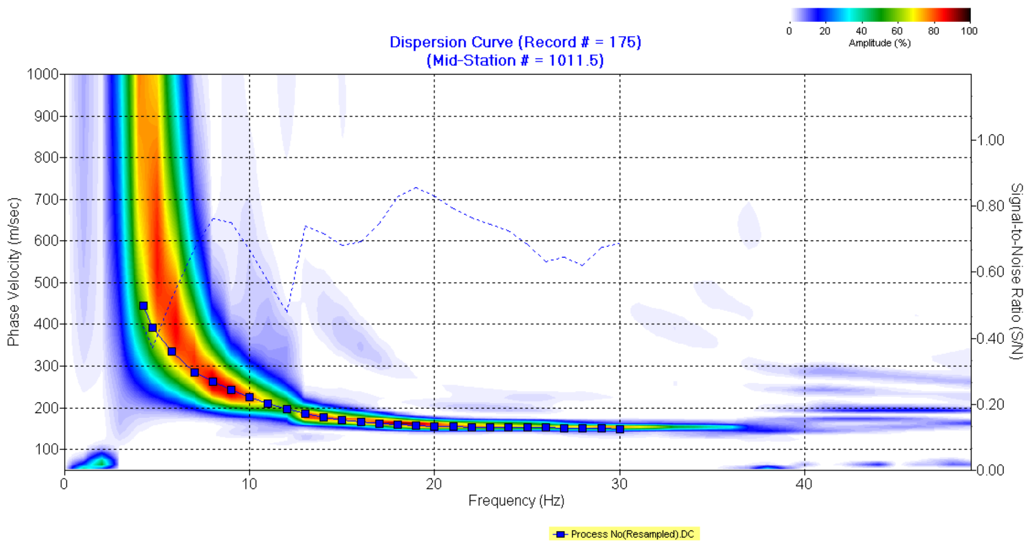

Figure A-51 Dispersion curve of Station No.26

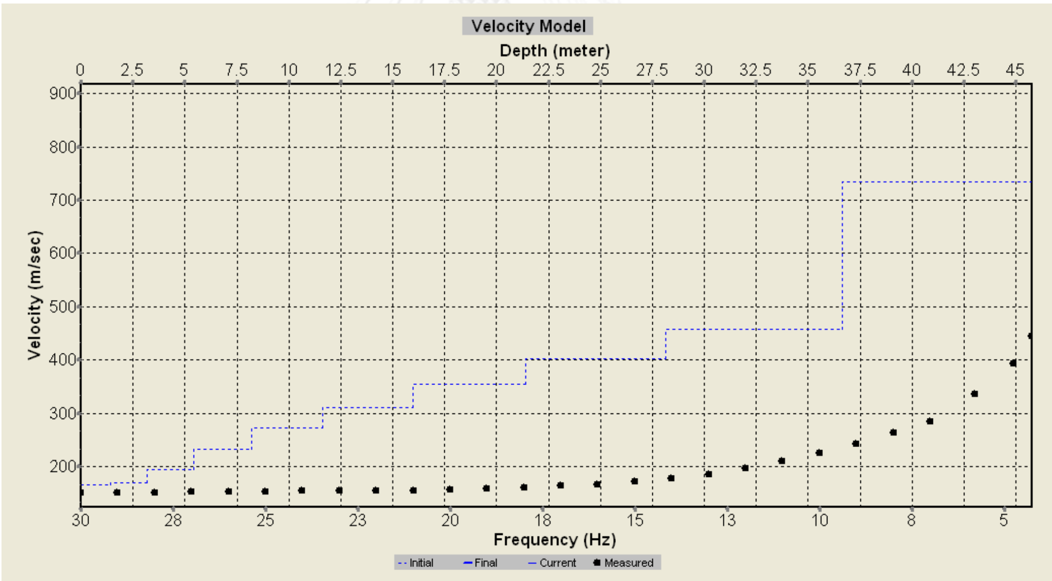

Figure A-52 Inversion of Station No.26

Station No. 27

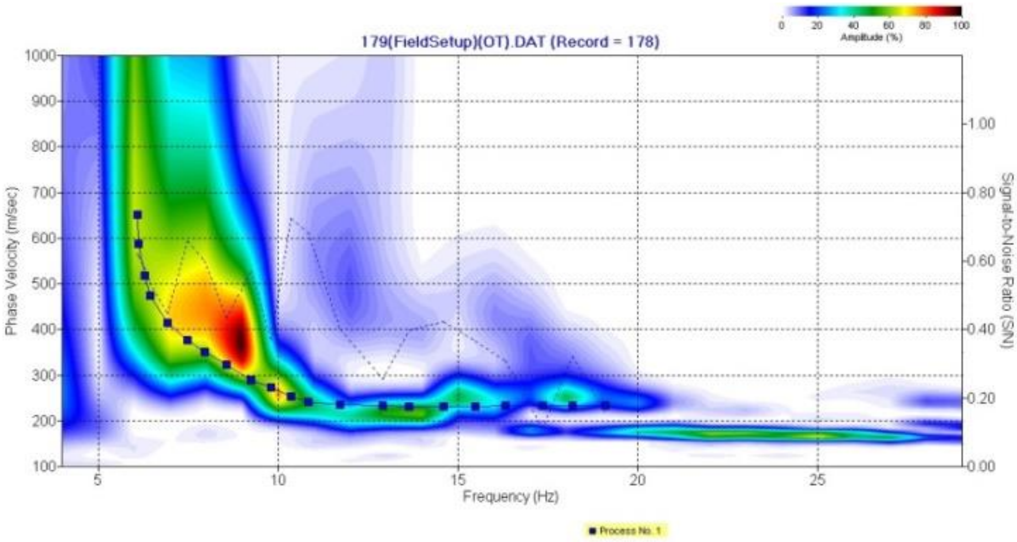

Figure A-53 Dispersion curve of Station No.27

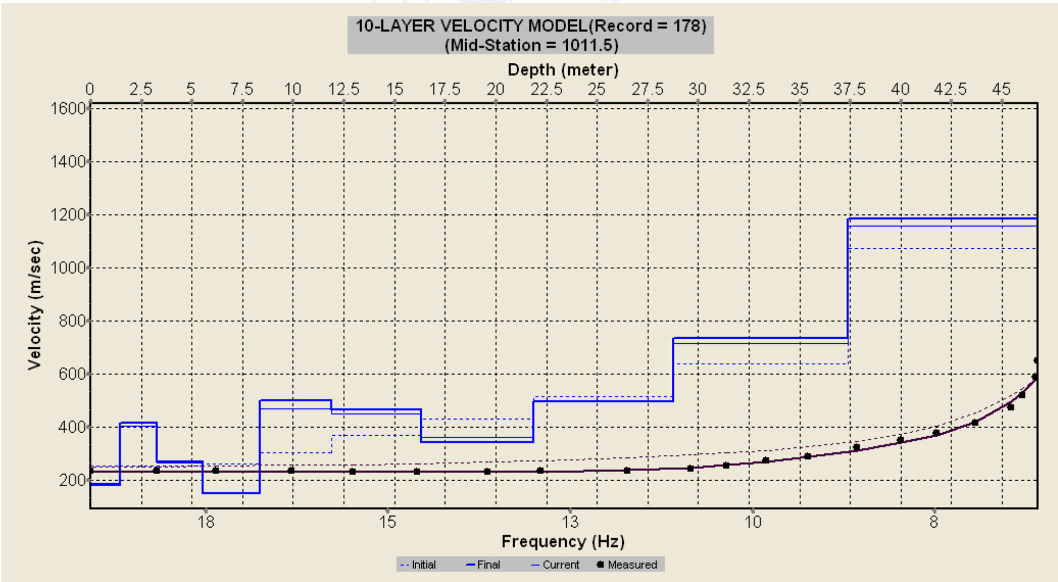

Figure A-54 Inversion of Station No.27

Station No. 28

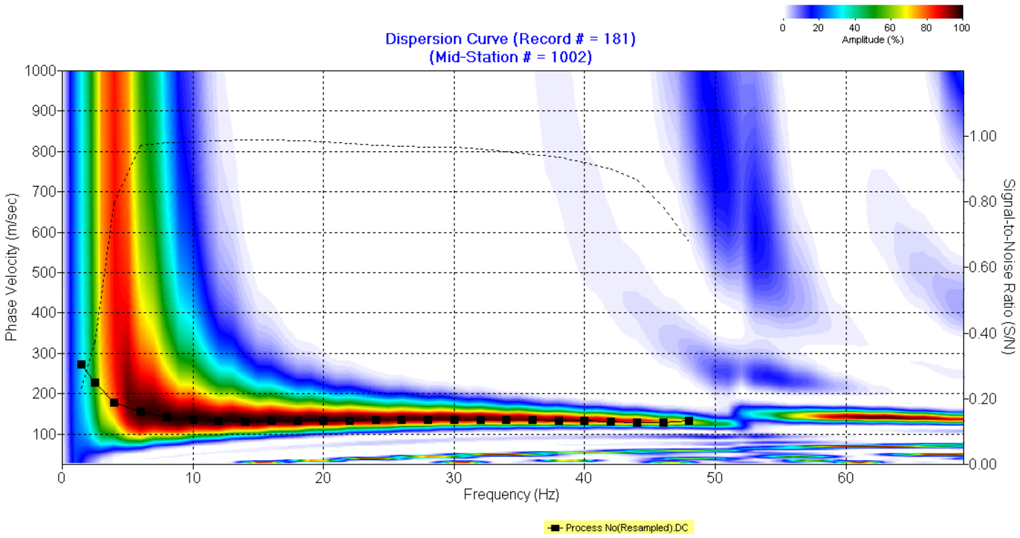

Figure A-55 Dispersion curve of Station No.28

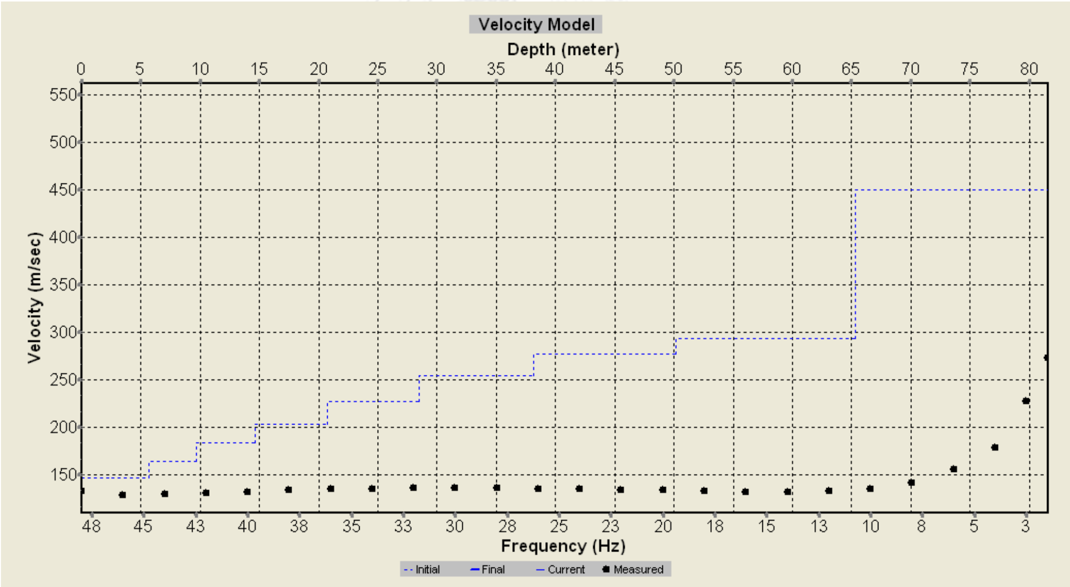

Figure A-56 Inversion of Station No.28

Station No. 29

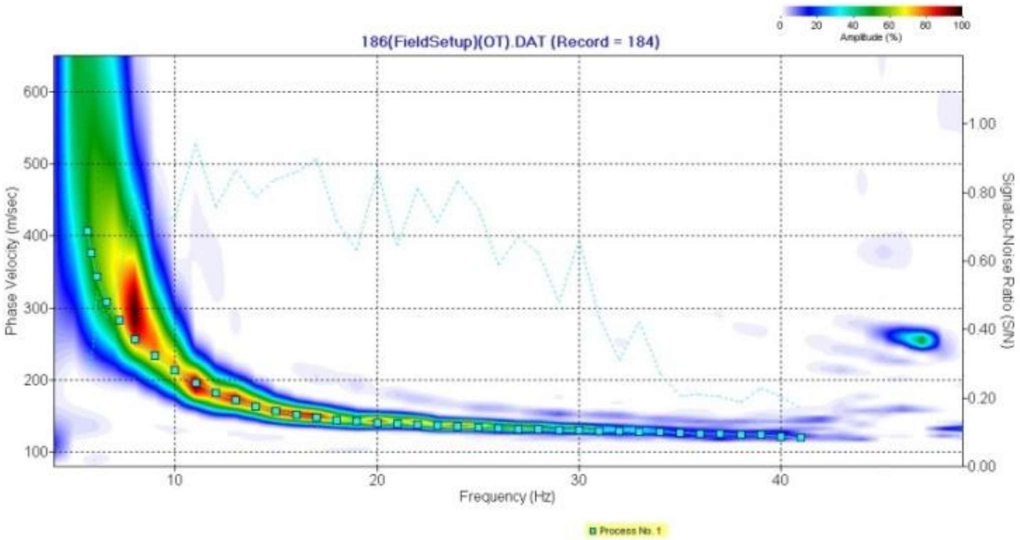

Figure A-57 Dispersion curve of Station No.29

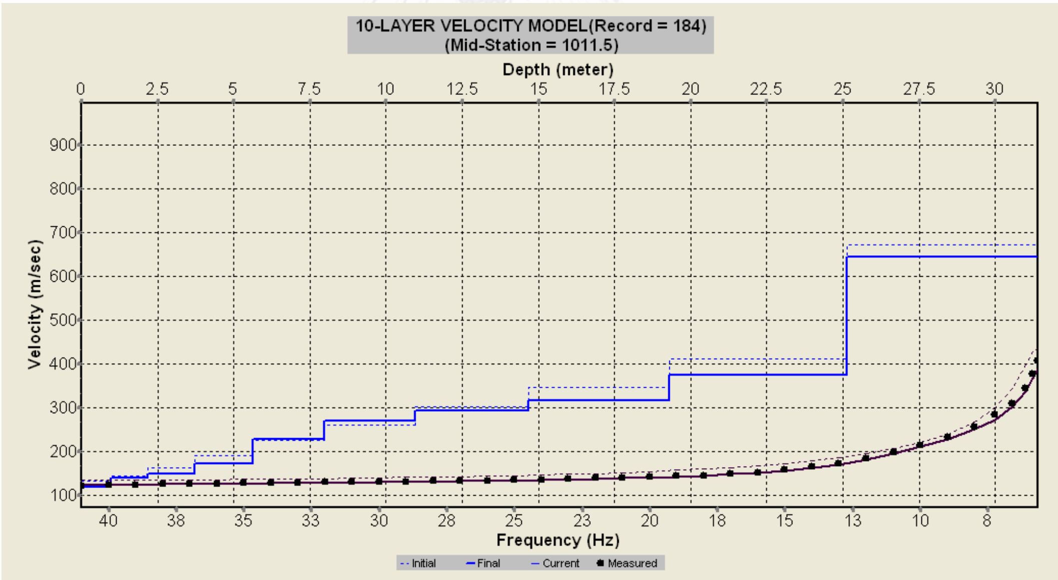

Figure A-58 Inversion of Station No.29

Station No. 30

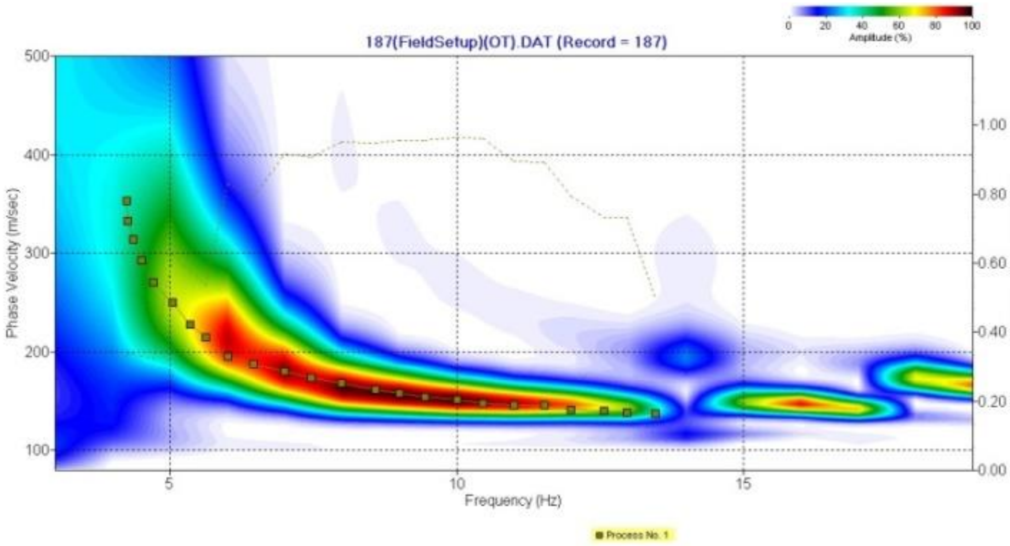

Figure A-59 Dispersion curve of Station No.30

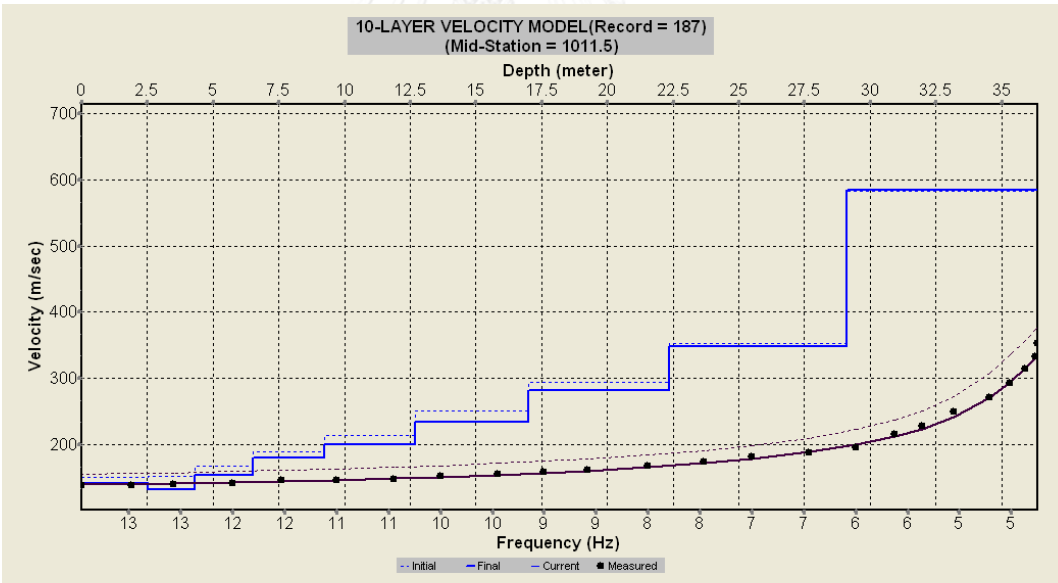

Figure A-60 Inversion of Station No.30

Station No. 31

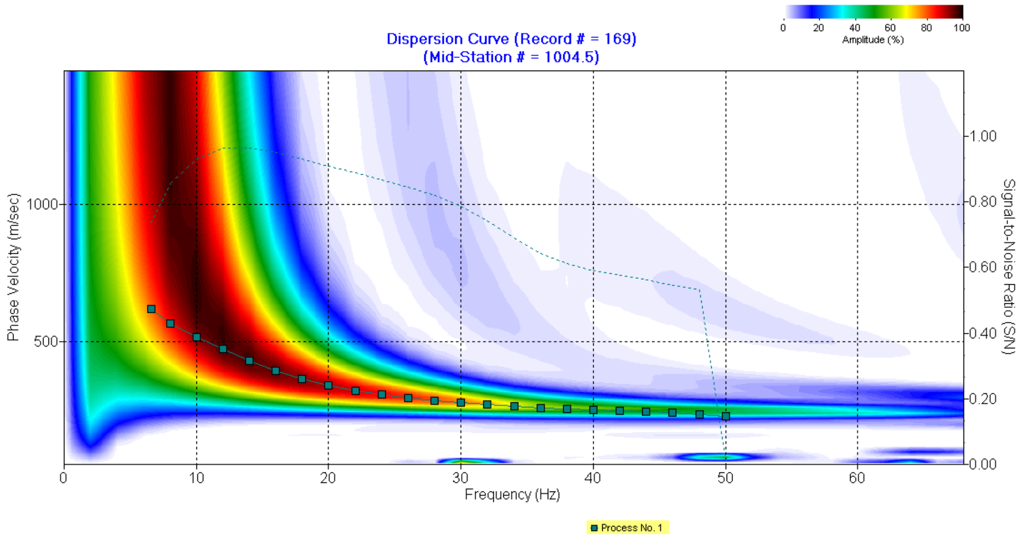

Figure A-61 Dispersion curve of Station No.31

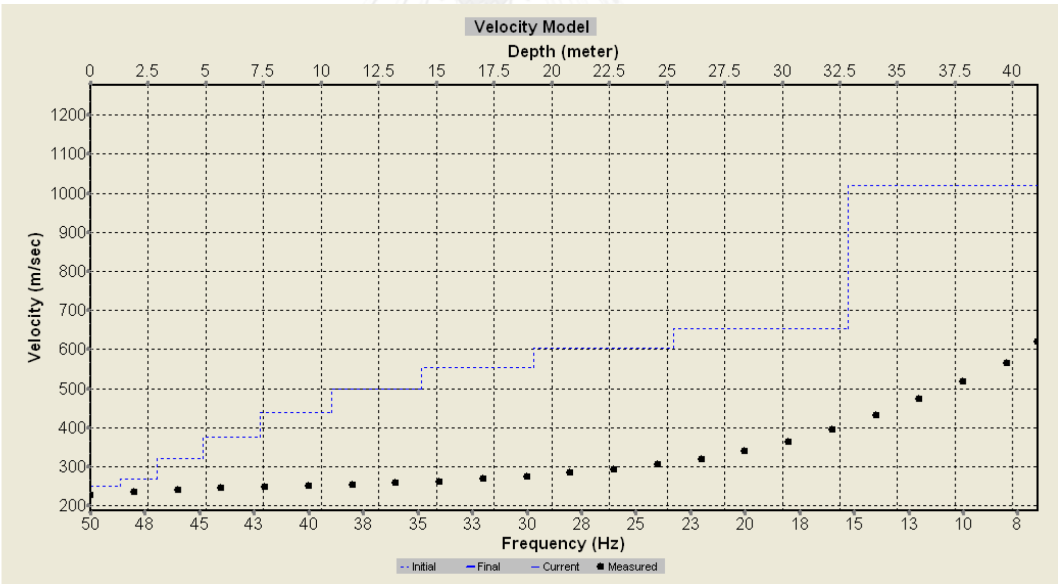

Figure A-62 Inversion of Station No.31

Station No. 32

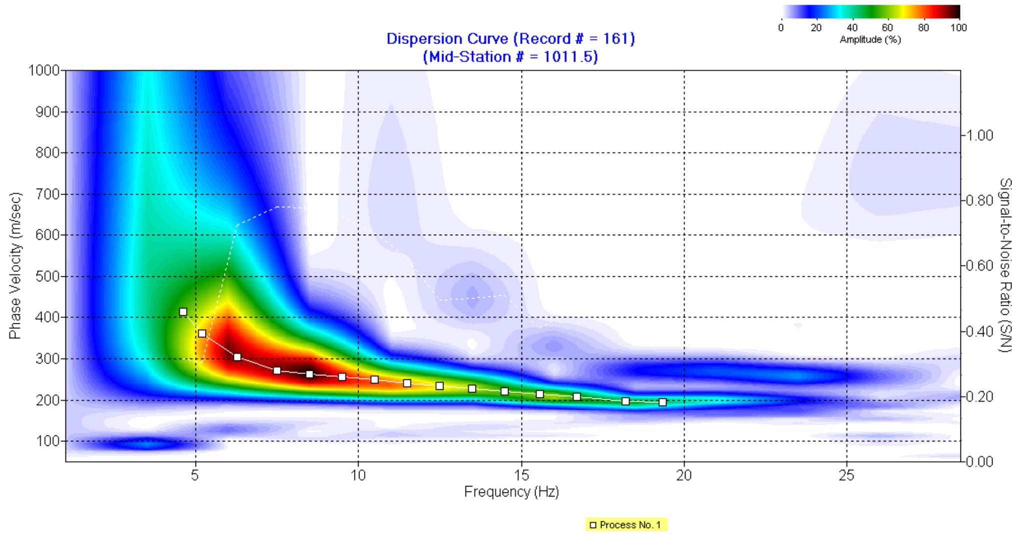

Figure A-63 Dispersion curve of Station No.32

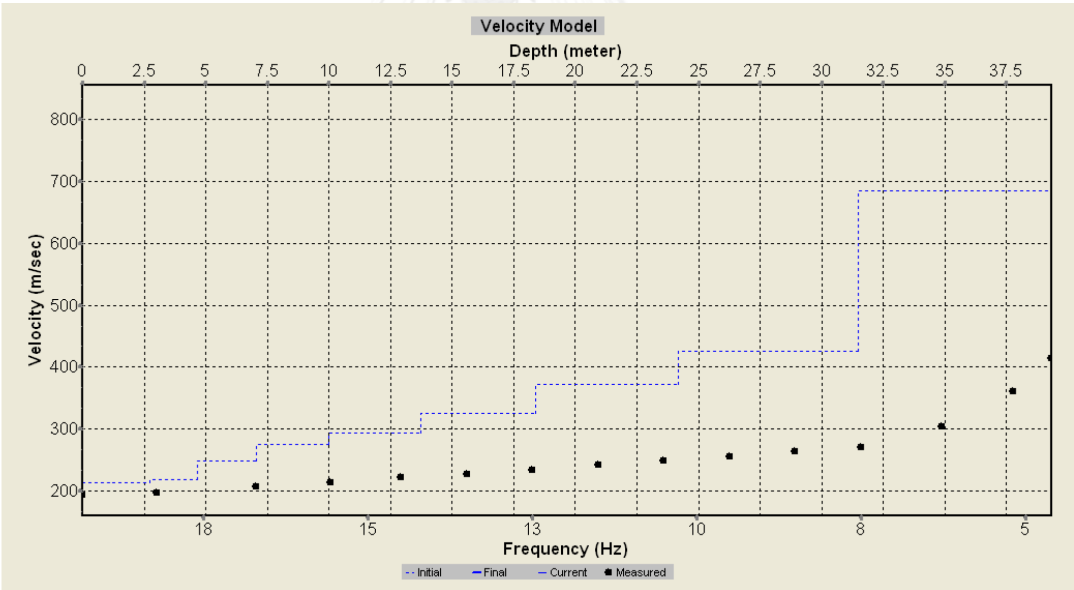

Figure A-64 Inversion of Station No.32

Station No. 33

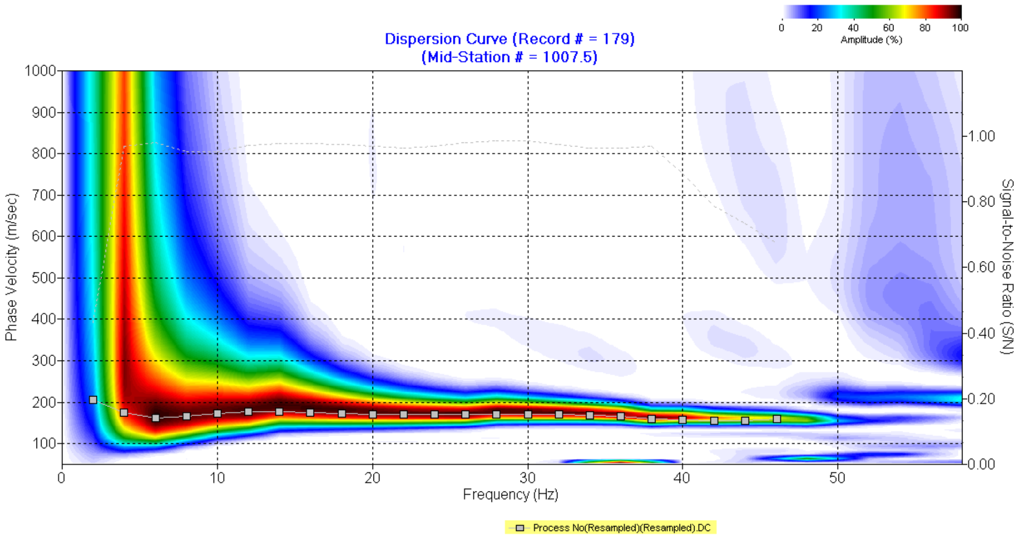

Figure A-65 Dispersion curve of Station No.33

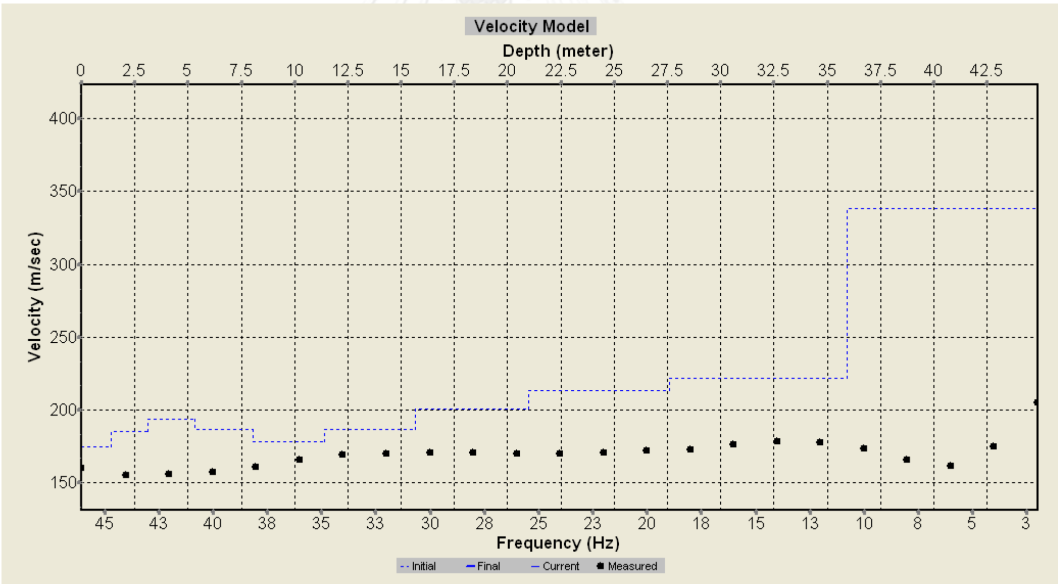

Figure A-66 Inversion of Station No.33

Station No. 34

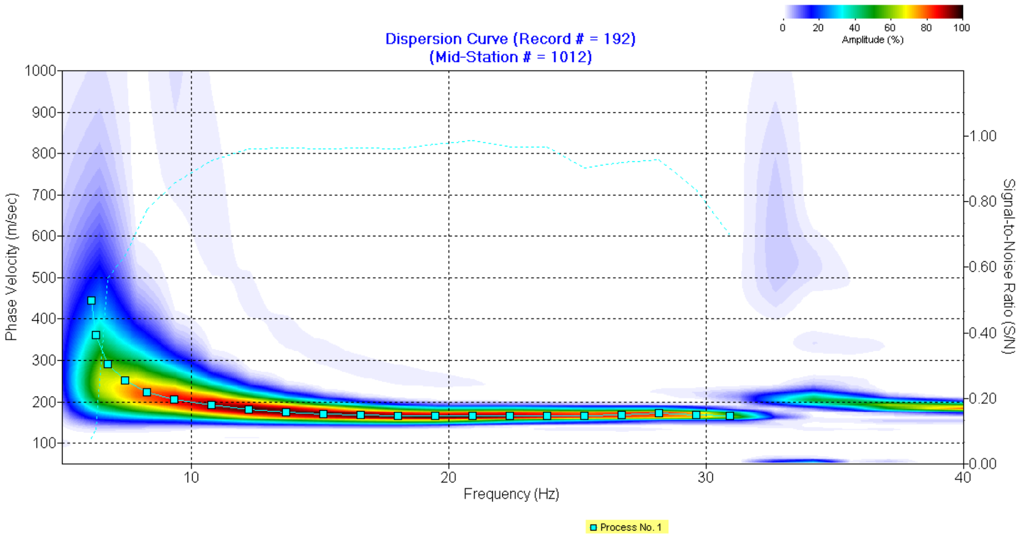

Figure A-67 Dispersion curve of Station No.34

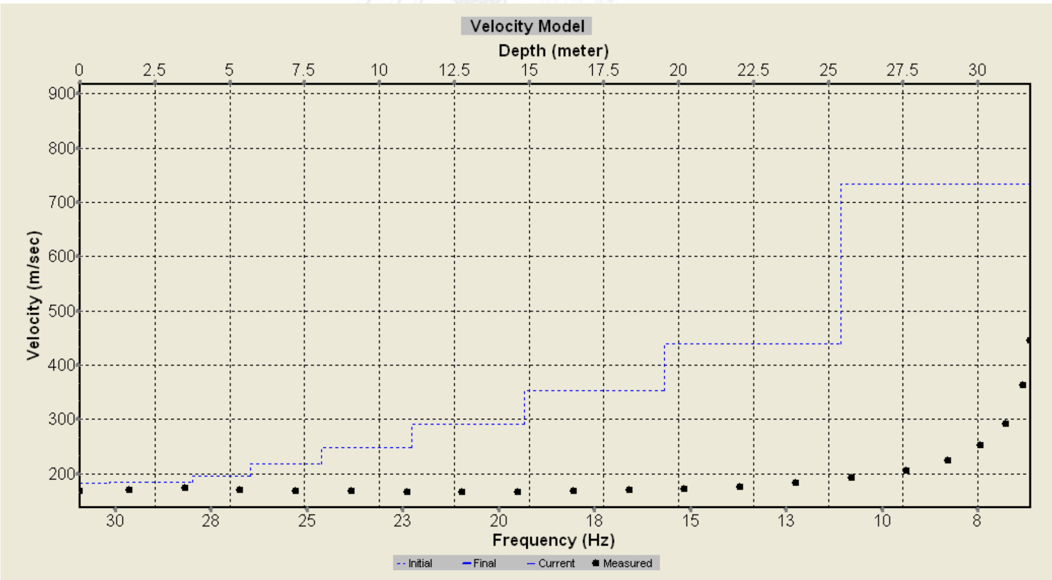

Figure A-68 Inversion of Station No.34

Station No. 35

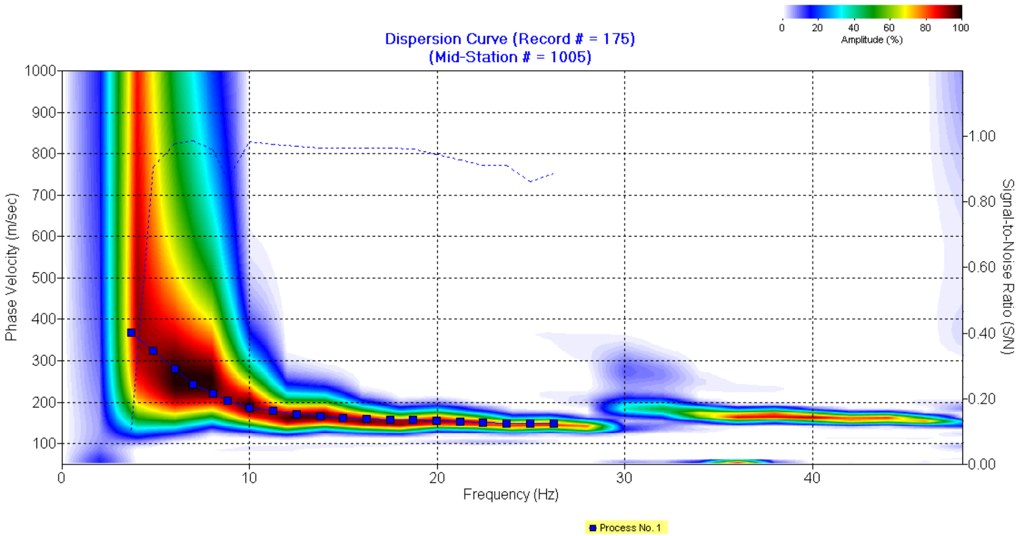

Figure A-69 Dispersion curve of Station No.35

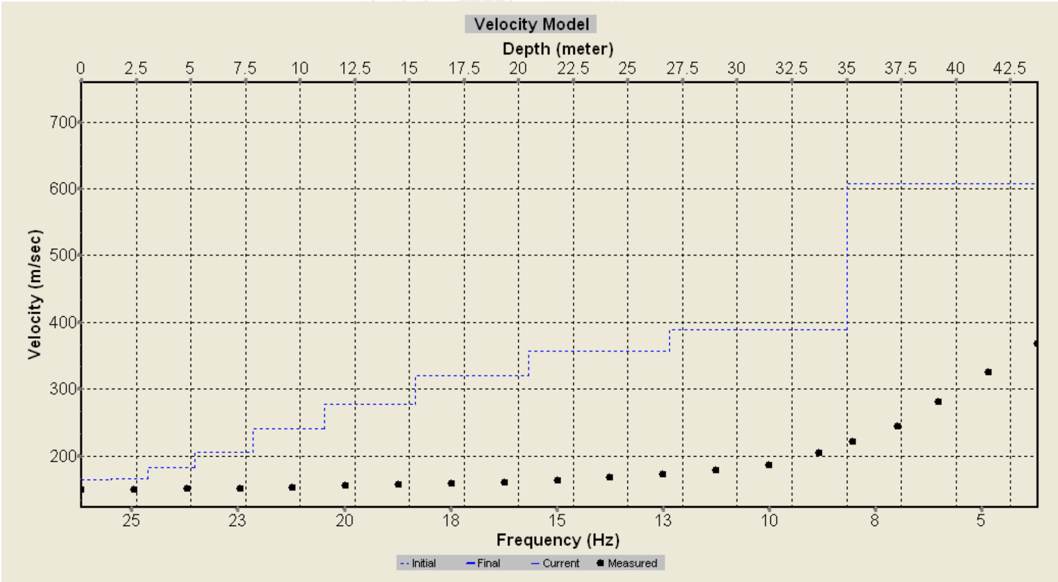

Figure A-70 Inversion of Station No.35

Station No. 36

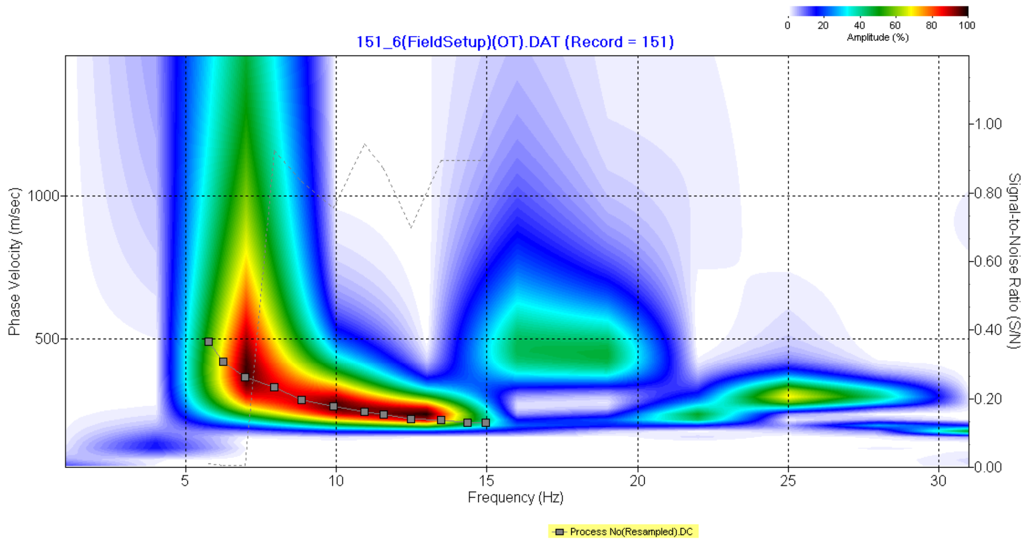

Figure A-71 Dispersion curve of Station No.36

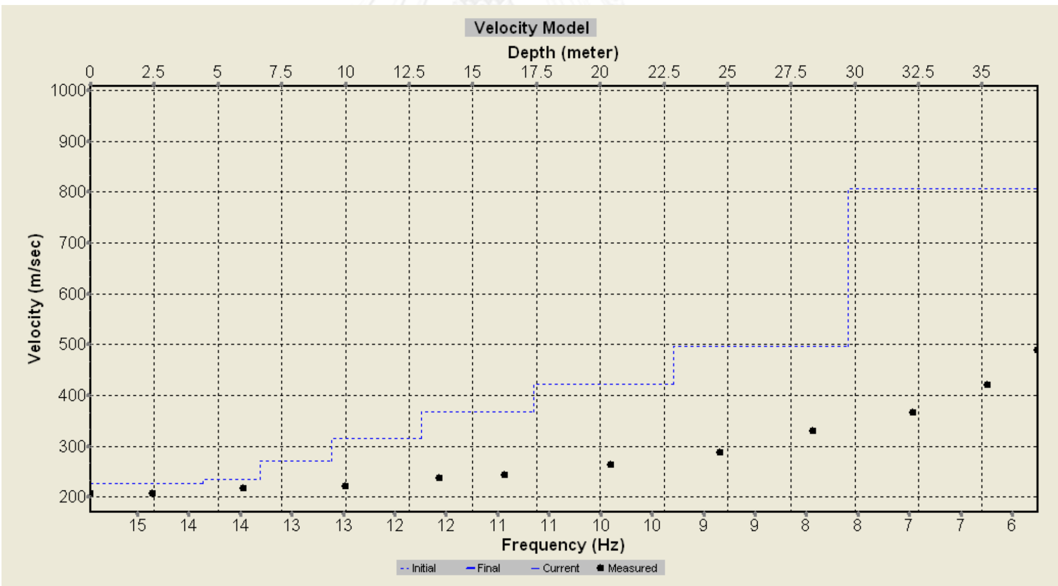

Figure A-72 Inversion of Station No.36

Station No. 37

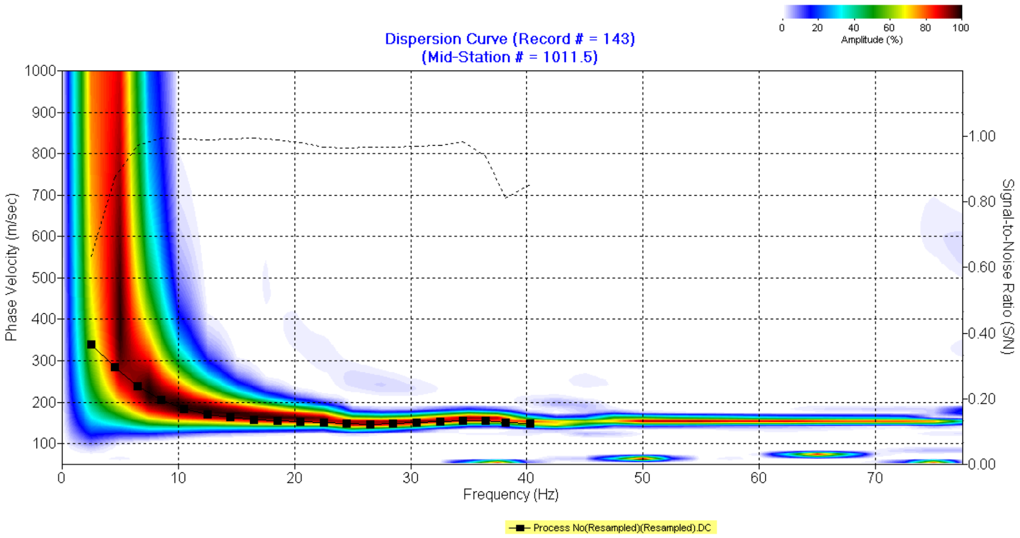

Figure A-73 Dispersion curve of Station No.37

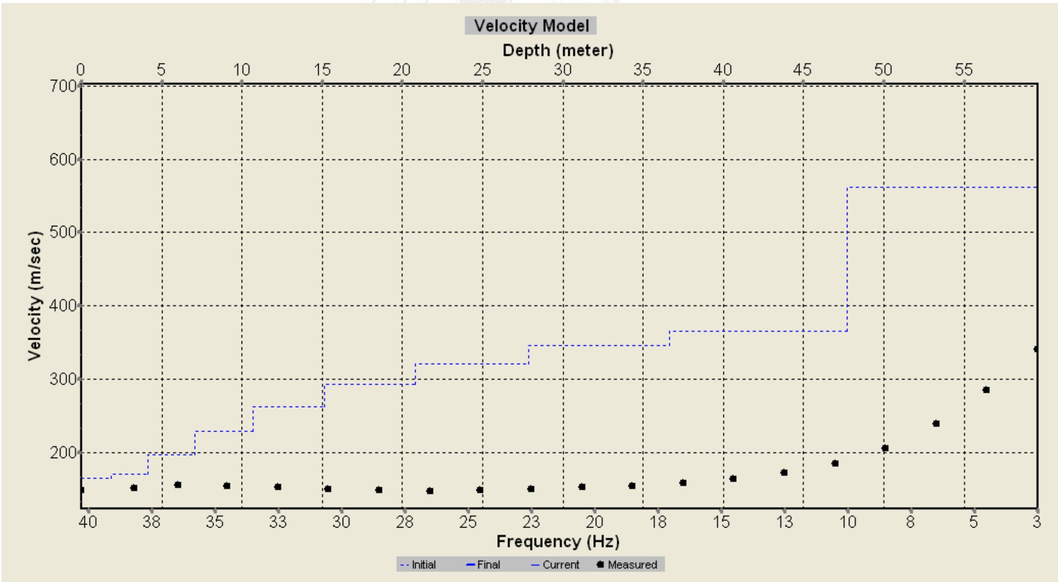

Figure A-74 Inversion of Station No.37

Station No. 38

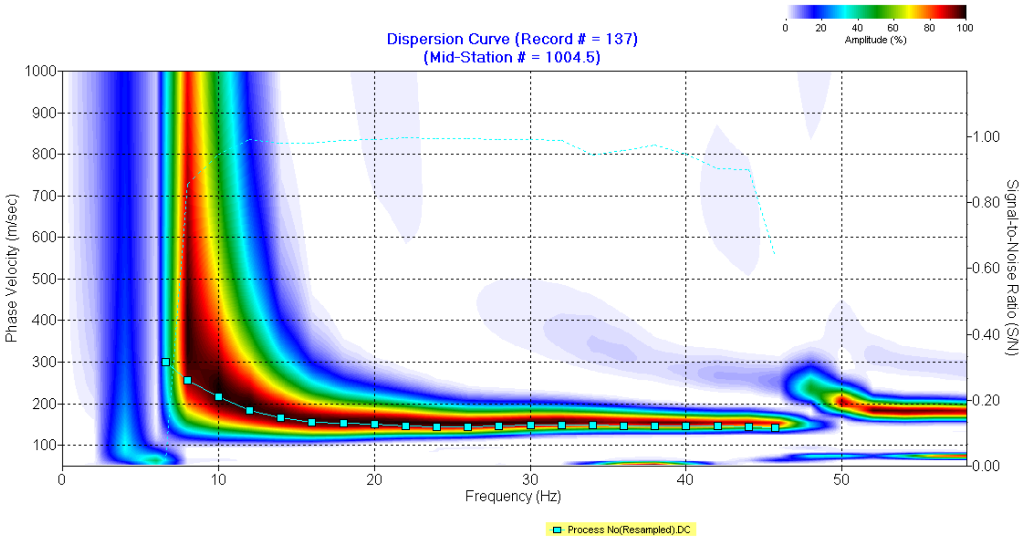

Figure A-75 Dispersion curve of Station No.38

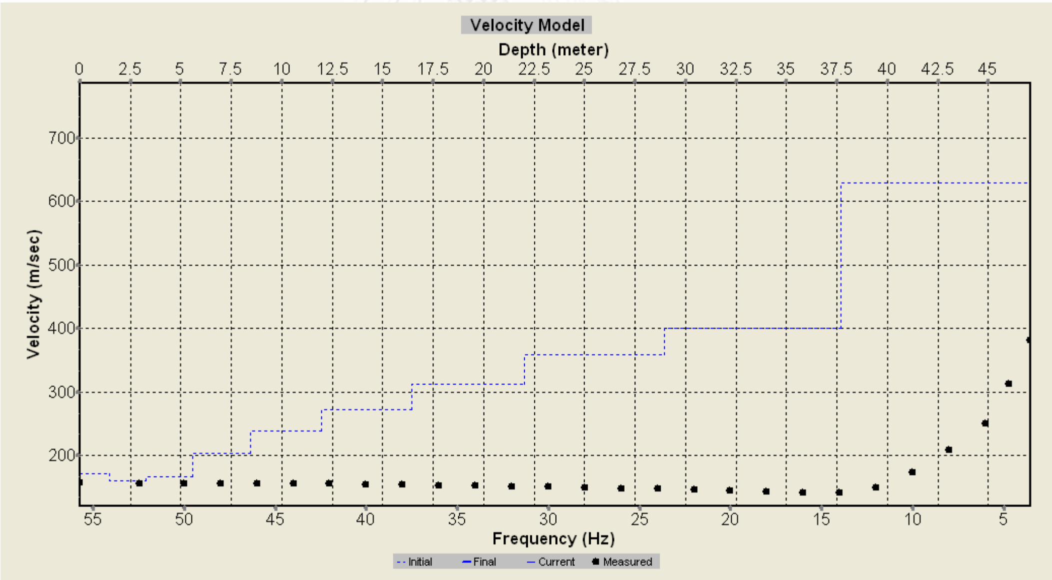

Figure A-76 Inversion of Station No.38

Station No. 39

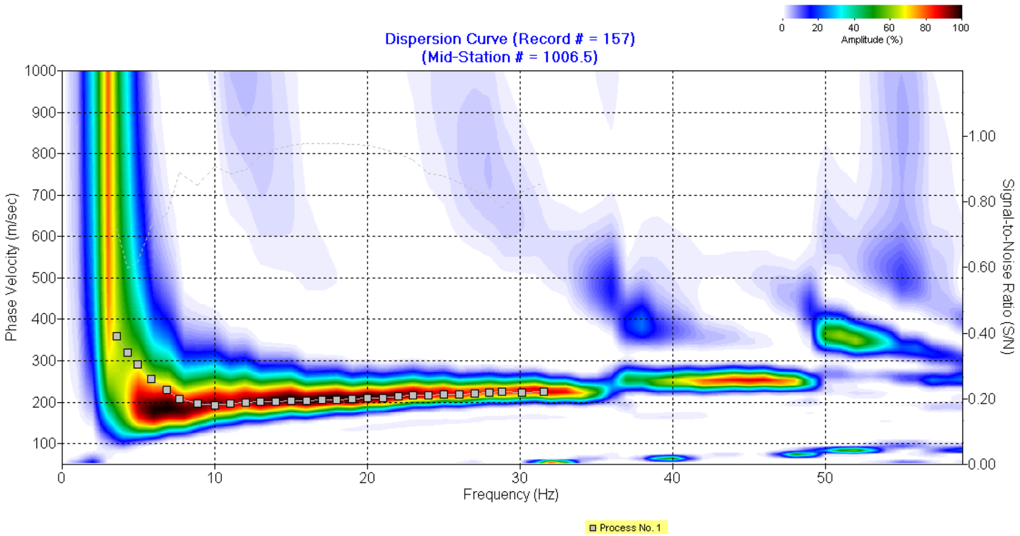

Figure A-77 Dispersion curve of Station No.39

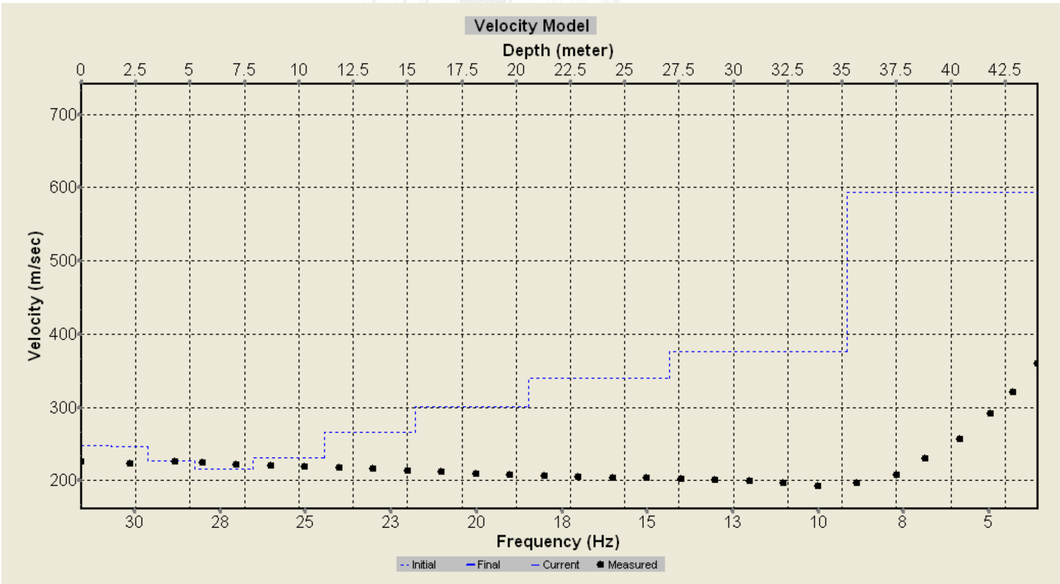

Figure A-78 Inversion of Station No.39

Station No. 40

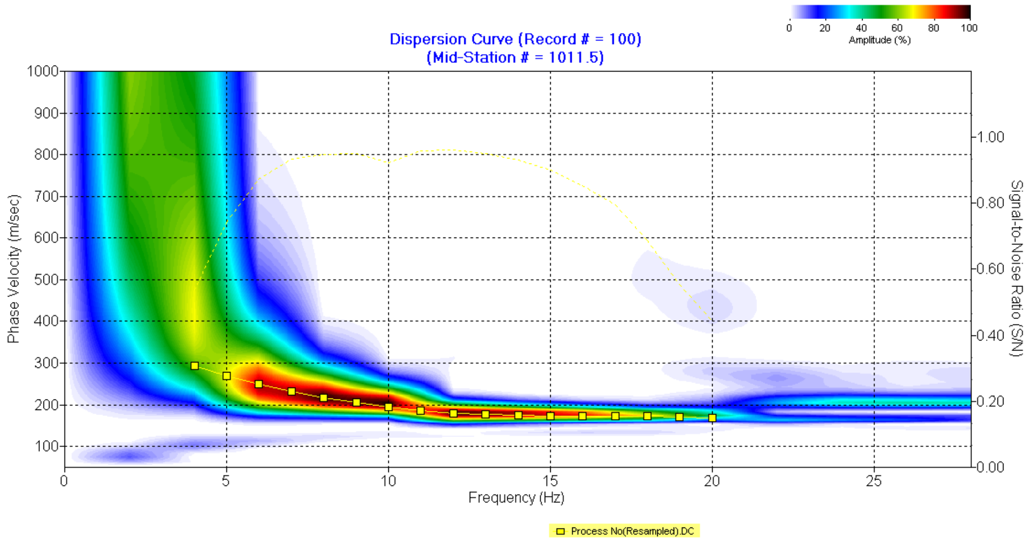

Figure A-79 Dispersion curve of Station No.40

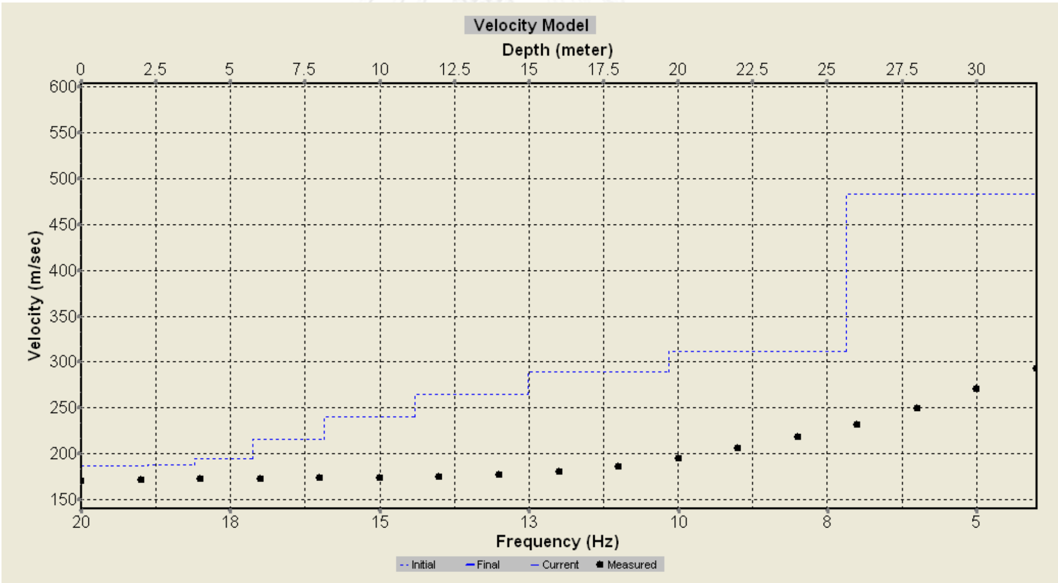

Figure A-80 Inversion of Station No.40

Station No. 41

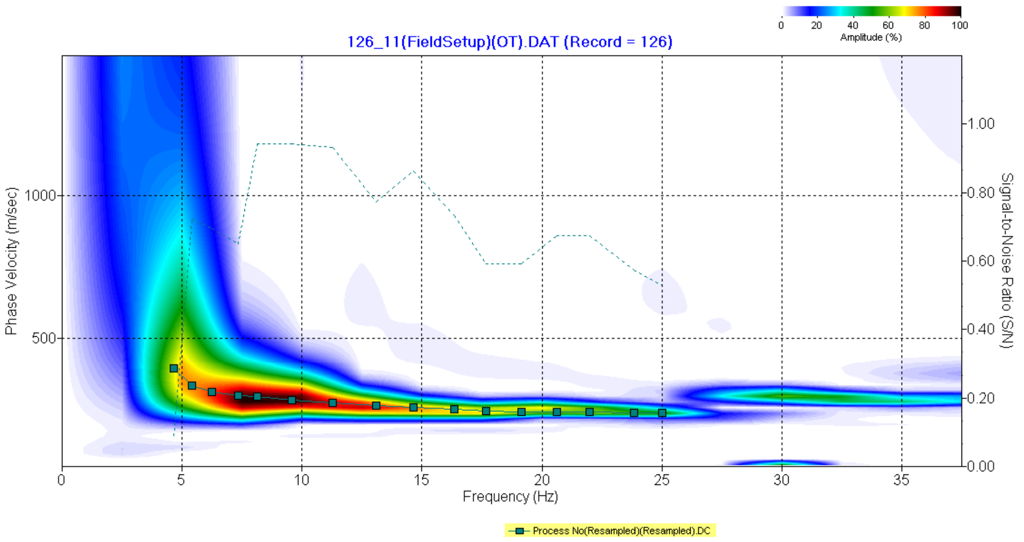

Figure A-81 Dispersion curve of Station No.41

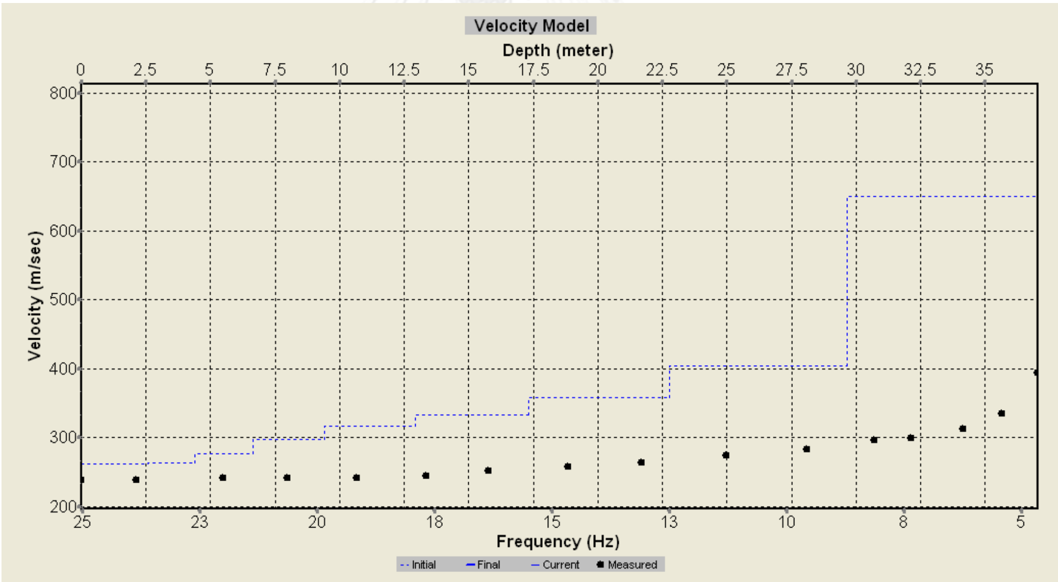

Figure A-82 Inversion of Station No.41

Station No. 42

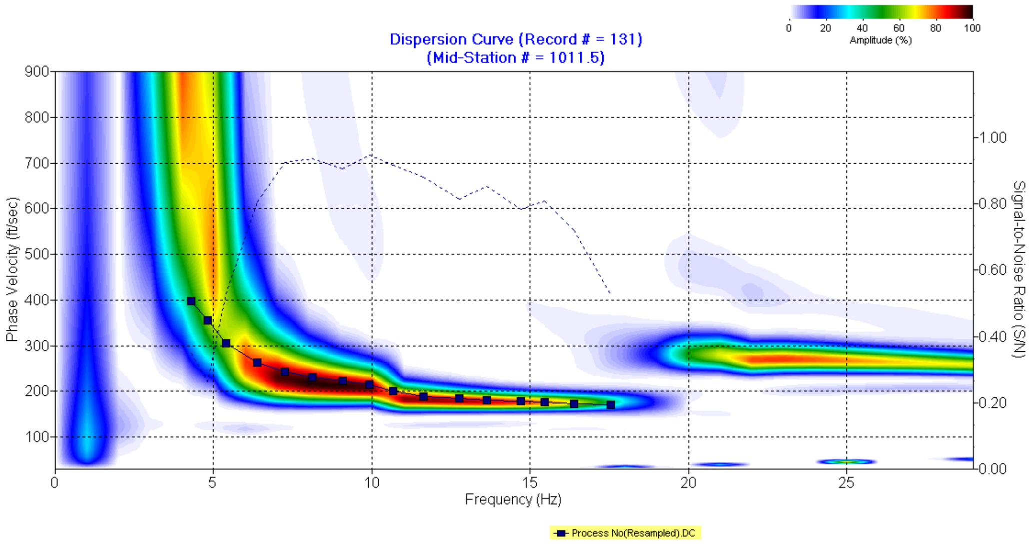

Figure A-83 Dispersion curve of Station No.42

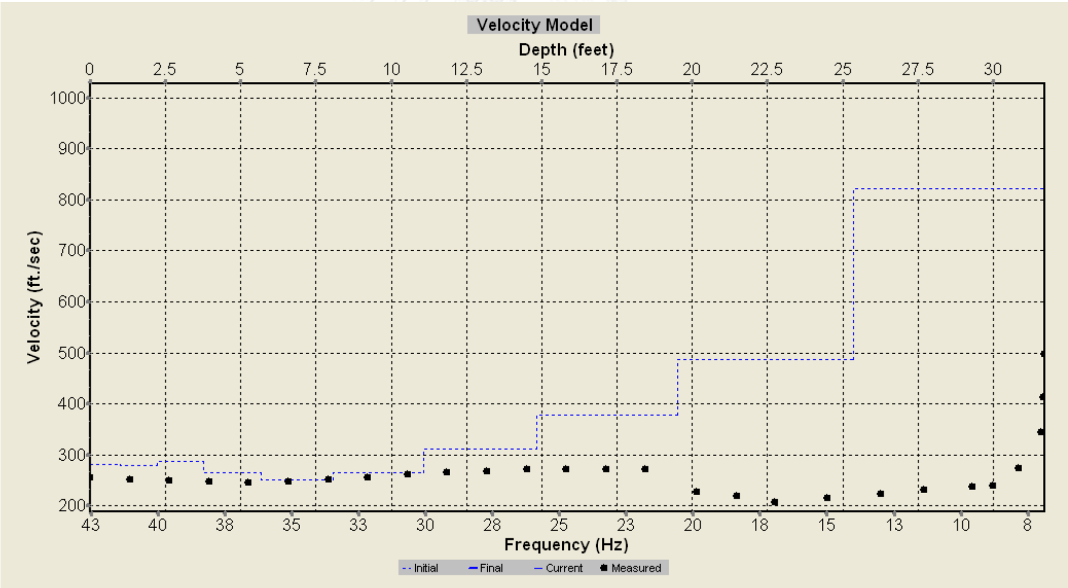

Figure A-84 Inversion of Station No.42

Station No. 43

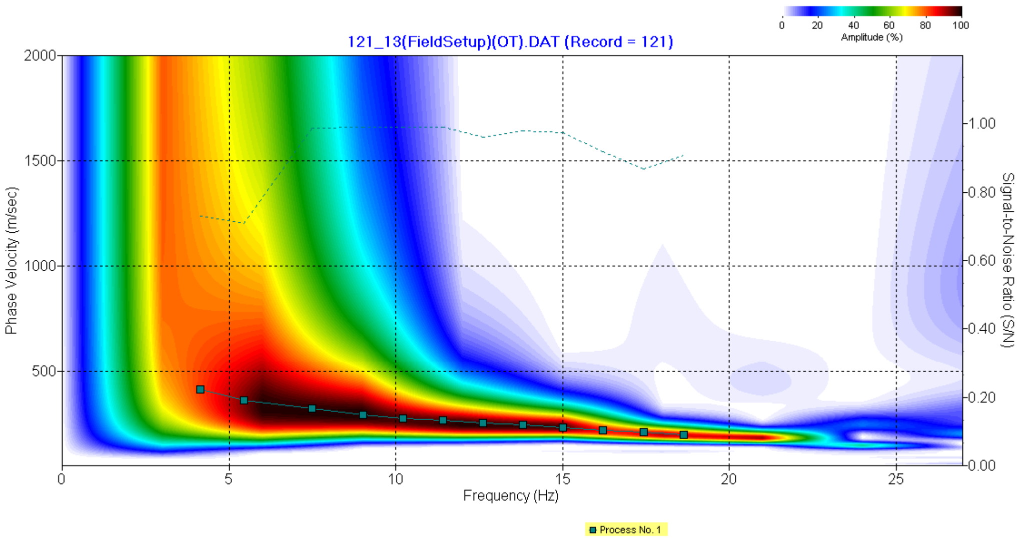

Figure A- 85 Dispersion curve of Station No.43

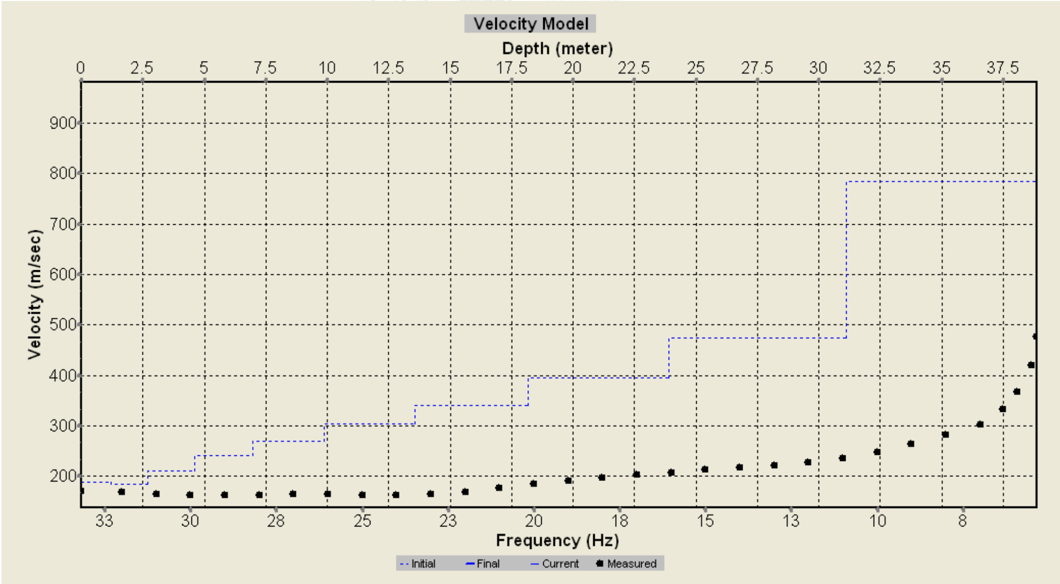

Figure A-86 Inversion of Station No.43

Station No. 44

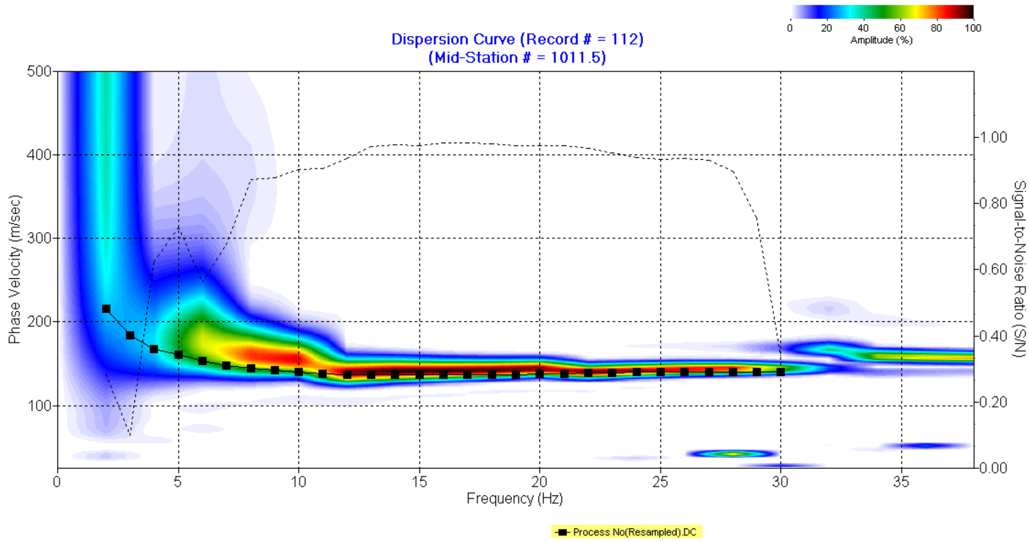

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Figure A- 87 Dispersion curve of Station No.44

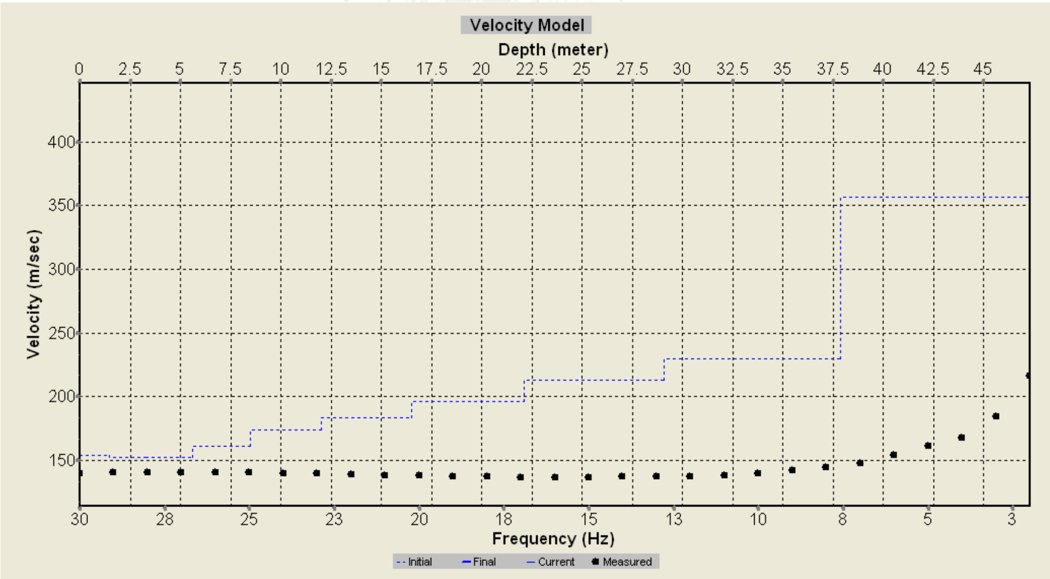

Figure A-88 Inversion of Station No.44

Station No. 45

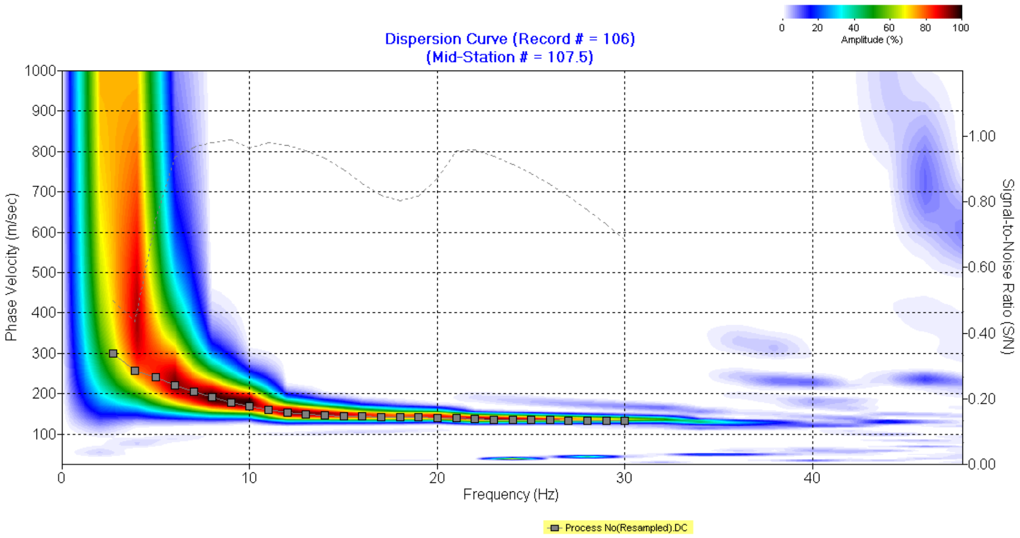

Figure A- 89 Dispersion curve of Station No.45

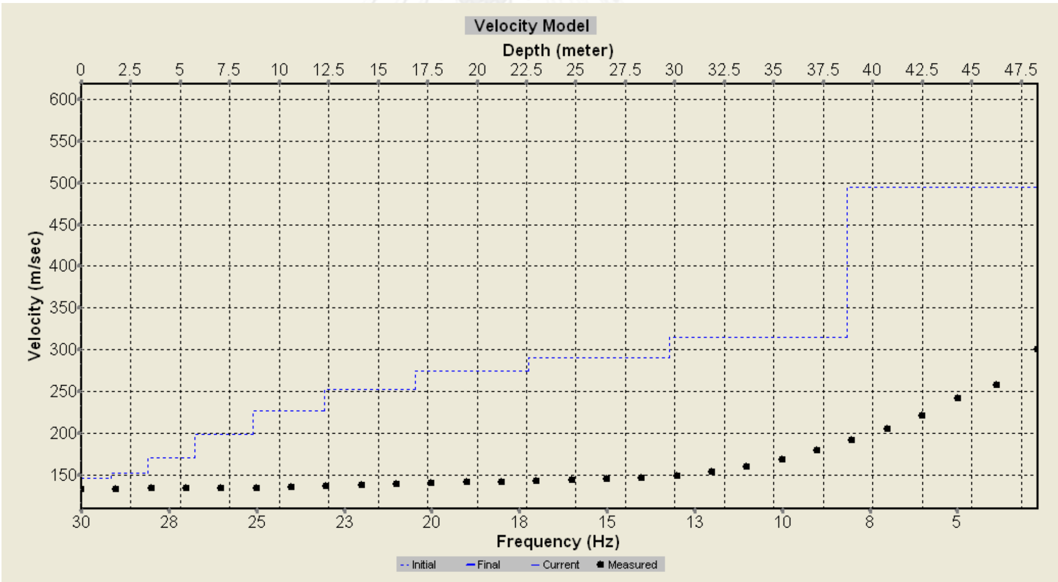

Figure A-90 Inversion of Station No.45

Station No. 46

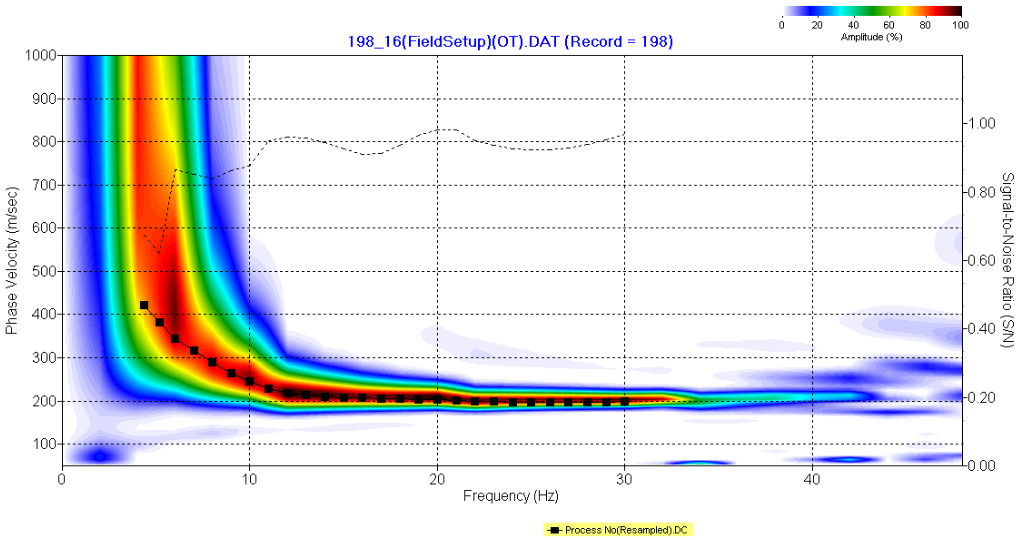

Figure A- 91 Dispersion curve of Station No.46

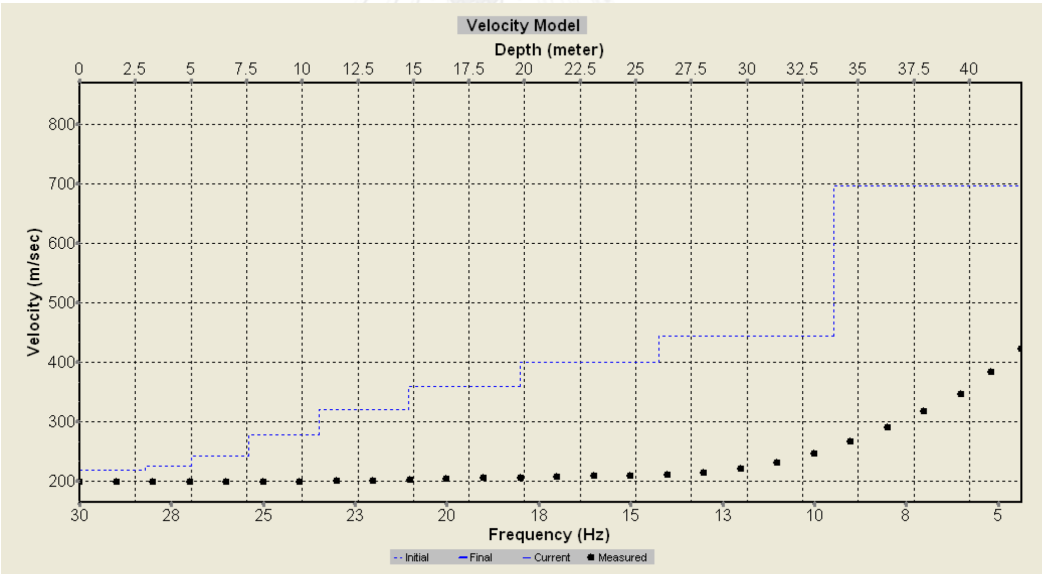

Figure A-92 Inversion of Station No.46

VITA

Ratchadaporn Jintaprasat was born in Amphoe Muang, changwat Yala, a south of Thailand, on April 26, 1992. She graduated Bachelor Degree of Science from Department of Earth Science, Faculty of Science, Kasaert University in 2014. She started to be a Master Degree student with a major of Geology, Department of Geology, Faculty of Science, Chulalongkorn University in 2014 and completed the program in July 2017.