สภาพไหวสะเทือนของแผ่นดินบริเวณภาคเหนือตอนกลางประเทศไทยจากข้อมูลการไหวสะเทือน ช่วงปี ๒๕๔๒-๒๕๕๓ ของโครงข่ายสถานีตรวจวัดแผ่นดินไหวแก่งเสือเต้น

นางวัฒนา คำคม

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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SEISMICITY OF CENTRAL NORTHERN THAILAND FROM 1999-2010

SEISMIC DATA OF THE KAENG SUA TEN SEISMOGRAPHIC NETWORK

Mrs. Watana Khamkom

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Geology
Department of Geology
Faculty of Science
Chulalongkorn University
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Thesis Title	SEISMICITY OF CENTRAL NORTHERN THAILAND FROM 1999-2010 SEISMIC DATA OF THE KAENG SUA TEN SEISMOGRAPHIC NETWORK
By	Mrs. Watana Khamkom
Field of Study	Geology
Thesis Advisor	Associate Professor Punya Charusiri, Ph.D.
Thesis Co-Advisor	Thanu Harnpattanapanich, Ph.D.

Accepted by the Faculty of Science, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

....Dean of the Faculty of Science

(Professor Supot Hannongbua, Dr.rer.nat.)

THESIS COMMITTEE

....Chairman

(Assistant Professor Santi Pailoplee, Ph.D.)

....Thesis Advisor

(Associate Professor Punya Charusiri, Ph.D.)

....Thesis Co-Advisor

(Thanu Harnpattanapanich, Ph.D.)

....Examiner

(Thanop Thitimakorn, Ph.D.)

....External Examiner

(Assistant Professor Passakorn Pananont, Ph.D.)

วัฒนา คำคม : สภาพไหวสะเทือนของแผ่นดินบริเวณภาคเหนือตอนกลางประเทศไทยจากข้อมูลการไหวสะเทือนช่วงปี ๒๕๔๒-๒๕๕๓ ของโครงข่ายสถานีตรวจวัดแผ่นดินไหวแก่งเสือเต้น (SEISMICITY OF CENTRAL NORTHERN THAILAND FROM 1999-2010 SEISMIC DATA OF THE KAENG SUA TEN SEISMOGRAPHIC NETWORK) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ดร.ปัญญา จารุศิริ, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: ดร. ธนู หาญพัฒนพานิชย์, 185 หน้า.

การวิจัยนี้เป็นการศึกษาลักษณะของแผ่นดินไหวที่เกิดขึ้นในพื้นที่ภาคเหนือตอนกลางประเทศไทย จากข้อมูลการไหวสะเทือนที่บันทึกได้จากสถานีตรวจวัดแผ่นดินไหวโครงข่ายแก่งเสือเต้น กรมชลประทาน ด้วยการกำหนดตำแหน่งใหม่ โดยพิจารณาจากเวลาที่คลื่นปฐมภูมิและคลื่นทุติยภูมิเดินทางมาถึง และวิธีโครงข่ายสามเหลี่ยม และการคำนวณเวลาเกิดแผ่นดินไหว 128 เหตุการณ์ ตั้งแต่ขนาด 2.2-6.2ML ในช่วง พ.ศ.2542 ถึง พ.ศ.2553

ผลการศึกษาพบว่าแผ่นดินไหวที่เกิดขึ้นในพื้นที่เป็นแผ่นดินไหวเล็กที่มีขนาดน้อยกว่า 4.9 ตามมาตราริกเตอร์ และเป็นแผ่นดินไหวตื้นที่มีความลึกของจุดศูนย์เกิดแผ่นดินไหวตั้งแต่ 0-61 กิโลเมตร ลักษณะการกระจายตัวของจุดเหนือศูนย์เกิดแผ่นดินไหวส่วนใหญ่ที่มีขนาดตั้งแต่ 3-4.9 เมื่อพิจารณาเฉพาะที่อยู่ห่างจากสถานีตรวจวัด 50 กิโลเมตร พบว่ามีความสัมพันธ์กับรอยเลื่อนมีพลังของกลุ่มรอยเลื่อนภาคเหนือของประเทศไทย แต่บางส่วนพบว่าไม่สัมพันธ์กับรอยเลื่อนที่มีรอยแตกปรากฏอยู่ที่ผิว และถูกพิจารณาว่าเป็นแผ่นดินไหวพื้นฐาน โดยเฉพาะแผ่นดินไหวที่มีขนาดเล็กกว่า 3 และอยู่ลึกน้อยกว่า 10 กิโลเมตร ผลการศึกษาสรุปว่าบริเวณที่มีอันตรายจากแผ่นดินไหวมากที่สุดเป็นบริเวณที่อยู่ระหว่างละติจูด 18.75°-19.75°N และ ลองจิจูด 98.75°-99.75°E โดยอาศัยความสัมพันธ์ของ Gutenberg-Richter Law ค่า b มีค่าเท่ากับ 0.59 ซึ่งน้อยกว่างานที่มีการศึกษาเมื่อก่อน จากการเปรียบเทียบข้อมูลจุดเหนือศูนย์เกิดแผ่นดินไหวที่ได้จากโครงข่ายแก่งเสือเต้นหลังจากกำหนดตำแหน่งใหม่แล้วกับข้อมูลก่อนการกำหนดตำแหน่ง และจากข้อมูลของกรมอุตุนิยมวิทยา พบว่ามีความแตกต่างกันทั้งตำแหน่งและขนาดของแผ่นดินไหว โดยตำแหน่งหลังการกำหนดตำแหน่งใหม่ มีความสัมพันธ์กับรอยเลื่อนมีพลังมากกว่า

ภาควิชา ธรณีวิทยา	ลายมือชื่อนิสิต ....
สาขาวิชา ธรณีวิทยา	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....
ปีการศึกษา 2557	ลายมือชื่อ อ.ที่ปรึกษาร่วม ....

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KEYWORDS: SEISMICITY / TRIANGULATION METHOD / ACTIVE FAULTS

WATANA KHAMKOM: SEISMICITY OF CENTRAL NORTHERN THAILAND FROM 1999-2010 SEISMIC DATA OF THE KAENG SUA TEN SEISMOGRAPHIC NETWORK. ADVISOR: ASSOC. PROF. PUNYA CHARUSIRI, Ph.D., CO-ADVISOR: THANU HARNPATTANAPANICH, Ph.D., 185 pp.

This thesis studies the characteristics of present-day earthquakes in northern Thailand from instrumental data recorded at the Kaeng Sua Ten seismographic network, Royal Irrigation Department, by relocating the earthquake location from event primary and secondary waves arriving times and the Triangulation method, from origin time of 128 earthquakes during the year 1999 to 2010.

The result of this study confirms that the earthquakes in the study area consist of small earthquake less than 4.9 on Richter magnitude scale and are shallow earthquakes with depth ranges from 0-61 kilometer. The earthquakes mostly have the magnitudes of 3-4.9. When considering those within 50 kilometers of the network center, it is found that the distribution of the earthquakes location is clearly and significantly associated with the fault zones of northern Thailand. However, some of the smaller than magnitude 3 and shallower than 10 kilometers which can be considered to be the back-ground earthquake did not relate to any lineament on the ground surface. The study also can be concluded that the highest seismic risk area is covered by latitude 18.75°-19.75° N and longitude 98.75°-99.75° E, based on Gutenberg-Richter relationship where the b-value is 0.59 which is smaller than the previously reported. The newly located epicenter of the Kaeng Sua Ten seismographic network’s when compared to the previously located data and with those of Thai Meteorological Department are different both in the epicenter location and the magnitude. The newly located epicenters correlate better to the existing active fault locations.

Department:	Geology	Student's Signature ....
Field of Study:	Geology	Advisor's Signature ....
Academic Year:	2014	Co-Advisor's Signature ....

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CHAPTER I

INTRODUCTION

1.1 General Information

Earthquake is a natural phenomenon which cannot be controlled and cannot predict when and where it will occur. The earthquake has low probability of occurrence but is highly damaging hazard as it can cause many casualties and destroy properties. For examples, the earthquake on December 26, 2004 with magnitude 9.1Mw along the northern Sumatra, Indonesia, caused more than 200,000 casualties in 14 countries.

For Thailand, from historical records, annals, stone inscription and chronicles stated that it has experienced the effects from moderate earthquakes to major earthquakes for many times, which caused damages to many regions within the country especially in the north and the west, for examples, the earthquakes on April 22, 1983 at the edge of Sri Nakarind dam in Kanchanaburi with magnitude 5.9, the earthquake on September 11, 1994 with magnitude 5.1 at Amphoe Mae Suai in Chiang Rai, the earthquake on December 13, 2006 with magnitude 5.1 at Amphoe Mae-Rim in Chiang Mai. Besides there are still earthquakes that have the epicenters around neighboring countries but the motions also effect Thailand, for examples, the earthquake on May 16, 2007 with magnitude 6.3 in the Democratic Republic of Laos, which is 110 km far from Chiang Rai to the northeast, the citizens in the upper north and in Bangkok could widely notice the motion of the earthquake. And for the latest one; the earthquake on May 5, 2014 with magnitude 6.3 in Mae Lao, Chiang Rai which caused great damage to more than 10,000 citizens households. Every time there is an earthquake in Thailand, there are always questions about the stability and safety of dams. Significant dams of the Royal Irrigation Department (RID) in northern Thailand are the Mae Suai dam, the Mae Kuang dam, the Mae Ngad dam, and also the Kaeng Sua Ten (KST) dam which hasn’t been constructed since there are problems concerning earthquake. The dam is still under monitoring for earthquake, with the setup of a local seismographic network to monitor the earthquake in the area of 150 km around the location of the KST dam since 1999 until present. However, the characteristic of data analysis is still manual, has no standard uniform and lack continuity in data analysis, this makes it impossible to explain the characteristics of the earthquakes those had occurred in northern Thailand, thus give an disadvantage to perform the environmental impact assessment from the earthquake on the RID's dam. For this reason this research is expected to study the earthquakes collected from the instruments from the KST seismographic network during the year 1999 to 2010. The work included the review of the precision and accuracy of analyses, by using the same data, analysis procedure, and assisting analysis programs, but emphases on earthquake origin time calculation, and comparison of analysis with the Thai Meteorological Department (TMD) data, and the relation of earthquakes with geological structures is added.

1.2 Objective

The main purpose of this thesis is to study the characteristics of present-day earthquakes in northern Thailand during the year 1999 to 2010 from instrumental data recorded at the KST seismographic network. The main knowledge and techniques used for this study include interpreting seismogram, analyzing magnitude-epicenter-depth, calculating origin time, analyzing ground motion parameters, and correlating the results of this study to the TMD data and the existing geological structures maps. Results of thesis are to fulfill the following goals;

1. Identify characteristics of earthquakes before and after re-locating,
2. Explanation of relationship between frequency and magnitude (b-value) before and after re-locating,
3. Scoping the area of high seismic hazard in the study area.

1.3 Study Area

The study area is located in the northern region of Thailand between the latitude 17-20.50N and longitude 98.5-101.50E (Figure 1.1), and covered the area around the KST seismographic network and the proposed KST dam in Phrae.

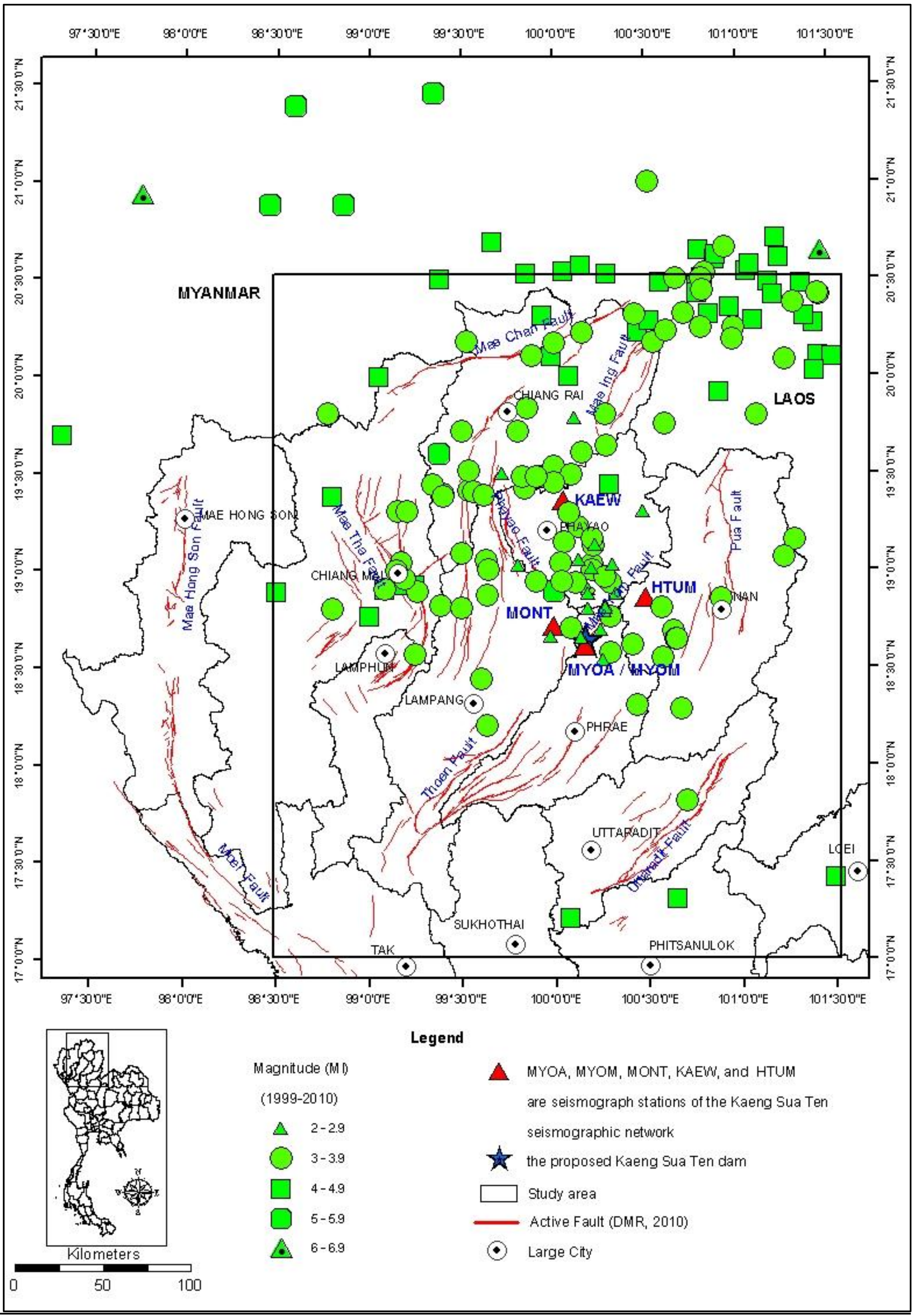


Figure 1. 1. Epicentral map during the year 1999 to 2010 of the KST seismographic network of this study.

1.4 Methodology

The methodology of this research can be listed into 5 steps (Figure 1.2) as following:

1.4.1 Planning and Preparation

The first step involves collecting data for supporting further steps of study. This data is composed of reviewing literatures for pervious work, collecting earthquake epicenters and seismograms, selecting topographic maps and satellite imageries, and other related technical and nontechnical documents.

1.4.2 Interpreting Seismograms

Interpreting all of seismograms from the seismograph stations of the KST network during the year 1999 to 2010 for classifying natural earthquakes and noise signal, and for re-checking the well-located earthquakes to locate epicenters, and interpreting seismograms of the KST's epicenters for screening of only well-located earthquakes to re-locate.

1.4.3 Re-locating Earthquakes

Analyzing magnitude and epicenter and depth by using triangulation (circle and cord) method and studying the arrival time of Primary (P) and Secondary (S) waves of at least 3 stations. Analyzing peak ground acceleration, duration of motion, and frequency content.

1.4.4 Comparison of Data from before and after Re-locating

Identify epicenter of earthquakes before and after re-locating, and frequency and magnitude relation (b-value) before and after re-locating, and relationship of earthquakes with geological structures, and correlation of the KST's epicenters with the TMD.

1.4.5 Discussion and Conclusion

Discussion related to the results from characteristics of seismicity before and after re-locating, and frequency-magnitude distribution (b-value) along with the existing previous works, for examples, the magnitudes and epicenter and depth, and relationship of earthquakes with geological structures, and characteristics of strong ground-motion earthquakes from ground motion parameters.

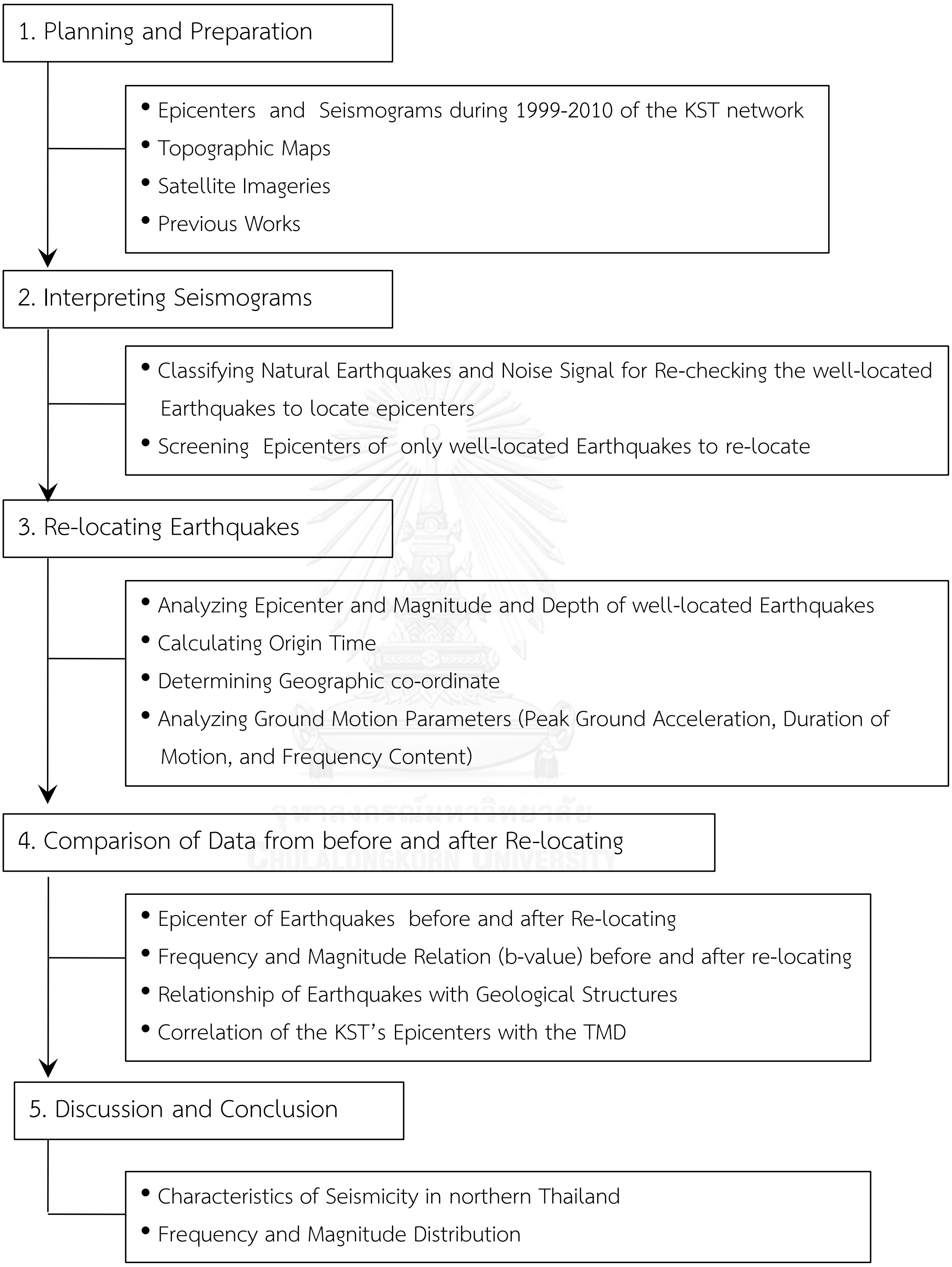


Figure 1. 2. Flow chart showing the methodology used in this study.

1.5 Research output

The main output of this study is;

1. Characteristics of seismicity before and after re-locating.
2. Frequency-magnitude distribution (b-value) before and after re-locating.
3. The earthquake catalogue during the year 1999 to 2010 after re-locating of the KST seismographic network and seismicity map at a scale1:2,500,000.

1.6 A Brief Guide to the Thesis

This thesis provides an emphasis on seismicity of central northern Thailand in succession of Chapters as following:

Chapter I mentions about an introduction, objective, study area, methodology and research output to the research project.

Chapter II notifies the seismology and earthquakes, seismic wave, locating earthquakes, origin time of earthquakes, measuring magnitudes, intensity of earthquakes, the Gutenberg-Richter Recurrence Law, acceleration of ground shaking, earthquakes study in northern Thailand and other areas.

Chapter III is the part of interpreting seismograms of the KST's epicenters for screening of only well-located earthquakes to re-locate, and classifying natural earthquakes and noise signal of all seismograms during the year 1999 to 2010 for re-checking the remaining well-located earthquakes to locate epicenters.

Chapter IV is the part of re-locating earthquakes which consist of analyzing magnitude and epicenter and depth, calculating origin time, and analyzing ground motion parameters.

Chapter V is the part of comparison of data from before and after re-locating, epicenter of earthquakes before and after re-locating, relationship of earthquakes with geological structures, and correlation of the KST's epicenters with the TMD.

Chapter VI is the part of discussion of characteristics of seismicity before and after re-locating, frequency-magnitude distribution (b-value).

Chapter VII is the conclusion deduced from the result of study project research. The clearly-defined characteristics of seismicity in northern Thailand during the year 1999 to 2010 and the seismicity map at a scale 1:2,500,000 form the main output of this study.

CHAPTER II
LITERATURE REVIEWS

2.1 Seismology and Earthquake

Seismology is the study of earthquakes and seismic waves that move through and around the earth. A seismologist is a scientist who studies earthquakes and seismic waves. Seismicity refers to the geographic and historical distribution of earthquakes and the frequency or magnitude of earthquake activity in a given area which seismic activity refers to the phenomenon of earthquake activity or the occurrence of artificially produced earth tremors. Earthquake is ground shaking and radiated seismic energy caused most commonly by sudden slip on a fault, volcanic or magmatic activity, or any other sudden stress changes in the earthquakes in the Earth.

Seismic waves are the waves of energy caused by the sudden breaking of rock within the earth or an explosion. They are the energy that travels through the earth and is recorded on seismographs. There are several different kinds of seismic waves, and they all move in different ways. The two main types of waves are body waves and surface waves. Body waves can travel through the earth's inner layers, but surface waves can only move along the surface of the planet like ripples on water. Earthquakes radiate seismic energy as both body and surface waves (Figure 2.1).

Body waves, emitted by an earthquake, which travelling through the interior of the earth, arrive before the surface waves. These waves are of a higher frequency than surface waves. The first kind of body wave is the P wave or primary wave. This is the fastest kind of seismic wave and consequently the first to arrive at a seismic station. The P wave can move through solid rock and fluids, like water or the liquid layers of the earth. It pushes and pulls the rock it moves through just like sound waves push and pull the air. P waves are also known as compression waves, because of the pushing and pulling they do. Particles subjected to a P wave move in the same direction that the wave is moving in, which is the direction that the energy is traveling in, and is sometimes called the direction of wave propagation. The second type of body wave is the S wave or secondary wave, which is the second wave that is observed in an earthquake. An S wave is slower than a P wave and can only move through solid rock, not through any liquid medium. It is this property of S waves that led seismologists to conclude that the Earth's outer core is a liquid. S waves move rock particles up and down, or side-to-side perpendicular to the direction that the wave is traveling in (the direction of wave propagation).

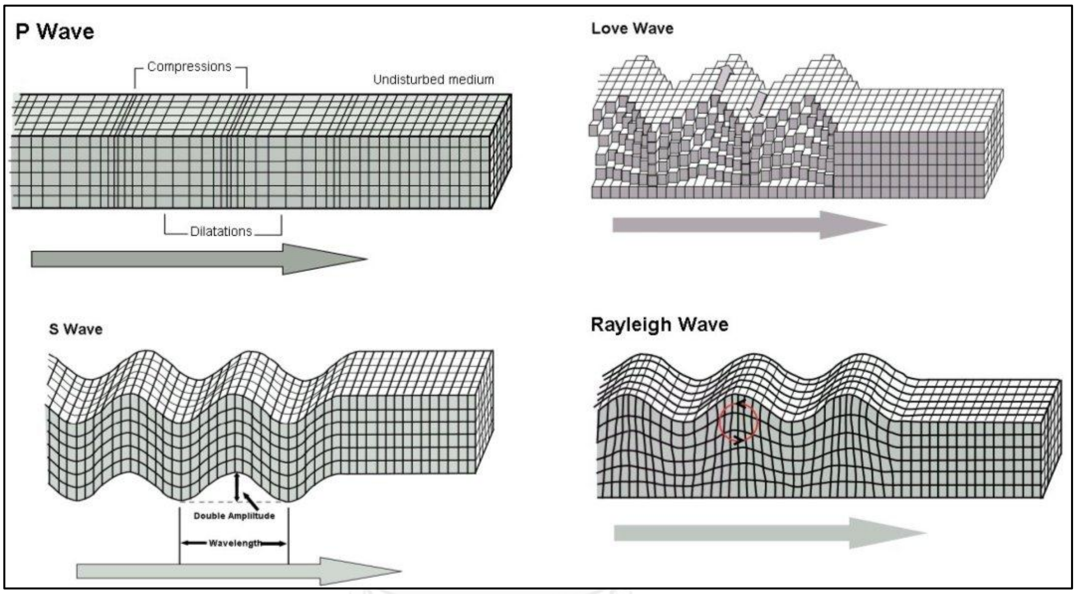


Figure 2. 1. Diagram illustrating the form of ground motion nears the ground surface in four types of earthquake waves (http://geo.cornel.edu/).

Travelling only through the crust, surface waves are of a lower frequency than body waves, and are easily distinguished on a seismogram as a result. Though they arrive after body waves, it is surface waves that are almost entirely responsible for the damage and destruction associated with earthquakes. Earthquakes occur all the time all over the world, both along plate edges and along faults. Most earthquakes occur along the edge of the oceanic and continental plates. The earth's crust (the outer layer of the planet) is made up of several pieces, called plates (Figure 2.2). The plates under the oceans are called oceanic plates and the rest are continental plates. The plates are moved around by the motion of a deeper part of the earth (the mantle) that lies underneath the crust. These plates are always bumping into each other, pulling away from each other, or past each other. The plates usually move (Figure 2.3) at about the same speed that finger nails grow. Earthquakes usually occur where two plates are running into each other or sliding past each other.

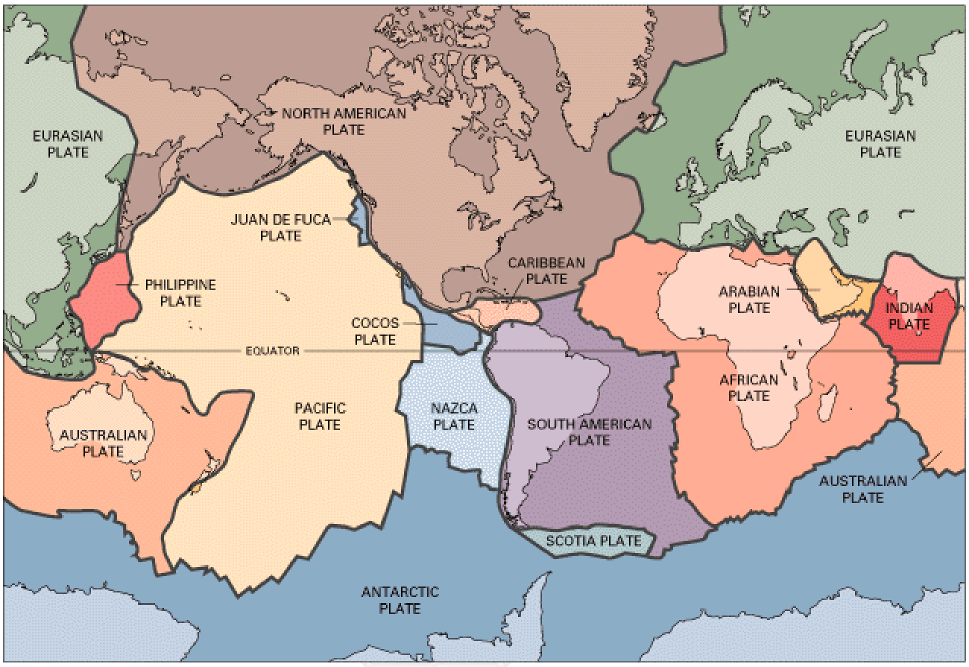


Figure 2. 2. An Image of the world's plates and their boundaries (http://www.usgs.gov/).

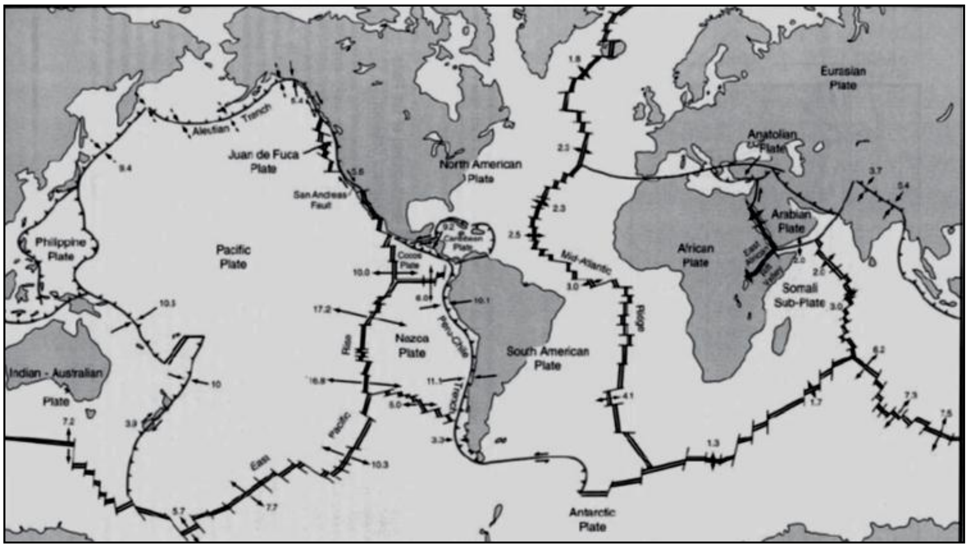


Figure 2. 3. Map of the major tectonic plates with arrows showing directions of movement. Amounts of movement are shown in centimeters per year (Abbott, 2004).

Earthquakes can also occur far from the edges of plates, along faults (Figure 2.4). Faults are cracks in the earth crust where sections of a plate (or two plates) are moving in different directions. Faults are caused by all that bumping and sliding the plates do. They are more common near the edges of the plates. Earthquakes occur when a fault ruptures and stored energy is released as seismic waves.

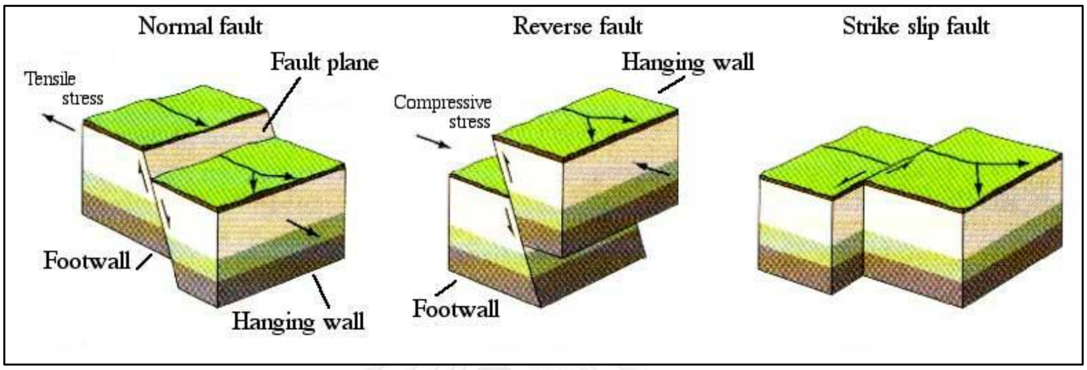


Figure 2. 4. Type of faults (http://www.geosci.usyd.edu.au/)

Normal faults are the cracks where one block of rock is sliding downward and away from another block of rock. These faults usually occur in areas where a plate is very slowly splitting apart or where two plates are pulling away from each other. A normal fault is defined by the hanging wall moving down relative to the footwall, which is moving up.

Reverse faults are cracks formed where one plate is pushing into another plate. They also occur where a plate is folding up because it is being compressed by another plate pushing against it. At these faults, one block of rock is sliding underneath another block or one block is being pushed up over the other. A reverse fault is defined by the hanging wall moving up relative to the footwall, which is moving down.

Strike-slip faults are the cracks between two plates that are sliding past each other. Strike-slip faults occur when the displacement is horizontal and parallel to the trend or strike of the fault. This type of fault trends to be very large and linear consisting of several parallel fractures. Strike-slip faults extend through the lithosphere and have motion between two plates is transformed faults.

Earthquakes are usually caused when rock underground suddenly breaks along a fault. This sudden release of energy causes the seismic waves that make the ground shake. When two blocks of rock or two plates are rubbing against each other, they stick a little. They do not just slide smoothly; the rocks catch on each other. The rocks are still pushing against each other, but not moving. After a while, the rocks break because of all the pressure that is built up. When the rocks break, the earthquake occurs. During the earthquake and afterward, the plates or blocks of rock start moving, and they continue to move until they get stuck again. The spot underground where the rock breaks is called the focus of the earthquake. The place right above the focus (on top of the ground) is called the epicenter of the earthquake (Figure 2.5).

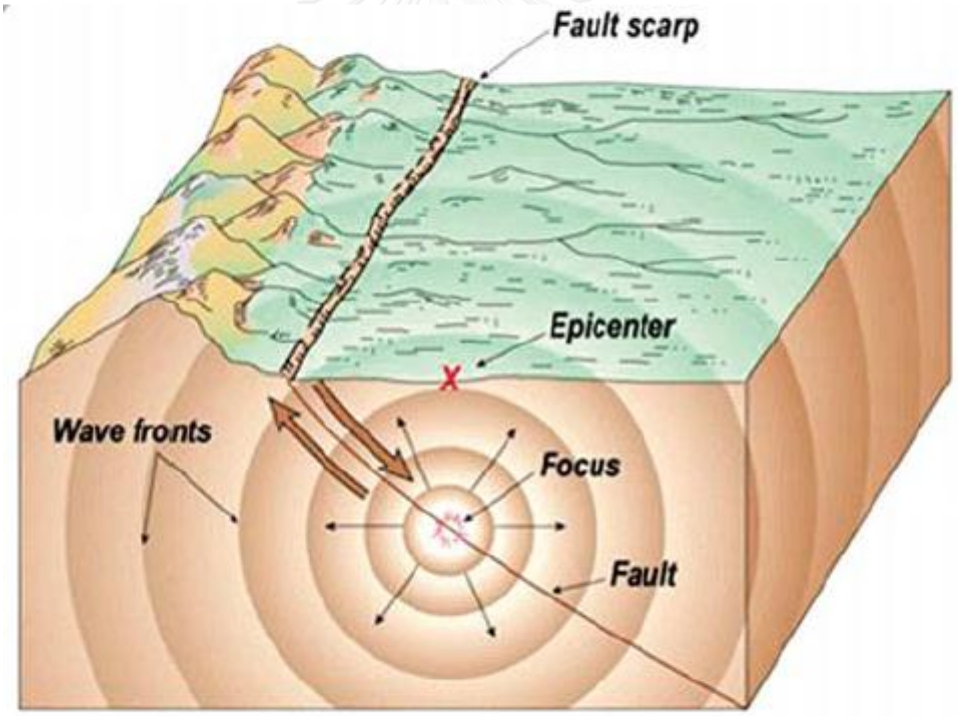


Figure 2. 5. The point on the fault that first ruptures is the focus. The point on the Earth's surface directly above the focus is the epicenter (http://www.sci.tsu.ac.th).

Earthquake-like seismic waves can also cause by explosions underground. The largest underground explosions, from tests of nuclear warheads (bombs), can create seismic waves very much like large earthquakes. This fact has been exploited as a means to enforce the global nuclear test ban, because no nuclear warhead can be detonated on earth without producing such seismic waves.

Seismologists study earthquakes by going out and looking at the damage caused by the earthquakes and by using seismographs. A seismograph is an instrument that records the shaking of the earth's surface caused by seismic waves. The term seismometer is also used to refer to the same device, and the two terms are often used interchangeably. The first seismograph was invented in 132 A.D. by the Chinese astronomer and mathematician Chang Heng. Most seismographs today are electronic, but a basic seismograph is made of a drum with paper on it (Figure 2.6), a bar or spring with a hinge at one or both ends, a weight, and a pen. The one end of the bar or spring is bolted to a pole or metal box that is bolted to the ground. The weight is put on the other end of the bar and the pen is stuck to the weight. The drum with paper on it presses against the pen and turns constantly. When there is an earthquake, everything in the seismograph moves except the weight with the pen on it. As the drum and paper shake next to the pen, the pen makes squiggly lines on the paper, creating a record of the earthquake called a seismogram.

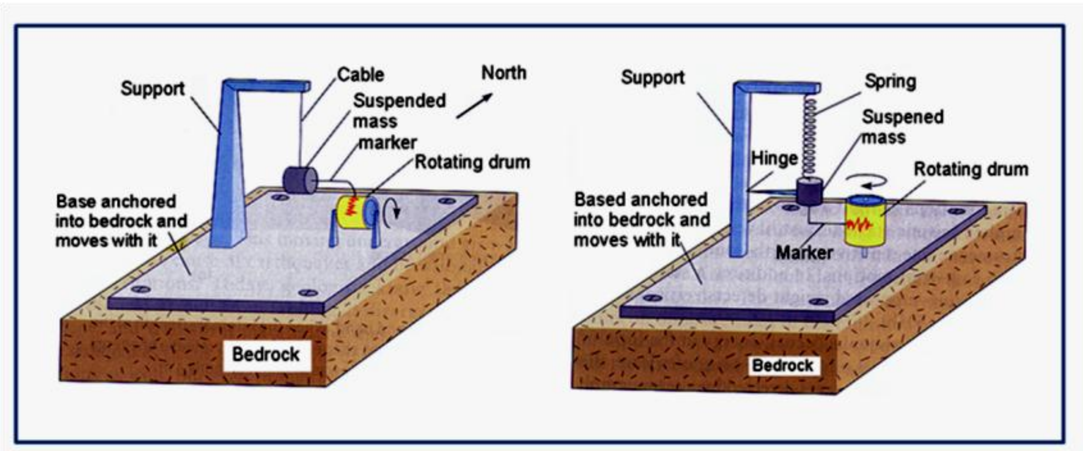


Figure 2. 6. Seismometer recording horizontal and vertical ground -motion (http://www.yorku.ca/).

By studying the seismogram, the seismologist can tell how far away the earthquake was and how strong it was. This record does not tell the seismologist exactly where the epicenter was, just that the earthquake happened so many miles or kilometers away from that seismograph. To find the exact epicenter, it needs to know what at least two other seismographs in other parts of the country or world recorded.

When look at a seismogram (Figure 2.7), there will be wiggly lines all across it. These are all the seismic waves that the seismograph has recorded. Most of these waves were so small that nobody felt them. These tiny microseisms can be caused by heavy traffic near the seismograph, waves hitting a beach, the wind, and any number of other ordinary things that cause some shaking of the seismograph. There may also be some little dots or marks evenly spaced along the paper. These are marks for every minute that the drum of the seismograph has been turning. How far apart these minute marks are will depend on kind of seismograph.

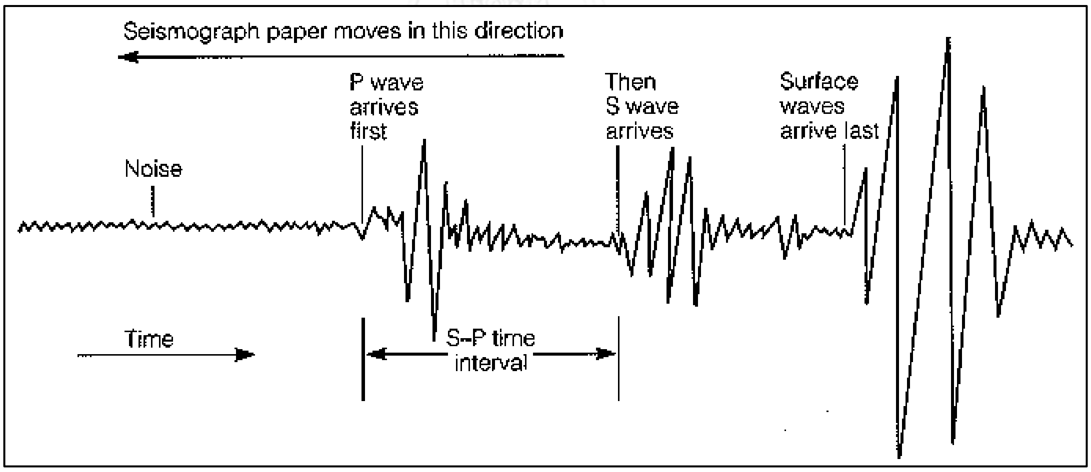


Figure 2. 7. A typical seismogram (http://samjshah.com/).

The P wave will be the first wiggle that is bigger than the rest of the little ones (the microseisms). Because P waves are the fastest seismic waves, they will usually be the first ones that a seismograph records. The next set of seismic waves on a seismogram will be the S waves. These are usually bigger than the P waves. The surface waves (Love and Rayleigh waves) are the other, often larger, waves marked on the seismogram. They have a lower frequency, which means that waves (the lines; the ups-and-downs) are more spread out. Surface waves travel a little slower than S waves (which, in turn, are slower than P waves) so they tend to arrive at the seismograph just after the S waves. For shallow earthquakes (earthquakes with a focus near the surface of the earth), the surface waves may be the largest waves recorded by the seismograph. Often they are the only waves recorded a long distance from medium-sized earthquakes.

2.1.1 Locating Earthquakes

In general to figure out just where that earthquake happened, it needs to look at a seismogram and need to know what at least two other seismographs recorded for the same earthquake. It will also need a map of the world, a ruler, a pencil, and a compass for drawing circles on the map.

Procedure for finding the distance to the epicenter and the earthquake's magnitude (Figure 2.8)

Step 1. Measure the distance between the first P wave and the first S wave. In this case, the first P and S waves are 24 seconds apart.

Step 2. Find the point for 24 seconds on the left side of the chart and mark that point. According to the chart, this earthquake's epicenter was 215 kilometers away.

Step 3. Measure the amplitude of the strongest wave. The amplitude is the height (on paper) of the strongest wave. On this seismogram, the amplitude is 23 millimeters. Find 23 millimeters on the right side of the chart and mark that point.

Step 4. Place a ruler (or straight edge) on the chart between the points one marked for the distance to the epicenter and the amplitude. The point where the ruler crosses the middle line on the chart marks the magnitude (strength) of the earthquake. This earthquake had a magnitude of 5.0.

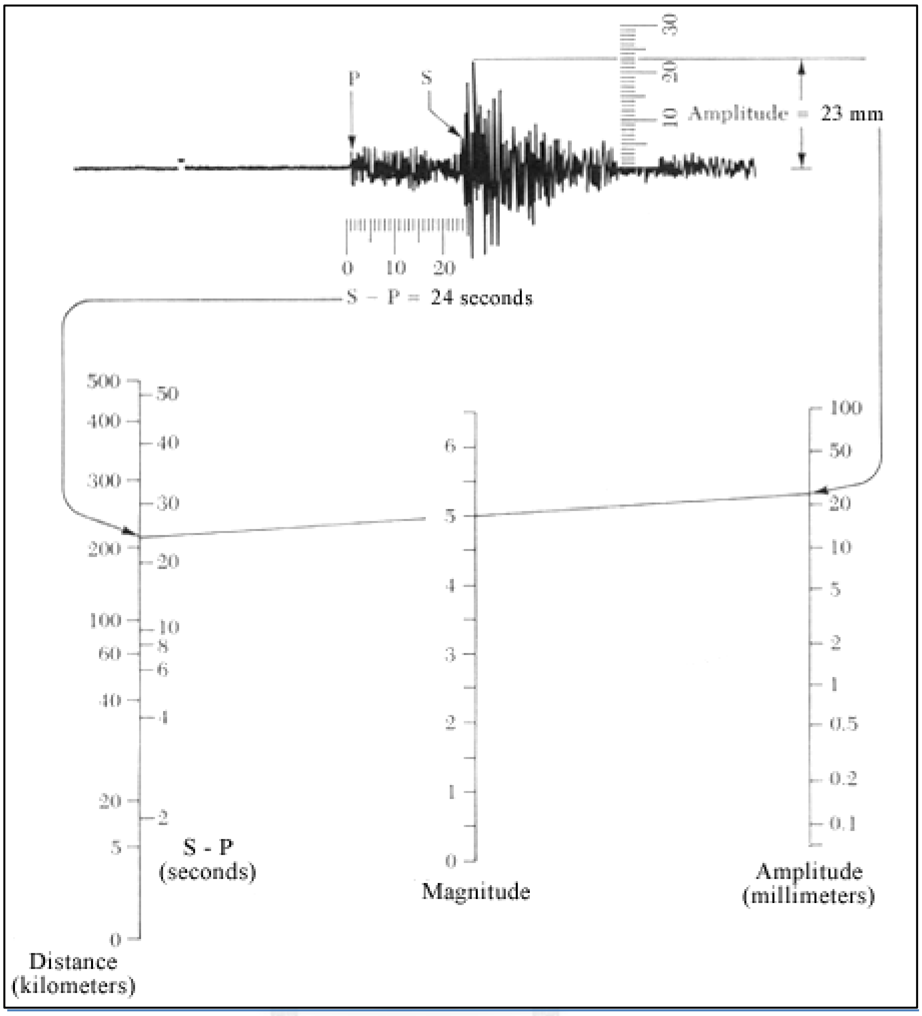


Figure 2. 8. Using the amplitude to derive the magnitude of the earthquake, and the distance from the earthquake to the station (Bolt, 1978).

Procedure for finding the distance to the epicenter (Figure 2.9).

Step 1. Check the scale on the map. It should look something like a piece of a ruler. All maps are different. On the map, one centimeter could be equal to 100 kilometers or something like that.

Step 2. Figure out how long the distance to the epicenter (in centimeters) is on the map. For example, say the map has a scale where one centimeter is equal to 100 kilometers. If the epicenter of the earthquake is 215 kilometers away, that equals 2.15 centimeters on the map.

Step 3. Using the compass, draw a circle with a radius equal to the number that came up with in Step #2 (the radius is the distance from the center of a circle to its edge). The center of the circle will be the location of the seismograph. The epicenter of the earthquake is somewhere on the edge of that circle.

Step 4. Do the same thing for the distance to the epicenter that the other seismograms recorded (with the location of those seismographs at the center of their circles). All of the circles should overlap. The point where all of the circles overlap is the approximate epicenter of the earthquake.

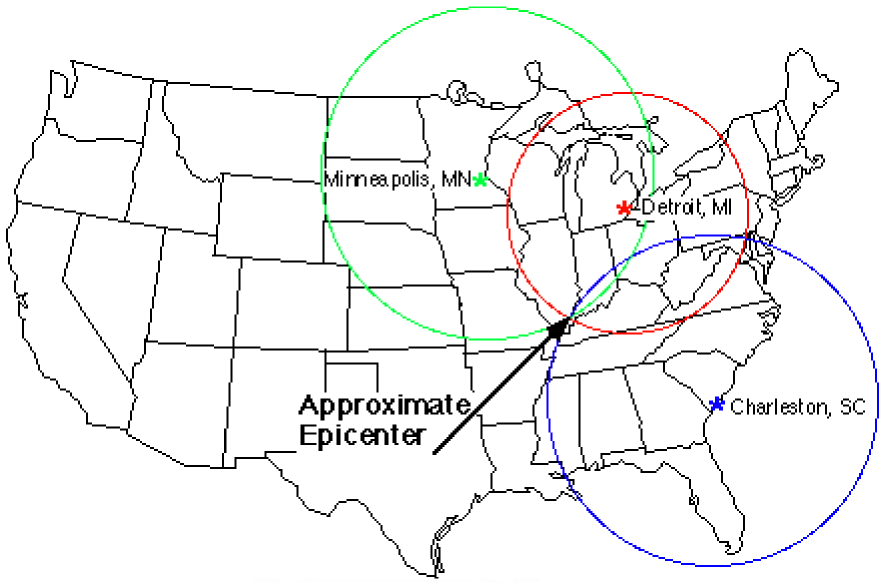


Figure 2. 9. The point where the three circles intersect is the epicenter of the earthquake. This technique is called triangulation (https://sites.google.com).

Havskov and Ottemoller (2008) described that the earthquake location is defined by the earthquake hypocenter and the origin time. The hypocenter is the physical location, usually longitude, latitude and depth below the surface. The epicenter is the projection of the earthquake location on the Earth's surface. The epicentral distance is the distance from the epicenter to the station along the surface of the earth. Generally, the distance can be obtained from the difference in arrival time of two phases, usually P and S, and the distance can be calculated as

$$\Delta = (t_s - t_p)\frac{VpVs}{Vp-Vs} \qquad (2.1)$$

where t_p and t_s are the P and S-arrival times (s) respectively,
v_p and v_s are the P and S velocities respectively and
Δ is the epicentral distance (km).

The equation (2.1) is applicable for the travel-time difference between Sg and Pg, i.e., the direct crustal phases of S and P, respectively (Figure 2.10). They are first onsets of the P-and S-wave groups of local events only for distance up to about 100-250 km, depending on crustal thickness and source depth.

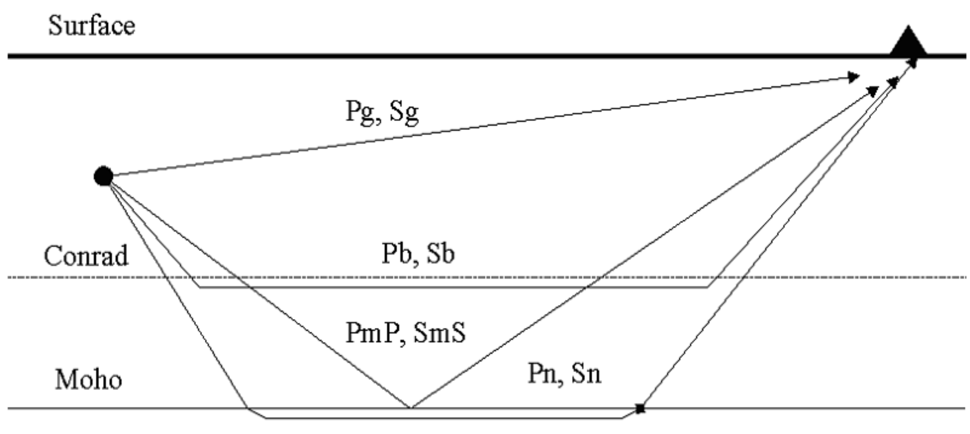


Figure 2. 10. A simplified model of the crust showing the most important crustal phases observed at local and regional distances (Bormann, 2012).

The basic method for determining the epicenter of local or regional seismic sources by hand, using the triangulation (circle and chord) method.

Procedures for finding the epicenter from the triangulation method are as following:

1. First, identify the seismic phases of earthquakes;
2. If no local travel-time curves are available, a first rough estimate of the hypocenter distance d or of the epicentral distance (both in km) may be found using the following "rules-of-thumb"

$$d = t(Sg - Pg) \times 8 \qquad (2.2)$$

Which t as the travel-time difference in seconds between the respective seismic phases. These rules are approximations for a single layer crust with an average Pg-wave velocity of 5.9 km/s and a sub-Moho velocity of 8 km/s and a velocity ratio $V_s/V_p = \sqrt{3}$;

3. Draw circles with a compass around each station Si, which is marked on a distance-true map projection, with the radius di determined from the records of each station;
4. The circles will usually cross at two points, not one point (the thought epicenter) thus forming an area of overlap (Figure 2.11, shaded area) within which the epicenter most probably lies;
5. Usually, it is assumed, that the best estimate of the epicenter position is the center of gravity of this shaded area of overlap. The best estimate of the epicenter is found by drawing so-called "chords", i.e., straight lines connecting the two crossing points of each pair of circles. The crossing point (or smaller area of overlap) of the chords should be the best estimate of the epicenter (Figure 2.11).

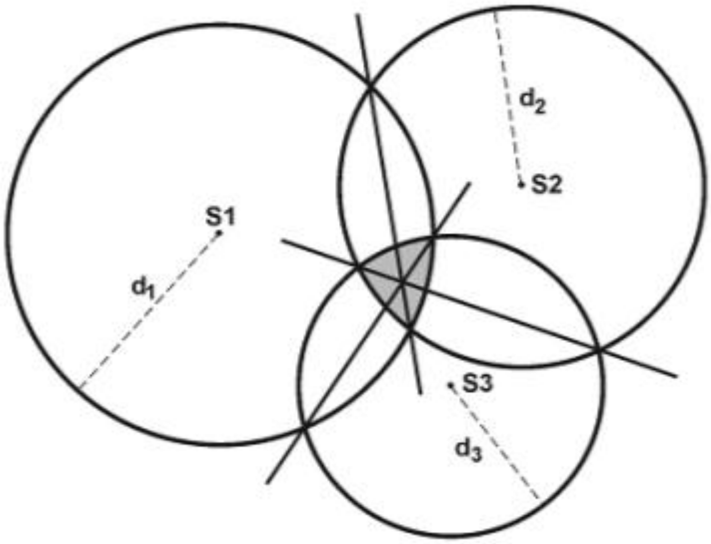


Figure 2. 11. Principle of epicenter estimation by using the "circle and chord" method. S – station sites and d – distance of the event determined for each station (Bormann, 2012).

The location of earthquake can be located when at least 3 seismic stations are available, a simple manual location can be made from drawing circles with the center at the station locations and the radii equal to the epicentral distances calculated from the S-P times.

The origin time or the actual time that the earthquake occurred at the source can be defined by the formula;

$$O_{time} = P - \left[(S - P) \times 1.37\right] \qquad (2.3)$$

When O_{time} is the occurrence time for the earthquake.

P is the arrival time of the primary wave.

S is the arrival time of the secondary wave.

1.37 is the constant value if Poisson's ratio is equal to 0.25 (Richter, 1958)

2.1.2 Measuring Magnitudes

Magnitude is an estimation of the energy release or the size of an earthquake. The estimates are generally calculated from the amplitude of wave energy on a seismograph adjusting for the magnification of the seismograph and the distance of the seismograph station from the earthquake. The first magnitude scale was defined by (Richter, 1935) for Southern California. The Richter magnitude is calculated from the amplitude of the largest seismic wave recorded for the earthquake, no matter what type of wave was the strongest. The Richter magnitudes are based on a logarithmic scale (base 10). What this means is that for each whole number one go up on the Richter scale, the amplitude of the ground motion recorded by a seismograph goes up ten times. Using this scale, a magnitude M5 earthquake would result in ten times the level of ground shaking as a magnitude M4 earthquake (and 32 times as much energy would be released). Most of the earthquakes that occur each year are magnitude M2.5 or less, too small to be felt by most people (Figure 2.12). The Richter magnitude scale can be used to describe earthquakes so small that they are expressed in negative numbers. The scale also has no upper limit, so it can describe earthquakes of unimaginable and (so far) inexperienced intensity, such as magnitude 10.0 and beyond.

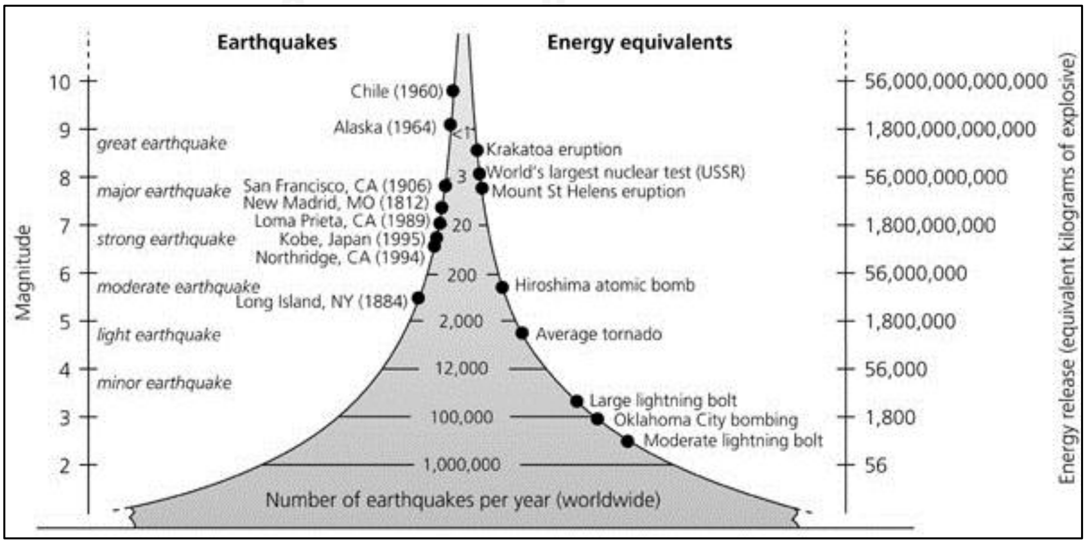


Figure 2. 12. Comparison of frequency magnitude and energy release (http://www.iris.edu/).

Although Richter originally proposed this way of measuring an earthquake's size, which only used a certain type of seismograph and measured shallow earthquakes in Southern California. Scientists have now made other magnitude scales, all calibrated to Richter's original method, to use a variety of seismographs and measure the depths of earthquakes of all sizes. All other magnitude scales are related to this scale. The local magnitude M_L is defined as shown in equation (2.4)

$$M_L = \log(A) - Q_d(\Delta) \qquad (2.4)$$

Where A is the maximum amplitude on a Wood-Anderson seismograph (which measures displacement for $f > 1.25$ Hz)

$Q_d(\Delta)$ is a distance correction function

Several magnitude scales use maximum amplitude and often the corresponding period. There are two ways of doing this;

a) Read the amplitude from the base line and the period from two peaks. However this might be difficult, at least when done manually, due to the location of the base line.

b) Read the maximum peak to peak amplitude and divide by 2. This is the most common practice and the simplest to do both manually and automatically. The period can be read either from two peaks or as half the period from the two extremes.

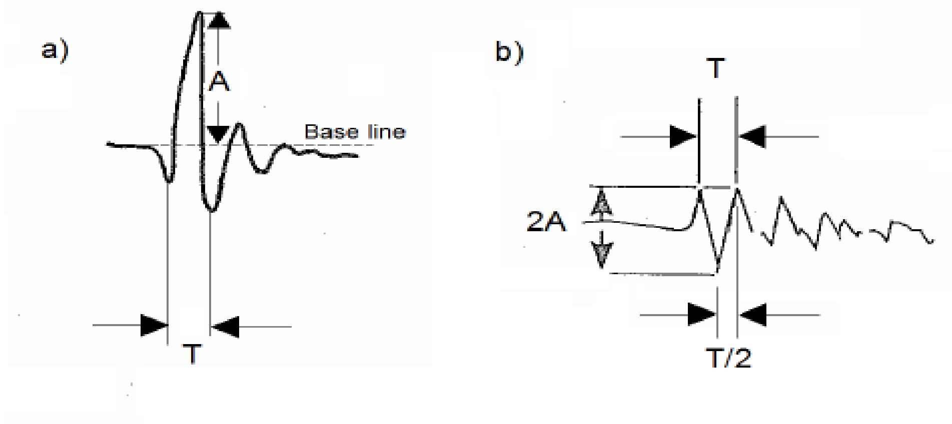


Figure 2. 13. Reading amplitudes. a) Reading the amplitude A from the base line and the period T from two peaks b) Reading the amplitude peak to peak (2A) (Havskov & Ottemoller, 2008).

2.1.3 Intensity of Earthquakes

Another way to measure the strength of an earthquake is to use the Mercalli scale. Invented by Giuseppe Mercalli in 1902, this scale uses the observations of the people who experienced the earthquake to estimate its intensity. The Mercalli scale is not considered as scientific as the Richter scale, though. Some witnesses of the earthquake might exaggerate just how bad things were during the earthquake and one may not find two witnesses who agree on what happened; everybody will say something different. The amount of damage caused by the earthquake may not accurately record how strong it was either.

Although numerous intensity scales have been developed over the last several hundred years to evaluate the effects of earthquakes, the one currently used in the United States is the Modified Mercalli Intensity (MMI) Scale. It was developed in 1931 by the American seismologists Harry Wood and Frank Neumann. This scale, composed of 12 increasing levels of intensity that range from imperceptible shaking to catastrophic destruction, is designated by Roman numerals. It does not have a mathematical basis; instead it is an arbitrary ranking based on observed effects.

The MMI value assigned to a specific site after an earthquake has a more meaningful measure of severity to the nonscientist than the magnitude because intensity refers to the effects actually experienced at that place. The maximum observed intensity generally occurs near the epicenter (Figure 2.14). The lower numbers of the intensity scale generally deal with the manner in which the earthquake is felt by people. The higher numbers of the scale are based on observed structural damage.

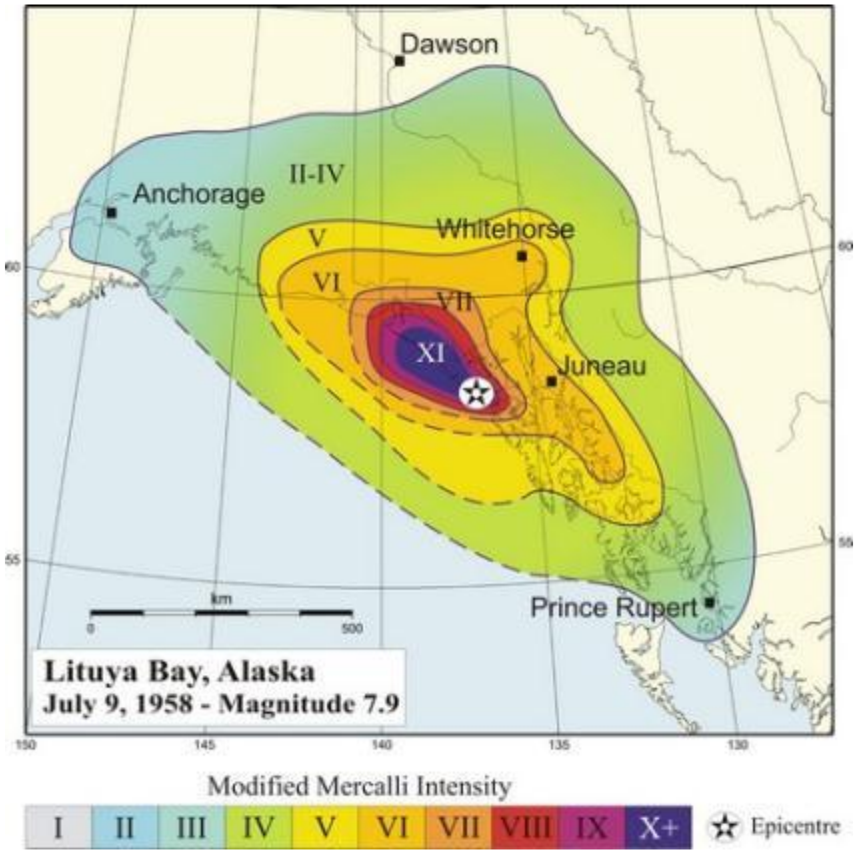


Figure 2. 14. Isoseismal map showing the distribution of Modified Mercalli intensities for the 1958 Lituya Bay, Alaska earthquake M7.9 (http://www.usgs.gov/).

The first main earthquake hazard (danger) is the effect of ground shaking. Buildings can be damaged by the shaking itself or by the ground beneath them settling to a different level than it was before the earthquake (subsidence). The second main earthquake hazard is ground displacement (ground movement) along a fault. The third main hazard is flooding as an earthquake can rupture (break) dams or levees along a river. The fourth main earthquake hazard is fire. However most of the hazards to people come from man-made structures themselves and the shaking they receive from the earthquake. The real dangers to people are being crushed in a collapsing building, drowning in a flood caused by a broken dam or levee, getting buried under a landslide, or being burned in a fire.

2.1.4 The Gutenberg-Richter Recurrence Law

In order to analyze seismic hazard of an areas, it is necessary to evaluate the frequencies of earthquakes that occur in that specific area, this can be calculated from the Gutenberg-Richter Recurrence Law (Gutenberg & Richter, 1944), which is the study of the numbers of the opportunity of earthquakes with different magnitudes occurrences within the specific area. The resulting Gutenberg-Richter law for earthquake recurrence was expressed as

$$\log \lambda_m = a - bm \qquad (2.5)$$

where λ_m is the mean annual rate of exceedance of magnitude m,
10^a is the mean yearly number of earthquakes of magnitude greater than or equal to zero,
b (the *b* value) describes the relative likelihood of large and small earthquakes.

The Gutenberg-Richter law is illustrated schematically in Figure 2.15a. As the *b* value increases, the number of larger magnitude earthquakes decrease compared to those of smaller magnitudes. The Gutenberg-Richter law is not restricted to the use of magnitude as a descriptor of earthquake size; epicentral intensity has also been used. Worldwide recurrence data are shown in Figure 2.15b.

The Gutenberg-Richter law described a pattern in the seismic data that related the number of earthquakes in a given area (or around the entire world) over a fixed period of time to the magnitude of those earthquakes. As it turns out, when Gutenberg-Richter plots are made for various data sets all over the world, most end up having a *b* value very close to 1, usually slightly less. This basic relation seems to be a universal property of seismicity.

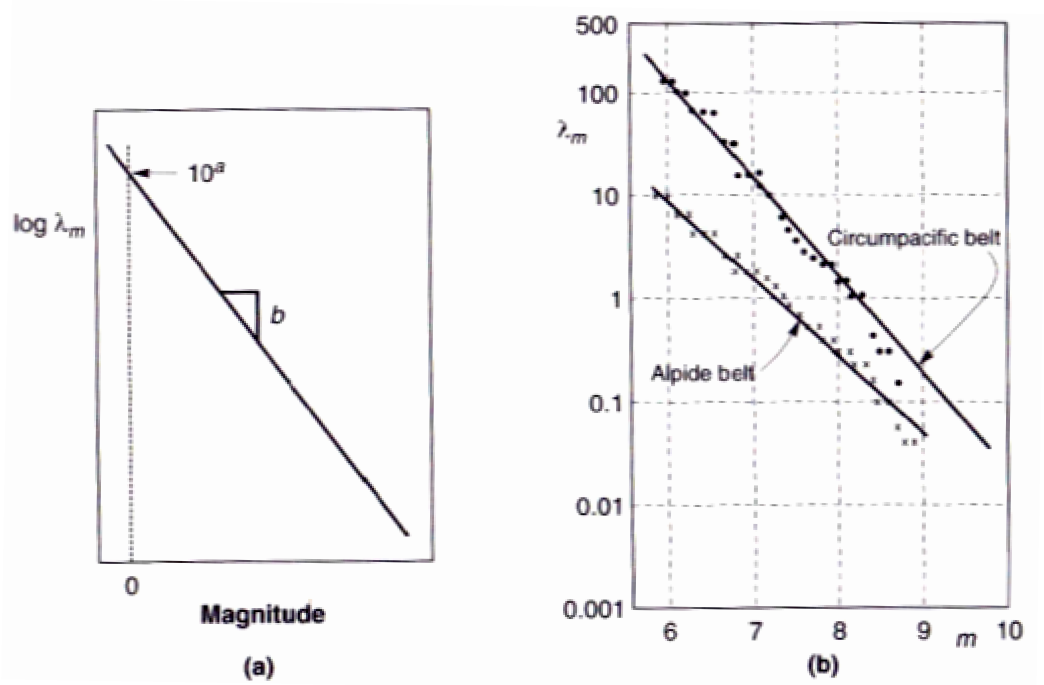


Figure 2. 15. (a) Gutenberg-Richter recurrence law, showing meaning of a and b parameters; and (b) application of Gutenberg-Richter law to worldwide seismicity data (Esteva, 1970).

2.1.5 Acceleration of Ground Shaking

(Bolt, 1999) described ground acceleration as another measure of size of earthquakes. The notion of acceleration is of key importance when trying to measure any type of varying motion such as strong ground shaking. The strong-motion seismographs have been specially designed to record the high-amplitude shaking of the ground. The records obtained can be directly read as acceleration, velocity, or displacement of the ground. Strong-motion seismographs are designed to record the strongest shaking and thus tell us about the felt and damaging motion near the source of the shaking. It is useful to scale acceleration against a value with which everyone is familiar. The magnitude of accelerations when stated in physical terms often expressed as a centimeter per second per second, or cm/sec^2. This base reference is the acceleration due to gravity; that is, the acceleration with which a ball falls if released at rest in vacuum (to eliminate wind resistance), and will call this acceleration 1.0g. Although acceleration of seismic motion is important, a full understanding of vibratory effects also requires an understanding of the velocity and displacement of the ground and such wave properties as frequency. In earthquakes, the values of ground acceleration, velocity, and displacement vary a great deal, depending on the frequency of the wave motion. High-frequency waves (higher frequencies than 10 hertz) tend to have high amplitudes of acceleration but small amplitudes of displacement, compared with long-period waves, which have small accelerations and relatively large velocities and displacement. Although peak or maximum, acceleration values are important, another point to recognize is that the damage to structures may be occurring throughout the entire period of strong ground shaking. Indeed, the overall damage may be more closely correlated to the total duration of the strong motion than to any particular peak on the record. For this reason, the second parameter of importance in acceleration records is the duration of strong shaking. A useful measure of duration is called the bracketed duration. This is the duration of shaking above certain threshold acceleration value, commonly taken to be 0.05g (Bolt, 1969) and is defined as the time between the first and last peaks of motion that exceed this threshold value. Studies indicate that damage is often attributable to the speed of the back-and-forth motion of the foundation rather than to its peak acceleration. Consequently, in general, the higher the seismic intensity, the higher the average velocity of the shaking. Nevertheless, the mean accelerations have much bearing on the forces affecting a structure (Table 2.1).

(Bolt, 1969) proposed bracketed duration, the duration at a particular frequency is the elapse time between the first and last acceleration excursion greater than a given level (0.05g). Due to duration of strong seismic shaking is a sensitive function of wave frequency, amplitude threshold, and Richter magnitude. The magnitude dependence arises from the finite geometry of fault rupture. Frequency dependence enters through the exponential attenuation law for rock; for larger earthquakes (greater fault breakage), duration of higher frequency (>1 Hz) horizontal wave with amplitudes above 0.05g ground acceleration is unlikely to exceed 35 to 40 sec. Lack of precise definition has led to exaggerated estimates of duration for some

Table 2.1. Abridged Modified Mercalli Intensity Scale. Note: The mean maximum acceleration and velocity values for the wave motion are for firm ground but vary greatly depending on type of earthquake source. (Bolt, 1999).

Average peak velocity (centimeter per second)	Intensity value and description	Average peak acceleration (g is gravity = 9.80 meter per second squared)
	I. Not felt except by a very few under especially favorable circumstances. (I Rossi-Forel scale)	
	II. Felt by only a few persons at rest, especially on upper floors of buildings; delicately suspended object may swing. (I to II Rossi-Forel scale)	
	III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake; standing motor cars may rock slightly; vibrations like passing of a truck; duration estimated. (III Rossi-Forel scale)	
1 - 2	**IV.** During the day felt indoors by many, outdoors by few; at night some awakened; dishes, windows, doors disturbed; walls make cracking sound; sensation like heavy truck striking building; standing motor cars rocked noticeably. (IV to V Rossi-Forel scale)	0.015g - 0.02g
2 - 5	**V.** Felt by nearly everyone, many awakened; some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned; disturbances of trees, piles, and other tall objects sometimes noticed; pendulum clocks may stop. (V to VI Rossi-Forel scale)	0.03g - 0.04g
5 - 8	**VI.** Felt by all, many frightened and run outdoors; some heavy furniture moved; a few instances of fallen plaster or damaged chimneys; damage slight. (VI to VII Rossi-Forel scale)	0.06g - 0.07g
8 - 12	**VII.** Everybody runs outdoors; 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; noticed by persons driving motor cars. (VIII Rossi-Forel scale)	0.10g - 0.15g
20 - 30	**VIII.** Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse, great in poorly built structures; panel walls thrown out of frame structures; fall of chimneys, factory stacks, columns, monuments, walls; heavy furniture overturned; sand and mud ejected in small amount; changes in well water; person driving motor car disturbed. (VIII+ to IX Rossi-Forel scale)	0.25g - 0.30g
45 - 55	**IX.** Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial building, with partial collapse; buildings shifted off foundations; ground cracked conspicuously; underground pipes broken. (IX+ Rossi-	0.5g - 0.55g
More than 60	**X.** Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked; rails bent; landslides considerable from river banks and steep slopes; shifted sand and mud; water splashed over banks. (X Rossi-	More than 0.60g
	XI. Few, if any (masonry) structures remain standing; bridges destroyed; broad fissures in ground; underground pipelines completely out of service; earth slumps and land slips in soft ground; rails bent greatly.	
	XII. Damage total; practically all works of construction are damaged greatly or destroyed; waves seen on ground surface; lines of sight and level are distorted; objects thrown into the air.	

design purposes. Filtered records of ground acceleration yield a table for “bracketed duration” as a function of magnitude and source-to-site distance.

(Kramer, 1996) stated that the dynamic response of compliant objects, be they buildings, bridge, slopes, or soil deposits, is very sensitive to the frequency at which they are loaded. Earthquakes produce complicated loading with components of motion that span a board range of frequencies. The frequency content describes how the amplitude of ground motion is distributed among different frequencies. Since the frequency content of an earthquake motion will strongly influence the effects of that motion, characterization of the motion cannot be complete without consideration of its frequency content. The frequency content of a ground motion can also be described by a power spectrum or power spectral density function. The power spectral density function can also be used to estimate the statistical properties of a ground motion and to compute stochastic response using random vibration techniques (Clough & Penzien, 1975; Vermarcke, 1976; Yang, 1986); Power spectral density (PSD) function shows the strength of the variations (energy) as a function of frequency. In other words, it shows at which frequencies variations are strong and at which frequencies variations are weak.

2.2 Earthquakes Study in Northern Thailand and Other Areas

Earthquake in Northern Thailand have been recognized for long time since the past historical period until present day but these earthquakes are just small to moderate levels. Although in this region great earthquakes have not been recorded, most of strong earthquakes have been reported frequently in Myanmar Andaman-Sumatra belt.

In an attempt to understand characteristics of earthquake ground motion of central northern Thailand in this research study, the results of related documents and papers from previous studies are necessary. They are listed below.

(Gutenberg & Ritchter, 1954) reported that there are two earthquake epicenters with M6 in Lao PDR, in December 22, 1925 and February 12, 1934.

(Bolt & Miller, 1971) studied seismicity of northern and central California during the period of 1965 to 1969. The results of this study found nine of the largest earthquakes with magnitudes 5-6.

(Nutalaya, Sodsri, & Arnold, 1985) studied the seismology of Thailand and structure framework of the Chao Phaya Basin and seismotectonic source zones are subsequently delineated. The seismic source zones in mainland Southeast Asia can be separated into twelve zones. Zones F and G on the west and the north are located within Thailand, respectively (Figure 2.16). The area of this study is situated in the zone G (Northern Thailand).

(Siribhakdi, 1986) studied seismogenic in Thailand and periphery and reported earthquakes in Thailand throughout her past 1,500 year history. Many of the earthquakes found have closed relation with four major faults including the Three Pagoda, the Si Sawat, the Moei-Uthai-Thani, and the Mae Hong Son-Mae Sariang Faults. He mentioned that the earthquakes in Thailand are associated with tectonism, interpreted to be related to subduction and spreading ridge in the Andaman Sea. Furthermore, the most seismicity area in Thailand is located in the west, and the present day seismicity might be related to the opening activities of Cenozoic basins.

(Hinthong, 1991) investigated the role of tectonic setting in earthquake events in Thailand. He reported that earthquakes in Thailand are closely related to two seismic source zones, Zone F of the Tenasserim Range and Zone G of the Northern Thailand (Nutalaya et al., 1985). The faults within zone F are interpreted to be more active than those of zone G which are inferred to be possibly potentially active faults.

(WCFS, 1996) estimated earthquake recurrence in northern Thailand (the project region of the KST dam site). The b-value of 0.92 ± 0.12 appears reasonable based on comparison with other estimates. The estimated recurrence for the project region suggests that M6 and grater earthquakes occur once every 56 years on average although the uncertainty in this return period is large.

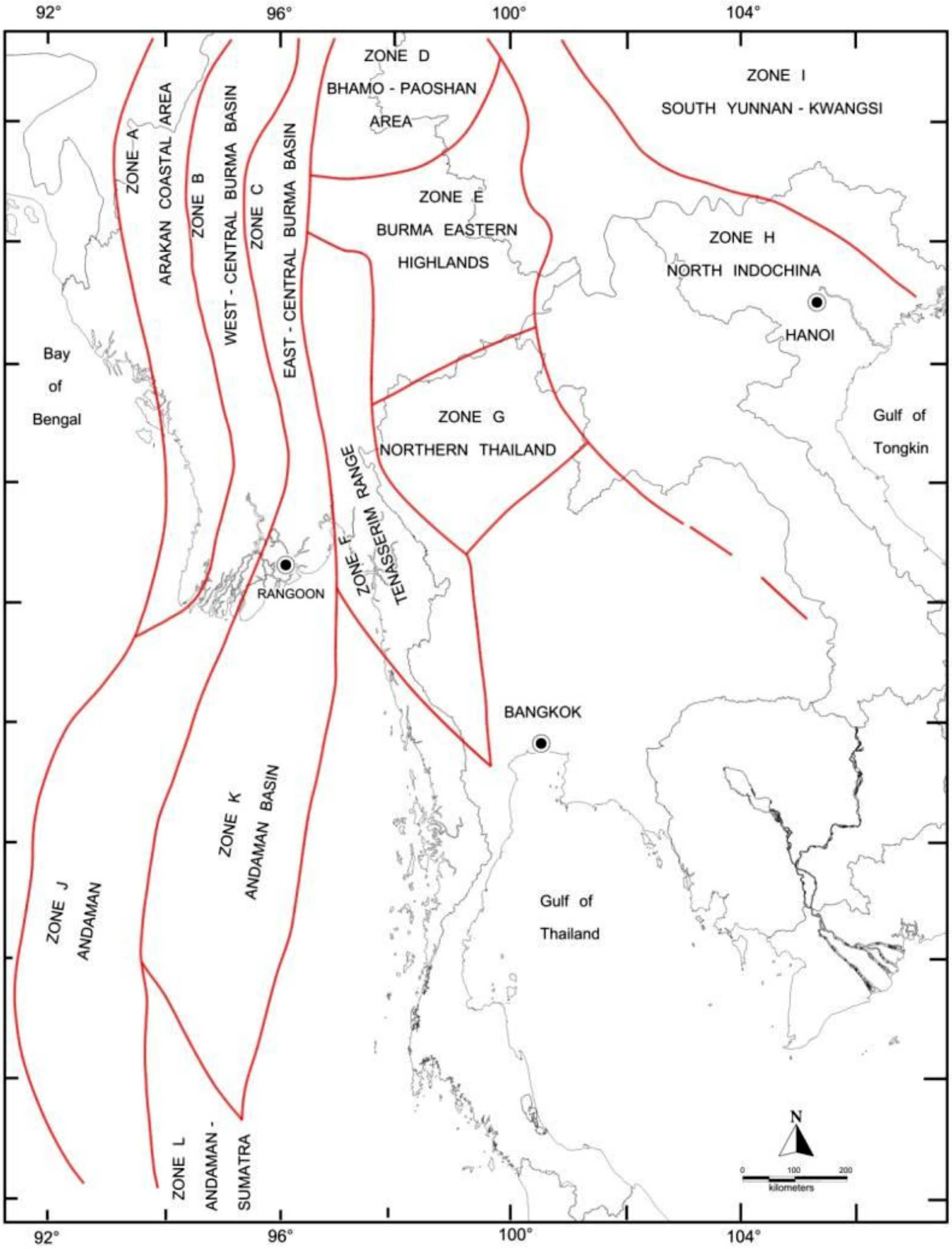


Figure 2. 16. Seismic source zones of Burma, Thailand and Indochina (Nutalaya et al., 1985). Noted that seismic source zones were recognized only in the Northern and western parts of Thailand.

(Charusiri, Daorerk, & Supajanya, 1996) applied several remote sensing techniques to study geological structures related to earthquakes in Thailand and neighboring countries. The results are useful in determining the seismic source zones to indicate the earthquake-prone areas and proposed a new seismotectonic (or seismic-source) map.

(Hinthong, 1997) studied the project entitled "Study of Active Faults in Thailand". According to various authors, three approaches to define active faults can be distinguished and applied, as general definition, engineering definition, and regulatory definition. Those three applications of definitions were discussed, based primarily on its original definition which was proposed in the context of a two-fold classification of dead and alive or active faults, and with respect to their potential for recurrence of displacement or offset. Based upon available data, and with the exclusion of the tentatively inactive and inactive classification, fault activity can be classified as three classes namely, active, potentially active, and tentatively active. Basically, there are three major criteria for recognition of active faults viz, geologic, historic, and seismologic criteria (Figure 2.17).

(Bott et al., 1997) mentioned that northern Thailand is similar to the Basin and Range province in the western United States of America in term of earthquake processes and tectonics. In northern Thailand, seismicity is diffusely distributed, of low to moderate levels, is generally not associated with known faults with surficial expression, and is probably confined to the upper 15 to 20 km of the crust, similar to the Basin and Range province. However, the largest known earthquake in the north has not exceeded magnitude 6.5Ml compared to the Basin and Range province in which record on paleoseismic investigation indicated maximum capable earthquake is about magnitude 6.75Mw and greater. The result based on focal mechanisms reveals that both regions have been formed by undergoing E-W extension resulting in active normal and oblique-slip faulting (Figure 2.18).

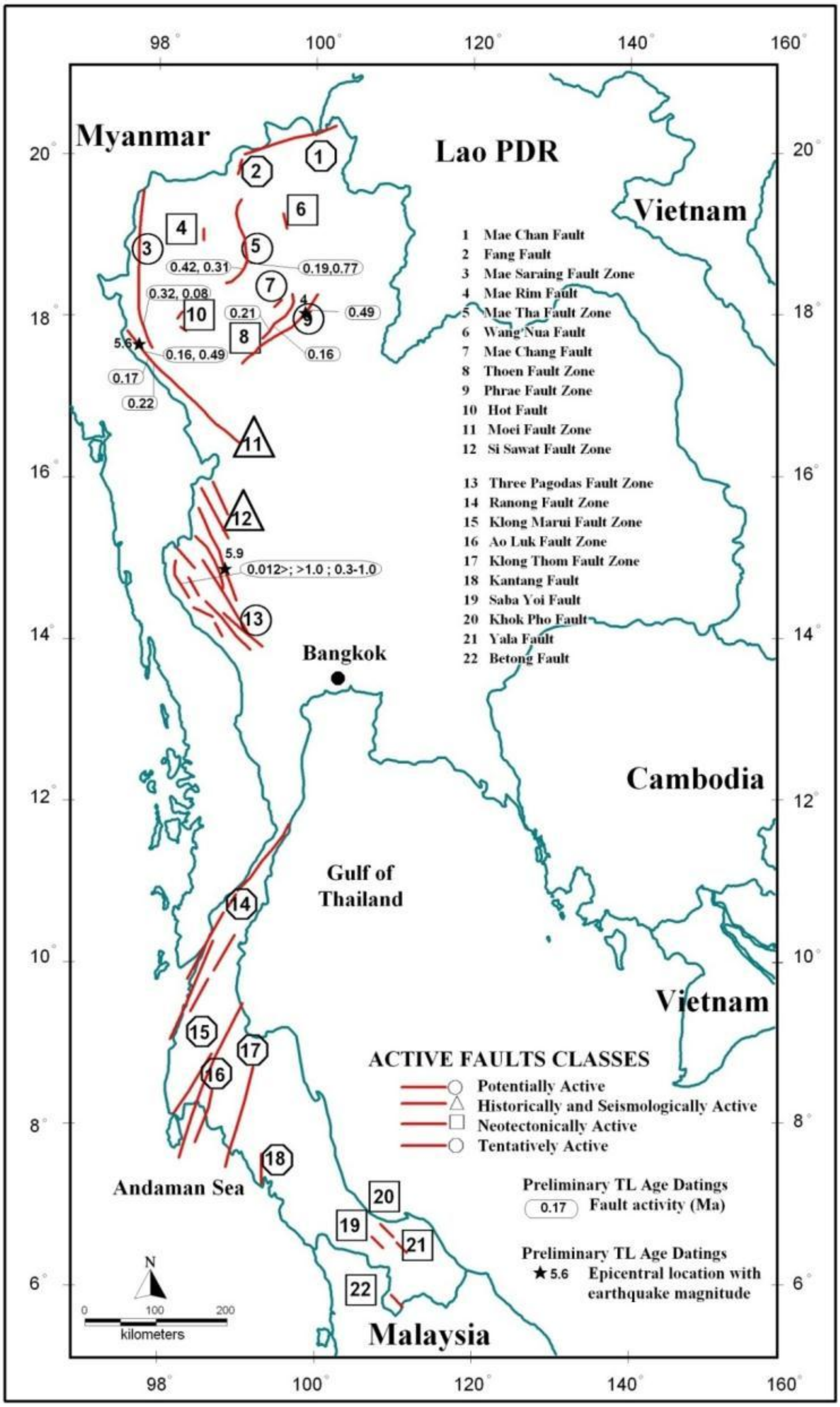


Figure 2. 17. Map showing active and suspected active faults in Thailand (Hinthong, 1997).

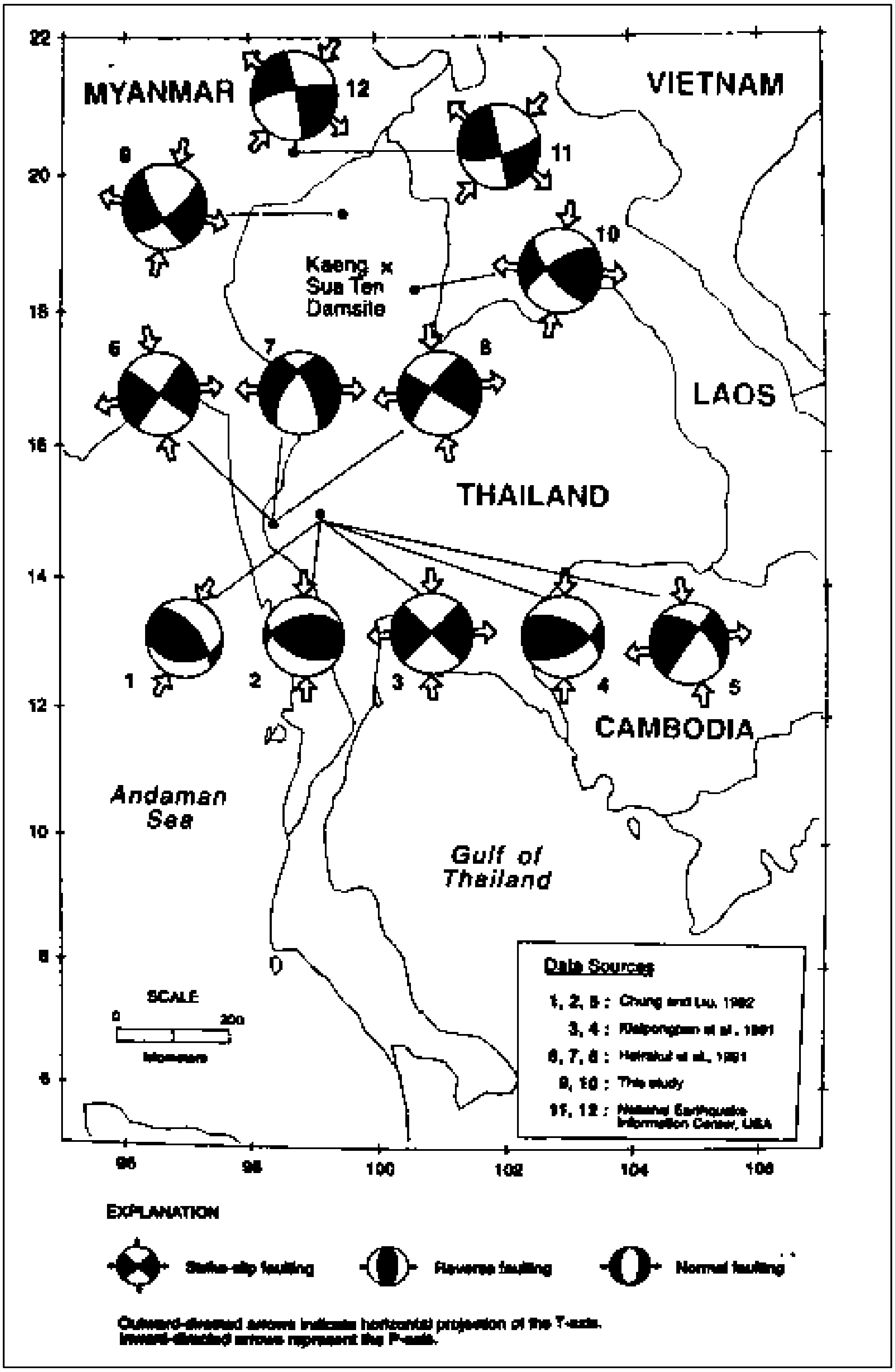


Figure 2. 18. Schematic focal mechanisms of Thailand and adjacent regions (Bott et al., 1997).

(C.H. Fenton, Charusiri, Hinthong, Lumjuan, & Mangkonkarn, 1997) studied on late Quaternary faulting in northern Thailand. Several tectonic geomorphological features, which indicate recent movements, had been observed along seven faults. These faults are the Phrae, the Phrae basin, the Long, the Nam Pat and the Phayao faults. The recurrence intervals of these faults range from thousand to tens of thousands years. These faults are capable to generate earthquakes equal or greater than magnitude 7Mw.

(Hongjatsee, 1999) investigated the major faults and seismic hazard in northern Thailand. Based on tectonic morphology of faults, such as stream offsets, triangular facets, and canyon shapes, the high slip rates of the Mae Chan and Wang Nua faults are given as 0.1-3.7 and 0.8-3.5 mm/yr, respectively. The Thoen and Phrae faults were assigned a low slip rates, in the range of about 0.01-0.1 mm/yr.

(Kosuwan, Saithong, A., Takashima, & Charusiri, 1999) applied remote-sensing, field investigation, dating data to evaluate paleoseismology of the Mae Chan Fault in the northern most part of Thailand. Based on dating result, fault movements gave rise to earthquake of about 92,000, 67,000, 48,000, 25,000 and 1,600 years in age. The 1,600 years ago event probably caused a characteristic earthquake with a magnitude greater than magnitude7Mw.

(Charusiri et al., 2001) published the map of seismically active belts (SAB) including active fault zones in Thailand. They classified the fault zone into 3 groups based mainly on the plenty TL dates of fault activities; active, potentially active, and tentatively active. Three new fault zones were proposed in this map; The Pua and Payao Faults in the north and the Tha Kheak Fault in the northeast. Note that, the Mae Hong Son Fault Zone in this map and the Mae Sariang Fault Zone proposed previously is identical.

(Rhodes, Perez, Lamjuan, & Kosuwan, 2002) studied kinematics of the Mae Kuang Fault and evidences from satellite images and aerial photographs. They suggested that the Mae Kuang fault accommodates the transfer of extension between Chiang Mai basin and Wiang
Pa Pao basin which is sinistral offset between 400 and 700 m and the slip rate must be between 0.175 and 0.7 mm/yr.

(Udchachon, 2002) investigated the neotectonics of the Phrae basin with integration of data from remote-sensing interpretation, field investigation, seismic profiles, and focal mechanism data. He estimated that the southeastern segment of the Phrae fault system is a potentially active fault with maximum slip-rate of 0.06 mm/yr. This evidence is consistent with the study on contemporary stress axis orientation in this area which reveals a roughly east-west trend and north-south trend of extensional and compressional axes, respectively.

(C. H. Fenton, Charusiri, & Wood, 2003) conducted the investigation of recent paleoseismic and identified a number of active faults in Northern and Western Thailand. Mae Chan fault and the Three Pagodas fault zones are determined as strike-slip faults, with slip rates 0.1-0.3 mm/yr and damage earthquake of magnitude 7.5. In the northern part of Thailand, six major faults show sense of movements as slip-rates between 0.5-2.0 mm/yr in normal-oblique fault, and damage earthquake about magnitude 7 (Figure 2.19).

(Charusiri et al., 2006) studied paleoearthquake along Mae Yom Fault Zone from the evidences of remote-sensing interpretation, field investigation, and GPR profiles. The appearances of sharp lineaments are well observed and they indicate the oblique-left-lateral sense of movement. The slip-rate of fault movement is 0.14-0.8 mm/yr and paleoearthquake magnitude using surface rupture length is magnitude 6.3-6.7 Mw.

(Harnpattanapanich, 2006a, 2006b, 2006c) studied macroseismic of a) Nam Pat in Uttaradit earthquake on June 5, 2005 , and b) Lampang earthquake on June 29, 2005 and c) Mae Suai in Chiang Rai earthquake on December 7, 2005. The intensity (isoseismal line) with the most severe (meizoseismal area) is consistent with the orientation of the main structure and along faults in the study area (Figure 2.20).

(Khaowiset, 2007) studied neotectonics along the Pua Fault in Nan. Based on remote-sensing and thermoluminescence dating , the Pua Fault is north-south trending, oblique-slip fault with a total length of about 130 km. The slip rate of this fault segment is estimated as 0.3 mm/yr and maximum paleoearthquake of magnitude 6.79 Mw.

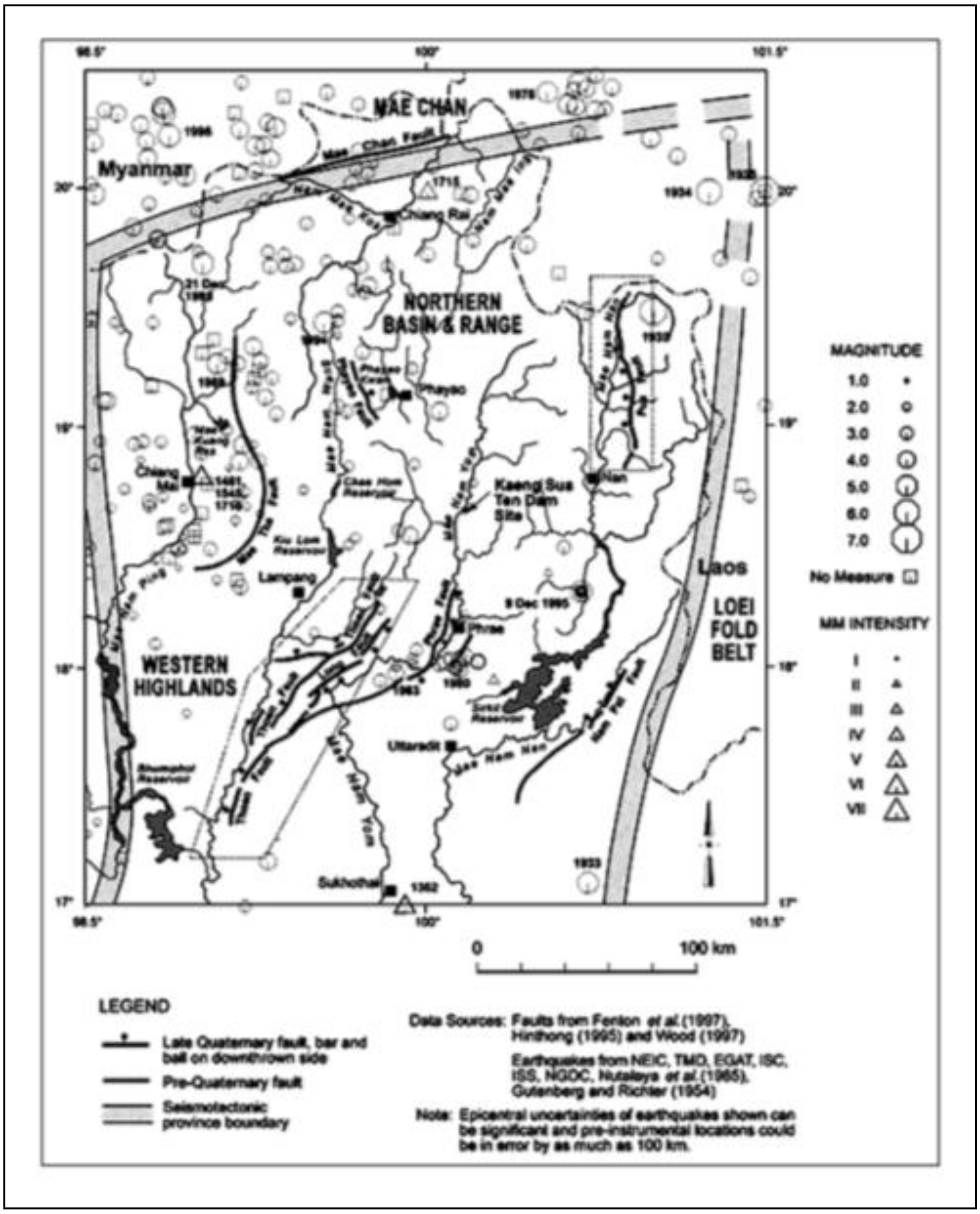


Figure 2. 19. Late Cenozoic faults and historical seismicity (1362 to 1996) of the Northern Basin and Range seismotectonic province. Figure modified from (Bott et al., 1997; C.H. Fenton et al., 1997).

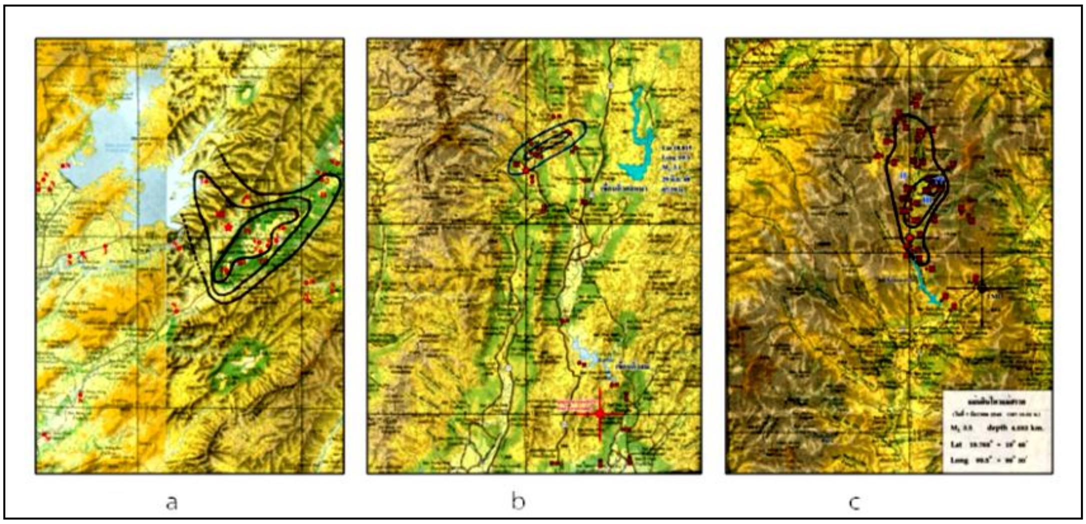


Figure 2. 20. Isoseismal Map of a) Nam Pat in Uttaradit earthquake on June 5, 2005, and b) Lampang earthquake on June 29, 2005, and c) Mae Suai in Chiang Rai earthquake on December 7, 2005 (Harnpattanapanich, 2006a, 2006b, 2006c).

(Khamkom, 2014) studied peak ground acceleration, peak ground velocity, duration of motion, and frequency content of main shock with magnitude 6.3 and aftershocks with magnitude 5-6 and magnitude 4-5 for the purpose to describe the characteristics of strong ground motion and to evaluate the seismic hazard of the Mae Suai dam by using more than one ground motion parameters since using of only peak ground acceleration is unable to describe clearly. The peak ground acceleration at the Mae Suai dam site of main shock with magnitude 6.3 on May 5, 2014 is 0.33 g in the East-West component which is the highest value from the instrumental data that have been recorded in Thailand. The earthquakes that affected the Mae Suai dam based on the PGA and bracketed duration (usually 0.05g) were earthquakes with magnitudes about 3.8 and greater.

CHAPTER III

INTERPRETING SEISMOGRAMS

In this step all of seismograms which were collected from the KST seismographic network was screening, and classifying for only the completed one that will be used in re-locating process and epicenter determination in the next step.

3.1 The KST Seismographic Network

The KST seismographic network of the RID was established with the objective for studying, observing, and recording local earthquakes, and the earthquakes that may occur from reservoir triggered seismicity (RTS) in the area of 150 km from the KST dam which is a construction project for enclosing the Mae Yom River around latitude 18.646N and longitude 100.168E with the location far from Phrae to the North about 50 km. The KST seismographic network comprised of the followings;

3.1.1 Seismograph Stations

3.1.1.1 The MYOA and the MYOM Stations

The MYOA and the MYOM stations were located in the area of Mae Yom National Park in Amphoe Song, Phrae and on the left side of the Mae Yom River which far from the proposed KST dam site about 3.5 km, between latitude 18.62N and longitude 100.16E at the elevation +200 m (MSL).

3.1.1.2 The KAEW Station

The KAEW station was located in the north of the proposed KST dam site in the area of Doi Kiew Kaew, Amphoe Chun in Pa-Yao between latitude 19.40N and longitude 100.10E, at the elevation +630 m (MSL).

3.1.1.3 The MONT Station

The MONT station was located in the west of the proposed KST dam site in the area of Mon Talai Non, Amphoe Ngao in Lumpang between latitude 18.70N and longitude 100.00E, at the elevation +370 m (MSL).

3.1.1.4 The HTUM Station

The HTUM station was located in the east of the proposed KST dam site in the area of Kao Huai Tum, Amphoe Baan Luang in Nan between latitude 18.87N and longitude 100.50E, at the elevation +750 m (MSL).

3.1.2 Types of Instruments

The instruments used at the KST seismographic network were manufactured by Kinemetrics.Inc in USA, which composed of 2 instruments; seismograph and accelerograph.

3.1.2.1 Seismograph

A seismograph, or seismometer, is an instrument used to detect and record earthquakes. Generally, it consists of a mass attached to a fixed base. During an earthquake, the base moves and the mass does not. The motion of the base with respect to the mass is commonly transformed into an electrical voltage. The electrical voltage is recorded on paper, magnetic tape, or another recording medium. This record is proportional to the motion of the seismometer mass relative to the earth, but it can be mathematically converted to a record of the absolute motion of the ground (http://earthquake.usgs.gov/learn/glossary).

The seismograph was designed to be set in the 4 seismic stations; the MYOM, the KAEW, the MONT, and the HTUM stations around the KST dam site and also covered the reservoir area of the KST dam (Figure 1.1). Each of the station will be set with 1 seismograph comprised of the K2 recorder and the SS-1 uniaxial short period sensor (Table 3.1), which can be set both vertically and horizontally, but for the KSTSN the seismographs will be set vertically to record the seismic data which are perpendicular to the Earth’s surface.

3.1.2.2 Accelerograph

An accelerograph is a seismograph whose output is proportion to ground acceleration (in comparison to the usual seismograph whose output is proportional to ground velocity). Accelerographs are typically used as instruments designed to record very strong ground motion useful in engineering design;

seismographs commonly record off scale in these circumstances. Normally, strong motion instruments do not record unless triggered by strong ground motion (Noson, Qamar, & Thorsen, 1988). The accelerograph was designed to be set at the MYOA station around the proposed KST dam site (Figure 1.1), which comprised of the ETNA recorder and the FBA-2g sensor (Table 3.1).

Table 3. 1 The information of the seismograph stations and types of instruments of this study.

Location	Station Name	Latitude (N)	Longitude (E)	Elevation (m, MSL)	Recording					Operation Date
					Type	Recorder Model	Serial No.	Sensor Model	Serial No.	
Mae Yom National Park Amphoe Song in Phrae	MYOA	18.63	100.16	200	Accelerograph Triaxial	ETNA	1474	FBA-2g	47336	1999-Present
	MYOM	18.62	100.16	200	Seismograph Uniaxial	K2	1141	SS-1 Velocity	3014	1999-Present
Doi Kiew Kaew Amphoe Chun in Phayao	KAEW	19.40	100.10	630	Seismograph Uniaxial	K2	1139	SS-1 Velocity	3013	1999-Present
Doi Mon Talai Non Amphoe Ngao in Lampang	MONT	18.70	100.00	370	Seismograph Uniaxial	K2	1138	SS-1 Velocity	3012	1999-Present
Khao Ban Huai Tum Amphoe Ban Luang in Nan	HTUM	18.87	100.50	750	Seismograph Uniaxial	K2	1140	SS-1 Velocity	2787	1999-Present

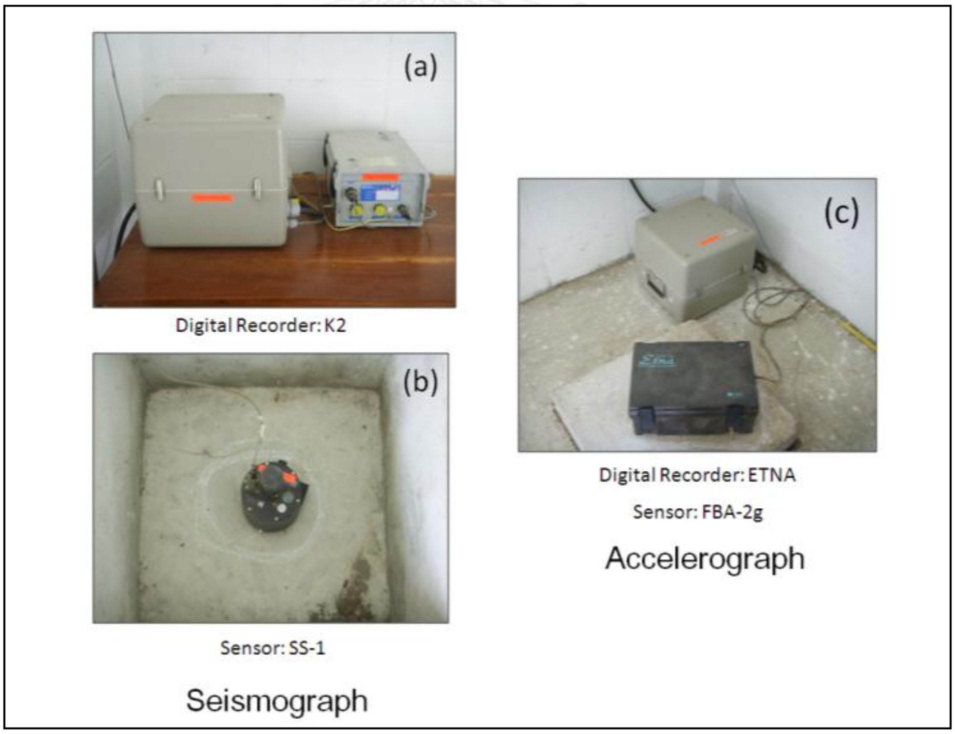


Figure 3. 1. The instruments types of the KST seismographic network.

3.2 Seismograms of the KST Network

The seismograms during the year 1999 to 2010 used in this study were collected from the KST seismographic network of the RID. There were 11,510 seismograms which can be categorized by stations; the HTUM for 901 seismograms, the KAEW for 697 seismograms, the MONT for 2,076 seismograms, the MYOM for 6,571 seismograms, and the MYOA for 1,265 seismograms (Figure 3.2). Typically, to collect seismograms (seismic data) of the KST network must go to collect the recorded data from seismograph stations in the field every month, by connecting the PC or laptop to the Kinematics Altus recorder via an RS 232 cable and using the KMI QuickTalk software to transfer files between the recorder and the PC (Figure 3.3).

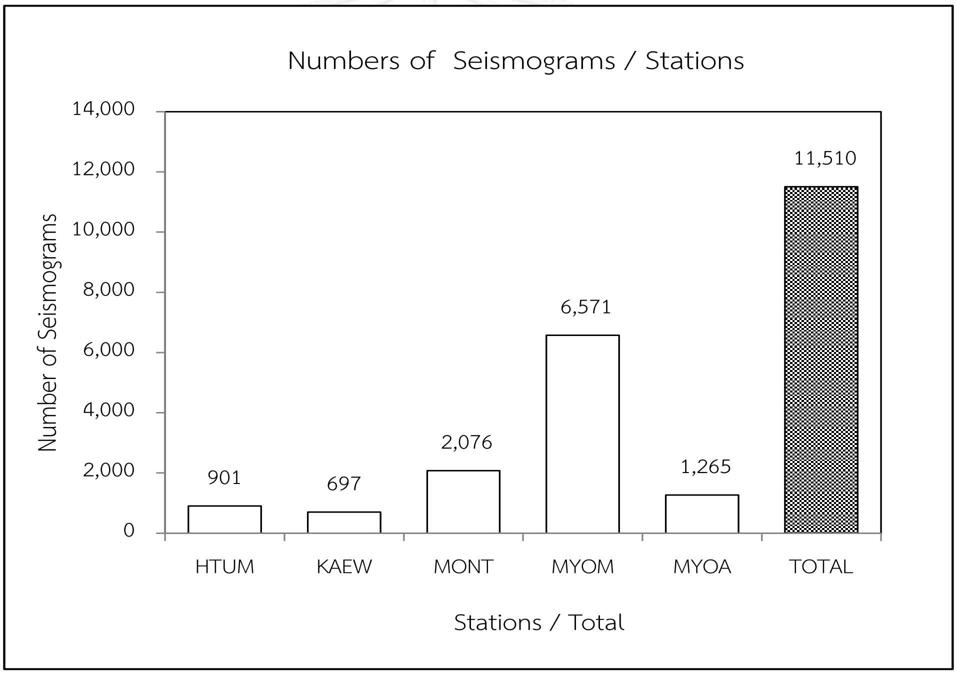
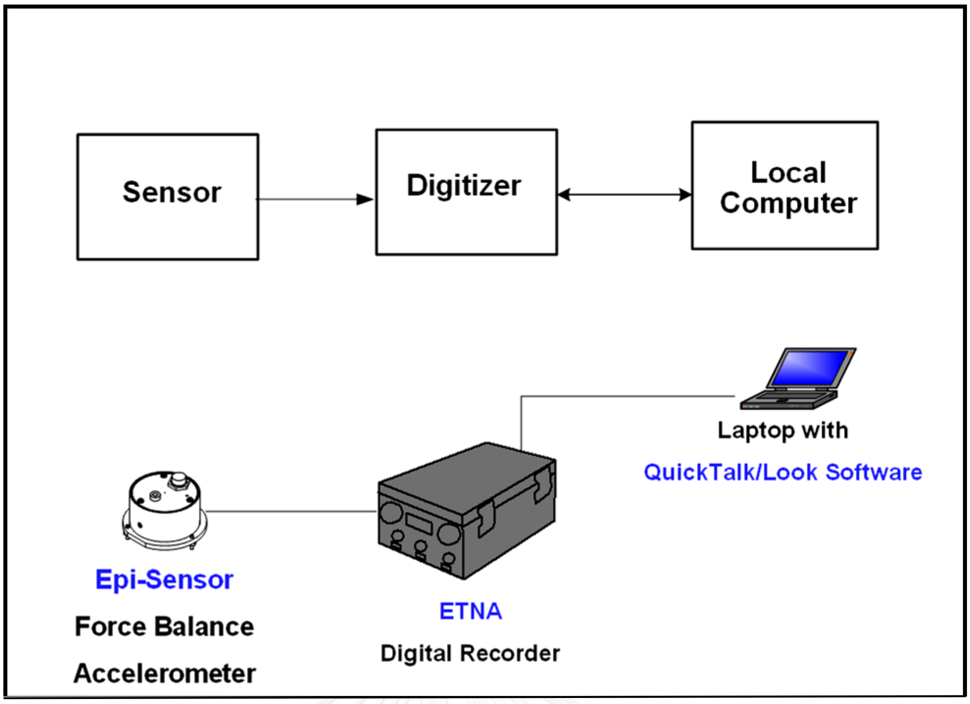
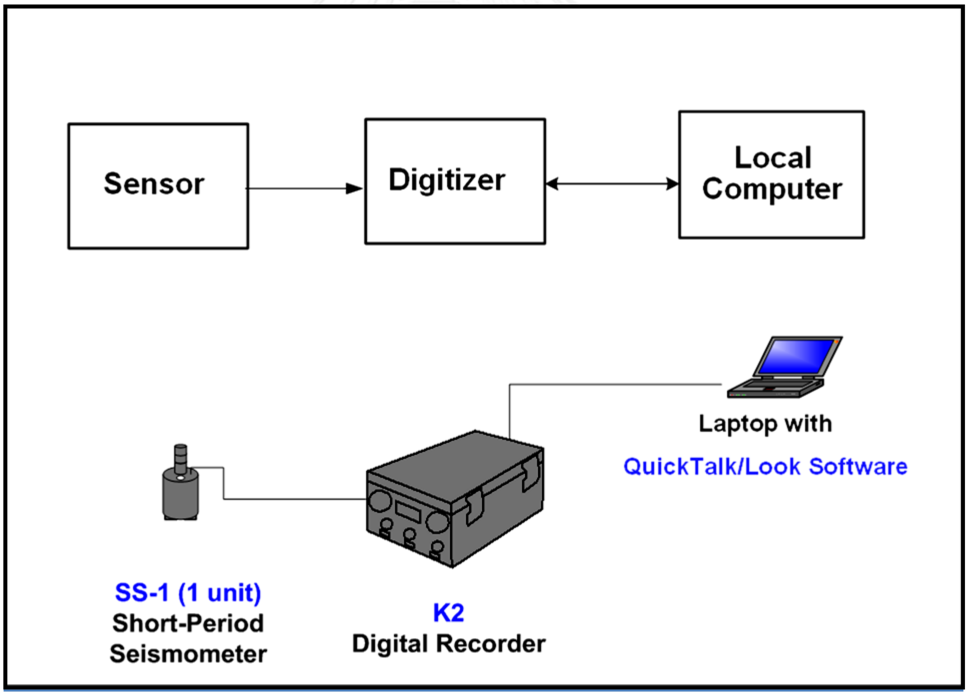


Figure 3. 2. The number of seismograms from each stations and the total number during the year 1999 to 2010 of this study.



(a)



(b)

Figure 3. 3. The method used to retrieve seismic data from (a) accelerometer of the MYOA station and (b) seismometer of the MYOM, the KAEW, the MONT and the HTUM stations of the KST seismographic network by using KMI QuickTalk/Look program.

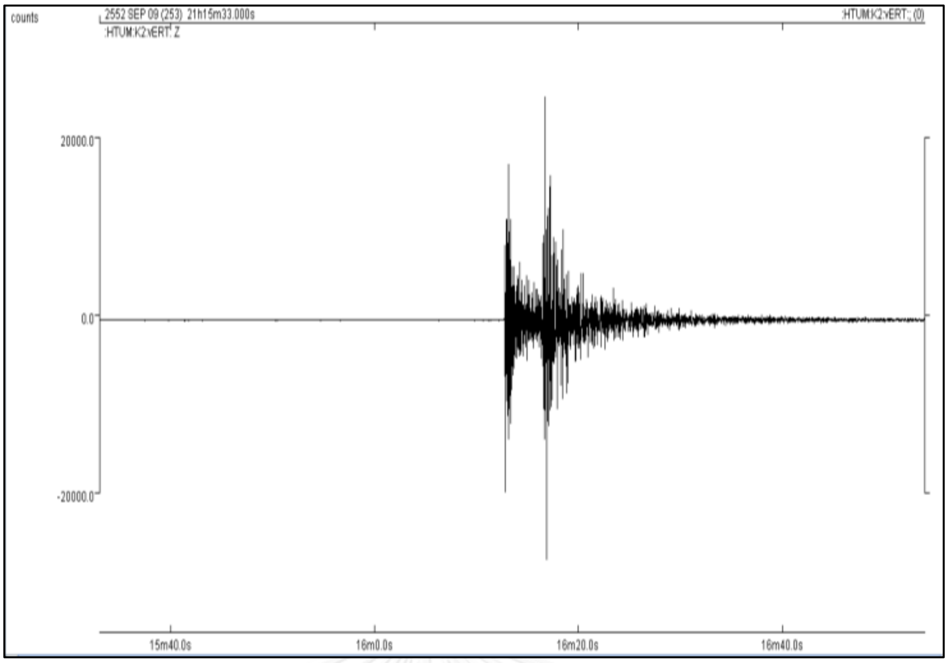
The data storage of recorded data is split into individual stations - year – month, to make it easier to analyze the data and prepare a report. In the first step, it is necessary to study the waveform (interpreting seismograms) of recoded data. The task was performed by using KMI QuickLook, and KMI Power Spectral Density program to separate natural earthquakes signal from noises signals based on the characteristics of typical frequencies from different seismic sources, and then to classify grade of natural earthquakes from the arrival time of P- and S-waves by using the criteria for considering from Table 3.2, and the natural earthquakes seismograms which used in locating epicenter and make a report of the KST network are the grade A1 only.

Table 3. 2 Description of seismograms and accelerograms and grade of data of this study.

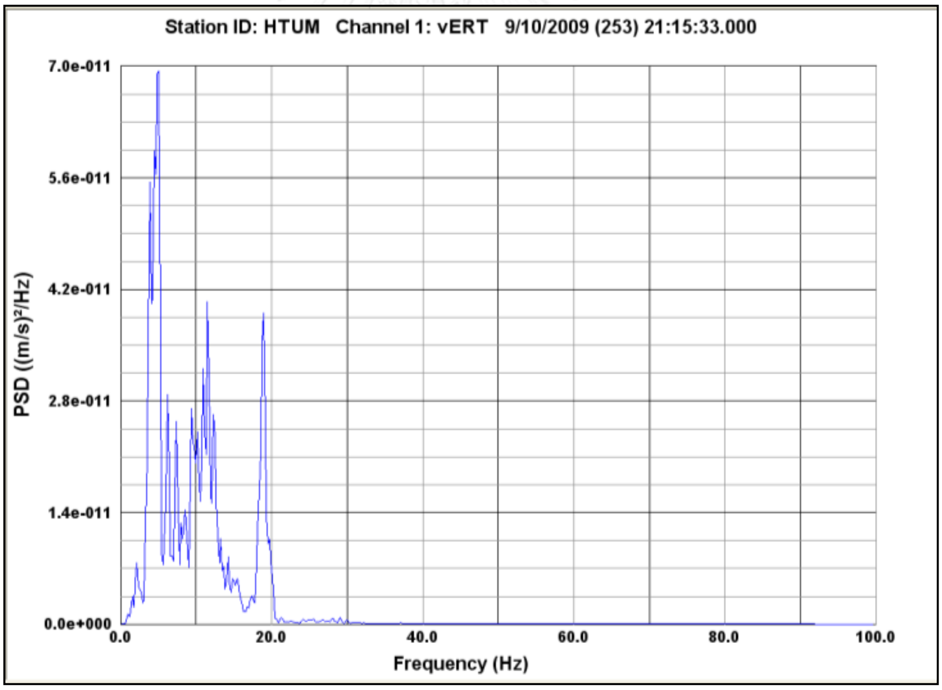
Grade/File No.	Description
A1	seismogram of 3 stations which can read the arrival time of primary and secondary wave, and used to
A2	seismogram of 3 stations which can read the arrival time of primary or secondary wave
B1	seismogram of 2 stations which can read the arrival time of primary and secondary wave
B2	seismogram of 2 stations which can read the arrival time of primary or secondary wave
C1	seismogram of 1 station which can read the arrival time of primary and secondary wave
C2	seismogram of 1 station which can read the arrival time of primary or secondary wave
SMA	accelerogram of strong ground-motion earthquakes
Red	seismogram of natural earthquakes which can read the arrival time of primary and secondary wave
Green	seismogram of natural earthquakes which can read the arrival time of primary or secondary wave
Blue	accelerogram of strong ground-motion earthquakes which used to calculate the peak ground acceleration
Black	seismogram and accelerogram of noise signal

(Bolt, 1999) stated that a seismogram appear to be no more than a complicated series of wavy lines, but from these lines a seismologist can determine the hypocenter location, magnitude, and source properties of an earthquake. Although experience is essential in interpreting seismograms, the first step in understanding the lines is to remember the following principles. First, earthquake waves consist predominantly of three types - P and S waves, which travel through the Earth, and a third type, surface waves, which travel around the Earth. Second, the arrival of seismic wave produces certain telltale changes on the seismogram trace. The trace is written more slowly or rapidly than just before; there is also an increase in amplitude; and the wave rhythm (frequency) changes. Third, from past experience with similar patterns, the reader of the seismogram can identify the pattern of arrivals of the various phases.

Due to signals that are commonly visible on seismographs may not be the one that caused by earthquakes or it may be caused by other seismic sources that is not an earthquake, such as explosions. These signals are often referred to as noise and come from many possible sources. Noise on the seismograph record can significantly affect the ability to detect or recognize an earthquake signal. The factors that affect the characteristics of the seismogram consist of earthquake epicenter to station distance, earthquake magnitude, earthquake depth, earthquake mechanism, propagation path, instrument response, noise level, seismograph sensitivity and gain, and site response. Earthquake seismograms can usually be recognized by fairly distinctive characteristics that result from the effects of the source, propagation path and seismograph response. Many of these distinctive characteristics are visible on the seismograms. With some experience, it is generally fairly easy to recognize earthquake or explosion seismic sources from background noise or other noise sources. The well-known noise sources are wind, trucks, machinery, walking, electronic, spikes, and dropout. Some example of interpreting natural earthquakes and noise signal with typical frequencies are shown in Figure 3.4-Figure 3.13.

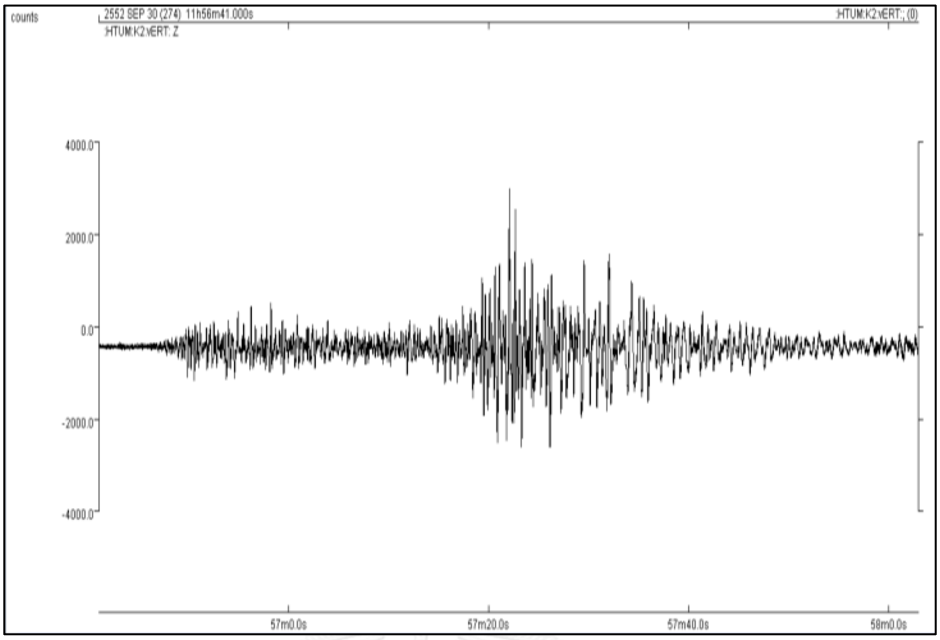


(a)



(b)

Figure 3. 4. (a) Seismogram of Amphoe Wiang Sa, Nan earthquake on September 10, 2009, M2.4, source-to-site HTUM 22.86 km, Azimuth 157.5433 degree (b) PSD and typical frequencies of seismic wave.



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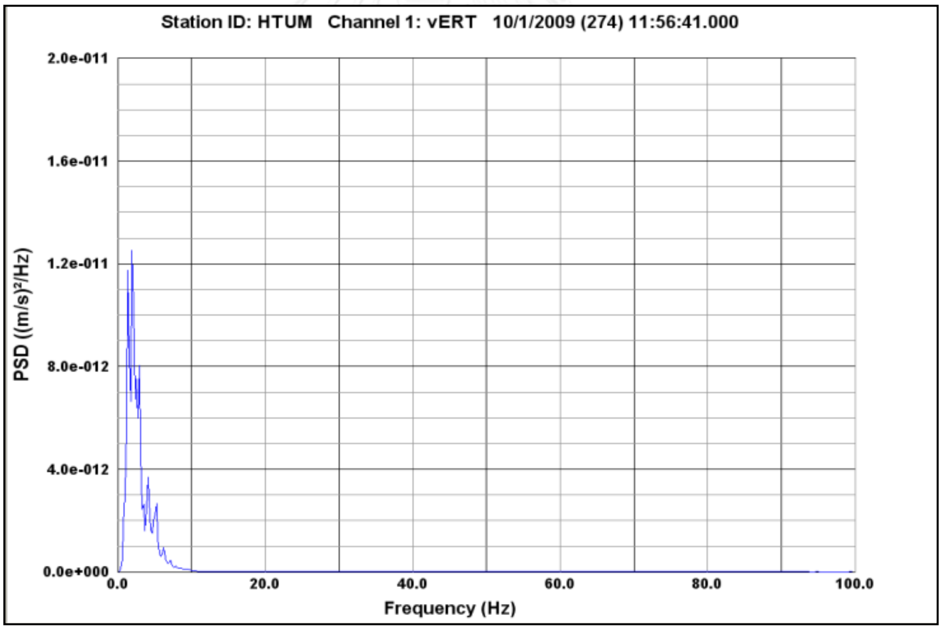
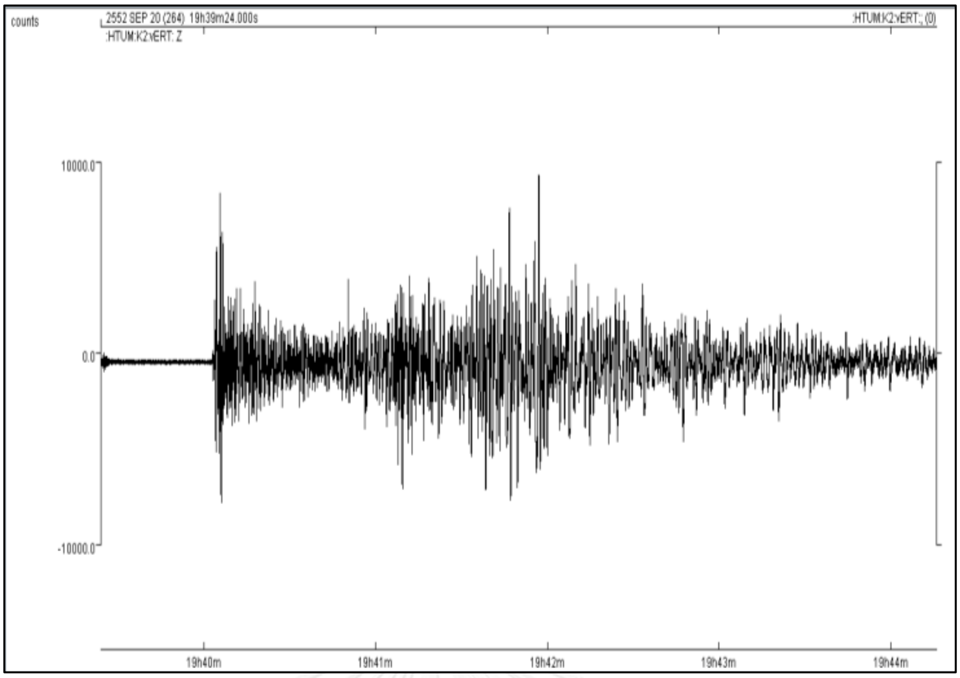
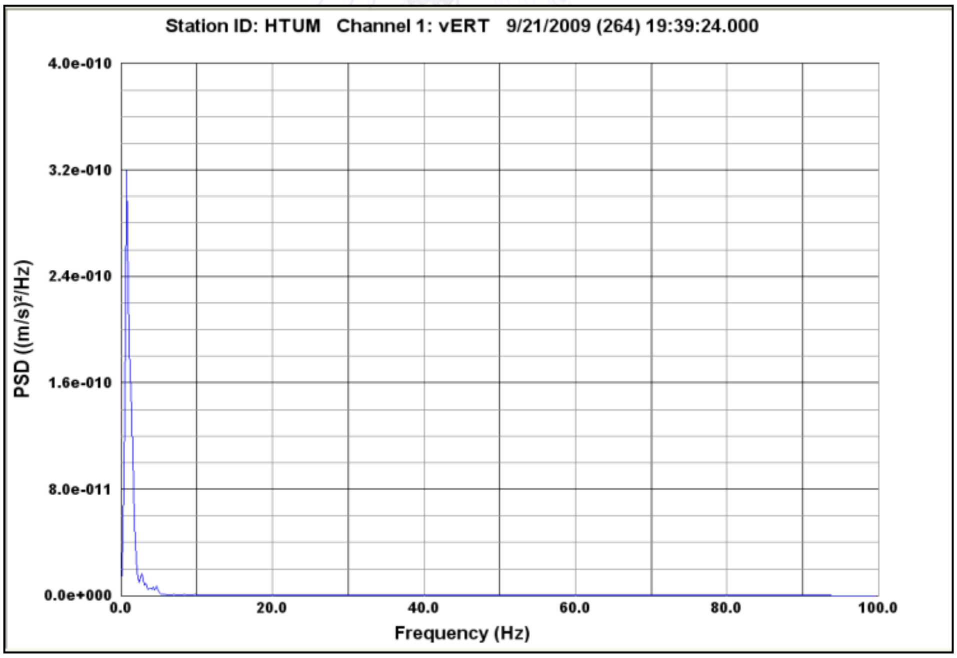


(b)

Figure 3. 5. (a) Seismogram of Laos earthquake on October 1, 2009, M3.7, source-to-site HTUM 255.3 km, Azimuth 127.7872 degree. (b) PSD and typical frequencies of seismic wave.

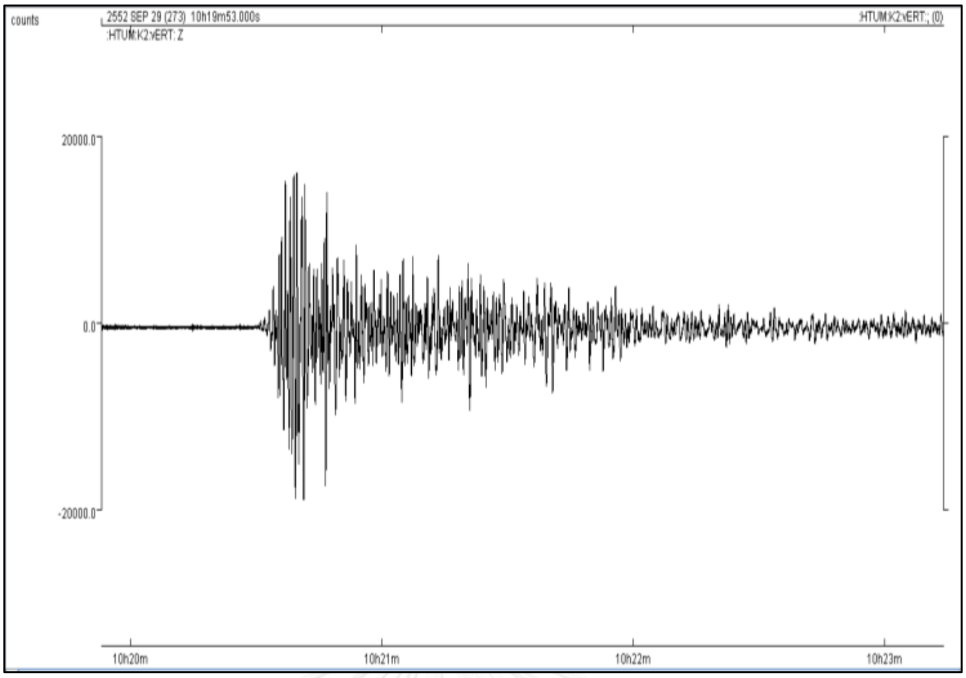


(a)

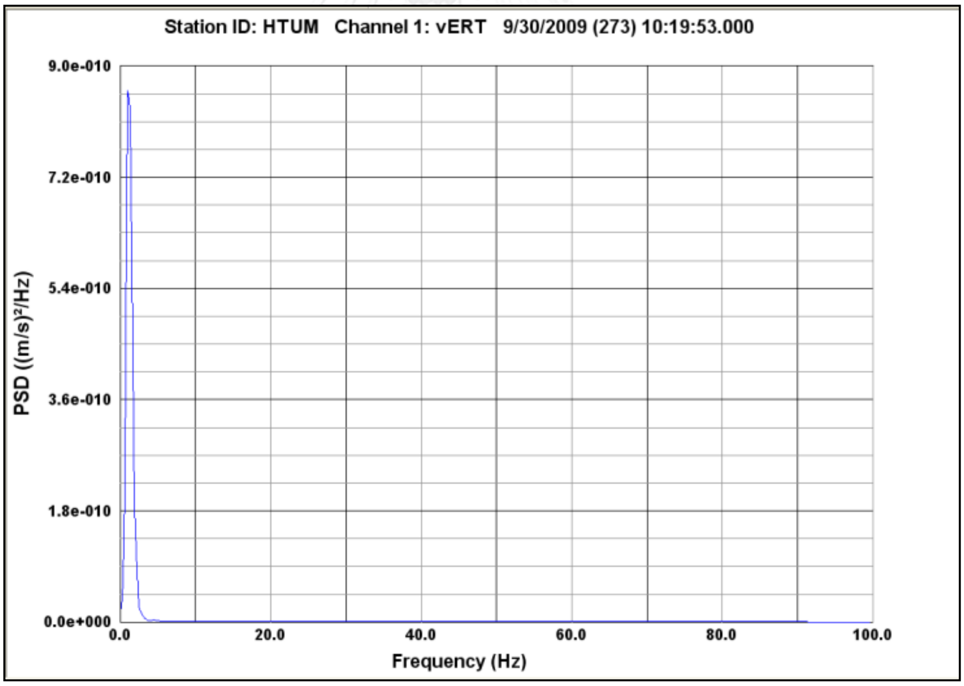


(b)

Figure 3. 6. (a) Seismogram of Myanmar earthquake on September 11, 2009, M5.7, source-to-site HTUM 291 km, Azimuth 277.8767 degree. (b) PSD and typical frequencies of seismic wave.

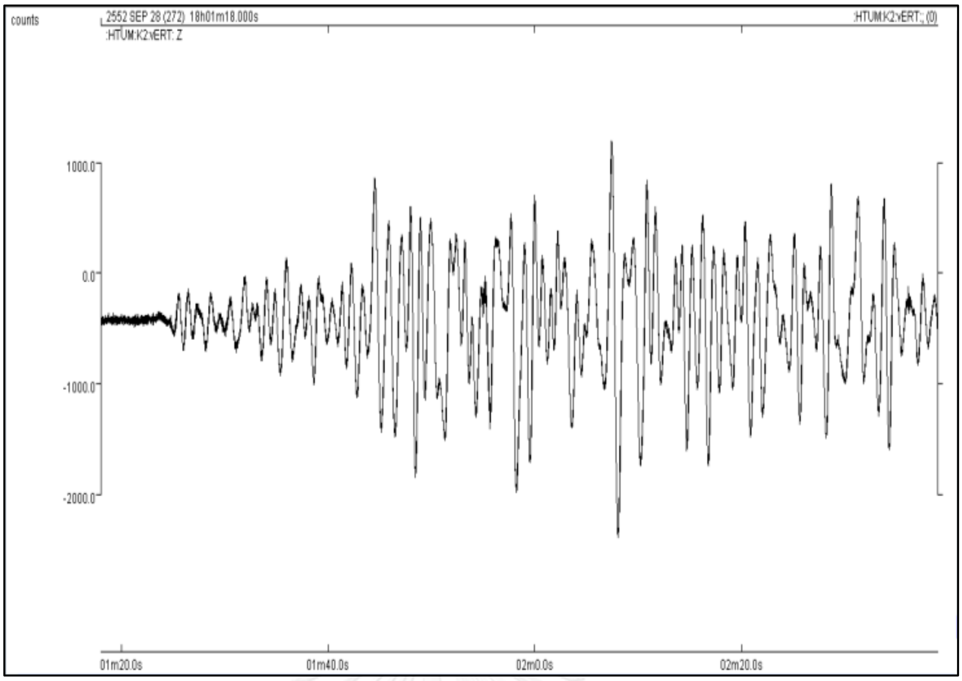


(a)

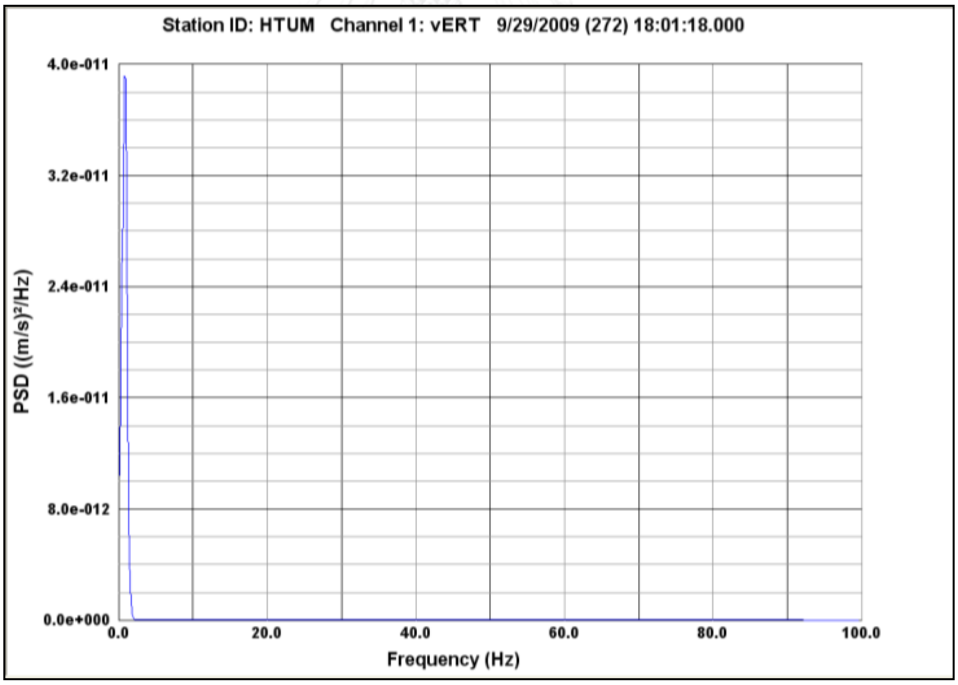


(b)

Figure 3. 7. (a) Seismogram of Southern Sumatra earthquake on September 30, 2009, M7.6, source-to-site HTUM 2,187 km, Azimuth 181.5158 degree. (b) PSD and typical frequencies of seismic wave.

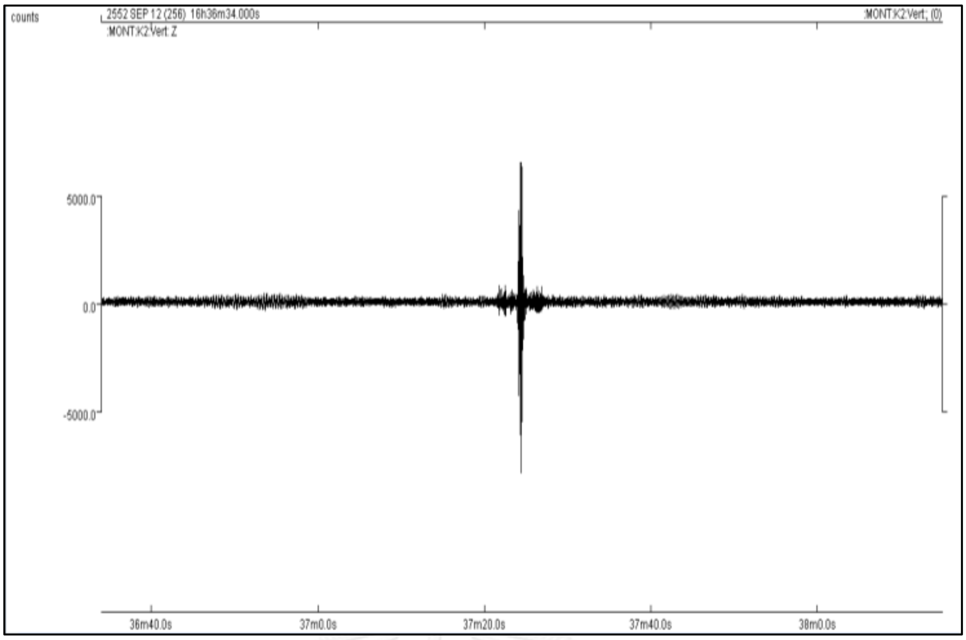


(a)



(b)

Figure 3. 8. (a) Seismogram of Samoa Islands earthquake on September 29, 2009, M8.0, source-to-site HTUM 10,300 km, Azimuth 108.8628 degree. (b) PSD and typical frequencies of seismic wave.



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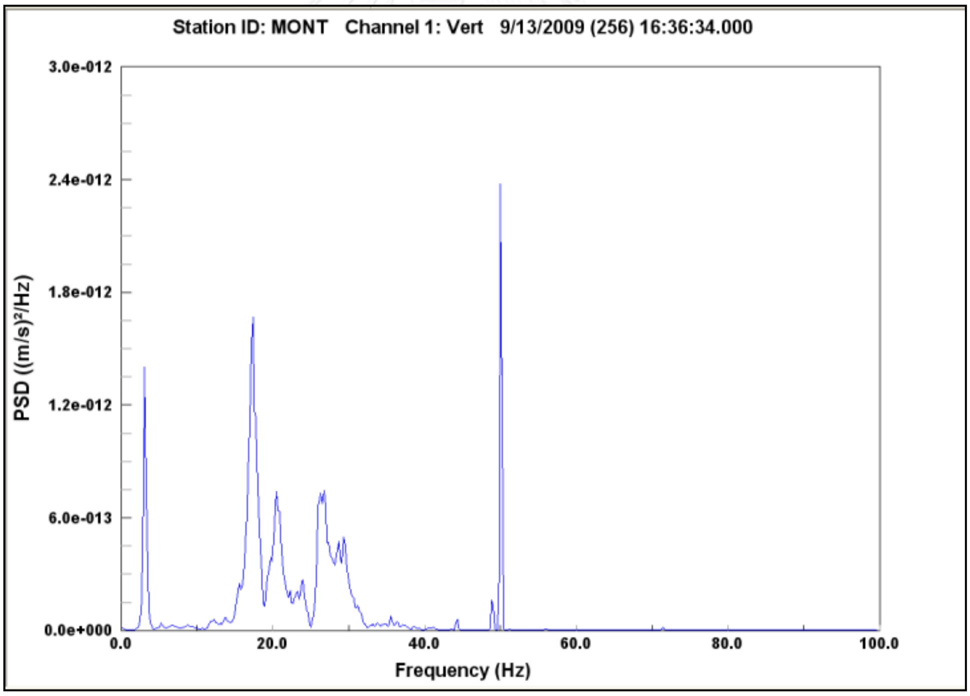
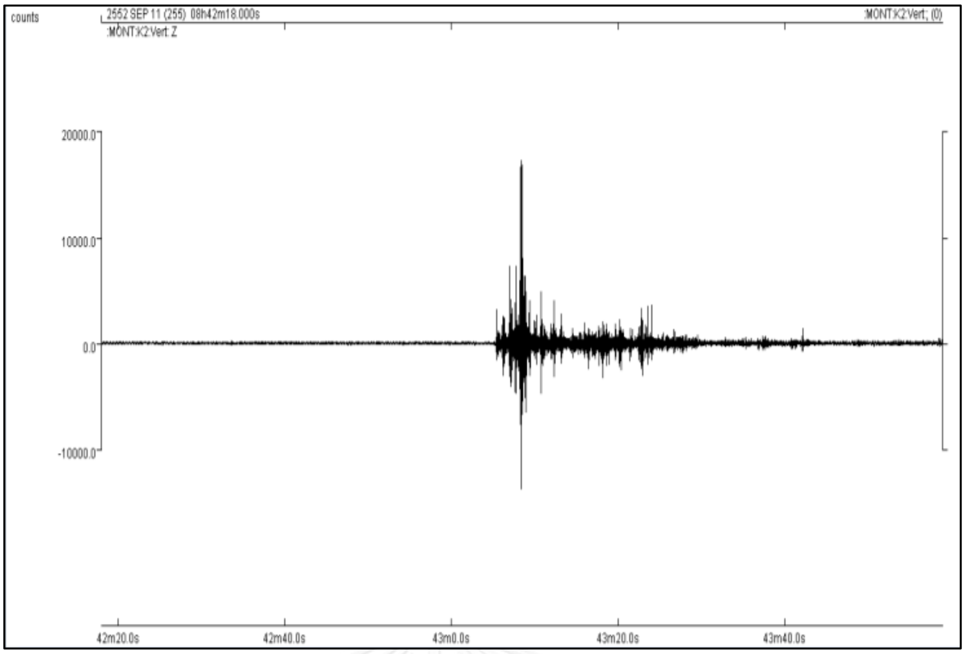
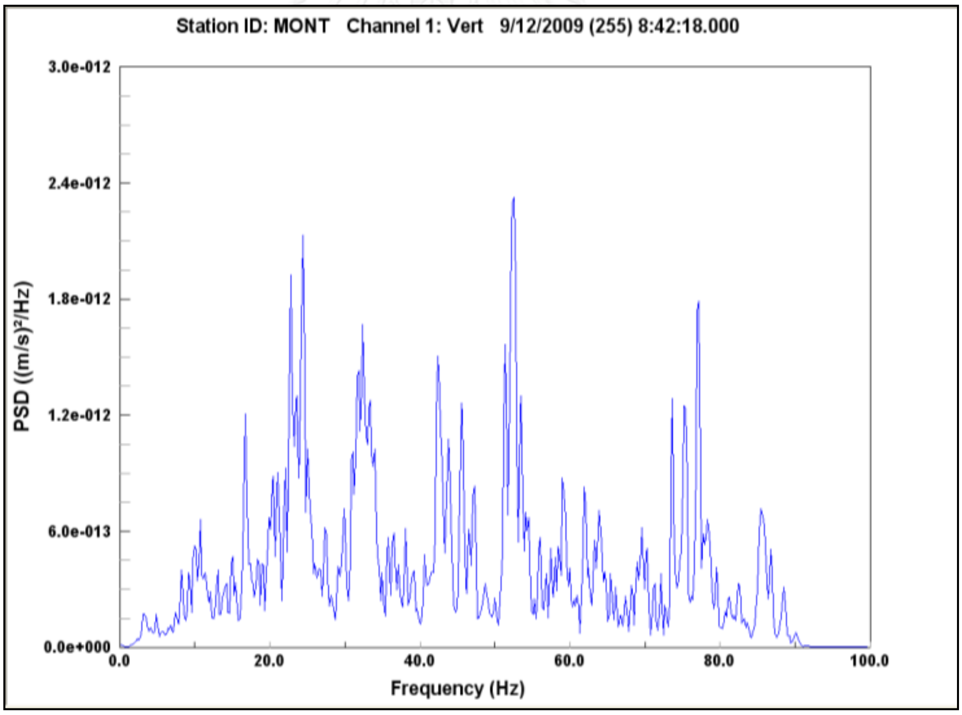


(b)

Figure 3. 9. (a) Seismogram of Local noise with 50Hz spike on September 13, 2009 at MONT station (b) PSD and typical frequencies of Local noise.

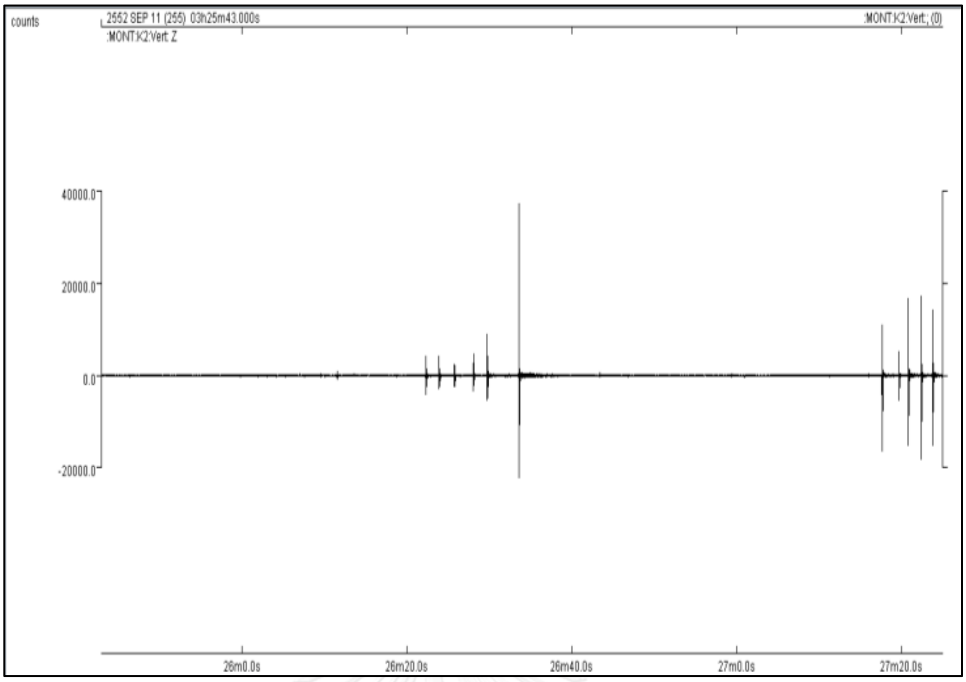


(a)

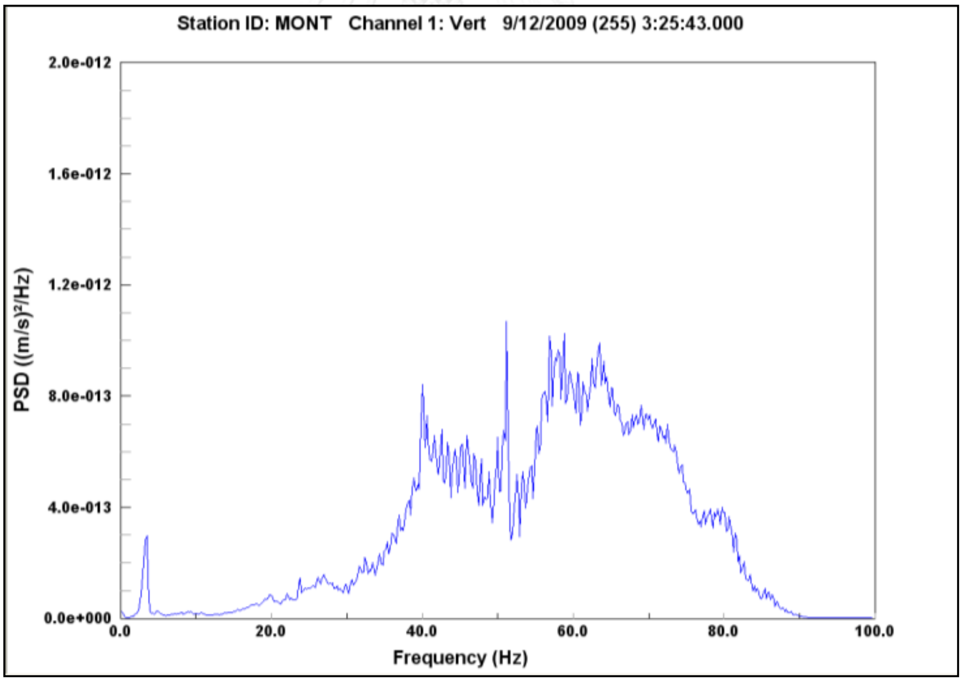


(b)

Figure 3. 10. (a) Seismogram of Human noise on September 12, 2009 source-to-site MONT 2.0 m (b) PSD and typical frequencies of Human noise.

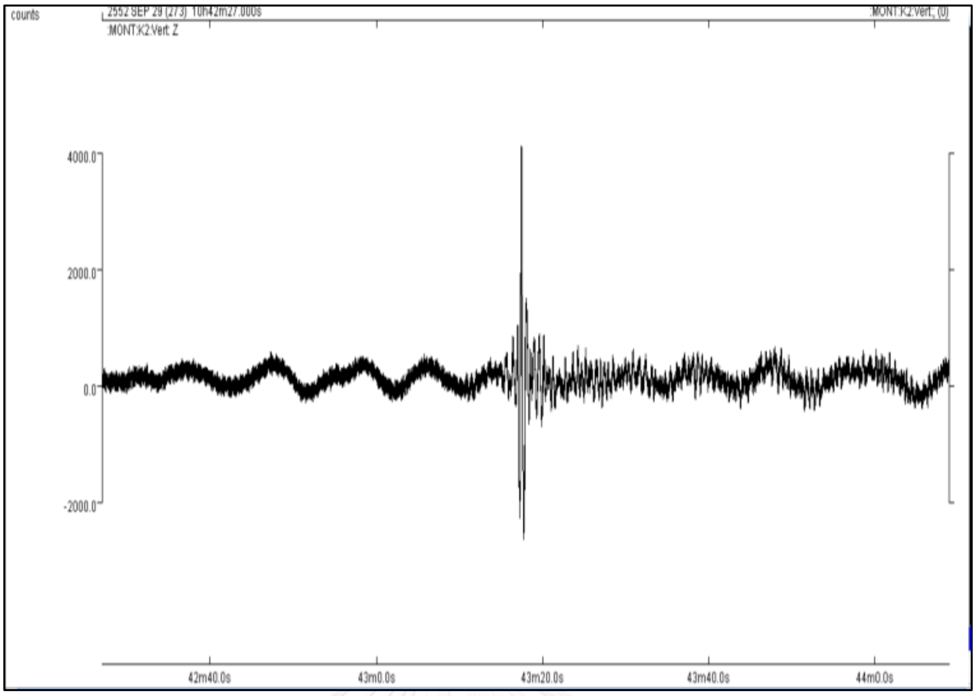


(a)

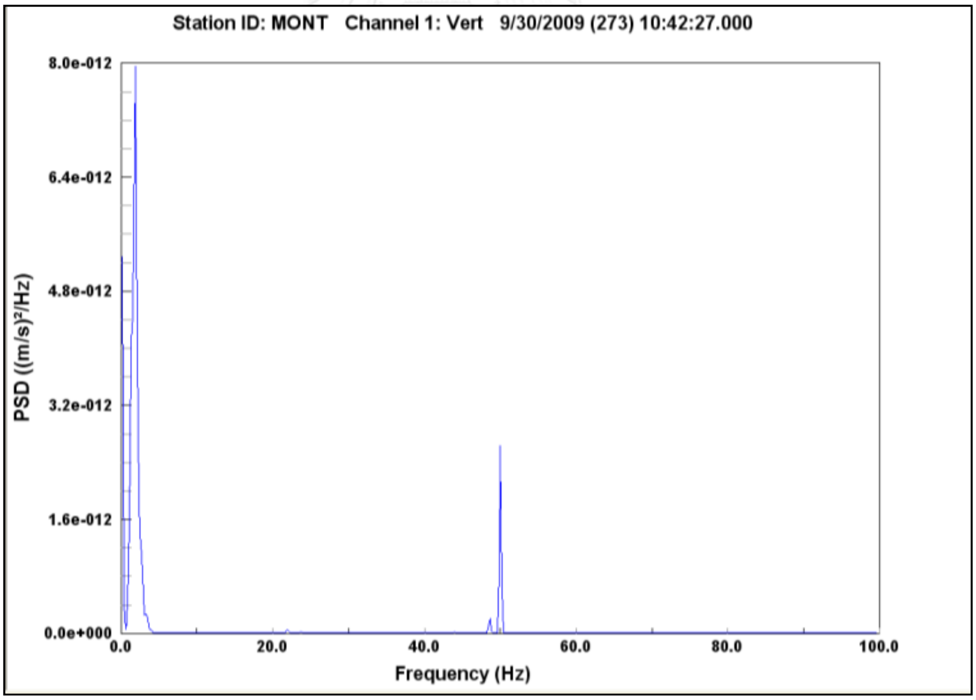


(b)

Figure 3. 11. (a) Seismogram of Car noise on September 12, 2009 source-to-site MONT 3.0 m (b) PSD and typical frequencies of Car noise.

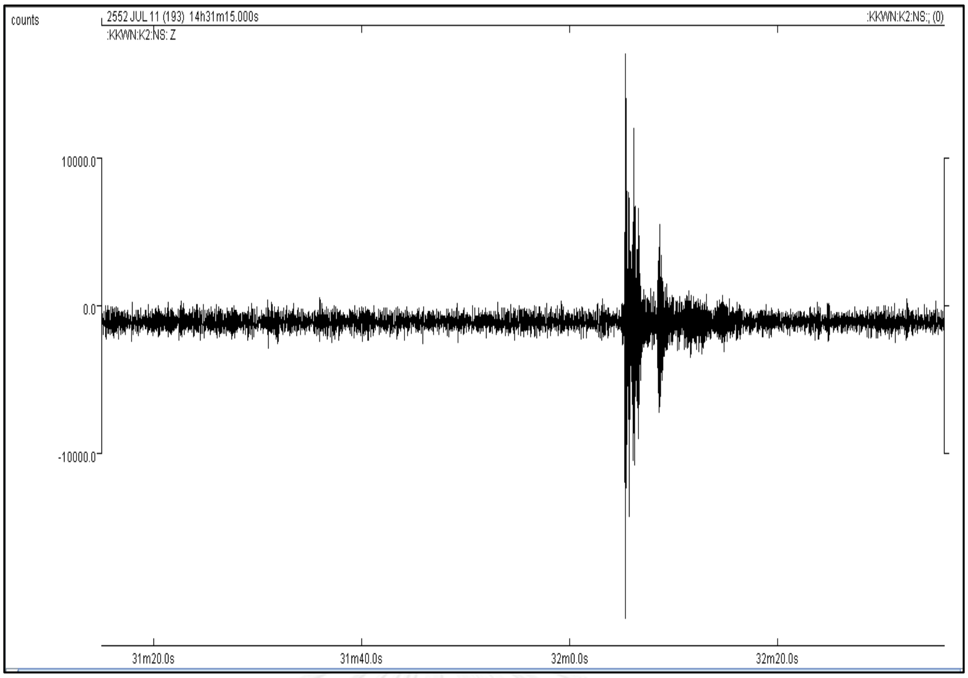


(a)

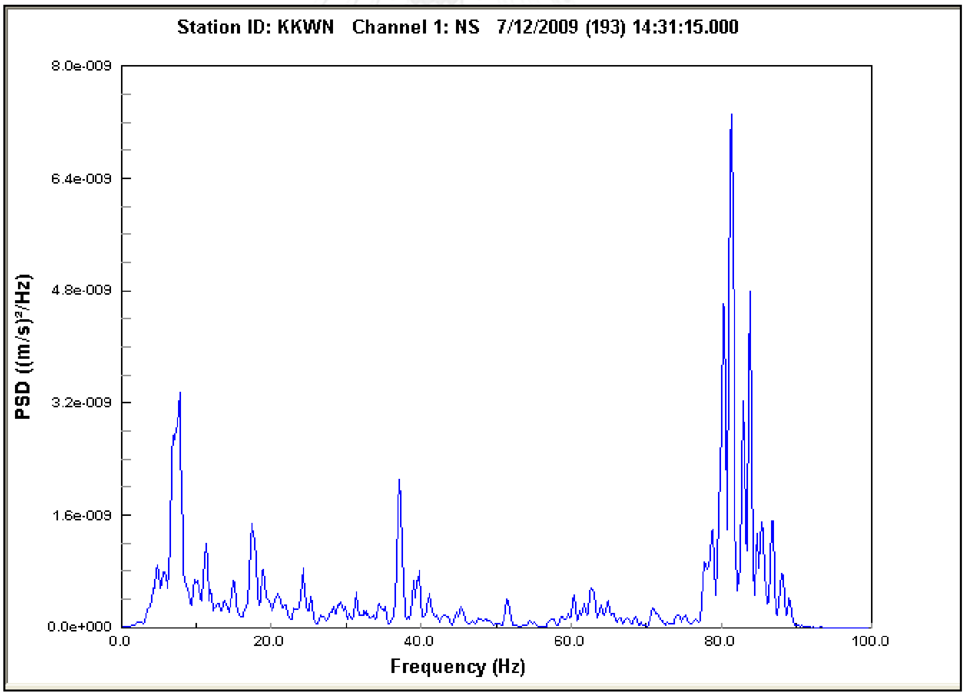


(b)

Figure 3. 12. (a) Seismogram of High Frequency noise + 50Hz spike on September 30, 2009 at MONT station (b) PSD and typical frequencies of High Frequency noise.



(a)



(b)

Figure 3. 13. (a) Seismogram of explosion on July 12, 2009 source-to-site KKWN 2.0 km, Azimuth 108.8628 degree at MONT station (b) PSD and typical frequencies of explosion noise.

After separating of 11,510 seismograms, there were 2,321 seismograms from natural earthquakes (or 20 %) and 9,095 seismograms from noise (or 80 %) (Figure 3.14) which can be categorize natural earthquakes seismograms by stations; the HTUM for 481 seismograms, the KAEW for 616 seismograms, the MONT for 806 seismograms, the MYOM for 398 seismograms, and the MYOA for 20 seismograms (Figure 3.15). The grade of natural earthquakes seismograms can be classified according to the description in Table 3.2 as follow; A1 for 128 events, A2 for 193 events, B1 for 85 events, B2 for 202 events, C1 for 290 events, C2 for 321 events, and SMA for 20 events (Figure 3.16). The natural earthquakes seismograms of the grade A1 or well-located earthquakes of 128 events can be classified according to year; in 1999 for 6 events, in 2000 for 2 events, in 2001 for 2 events, in 2002 for 9 events, in 2003 for 5 events, in 2004 for 6 events, in 2005 for 13 events, in 2006 for 14 events, in 2007 for 39 events, in 2008 for 9 events, in 2009 for 18 events, and in 2010 for 5 events (Figure 3.17). The strong ground-motion earthquakes or the grade of SMA of 20 events can be classified according to year; in 1999 for 2 events, in 2002 for 2 events, in 2003 for 1 events, in 2004 for 8 events, in 2006 for 2 events, in 2007 for 2 events, in 2008 for 1 event, and in 2009 for 1 event (Figure 3.18 and Table 3.). The details of 11,510 seismograms of the KST network with 5 seismograph stations are summarized in the table include date, time, file name, grade of seismogram and events in the example shown in Table 3.4.

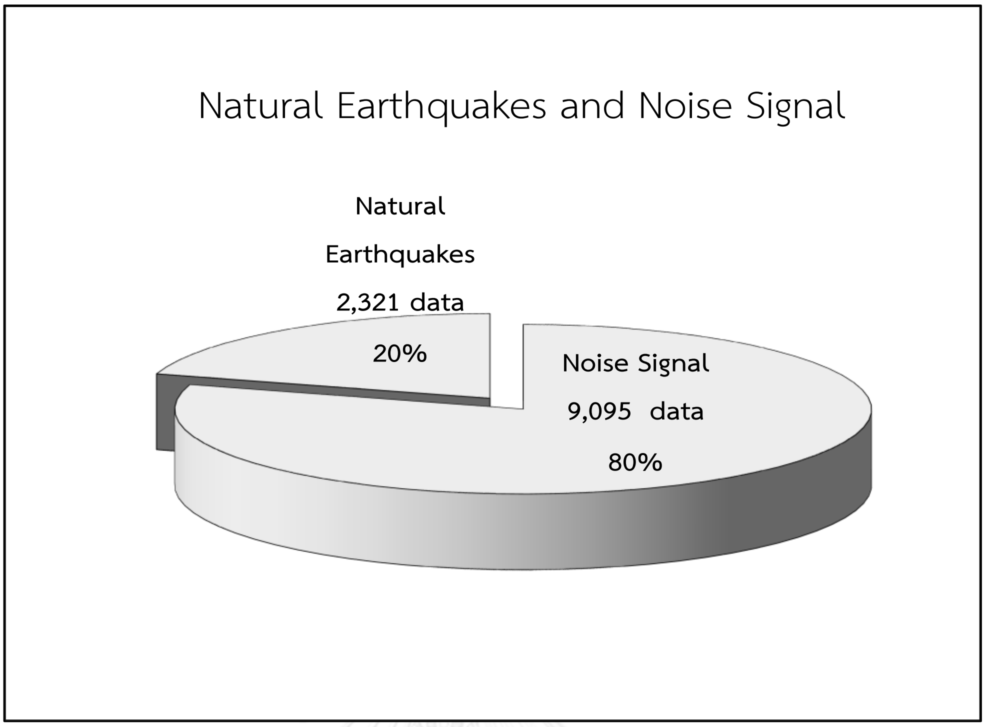


Figure 3. 14. The number of natural earthquakes and noise signal during the year 1999 to 2010.from the KST seismographic network.

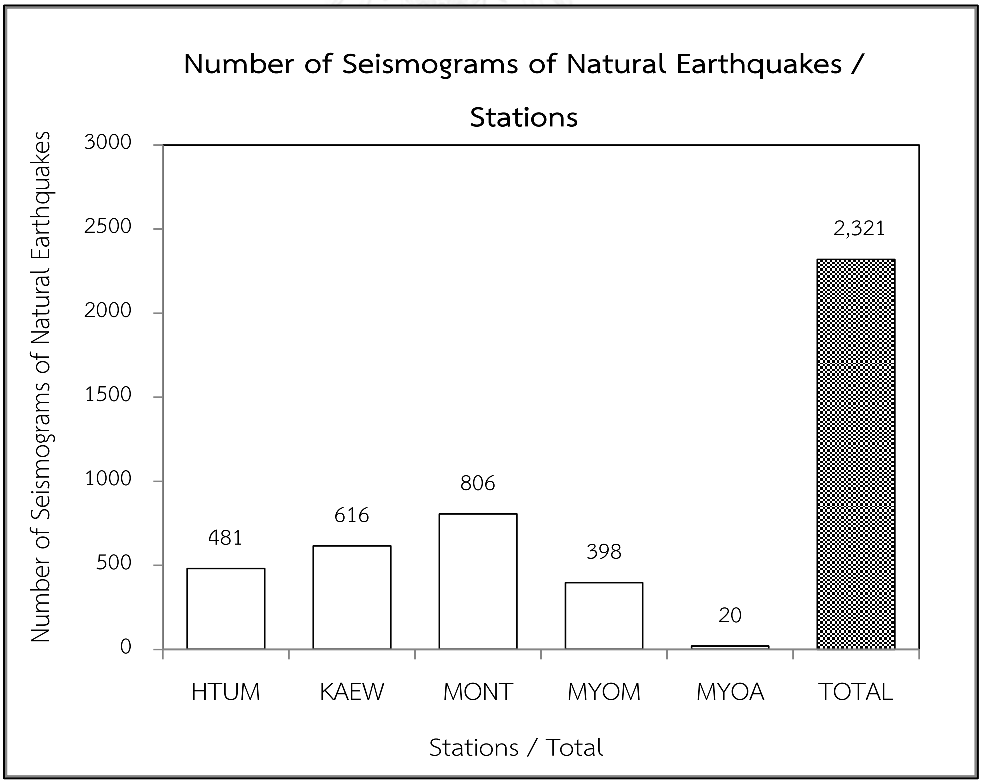


Figure 3. 15. The number of seismograms of natural earthquakes from each station and total after separating by interpreting seismogram.

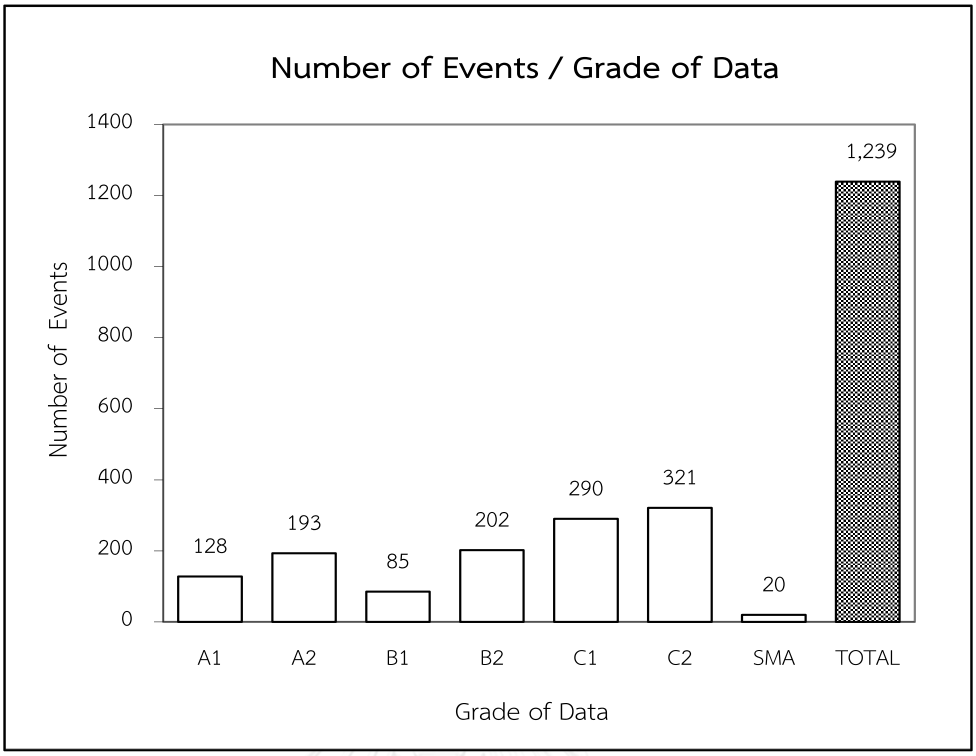


Figure 3. 16. The numbers of events and grade of data and total.

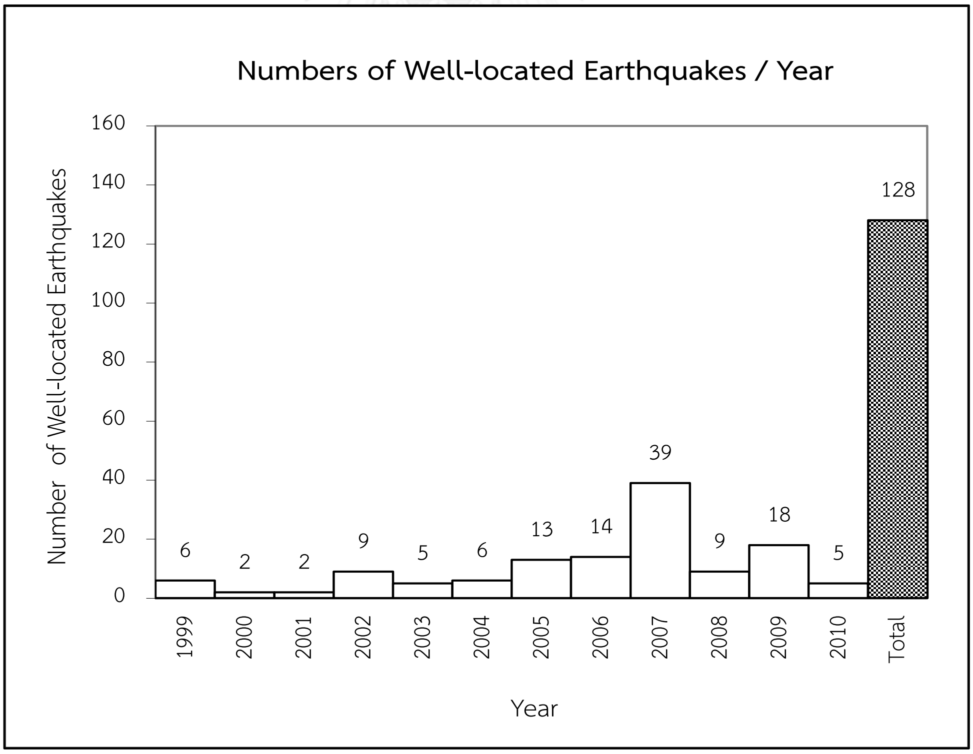


Figure 3. 17. The number of well-located earthquakes during the year of 1999 to 2010.

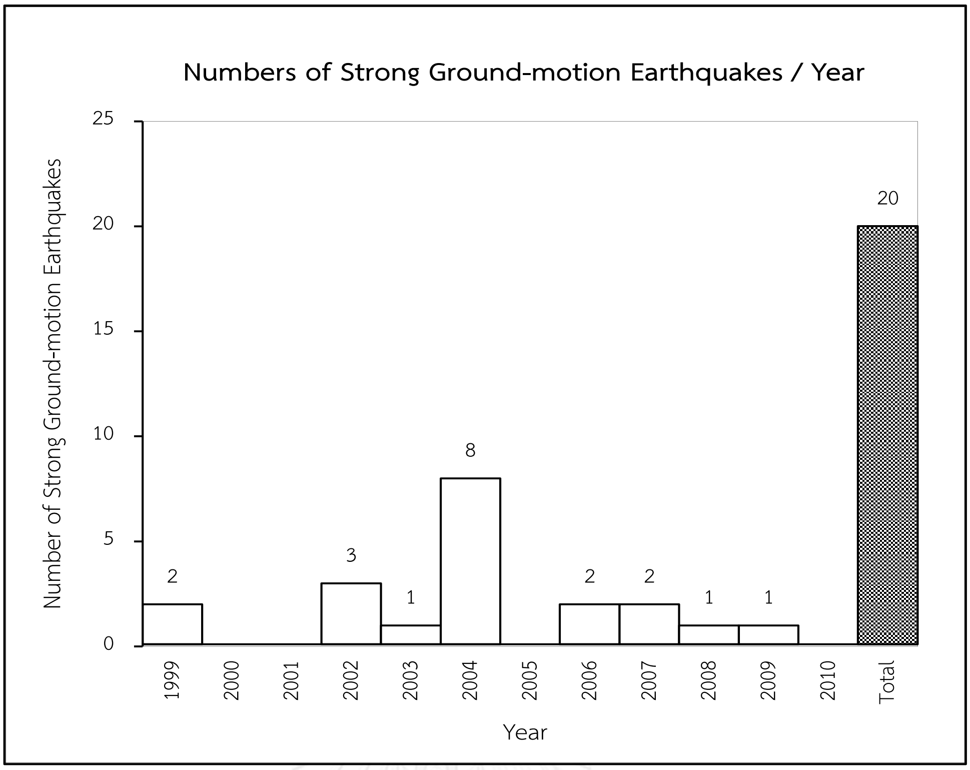


Figure 3. 18. The number of strong ground-motion earthquakes during the year of 1999 to 2010.

Table 3. 3 Details of the 20 strong ground-motion earthquakes of this study.

No	Date	Starting Time (UTC)	Station	File name	Lat	Long	M	Region
1	10-Aug-1999	23:14:37	MYOA	AK026	18.950	100.040	3.10	Amphoe Mueang, Phayao
2	19-Nov-1999	23:21:49	MYOA	AO006	19.790	100.110	2.90	Amphoe Phaya Meng Rai,
3	26-Apr-2002	20:31:54	MYOA	BJ003	18.910	99.080	4.48	Amphoe San Sai, Chiang Mai
4	2-Jul-2002	03:54:31	MYOA	BM004	19.610	99.380	4.97	Amphoe Mae Suai, Chiang Rai
5	7-Sep-2002	06:11:33	MYOA	BN008	18.580	100.300	3.50	Amphoe Song, Phrae
6	21-Sep-2003	18:18:14	MYOA	BR009	19.900	95.730	6.60	Myanmar
7	26-Dec-2004	01:08:28	MYOA	BZ012	3.316	95.854	9.10	Sumatra Island, Indonesia
8	26-Dec-2004	01:9:30	MYOA	BZ013	3.316	95.854	9.10	Sumatra Island, Indonesia
9	26-Dec-2004	01:11:11	MYOA	BZ014	3.316	95.854	9.10	Sumatra Island, Indonesia
10	26-Dec-2004	01:11:36	MYOA	BZ015	3.316	95.854	9.10	Sumatra Island, Indonesia
11	26-Dec-2004	01:13:05	MYOA	BZ016	3.316	95.854	9.10	Sumatra Island, Indonesia
12	26-Dec-2004	01:13:43	MYOA	BZ017	3.316	95.854	9.10	Sumatra Island, Indonesia
13	26-Dec-2004	01:14:34	MYOA	BZ018	3.316	95.854	9.10	Sumatra Island, Indonesia
14	26-Dec-2004	01:31:12	MYOA	BZ019	21.630	103.300	6.60	Myanmar
15	18-Oct-2006	12:01:01	MYOA	CS011	18.945	100.116	3.23	Amphoe Dok Kam Tai, Phayao
16	12-Dec-2006	17:02:44	MYOA	CT012	18.934	99.245	4.70	Amphoe Doi Saket, Chiang Mai
17	16-May-2007	08:56:34	MYOA	CZ004	20.646	101.445	6.13	Laos
18	19-Jun-2007	05:06:36	MYOA	DA006	18.931	99.178	4.40	Amphoe Doi Saket, Chiang Mai
19	2-Mar-2008	03:22:59	MYOA	DI009	18.707	100.088	3.13	Amphoe Ngao, Lampang
20	1-Jun-2009	12:43:53	MYOA	DZ003	18.815	100.578	3.12	Amphoe Ban Luang, Nan

Table 3. 4 Examples of the detailed summary table of the KST's seismograms, and grades of data.

Date	HTUM Station		KAEW Station		MONT Station		MYOM Station		MYOA Station		Grade
	File No.	Start Time (UTC)	File No.	Start Time (UTC)	File No.	Start Time (UTC)	File No.	Start Time (UTC)	File No.	Start Time (UTC)	
1-Jul-2002											
2-Jul-2002	EG005	3:54:04	AG012	3:54:00	HZ114	3:54:10	GK013	3:54:10	BM004	3:54:31	A1
	EG006	5:01:39	AG013	5:01:46							B1
	EG007	8:03:49	AG014	8:03:54	HZ115	8:03:53					A1
							GK014	8:57:09			
	EG008	17:55:19	AG015	17:55:16	HZ116	17:55:24	GK015	17:55:24			A1
3-Jul-2002	EG009	0:17:48	AG016	0:17:44	HZ117	0:17:53	GK016	0:17:54			A1
							GK017	7:25:14			
							GK018	8:45:53			
4-Jul-2002							GK019	4:39:06			
5-Jul-2002			AG017	13:33:56							C1
6-Jul-2002											
7-Jul-2002											
8-Jul-2002							GK020	11:14:42			
9-Jul-2002											
10-Jul-2002											
11-Jul-2002											
12-Jul-2002			AG018	5:50:19	HZ118	5:50:18					B1
					HZ119	5:50:37					C2
13-Jul-2002											
14-Jul-2002	EG010	1:16:59									C2
15-Jul-2002							GK021	9:27:20			
							GL001	9:33:36			
							GL002	9:34:43			
							GM001	9:52:27			
									BM005	9:58:26	
									BN001	10:00:29	
									BN002	10:04:32	
							GM004	10:07:00	BN004	10:13:33	
16-Jul-2002					IA001	5:30:47					
17-Jul-2002					IA002	1:02:39					
18-Jul-2002	EG011	9:51:55	AG019	9:51:02	IA003	9:51:11	GM005	9:51:54			A2
			AG020	15:53:15	IA004	15:53:24					B2
	EG012	15:54:12	AG021	15:53:46			GM006	15:54:15			A2
19-Jul-2002			AG022	5:40:05	IA005	5:40:14					B2
			AG023	5:40:35	IA006	5:40:54					B2
	EG013	18:40:29			IA007	18:40:20					B2
					IA008	18:40:41					C2
20-Jul-2002											
21-Jul-2002	EG014	22:49:46	AG024	22:49:41	IA009	22:49:51	GM007	22:49:52			A1
							GM008	22:50:10			C1
22-Jul-2002							GM009	1:37:45			
			AG025	1:53:11	IA010	1:53:14					B1
							GM010	2:44:06			
23-Jul-2002											

3.3 Seismograms of the KST's Epicenters

The KST's epicenters during the year 1999 to 2010 which collected from the RID consist of 181 events (Figure 1.1, Figure 3.19 and Table 3.5). Before re-locating earthquakes, interpreting seismogram is needed first in order to screening off the only well-located earthquake events that can read out the arrival time of P and S-wave (Figure 3.20) from at least 3 seismic stations (Figure 3.25). In this study the KMI QuickLook program which belongs to the Kinemetrics.Inc, is used to display the event files of seismograms, which then can be used to study waveform, and to read the arrival time of P and S-wave. In each earthquake events from No 1 to 181 already have the details of date and time, name of seismic stations, and file name of seismograms has been provided, which is used in the interpreting work in this step. Example of typical seismograms which was used for screening waveform are shown in Figure 3.20-Figure 3.28.

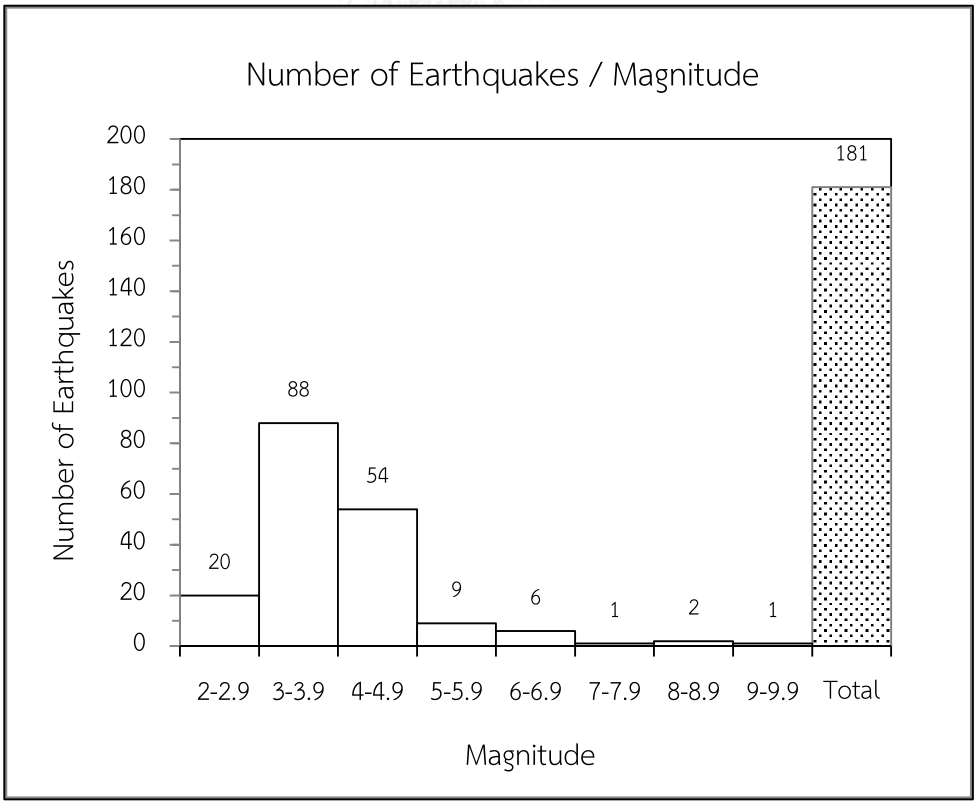


Figure 3. 19. Number of earthquakes and magnitude of the KST's epicenters before screening.

Table 3.5 The 181 KST's epicenters during the year 1999 to 2010 of this study.

No	Date	Start Time (UTC)			Station	File name	Location		M	Region
		hr	min	sec			Lat	Long		
		15	23	31	MYOM	BY080				
1	22-May-1999	15	23	33	KAEW	AX010	18.900	100.200	2.0	Amphoe Chiang Muan, Phayao
		15	23	33	HTUM	CZ006				
		14	16	16	KAEW	AX012				
2	27-May-1999	14	16	17	MONT	CI106	18.900	98.500	4.2	Amphoe Mae Chaem-Sa Moeng, Chiang Mai
		14	16	21	MYOM	CB001				
		23	14	30	MONT	CI185				
3	10-Aug-1999	23	14	33	KAEW	AY011	18.950	100.040	3.1	Amphoe Mueang, Phayao
		23	14	34	HTUM	CZ015				
		23	19	31	MONT	CP001				
		23	19	35	KAEW	AY015				
4	15-Aug-1999	23	19	36	MYOM	IW018	18.900	100.00	5.9	Amphoe Ngao, Lampang
		23	19	57	HTUM	FW001				
		9	19	34	KAEW	BA002				
5	23-Aug-1999	9	19	42	HTUM	FW006	20.180	100.540	4.0	Laos
		9	19	45	MONT	CQ006				
		23	21	46	MONT	ES011				
6	19-Nov-1999	23	21	47	MYOM	OX002	19.790	100.110	2.9	Amphoe Phaya Meng Rai, Chiang Rai
		23	21	57	KAEW	BC002				
		17	22	56	KAEW	BG001				
7	27-Feb-2000	17	23	5	HTUM	MK003	23.040	94.270	4.9	Myanmar
		17	23	13	MONT	KH003				
		22	16	13	HTUM	NU001				
8	3-Mar-2000	22	16	14	MYOM	AL126	18.810	100.180	2.6	Amphoe Song, Phrae
		22	16	15	MONT	NP001				
		8	57	13	HTUM	NU004				
9	7-Mar-2000	8	57	18	KAEW	BV001	19.800	101.100	3.3	Laos
		8	57	27	MONT	NP002				
		13	13	50	HTUM	NU014				
10	13-Apr-2000	13	13	56	KAEW	BV006	19.310	100.480	3.0	Amphoe Pong, Phayao
		13	14	6	MONT	NP029				
		4	4	13	MYOM	AL255				
11	4-May-2000	4	4	20	MONT	OG004	17.423	101.500	4.2	Amphoe Phu Ruea, Loei
		4	27	24	HTUM	NU022				
		22	33	20	KAEW	WK001				
12	27-May-2000	22	33	40	MONT	QW003	19.022	100.200	2.9	Amphoe Chiang Muan, Phayao
		23	33	40	HTUM	SV001				
		19	41	16	MONT	QW004				
13	28-May-2000	19	41	19	MYOM	AL285	18.767	100.300	3.5	Amphoe Song, Phrae
		19	41	44	HTUM	SV002				
		7	35	45	KAEW	KN001				
14	28-Jun-2000	7	35	55	MONT	RF001	18.910	100.180	2.9	Amphoe Chiang Muan, Phayao
		7	36	26	MYOM	AL336				
		7	33	45	MYOM	AL413				
15	6-Aug-2000	7	33	45	KAEW	GF001	18.970	100.270	3.1	Amphoe Chiang Muan, Phayao
		7	33	45	MONT	RM003				
		19	19	50	KAEW	JV001				
16	19-Aug-2000	19	20	26	MONT	RM006	18.290	100.680	3.5	Amphoe Na Noi, Nan
		19	20	27	HTUM	TZ003				
		11	44	24	KAEW	MZ002				
17	5-Sep-2000	11	44	28	MONT	RO001	19.150	100.050	3.2	Amphoe Dok Kham Tai, Phayao
		11	44	36	MYOM	AM031				
		4	3	20	KAEW	HU002				
		4	3	33	MONT	UL012				
18	4-Jan-2001	4	3	33	HTUM	UO004	21.400	98.600	5.2	Myanmar
		4	3	36	MYOM	AO071-2				
		17	52	55	HTUM	UO007				
		17	52	56	KAEW	KG001				
19	13-Jan-2001	17	52	57	MONT	UL015	19.230	100.130	3.5	Amphoe Chun, Phayao
		17	52	58	MYOM	AO076				
		19	33	26	MYOM	AS046				
20	13-Feb-2001	19	33	27	MONT	UL036	17.220	100.080	4.2	Amphoe Phi Chai, Uttaradit
		19	33	30	HTUM	UQ002				
		14	22	15	KAEW	ZU001-2				
		14	22	15	HTUM	UQ006-7				
21	26-Feb-2001	14	22	21	MYOM	AS062	19.170	100.200	3.0	Amphoe Pong, Phayao
		14	22	21	MONT	UL054-5				
		1	4	14	MYOM	EI045				
22	7-May-2001	1	4	15	HTUM	AL004	18.310	100.440	3.3	Amphoe Rong Kwang, Phrae
		1	4	18	MONT	WZ002				

Table 3.5 The 181 KST's epicenters during the year 1999 to 2010 of this study (cont.).

No	Date	Start Time (UTC)			Station	File name	Location		M	Region
		hr	min	sec			Lat	Long		
23	3-Jul-2001	13	17	36	HTUM	AL020	18.890	100.180	2.9	Amphoe Chiang Muan, Phayao
		13	17	37	MONT	XA096				
		13	17	39	MYOM	EJ071				
		13	17	39	KAEW	TP001				
24	19-Jan-2002	22	14	52	HTUM	AN012-3	19.300	100.080	3.4	Amphoe Dok Kham Tai, Phayao
		22	14	56	MONT	HY006				
		22	14	57	MYOM	GI129				
25	25-Apr-2002	11	49	33	MONT	HZ073	18.910	99.080	3.6	Amphoe San Sai, Chiang Mai
		11	49	42	MYOM	GI315				
		11	49	52	HTUM	AO009				
26	26-Apr-2002	20	31	37	MONT	HZ076	18.910	99.080	4.5	Amphoe San Sai, Chiang Mai
		20	31	40	MYOM	GI316				
		20	31	47	HTUM	AO011				
27	24-May-2002	6	35	54	HTUM	EF004	20.110	99.880	3.7	Amphoe Mueang, Chiang Rai
		6	35	58	KAEW	HI001				
		6	36	21	MYOM	GI340				
		6	36	23	MONT	HZ083				
28	28-Jun-2002	17	25	21	KAEW	AG009	20.010	100.080	4.7	King Amphoe Wiang Chiang Rung, Chiang Rai
		17	25	22	HTUM	EG002				
		17	25	25	MYOM	GK011				
		17	25	26	MONT	HZ112				
29	2-Jul-2002	3	54	0	KAEW	AG012	19.610	99.380	5.0	Amphoe Mae Suai, Chiang Rai
		3	54	4	HTUM	EG005				
		3	54	11	MYOM	GK013				
		3	54	10	MONT	HZ114				
30	3-Jul-2002	0	17	44	KAEW	AG016	19.810	100.280	3.7	Amphoe Khun Tan, Chiang Rai
		0	17	48	HTUM	EG009				
		0	17	53	MONT	HZ117				
		0	17	54	MYOM	GK016				
31	21-Jul-2002	22	49	41	KAEW	AG024	19.920	100.900	4.1	Laos
		22	49	46	HTUM	EG014				
		22	49	51	MONT	IA009				
		22	50	10	MYOM	GM008				
32	19-Aug-2002	11	12	35	HTUM	EG017	19.040	100.200	3.5	Amphoe Pong, Phayao
		11	12	37	MONT	IB001				
		11	12	37	KAEW	AG030				
		11	12	40	MYOM	GM016				
33	19-Aug-2002	11	19	47	HTUM	EG018	19.010	100.200	3.4	Amphoe Chiang Muan, Phayao
		11	19	48	MONT	IB002				
		11	19	49	KAEW	AG031				
		11	19	52	MYOM	GM017				
34	7-Sep-2002	6	11	29	MYOM	GM035	18.580	100.300	3.5	Amphoe Song, Phrae
		6	11	31	HTUM	EH003				
		6	11	32	MONT	IR001				
		6	11	58	KAEW	AG033				
35	13-Sep-2002	22	31	4	MYOM	GM038	19.050	99.170	3.7	Amphoe Phrao, Chiang Mai
		22	30	38	KAEW	AG034				
		22	30	28	HTUM	EH004				
36	25-Sep-2002	14	27	36	KAEW	AG039	19.390	99.400	3.6	Amphoe Wiang Pa Pao, Chiang Rai
		14	27	41	MONT	LF001				
		14	27	44	MYOM	GM084				
		14	27	47	HTUM	EI001				
37	24-Oct-2002	21	56	45	MYOM	GM200	19.060	100.130	3.0	Amphoe Pong, Phayao
		21	56	52	KAEW	AG042				
		21	56	50	HTUM	EI006				
38	6-Nov-2002	5	21	10	MONT	OE001	18.670	99.980	2.9	Amphoe Ngao, Lampang
		5	21	12	MYOM	GM221				
		5	21	29	HTUM	EI009				
39	17-Nov-2002	5	1	24	KAEW	AG044	18.940	100.300	3.9	Amphoe Chiang Muan, Phayao
		5	1	25	HTUM	EI012				
		5	1	28	MYOM	GM248				
		5	1	28	MONT	OX003				
40	6-Dec-2002	5	5	40	MONT	QQ001-2	18.450	99.600	4.0	Amphoe Mueang, Lampang
		5	6	28	KAEW	AG047				
		5	6	36	MYOM	GM261				
		5	6	48	HTUM	EI015				
41	18-Dec-2002	13	47	10	KAEW	AG048	19.390	98.800	4.9	Amphoe Chiang Dao, Chiang Mai
		13	47	12	MONT	RM002				
		13	47	15	MYOM	GM287				
		13	47	19	HTUM	EI016				

Table 3.5 The 181 KST's epicenters during the year 1999 to 2010 of this study (cont.).

No	Date	Start Time (UTC)			Station	File name	Location		M	Region
		hr	min	sec			Lat	Long		
		7	14	20	KAEW	AG058				
42	29-Jan-2003	7	14	32	MONT	UM001	19.760	100.600	3.9	Laos
		7	14	33	MYOM	GN042				
		10	22	36	MYOM	GN088				
43	20-Feb-2003	10	22	36	MONT	VO037	19.650	100.280	3.6	Amphoe Thoeng, Chiang Rai
		10	23	5	KAEW	AG060				
		8	57	38	MYOM	GQ045				
44	23-Aug-2003	8	57	28	KAEW	AG079	18.577	99.244	3.5	Amphoe Mueang, Lamphun
		8	57	23	MONT	EN001				
		11	4	15	KAEW	AG080				
45	18-Sep-2003	11	4	26	MONT	FV001	20.547	100.057	4.5	Myanmar
		11	4	28	MYOM	GQ096				
		12	31	21	KAEW	AG094				
46	16-Oct-2003	12	31	44	MYOM	GR035	19.157	101.300	3.9	Laos
		12	31	46	MONT	HJ001				
		15	23	27	MYOM	GR077				
47	30-Oct-2003	15	23	17	KAEW	AG096	-	-	5.7	
		15	23	47	HTUM	ON001				
		15	8	20	KAEW	AG100				
48	23-Nov-2003	15	8	25	HTUM	ON002	20.480	101.350	4.5	Laos
		15	8	32	MYOM	GR096				
		20	22	22	KAEW	AG103				
49	7-Dec-2003	20	22	50	MYOM	GR165	19.060	99.630	3.6	Amphoe Wang Nuea, Lampang
		20	23	3	HTUM	ON005				
		5	49	35	KAEW	AG114				
		5	49	39	HTUM	OW001				
50	14-Mar-2004	5	49	44	MYOM	GR299-300	20.174	100.000	3.9	Amphoe Mae Chan, Chiang Rai
		5	49	44	MONT	ME006				
		4	5	26	KAEW	AG117				
		4	5	33	MONT	ME009				
51	27-Mar-2004	4	5	36	MYOM	GR324	19.720	99.800	3.7	Amphoe Phan, Chiang Rai
		4	5	37	HTUM	OW006				
		14	39	8	MYOM	GR605				
		14	39	10	MONT	MT007				
52	25-Jul-2004	14	39	15	KAEW	AG123	18.950	99.900	3.8	Amphoe Ngao, Lampang
		14	39	17	HTUM	OX003				
		18	54	6	HTUM	OX007				
		18	54	7	MONT	MT010				
53	17-Aug-2004	18	54	20	MYOM	GR632	17.320	100.650	4.1	Amphoe Chat Trakan, Phitsanulok
		18	54	46	KAEW	AG125				
		1	31	56	MONT	MT015				
54	11-Sep-2004	1	32	18	MYOM	GR651	18.810	98.800	3.6	Amphoe Hang Dong, Chiang Mai
		1	32	18	KAEW	AG126				
		20	56	41	KAEW	AG135				
		20	56	54	MONT	MV011				
55	13-Dec-2004	20	57	27	HTUM	PB001	19.308	99.149	3.9	Amphoe Phrao, Chiang Mai
		20	57	33	MYOM	GR908				
		1	2	28	MYOM	GR946				
		1	2	37	KAEW	AG136				
56	26-Dec-2004	1	2	22	MONT	MV014	3.300	95.940	9.0	Sumatra Islands, Indonesia
		1	2	34	HTUM	PB002				
		1	30	20	MYOM	GR953				
		1	30	10	KAEW	AG143				
57	26-Dec-2004	1	30	16	MONT	MV022	21.630	103.300	6.6	Myanmar
		1	30	19	HTUM	PB006				
		7	13	14	KAEW	AG148				
58	26-Dec-2004	7	13	20	MONT	MV031	19.094	99.500	3.4	Amphoe Wiang Pa Pao, Chiang Rai
		7	13	27	MYOM	GR957				
		23	55	9	KAEW	AG157				
		23	55	10	MONT	MV053				
59	30-Dec-2004	23	55	18	HTUM	PB011	20.940	97.750	6.4	Myanmar
		23	55	23	MYOM	GR965				
		6	29	7	MONT	MV055				
60	1-Jan-2005	6	29	12	MYOM	GR969	18.210	99.631	3.4	Amphoe Mae Tha, Lampang
		6	29	16	HTUM	PB012				
		16	31	19	KAEW	AG160				
61	25-Jan-2005	16	31	32	MONT	MV063	22.520	100.740	4.9	Myanmar
		16	31	29	HTUM	PE001				

Table 3.5 The 181 KST's epicenters during the year 1999 to 2010 of this study (cont.).

No	Date	Start Time (UTC)			Station	File name	Location		M	Region
		hr	min	sec			Lat	Long		
		12	27	56	HTUM	PE003				
62	5-Feb-2005	12	27	58	MONT	MV068	18.623	100.417	3.3	Amphoe Wiang Sa, Nan
		12	28	1	KAEW	AG166				
		10	48	56	HTUM	PF001				
		10	48	57	MYOM	GR1170				
63	2-Mar-2005	10	48	59	MONT	MX004	18.858	100.900	3.7	King Amphoe Phu Phiang-Santi Suk, Nan
		10	49	2	KAEW	AG171				
		16	13	25	MONT	MX011				
		16	13	26	MYOM	GR1205				
64	28-Mar-2005	16	13	30	HTUM	PF004	2.074	97.013	8.7	Sumatra Islands, Indonesia
		16	13	35	KAEW	AG176				
		7	18	13	KAEW	AG185				
65	1-Apr-2005	7	18	18	MONT	MY001	19.398	99.399	3.7	Amphoe Wiang Pa Pao, Chiang Rai
		7	18	23	HTUM	PF017				
		17	22	12	KAEW	AG186				
66	2-Apr-2005	17	22	24	MONT	MY002	19.450	99.341	3.6	Amphoe Wiang Pa Pao, Chiang Rai
		17	23	7	HTUM	PF018				
		10	33	35	HTUM	PF019				
67	10-Apr-2005	10	33	36	MONT	MY004	19.496	100.094	3.5	Amphoe Chun, Phayao
		10	33	38	MYOM	GR1243				
		23	1	39	MYOM	GU029				
68	4-Jun-2005	23	1	40	HTUM	PF031	17.817	100.706	3.8	Amphoe Nam Pat, Uttaradit
		23	1	41	MONT	NA013				
		21	7	40	MYOM	GU036				
69	9-Jun-2005	21	7	42	MONT	NB002	18.544	100.259	2.4	Amphoe Song, Phrae
		21	7	48	HTUM	PF032				
		0	38	41	MONT	NC002				
		0	38	43	MYOM	GU126				
70	29-Jun-2005	0	38	51	HTUM	PF033	18.815	99.500	3.1	Amphoe Mueang Pan, Lampang
		0	39	5	KAEW	AJ001				
		15	45	8	MONT	NC005				
		15	45	12	MYOM	GU215				
71	24-Jul-2005	15	45	13	KAEW	AJ002	7.900	92.100	7.2	Nicobar Islands, India Region
		15	45	17	HTUM	PG001				
		9	34	33	MONT	NI015				
		9	34	36	MYOM	GU591				
72	4-Dec-2005	9	34	38	KAEW	AJ022	18.770	99.000	4.2	Amphoe Mueang, Chiang Mai
		9	34	43	HTUM	QK004-5				
		9	0	52	KAEW	AJ051				
		9	1	2	MONT	NI017				
73	7-Dec-2005	9	1	4	HTUM	QK006-7	19.720	99.500	3.6	Amphoe Mae Suai, Chiang Rai
		9	1	24	MYOM	GU605				
		6	48	22	KAEW	AJ053				
		6	48	34	MONT	NI018				
74	15-Dec-2005	6	48	35	HTUM	QL002	19.450	100.300	4.1	Amphoe Chiang Kham, Phayao
		6	48	36	MYOM	GU639				
		23	13	0	KAEW	AJ055				
75	15-Dec-2005	23	13	14	MONT	NI019	19.490	99.900	3.0	Amphoe Phan, Chiang Rai
		23	13	27	HTUM	QL003				
		2	13	30	KAEW	AJ057				
		2	13	41	MONT	NI020				
76	16-Dec-2005	2	13	43	MYOM	GU640	19.490	99.830	3.6	Amphoe Phan, Chiang Rai
		2	13	45	HTUM	QL005				
		2	15	24	KAEW	AJ058				
		2	15	36	MONT	NI021				
77	16-Dec-2005	2	15	38	MYOM	GU641	19.490	99.930	3.7	Amphoe Pa Daed, Chiang Rai
		2	13	37	HTUM	QL006				
		10	59	1	KAEW	AJ065				
78	17-Dec-2005	10	59	27	HTUM	QJ007	19.610	100.150	3.2	Amphoe Thoeng, Chiang Rai
		10	59	33	MONT	NI022				
		11	47	50	KAEW	AJ066				
		11	48	3	MONT	NI023				
79	17-Dec-2005	11	48	4	MYOM	GU672	19.460	100.000	3.3	Amphoe Pa Daed, Chiang Rai
		11	48	5	HTUM	QL008				
		13	42	25	KAEW	AJ081				
80	24-Jan-2006	13	42	33	MONT	NI036	20.890	98.460	5.5	Myanmar
		13	42	38	HTUM	QL014				
		16	3	1	KAEW	AJ091				
81	1-Feb-2006	16	3	8	HTUM	QL019	20.534	99.849	4.2	Myanmar
		16	3	13	MONT	NI039				

Table 3.5 The 181 KST's epicenters during the year 1999 to 2010 of this study (cont.).

No	Date	Start Time (UTC)			Station	File name	Location		M	Region
		hr	min	sec			Lat	Long		
		0	32	43	KAEW	AJ092				
82	3-Feb-2006	0	32	50	HTUM	QL021	20.190	100.969	3.8	Laos
		0	32	55	MONT	NI041				
		16	54	2	KAEW	AJ094				
83	15-Feb-2006	16	54	5	MONT	NI044	19.134	100.207	3.4	Amphoe Pong, Phayao
		16	54	6	MYOM	GV147				
		18	33	47	KAEW	AJ098				
84	20-Feb-2006	18	33	51	MONT	NI045	19.138	100.221	2.8	Amphoe Pong, Phayao
		18	33	51	MYOM	GV156				
		15	35	7	KAEW	AK005				
85	13-Oct-2006	15	35	21	MONT	NY003	20.229	100.157	3.7	King Amphoe Doi Luang, Chiang Rai
		15	35	35	HTUM	UF001				
		12	0	35	MONT	NY005				
86	18-Oct-2006	12	0	37	MYOM	HD143	18.945	100.116	3.2	Amphoe Dok Kham Tai, Phayao
		12	0	39	HTUM	UF002				
		12	0	39	KAEW	AK006				
		1	58	31	KAEW	AK007				
87	21-Oct-2006	1	58	39	HTUM	UF003	20.325	100.846	4.2	Laos
		1	58	42	MONT	NY006				
		1	58	44	MYOM	HD144				
		18	38	32	KAEW	AK013				
88	16-Nov-2006	18	38	44	MONT	NY013	19.540	99.999	3.7	Amphoe Pa Daed, Chiang Rai
		18	38	46	HTUM	UG002				
		18	38	47	MYOM	HE021				
		19	32	32	HTUM	UG004				
89	26-Nov-2006	19	32	38	MYOM	HE036	19.069	101.239	3.8	Amphoe Bo Kluea, Nan
		19	32	41	MONT	NZ001				
		19	32	41	KAEW	AK014				
		4	1	12	MONT	NZ002				
90	1-Dec-2006	4	2	17	MYOM	HE037	19.033	99.806	3.0	Amphoe Ngao, Lampang
		4	2	24	KAEW	AK015				
		17	2	6	MONT	NZ006				
91	12-Dec-2006	17	2	8	KAEW	AK016	18.934	99.245	4.7	Amphoe Doi Saket, Chiang Mai
		17	2	9	MYOM	NB001				
		17	2	14	HTUM	UG007				
		17	2	6	MONT	NZ006				
92	12-Dec-2006	17	4	45	KAEW	AK017	19.009	99.644	3.0	Amphoe Wang Nuea, Lampang
		17	4	48	MYOM	NB002				
		19	49	15	MONT	NZ011				
93	12-Dec-2006	19	49	30	KAEW	AK019	18.965	99.189	3.8	Amphoe Doi Saket, Chiang Mai
		19	49	42	HTUM	UG008				
		22	21	33	MONT	NZ012				
94	12-Dec-2006	22	21	36	KAEW	AK020	19.008	99.144	3.6	Amphoe Doi Saket, Chiang Mai
		22	22	2	HTUM	UG009				
		5	48	41	MONT	NZ014				
95	13-Dec-2006	5	48	56	KAEW	AK022	18.899	99.256	3.9	Amphoe Doi Saket, Chiang Mai
		5	48	58	MYOM	NO001				
		11	48	56	MONT	OA008				
96	23-Dec-2006	11	49	13	KAEW	AK025	18.880	99.638	3.2	Amphoe Chae Hom, Lampang
		11	49	15	MYOM	VW001				
		11	33	30	HTUM	UH003				
97	21-Jan-2007	11	33	35	MYOM	XY015	19.841	99.856	3.9	Mueang, Chiang Rai
		11	33	37	MONT	OB003				
		22	29	37	MONT	OB007				
98	25-Jan-2007	22	29	43	KAEW	AK032	18.824	99.387	3.2	Amphoe Mueang Pan, Lampang
		22	29	44	MYOM	XY187				
		8	52	23	HTUM	UI001				
99	18-Feb-2007	8	52	25	MYOM	YB006	18.555	100.582	3.1	Amphoe Wiaeng Sa, Nan
		8	52	28	MONT	OB013				
		8	5	36	KAEW	AK035				
100	20-Feb-2007	8	5	37	MONT	OB014	19.047	100.031	3.2	Amphoe Mueang, Phayao
		8	5	38	MYOM	YB007				
		8	5	39	HTUM	UI002				
		6	17	31	KAEW	AK045				
101	22-Apr-2007	6	17	39	MONT	OD009	19.427	99.838	4.0	Amphoe Pa Daed, Chiang Rai
		6	17	42	MYOM	YB139				
		6	17	43	HTUM	UJ004				
		6	17	31	KAEW	AK045				
102	22-Apr-2007	6	17	39	MONT	OD009	19.413	99.562	3.6	Amphoe Wiaeng Pa Pao, Chiang Rai
		6	17	42	MYOM	YB139				
		6	17	43	HTUM	UJ004				

Table 3.5 The 181 KST's epicenters during the year 1999 to 2010 of this study (cont.).

No	Date	Start Time (UTC)			Station	File name	Location		M	Region
		hr	min	sec			Lat	Long		
103	15-May-2007	14	28	33	KAEW	AK051	20.489	100.579	4.7	Laos
		14	28	37	HTUM	UJ009				
		14	28	54	MONT	OE002				
		14	28	56	MYOM	YC005				
104	16-May-2007	8	55	58	KAEW	AK052(1)	20.646	101.445	6.1	Laos
		8	56	4	HTUM	UJ010(1)				
		8	56	8	MONT	OE003(1)				
		8	56	8	MYOM	YC007(1)				
105	16-May-2007	8	55	58	KAEW	AK052(2)	20.108	99.986	4.9	Amphoe Mae Chan, Chiang Rai
		8	56	4	HTUM	UJ010(2)				
		8	56	8	MONT	OE003(2)				
		8	56	8	MYOM	YC007(2)				
106	16-May-2007	8	55	58	KAEW	AK052(3)	20.294	100.525	4.3	Thai-Laos Border
		8	56	4	HTUM	UJ010(3)				
		8	56	8	MONT	OE003(3)				
		8	56	8	MYOM	YC007(3)				
107	16-May-2007	9	7	36	KAEW	AK054	20.102	101.512	4.2	Laos
		9	7	41	HTUM	UJ011				
		9	7	45	MONT	OE005				
		9	7	48	MYOM	YC008				
108	16-May-2007	9	8	23	MYOM	YC009	20.421	101.440	3.9	Laos
		9	9	54	KAEW	AK055				
		9	10	29	HTUM	UJ012				
		9	10	32	MONT	OE006				
109	16-May-2007	9	13	14	KAEW	AK056	20.361	100.962	4.0	Laos
		9	13	19	HTUM	UJ013				
		9	13	25	MONT	OE007				
		9	13	54	MYOM	YC010				
110	16-May-2007	9	16	52	KAEW	AK059	20.504	100.805	3.9	Laos
		9	17	2	MONT	OE008				
		9	17	3	HTUM	UJ014				
111	16-May-2007	9	28	8	KAEW	AK062	20.317	99.936	4.3	Amphoe Chiang San, Chiang Rai
		9	28	26	HTUM	UJ015				
		9	28	41	MONT	OE011				
112	16-May-2007	9	30	49	KAEW	AK063	20.234	100.611	3.8	Laos
		9	31	1	MONT	OE012				
		9	31	19	HTUM	UJ016				
		9	31	31	MYOM	YC011				
113	16-May-2007	10	4	23	KAEW	AK066	21.003	100.514	4.0	Laos
		10	4	30	HTUM	UJ018				
		10	4	35	MONT	OE013				
		10	5	9	MYOM	YC012				
114	16-May-2007	10	15	31	KAEW	AK067	20.666	100.934	4.0	Laos
		10	15	36	HTUM	UJ019				
		10	15	42	MONT	OE014				
		10	16	10	MYOM	YC013				
115	16-May-2007	10	25	49	KAEW	AK068	20.581	101.070	4.1	Laos
		10	25	55	HTUM	UJ020				
		10	25	58	MONT	OE015				
116	16-May-2007	11	15	47	KAEW	AK069	20.420	101.197	4.2	Laos
		11	15	53	HTUM	UJ021				
		11	15	57	MONT	OE016				
		11	15	59	MYOM	YC014				
117	16-May-2007	11	35	3	KAEW	AK071	20.533	100.822	3.9	Laos
		11	35	9	HTUM	UJ022				
		11	35	15	MONT	OE017				
118	16-May-2007	11	43	42	KAEW	AK072	20.716	101.214	4.1	Laos
		11	43	48	HTUM	UJ023				
		11	43	51	MONT	OE018				
		11	43	57	MYOM	YC015				
119	16-May-2007	13	17	56	KAEW	AK074	20.540	101.051	4.5	Laos
		13	18	2	HTUM	UJ024				
		13	18	6	MONT	OE019				
		13	18	8	MYOM	YC016				
120	16-May-2007	15	22	17	KAEW	AK076(1)	20.424	101.436	3.8	Laos
		15	22	59	MONT	OE020				
		15	23	13	HTUM	UJ026				
		15	23	25	MYOM	YC017				

Table 3.5 The 181 KST's epicenters during the year 1999 to 2010 of this study (cont.).

No	Date	Start Time (UTC)			Station	File name	Location		M	Region
		hr	min	sec			Lat	Long		
121	16-May-2007	17	8	43	KAEW	AK078	20.309	101.364	4.1	Laos
		17	8	48	HTUM	UJ027				
		17	8	53	MONT	OE021				
		17	8	55	MYOM	YC018				
122	17-May-2007	3	25	32	KAEW	AK081	20.029	101.416	4.1	Laos
		3	25	39	HTUM	UJ029				
		3	25	43	MONT	OE023				
		3	26	11	MYOM	YC019				
123	18-May-2007	0	1	44	KAEW	AK082	20.087	101.254	3.9	Laos
		0	1	49	HTUM	UJ030				
		0	2	21	MONT	OE024				
		0	2	25	MYOM	YC022				
124	18-May-2007	1	41	3	KAEW	AK083	20.253	100.798	3.9	Laos
		1	41	9	HTUM	UJ031				
		1	41	24	MONT	OE025				
125	18-May-2007	13	5	4	KAEW	AK087	20.612	101.232	4.2	Laos
		13	5	11	HTUM	UJ032				
		13	5	16	MONT	OE026				
126	20-May-2007	1	21	7	KAEW	AK089	20.441	100.812	3.9	Laos
		1	21	14	HTUM	UJ033				
		1	21	32	MONT	OE027				
127	23-May-2007	17	6	15	KAEW	AK096	20.434	100.781	4.0	Laos
		17	6	21	HTUM	UJ034				
		18	6	26	MONT	OE030				
128	24-May-2007	11	15	4	KAEW	AL001	20.507	100.666	3.9	Laos
		11	15	10	HTUM	UK002				
		11	15	17	MONT	OF001				
129	7-Jun-2007	17	20	54	KAEW	AL007	20.606	100.879	4.7	Laos
		17	21	0	HTUM	UK011				
		17	21	3	MONT	OF006				
		17	21	6	MYOM	YF002				
130	19-Jun-2007	5	6	19	MONT	OF008	18.931	99.178	4.4	Amphoe Doi Saket, Chiang Mai
		5	6	21	KAEW	AL010				
		5	6	22	MYOM	YF008				
		5	6	29	HTUM	UK013				
131	23-Jun-2007	6	53	54	KAEW	AM001	19.629	96.758	4.9	Myanmar
		6	54	7	MONT	OG001				
		6	54	8	HTUM	UL001				
		6	54	43	MYOM	YG003				
132	23-Jun-2007	6	57	39	KAEW	AM002	19.698	97.331	4.6	Myanmar
		6	58	24	HTUM	UL002				
		6	58	29	MONT	OG002				
		6	59	4	MYOM	YG004				
133	23-Jun-2007	8	17	13	KAEW	AM003	20.887	98.861	5.9	Myanmar
		8	17	21	HTUM	UL003				
		8	17	23	MONT	OG003				
		8	17	24	MYOM	YG005-6				
134	23-Jun-2007	8	27	44	KAEW	AM004	21.461	99.352	5.8	Myanmar
		8	27	51	HTUM	UL004				
		8	27	53	MONT	OG004				
		8	28	1	MYOM	YG007				
135	28-Jul-2007	21	33	45	KAEW	AN005	20.576	100.153	4.3	Laos
		21	33	56	MONT	OI006				
		21	33	58	HTUM	UM003				
136	30-Jul-2007	22	42	32	KAEW	AN006	19.186	112.033	6.3	
		22	42	44	MONT	OI008				
		22	42	49	MYOM	YH028				
		22	42	57	HTUM	UM004				
137	6-Aug-2007	6	53	40	KAEW	AN010	20.501	100.814	4.1	Laos
		6	53	46	HTUM	UM006				
		6	53	52	MONT	OI013				
		6	54	17	MYOM	YH032				
138	6-Aug-2007	8	50	39	KAEW	AN011	20.327	100.704	3.8	Laos
		8	50	53	MONT	OI014				
		8	51	8	HTUM	UM007				
139	7-Aug-2007	8	53	18	KAEW	AN012	20.490	101.172	4.3	Laos
		8	53	26	HTUM	UM008				
		8	53	29	MONT	OI015				
		8	53	34	MYOM	YH033				

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No	Date	Start Time (UTC)			Station	File name	Location		M	Region
		hr	min	sec			Lat	Long		
140	8-Aug-2007	9	15	18	KAEW	AO001	20.320	100.441	3.9	Laos
		9	15	25	HTUM	OM009				
		9	15	30	MONT	OJ001				
		9	15	56	MYOM	YI002				
141	8-Aug-2007	17	9	24	MYOM	YI003-4	16.934	95.918	5.6	
		17	9	25	MONT	OJ002-3				
		17	9	31	KAEW	AO002				
		17	9	34	HTUM	UN001				
142	19-Aug-2007	11	16	43	KAEW	AO007	19.815	98.775	3.8	Thai-Laos Border
		11	16	49	MONT	OJ006				
		11	17	14	MYOM	YI007				
		11	17	19	HTUM	UN002				
143	8-Sep-2007	7	12	39	KAEW	AP001	20.466	100.783	4.1	Laos
		7	12	44	HTUM	UN001				
		7	12	50	MONT	OJ007				
		7	12	52	MYOM	YI024				
144	16-Oct-2007	2	38	47	MYOM	YJ005	18.661	100.142	2.5	Amphoe Song, Phrae
		2	38	53	MONT	OJ028				
		2	38	54	HTUM	UP003				
145	16-Oct-2007	6	46	42	KAEW	AP011	20.512	100.808	4.5	Laos
		6	46	48	HTUM	UP004				
		6	46	52	MONT	OJ029				
		6	46	54	MYOM	YJ006				
146	1-Nov-2007	19	5	33	KAEW	AR004	20.234	100.460	4.6	Laos
		19	5	39	HTUM	UP006				
		19	5	42	MONT	OJ035				
		19	5	46	MYOM	YJ018				
147	23-Dec-2007	11	18	57	HTUM	UP016	18.652	100.655	3.1	Amphoe Mueang, Nan
		11	19	4	MONT	OJ046				
		11	19	7	MYOM	EF243				
148	2-Mar-2008	3	22	17	MONT	OK016	18.707	100.088	3.1	Amphoe Ngao, Lampang
		3	22	58	MYOM	AJ027				
		3	23	5	HTUM	UQ007				
149	9-Apr-2008	15	47	44	MONT	OM001	19.394	99.620	3.2	Amphoe Wang Nuea, Lampang
		15	49	5	KAEW	AY001				
		15	49	22	MYOM	AL011				
150	12-May-2008	6	28	36	MONT	OM007	33.371	141.658	8.1	China
		6	30	31	HTUM	US005				
		6	30	38	KAEW	AY006				
		6	30	48	MYOM	AY109				
151	10-Jun-2008	21	35	17	MONT	OO004	20.652	100.794	4.8	Laos
		21	37	28	KAEW	BA002				
		21	37	34	HTUM	UU002				
		21	37	39	MYOM	AN006				
152	1-Jul-2008	9	42	45	MONT	OO006	19.420	99.538	3.8	Amphoe Wiaeng Pa Pao, Chiang Rai
		9	45	24	KAEW	BA003				
		9	45	32	MYOM	AN086				
		9	45	34	HTUM	UU005				
153	9-Jul-2008	4	36	22	MONT	OP004	18.701	100.248	2.2	Amphoe Song, Phrae
		4	39	11	MYOM	AO008				
		4	39	19	HTUM	UV003				
154	21-Aug-2008	12	25	25	KAEW	BB006-7	23.135	99.769	6.5	Myanmar-China Border
		12	25	33	HTUM	UV011				
		12	26	0	MYOM	AP020				
155	25-Nov-2008	8	5	35	MONT	XY013	18.816	100.277	2.6	Amphoe Chiaeng Muan, Phayao
		8	10	18	HTUM	UY009				
		8	10	18	MYOM	AT017				
156	29-Nov-2008	8	1	32	MONT	XY012	20.630	100.890	4.0	Laos
		8	6	12	KAEW	BF004				
		8	6	18	HTUM	UY010				
		8	6	29	MYOM	AT019				
157	31-Dec-2008	7	54	22	MONT	XZ005	18.653	100.650	3.7	Amphoe Mueang, Nan
		7	59	26	HTUM	UZ004				
		7	59	55	KAEW	BG004				
158	31-Dec-2008	7	58	32	MONT	XZ006	18.694	100.642	3.7	Amphoe Mueang, Nan
		8	3	36	HTUM	UZ005				
		8	4	5	KAEW	BG005				
159	29-Jan-2009	23	23	52	MONT	AC006	19.039	100.317	2.8	Amphoe Chiaeng Muan, Phayao
		23	23	57	KAEW	BI002				
		23	23	58	HTUM	VC002				

Table 3.5 The 181 KST's epicenters during the year 1999 to 2010 of this study (cont.).

No	Date	Start Time (UTC)			Station	File name	Location		M	Region
		hr	min	sec			Lat	Long		
160	6-Feb-2009	1	38	35	KAEW	BI003	19.505	99.717	2.8	Amphoe Phan, Chiang Rai
		1	38	59	HTUM	VC005				
		1	39	3	MONT	AD001				
161	22-May-2009	7	57	48	KAEW	BL003	20.294	101.086	4.3	Laos
		7	57	57	MONT	AZ005				
		7	58	3	HTUM	VE013				
		7	58	25	MYOM	NO010				
162	22-May-2009	18	50	28	KAEW	BL004	20.984	102.471	5.1	Laos
		18	50	37	MONT	AZ006				
		18	50	40	HTUM	VE016				
		18	50	42	MYOM	NO011				
163	1-Jun-2009	12	43	46	MYOM	NO 015	18.815	100.578	3.1	Amphoe Ban Luang, Nan
		12	43	49	MONT	AZ 013				
		12	43	50	HTUM	VE 021				
		12	44	6	KAEW	BL 009				
164	10-Jun-2009	0	23	14	MYOM	NO017	18.798	100.269	2.7	Amphoe Song, Phrae
		0	23	15	MONT	AZ015				
		0	23	24	HTUM	VE022				
165	10-Jun-2009	0	24	20	MYOM	NO018	18.829	100.277	2.7	Amphoe Chiang Muan, Phayao
		0	24	21	MONT	AZ016				
		0	24	30	HTUM	VE023				
		0	24	33	KAEW	BL011				
166	18-Jun-2009	19	49	31	MYOM	NP006	18.890	100.330	2.6	Amphoe Chiang Muan, Phayao
		19	49	32	MONT	BA004				
		19	49	41	HTUM	VF004				
		19	49	44	KAEW	BM005				
167	10-Aug-2009	19	56	53	MONT	GU003	14.967	94.629	6.8	Andaman Islands, India Region
		19	57	2	MYOM	NR002				
		19	57	4	KAEW	BW004				
		19	57	14	HTUM	VH003				
168	16-Aug-2009	17	56	59	MONT	IN004	20.535	100.288	4.2	Loas-Mynmar Border
		17	57	1	MYOM	NR011				
		17	57	4	HTUM	VH010				
169	1-Oct-2009	11	56	31	KAEW	DX001	20.022	103.047	4.1	Loas
		11	56	41	HTUM	VI026				
		11	56	44	MONT	JT018				
170	14-Oct-2009	1	58	30	KAEW	EL001	20.205	102.039	4.8	Loas
		1	58	38	MONT	JV007				
		1	58	41	HTUM	VL001				
		1	59	11	MYOM	PP001				
171	7-Nov-2009	3	55	21	KAEW	FJ001	20.377	101.304	3.9	Loas
		3	55	30	HTUM	WK001				
		3	55	35	MONT	JV036				
172	10-Nov-2009	7	36	45	KAEW	FM002	20.590	102.088	4.8	Loas
		7	36	9	MONT	JW001				
		7	36	18	HTUM	WN002				
		7	37	13	MYOM	QR003				
173	10-Nov-2009	8	2	6	MONT	JW002	20.109	101.440	4.3	Loas
		8	2	9	KAEW	FM003				
		8	2	18	HTUM	WN003				
174	10-Nov-2009	8	40	50	KAEW	FM004	20.276	101.413	4.1	Loas
		8	41	4	HTUM	WN004				
		8	41	2	MONT	JW003				
175	2-Dec-2009	7	2	32	KAEW	GJ001	19.310	99.203	3.3	Amphoe Phrao, Chiang Mai
		7	2	32	MONT	JW014				
		7	2	52	MYOM	RN001				
		7	3	7	HTUM	XK001				
176	26-Dec-2009	1	11	31	KAEW	HH001	20.695	99.665	4.0	Myanmar
		1	11	40	MONT	JX008				
		1	12	23	HTUM	YI001				
177	9-Mar-2010	13	3	6	KAEW	KC001	20.508	99.383	4.2	Myanmar
		13	3	15	MONT	KA004				
		13	3	18	MYOM	VP003				
178	26-Jun-2010	2	23	32	KAEW	OI001	20.183	99.524	3.9	Thai-Myanmar Border
		2	24	6	MONT	KC009				
		2	24	13	HTUM	FT002				
179	6-Jul-2010	15	23	25	HTUM	GD001	20.004	99.054	4.1	Thai-Myanmar Border
		15	23	3	KAEW	OS001				
		15	23	16	MONT	KC001				
		15	23	40	MYOM	AH001				

Table 3.5 The 181 KST's epicenters during the year 1999 to 2010 of this study (cont.).

No	Date	Start Time (UTC)			Station	File name	Location		M	Region
		hr	min	sec			Lat	Long		
180	18-Jul-2010	12	53	14	HTUM	GP001	20.249	100.978	3.8	Loas
		12	53	18	KAEW	PE001				
		12	53	11	MONT	KD001				
181	29-Aug-2010	8	18	46	HTUM	ID001	19.520	99.540	3.4	Amphoe Mae Suai, Chiang Rai
		8	18	24	KAEW	QU001				
		8	18	33	MONT	KD009				
		8	18	50	MYOM	CO001				

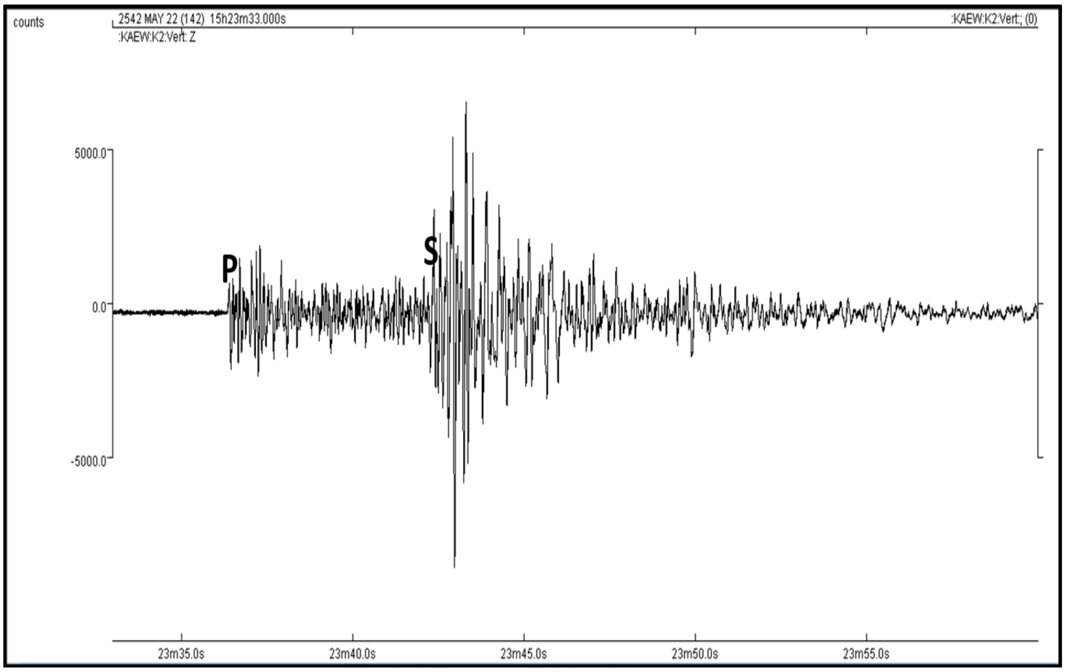


Figure 3. 20. Typical of seismogram which can read the arrival time of P- and S-wave (P: primary wave and S: secondary wave).

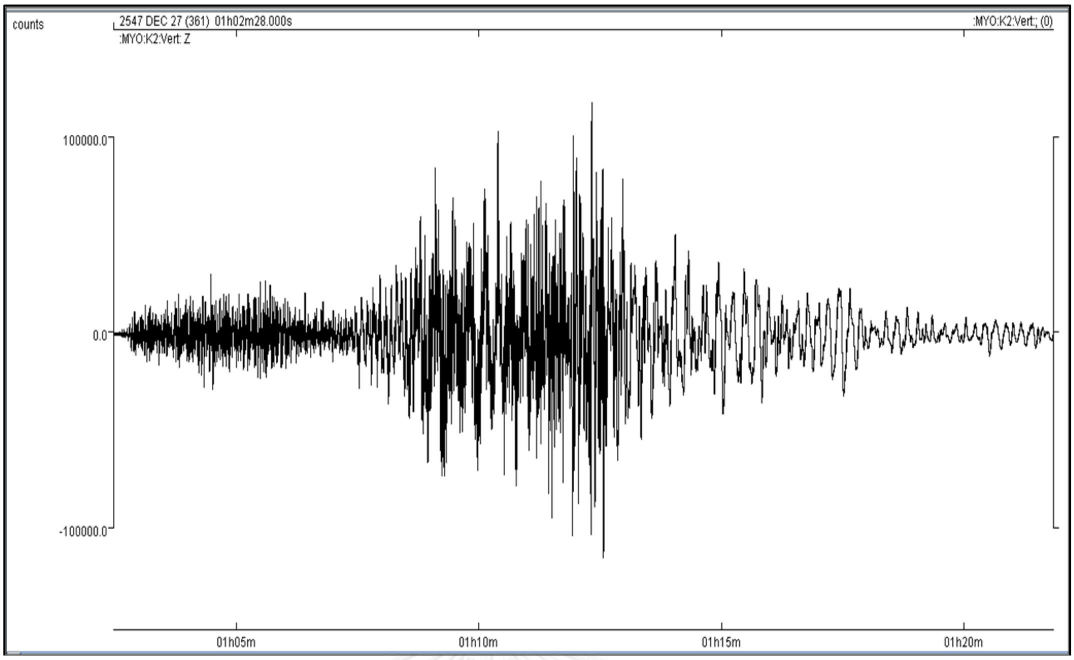


Figure 3. 21. Typical seismogram of teleseismic earthquake.

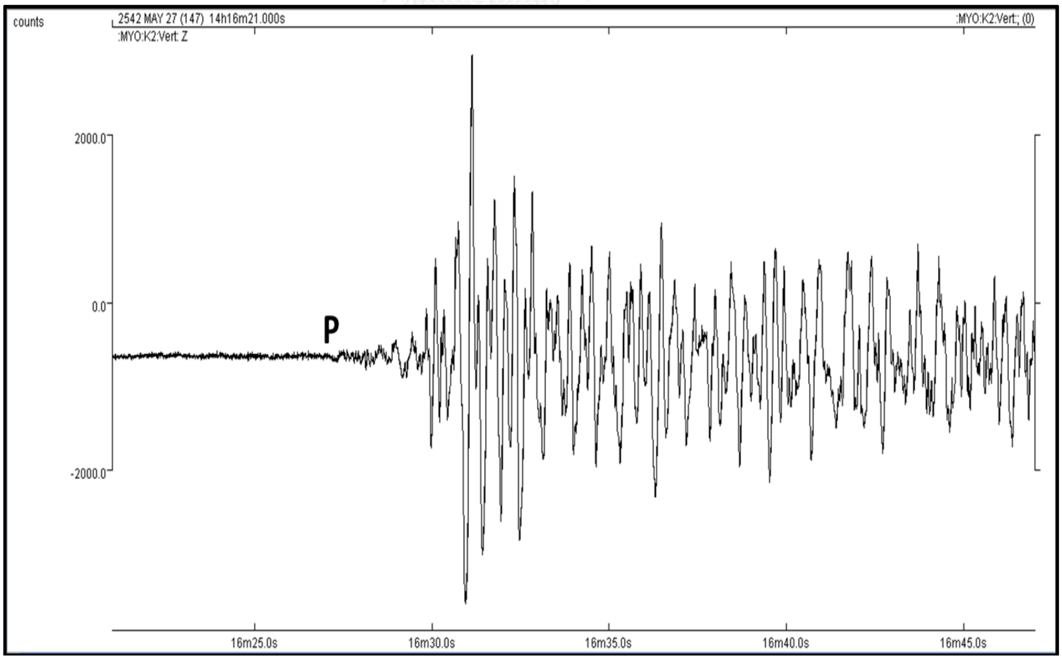


Figure 3. 22. Typical of seismogram which can read the arrival time of P-wave only (P: primary wave).

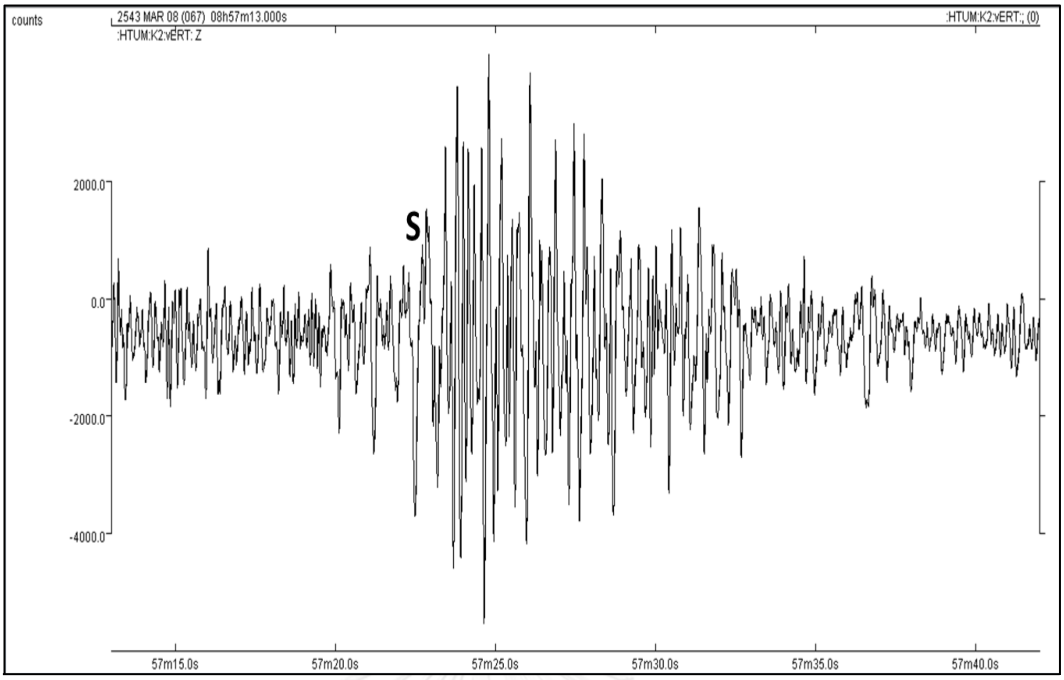


Figure 3. 23. Typical of seismogram which can read the arrival time of S-wave only (S: primary wave).

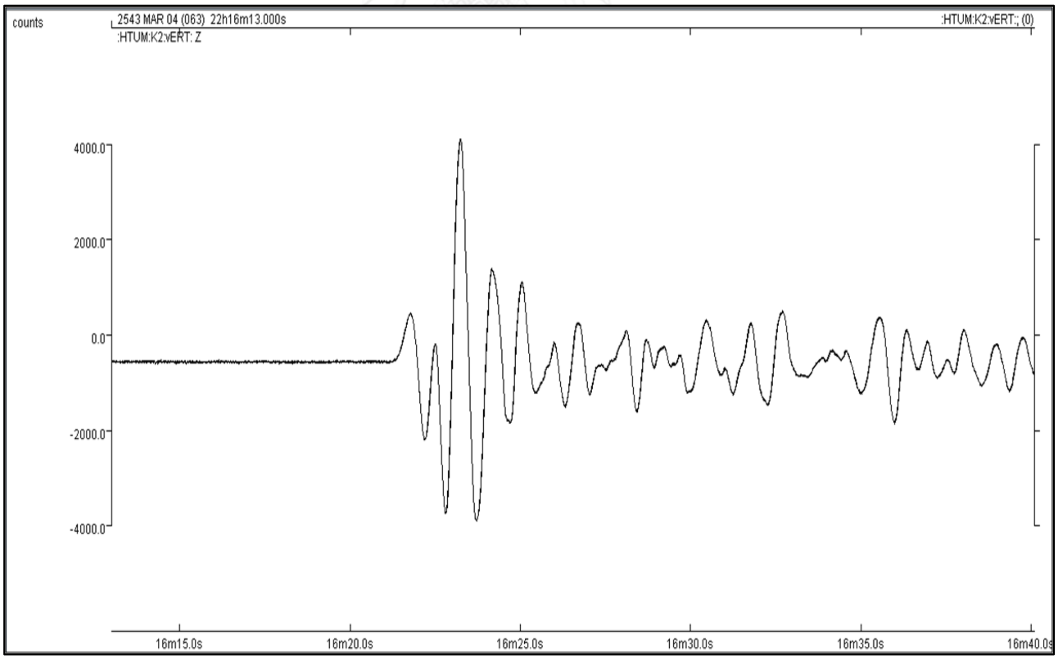


Figure 3. 24. Typical seismogram of long period wave.

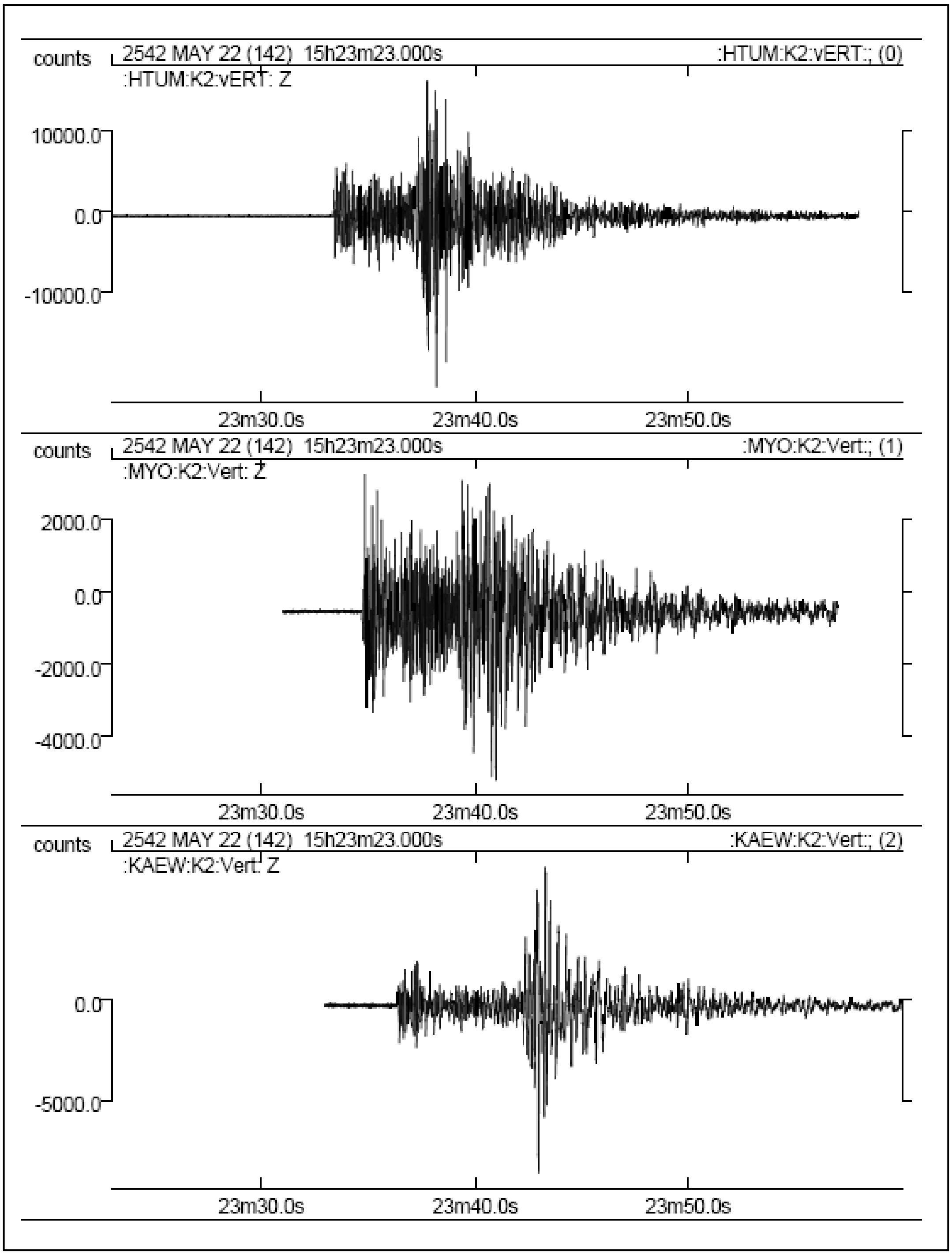


Figure 3. 25. Seismograms of earthquake on May 22, 1999 which the HTUM, the MYO, and the KAEW stations can read the arrival time of P-and S-wave.

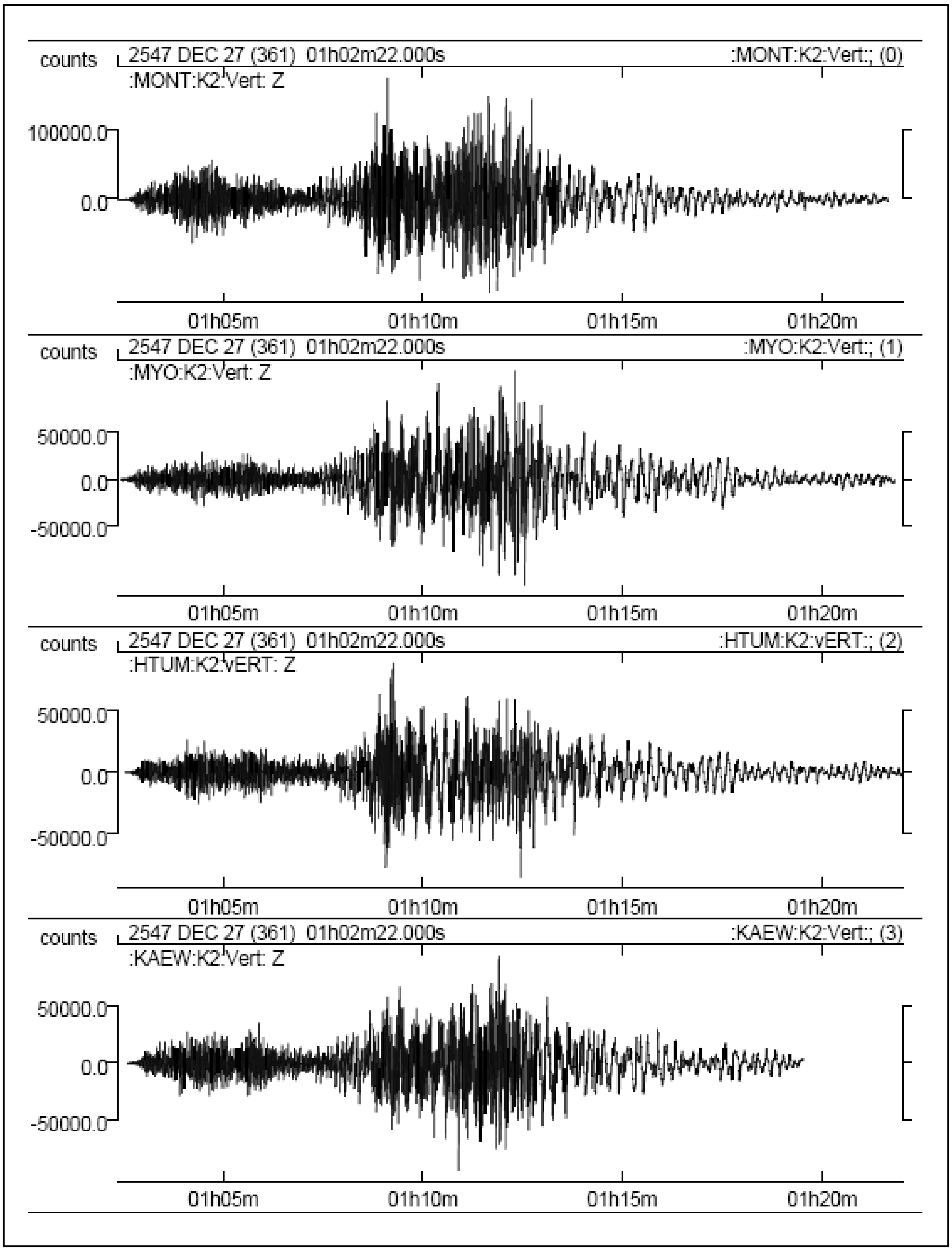


Figure 3. 26. Seismograms of teleseismic earthquake on December 26, 2004.

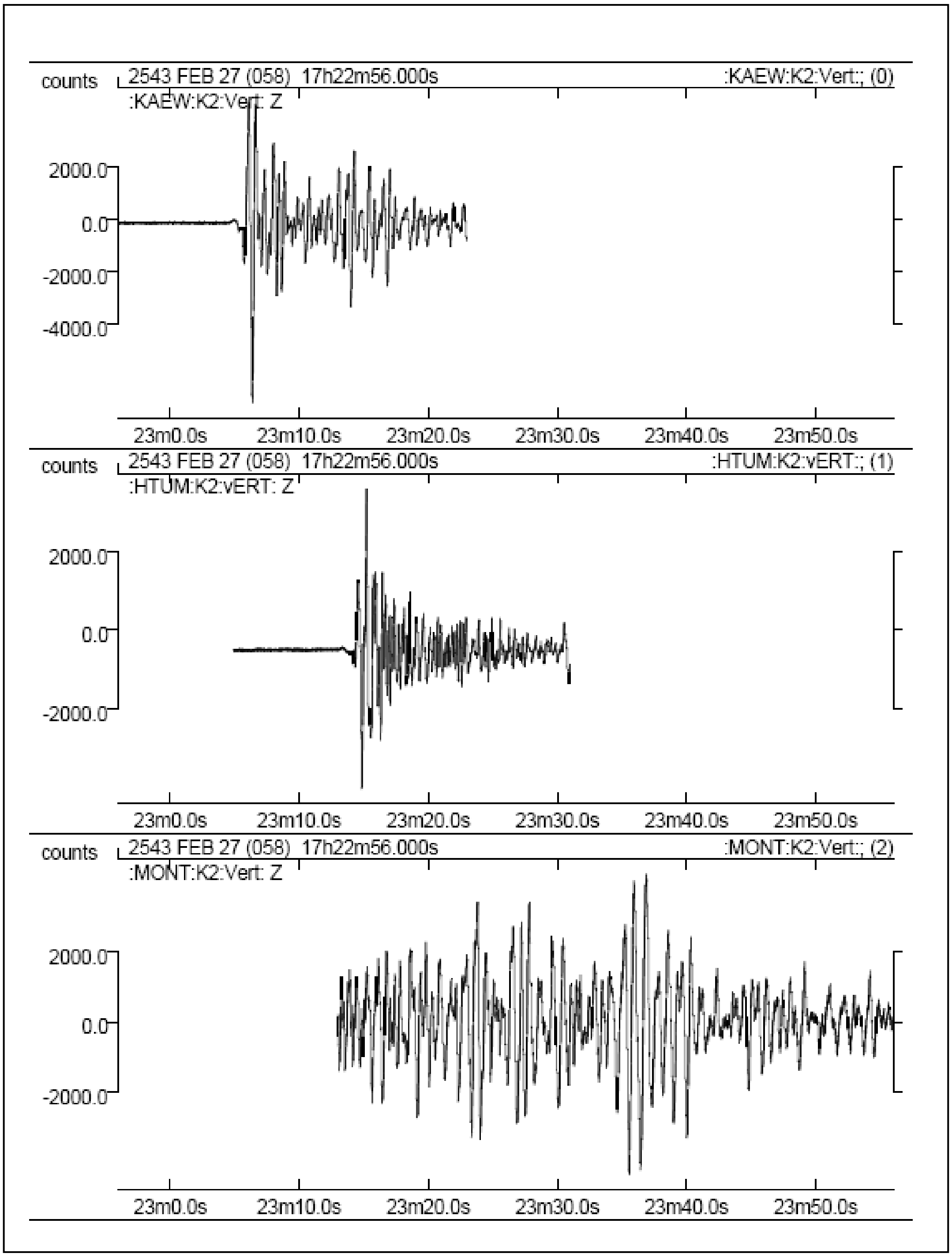


Figure 3. 27. Seismograms of earthquake on February 27, 2000 which the KAEW and the HTUM stations cannot read the arrival time of S-wave, and the MONT station cannot read the arrival time of P-wave.

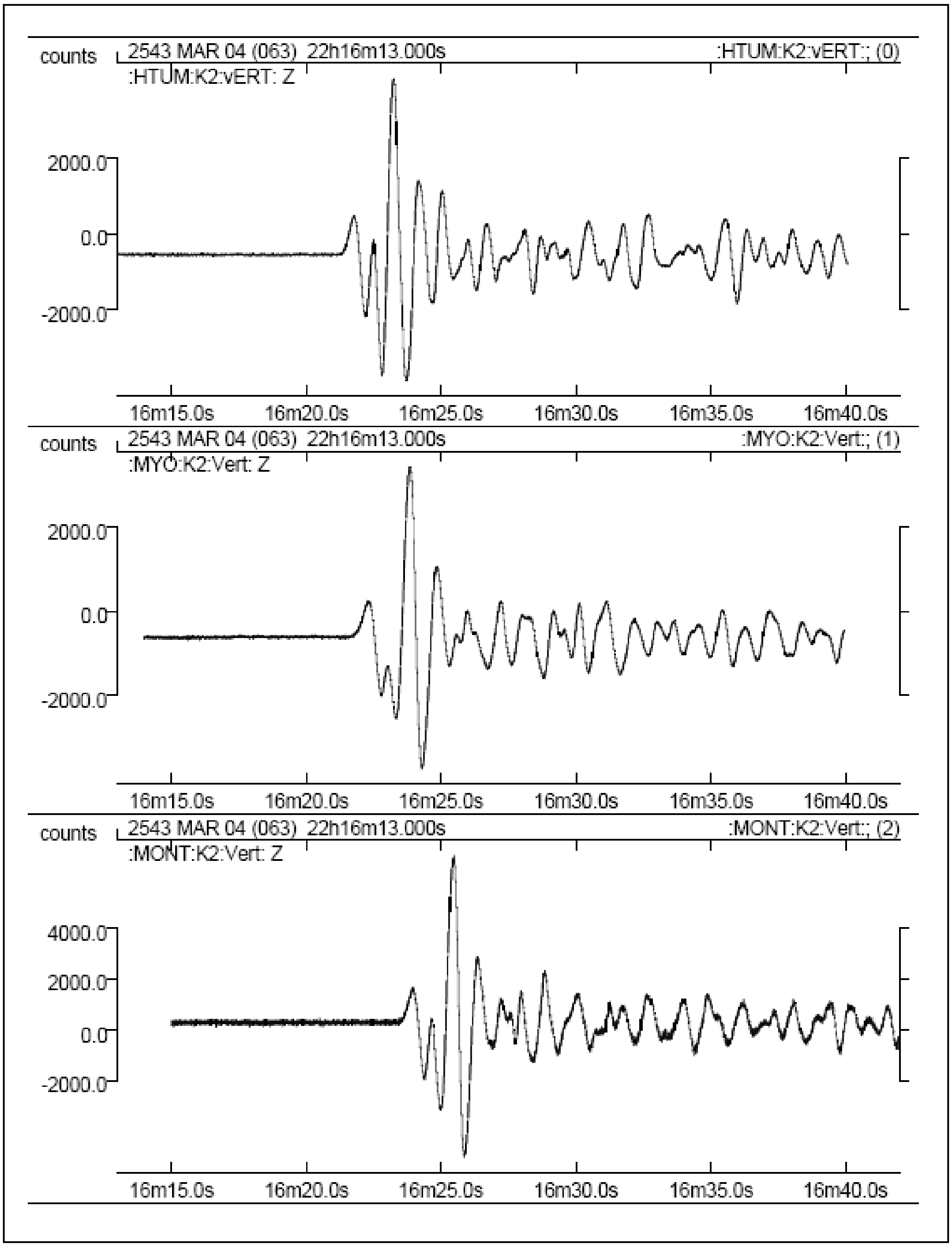


Figure 3. 28. Seismograms of long period earthquake on March 4, 2000.

After interpreting and screening seismograms of the 181 KST's epicenters, there were 118 events (Figure 3.29 and Table 3.6) of well-posted earthquakes data to be re-locating on the next step.

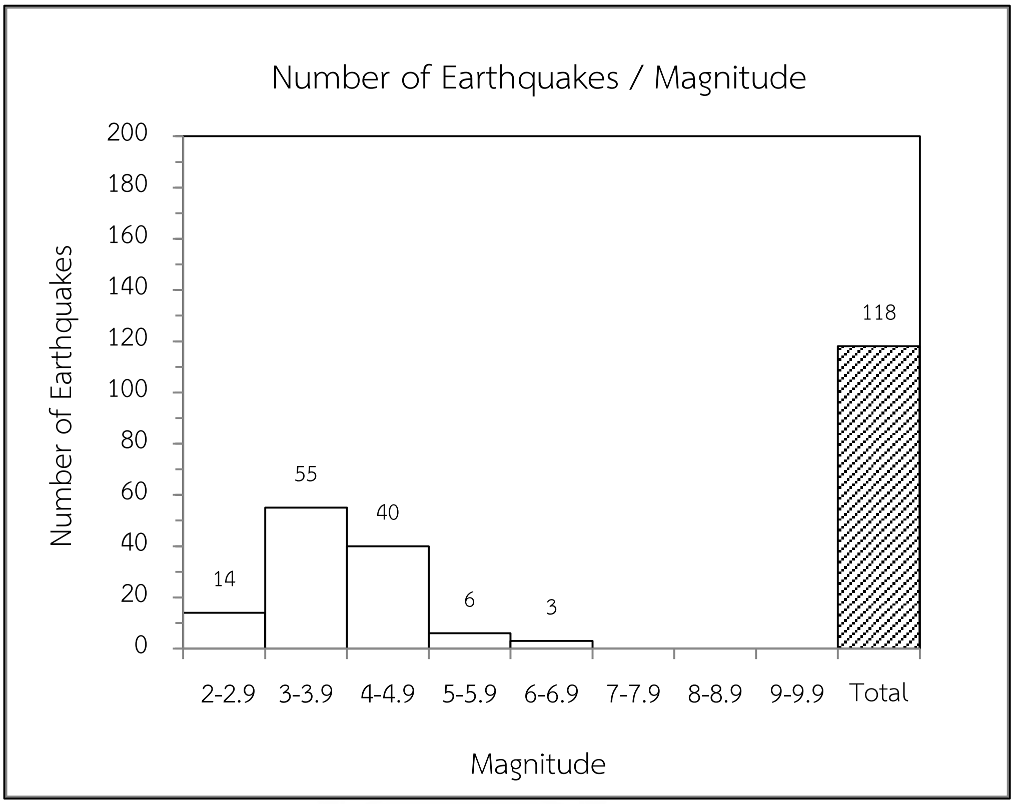


Figure 3. 29. Number of earthquakes and magnitude of the KST's epicenters after screening.

Table 3. 6 The 118 KST's epicenters of well-located earthquakes after screening.

No	Date	Start Time (UTC)			Station	File name	Location		M	Region
		hr	min	sec			Lat	Long		
1	22-May-1999	15	23	31	MYOM	BY080	18.900	100.200	2.0	Amphoe Chiang Muan, Phayao
		15	23	33	KAEW	AX010				
		15	23	33	HTUM	CZ006				
2	10-Aug-1999	23	14	30	MONT	CI185	18.950	100.040	3.1	Amphoe Mueang, Phayao
		23	14	33	KAEW	AY011				
		23	14	34	HTUM	CZ015				
3	19-Nov-1999	23	21	46	MONT	ES011	19.790	100.110	2.9	Amphoe Phaya Meng Rai, Chiang Rai
		23	21	47	MYOM	OX002				
		23	21	57	KAEW	BC002				
4	13-Apr-2000	13	13	50	HTUM	NU014	19.310	100.480	3.0	Amphoe Pong, Phayao
		13	13	56	KAEW	BV006				
		13	14	6	MONT	NP029				
5	5-Sep-2000	11	44	24	KAEW	MZ002	19.150	100.050	3.2	Amphoe Dok Kham Tai, Phayao
		11	44	28	MONT	RO001				
		11	44	36	MYOM	AM031				
6	7-May-2001	1	4	14	MYOM	EI045	18.310	100.440	3.3	Amphoe Rong Kwang, Phrae
		1	4	15	HTUM	AL004				
		1	4	18	MONT	WZ002				
7	26-Apr-2002	20	31	37	MONT	HZ076	18.910	99.080	4.5	Amphoe San Sai, Chiang Mai
		20	31	40	MYOM	GI316				
		20	31	47	HTUM	AO011				
8	2-Jul-2002	3	54	0	KAEW	AG012	19.610	99.380	5.0	Amphoe Mae Suai, Chiang Rai
		3	54	4	HTUM	EG005				
		3	54	11	MYOM	GK013				
		3	54	10	MONT	HZ114				
9	3-Jul-2002	0	17	44	KAEW	AG016	19.810	100.280	3.7	Amphoe Khun Tan, Chiang Rai
		0	17	48	HTUM	EG009				
		0	17	53	MONT	HZ117				
		0	17	54	MYOM	GK016				
10	21-Jul-2002	22	49	41	KAEW	AG024	19.920	100.900	4.1	Laos
		22	49	46	HTUM	EG014				
		22	49	51	MONT	IA009				
		22	50	10	MYOM	GM008				
11	7-Sep-2002	6	11	29	MYOM	GM035	18.580	100.300	3.5	Amphoe Song, Phrae
		6	11	31	HTUM	EH003				
		6	11	32	MONT	IR001				
		6	11	58	KAEW	AG033				
12	25-Sep-2002	14	27	36	KAEW	AG039	19.390	99.400	3.6	Amphoe Wiang Pa Pao, Chiang Rai
		14	27	41	MONT	LF001				
		14	27	44	MYOM	GM084				
		14	27	47	HTUM	EI001				
13	6-Nov-2002	5	21	10	MONT	OE001	18.670	99.980	2.9	Amphoe Ngao, Lampang
		5	21	12	MYOM	GM221				
		5	21	29	HTUM	EI009				
14	18-Dec-2002	13	47	10	KAEW	AG048	19.390	98.800	4.9	Amphoe Chiang Dao, Chiang Mai
		13	47	12	MONT	RM002				
		13	47	15	MYOM	GM287				
		13	47	19	HTUM	EI016				
15	29-Jan-2003	7	14	20	KAEW	AG058	19.760	100.600	3.9	Laos
		7	14	32	MONT	UM001				
		7	14	33	MYOM	GN042				
16	23-Aug-2003	8	57	38	MYOM	GQ045	18.577	99.244	3.5	Amphoe Mueang, Lamphun
		8	57	28	KAEW	AG079				
		8	57	23	MONT	EN001				
17	18-Sep-2003	11	4	15	KAEW	AG080	20.547	100.057	4.5	Myanmar
		11	4	26	MONT	FV001				
		11	4	28	MYOM	GQ096				
18	23-Nov-2003	15	8	20	KAEW	AG100	20.480	101.350	4.5	Laos
		15	8	25	HTUM	ON002				
		15	8	32	MYOM	GR096				
19	14-Mar-2004	5	49	35	KAEW	AG114	20.174	100.000	3.9	Amphoe Mae Chan, Chiang Rai
		5	49	39	HTUM	OW001				
		5	49	44	MYOM	GR299-300				
		5	49	44	MONT	ME006				
20	27-Mar-2004	4	5	26	KAEW	AG117	19.720	99.800	3.7	Amphoe Phan, Chiang Rai
		4	5	33	MONT	ME009				
		4	5	36	MYOM	GR324				
		4	5	37	HTUM	OW006				

Table 3.6 The 118 KST's epicenters of well-located earthquakes after screening (cont.).

No	Date	Start Time (UTC)			Station	File name	Location		M	Region
		hr	min	sec			Lat	Long		
21	17-Aug-2004	18	54	6	HTUM	OX007	17.320	100.650	4.1	Amphoe Chat Trakan, Phitsanulok
		18	54	7	MONT	MT010				
		18	54	20	MYOM	GR632				
		18	54	46	KAEW	AG125				
22	11-Sep-2004	1	31	56	MONT	MT015	18.810	98.800	3.6	Amphoe Hang Dong, Chiang Mai
		1	32	18	MYOM	GR651				
		1	32	18	KAEW	AG126				
23	26-Dec-2004	1	30	20	MYOM	GR953	21.630	103.300	6.6	Myanmar
		1	30	10	KAEW	AG143				
		1	30	16	MONT	MV022				
		1	30	19	HTUM	PB006				
24	30-Dec-2004	23	55	9	KAEW	AG157	20.940	97.750	6.4	Myanmar
		23	55	10	MONT	MV053				
		23	55	18	HTUM	PB011				
		23	55	23	MYOM	GR965				
25	25-Jan-2005	16	31	19	KAEW	AG160	22.520	100.740	4.9	Myanmar
		16	31	32	MONT	MV063				
		16	31	29	HTUM	PE001				
26	1-Apr-2005	7	18	13	KAEW	AG185	19.398	99.399	3.7	Amphoe Wiang Pa Pao, Chiang Rai
		7	18	18	MONT	MY001				
		7	18	23	HTUM	PF017				
27	4-Jun-2005	23	1	39	MYOM	GU029	17.817	100.706	3.8	Amphoe Nam Pat, Uttaradit
		23	1	40	HTUM	PF031				
		23	1	41	MONT	NA013				
28	9-Jun-2005	21	7	40	MYOM	GU036	18.544	100.259	2.4	Amphoe Song, Phrae
		21	7	42	MONT	NB002				
		21	7	48	HTUM	PF032				
29	29-Jun-2005	0	38	41	MONT	NC002	18.815	99.500	3.1	Amphoe Mueang Pan, Lampang
		0	38	43	MYOM	GU126				
		0	38	51	HTUM	PF033				
		0	39	5	KAEW	AJ001				
30	4-Dec-2005	9	34	33	MONT	NI015	18.770	99.000	4.2	Amphoe Mueang, Chiang Mai
		9	34	36	MYOM	GU591				
		9	34	38	KAEW	AJ022				
		9	34	43	HTUM	QK004-5				
31	7-Dec-2005	9	0	52	KAEW	AJ051	19.720	99.500	3.6	Amphoe Mae Suai, Chiang Rai
		9	1	2	MONT	NI017				
		9	1	4	HTUM	QK006-7				
		9	1	24	MYOM	GU605				
32	15-Dec-2005	6	48	22	KAEW	AJ053	19.450	100.300	4.1	Amphoe Chiang Kham, Phayao
		6	48	34	MONT	NI018				
		6	48	35	HTUM	QL002				
		6	48	36	MYOM	GU639				
33	15-Dec-2005	23	13	0	KAEW	AJ055	19.490	99.900	3.0	Amphoe Phan, Chiang Rai
		23	13	14	MONT	NI019				
		23	13	27	HTUM	QL003				
34	16-Dec-2005	2	13	30	KAEW	AJ057	19.490	99.830	3.6	Amphoe Phan, Chiang Rai
		2	13	41	MONT	NI020				
		2	13	43	MYOM	GU640				
		2	13	45	HTUM	QL005				
35	16-Dec-2005	2	15	24	KAEW	AJ058	19.490	99.930	3.7	Amphoe Pa Daed, Chiang Rai
		2	15	36	MONT	NI021				
		2	15	38	MYOM	GU641				
		2	13	37	HTUM	QL006				
36	17-Dec-2005	10	59	1	KAEW	AJ065	19.610	100.150	3.2	Amphoe Thoeng, Chiang Rai
		10	59	27	HTUM	QJ007				
		10	59	33	MONT	NI022				
37	17-Dec-2005	11	47	50	KAEW	AJ066	19.460	100.000	3.3	Amphoe Pa Daed, Chiang Rai
		11	48	3	MONT	NI023				
		11	48	4	MYOM	GU672				
		11	48	5	HTUM	QL008				
38	24-Jan-2006	13	42	25	KAEW	AJ081	20.890	98.460	5.5	Myanmar
		13	42	33	MONT	NI036				
		13	42	38	HTUM	QL014				
39	15-Feb-2006	16	54	2	KAEW	AJ094	19.134	100.207	3.4	Amphoe Pong, Phayao
		16	54	5	MONT	NI044				
		16	54	6	MYOM	GV147				

Table 3.6 The 118 KST's epicenters of well-located earthquakes after screening (cont.).

No	Date	Start Time (UTC)			Station	File name	Location		M	Region
		hr	min	sec			Lat	Long		
40	20-Feb-2006	18	33	47	KAEW	AJ098	19.138	100.221	2.8	Amphoe Pong, Phayao
		18	33	51	MONT	NI045				
		18	33	51	MYOM	GV156				
41	13-Oct-2006	15	35	7	KAEW	AK005	20.229	100.157	3.7	King Amphoe Doi Luang, Chiang Rai
		15	35	21	MONT	NY003				
		15	35	35	HTUM	UF001				
42	18-Oct-2006	12	0	35	MONT	NY005	18.945	100.116	3.2	Amphoe Dok Kham Tai, Phayao
		12	0	37	MYOM	HD143				
		12	0	39	HTUM	UF002				
		12	0	39	KAEW	AK006				
43	21-Oct-2006	1	58	31	KAEW	AK007	20.325	100.846	4.2	Laos
		1	58	39	HTUM	UF003				
		1	58	42	MONT	NY006				
		1	58	44	MYOM	HD144				
44	16-Nov-2006	18	38	32	KAEW	AK013	19.540	99.999	3.7	Amphoe Pa Daed, Chiang Rai
		18	38	44	MONT	NY013				
		18	38	46	HTUM	UG002				
		18	38	47	MYOM	HE021				
45	26-Nov-2006	19	32	32	HTUM	UG004	19.069	101.239	3.8	Amphoe Bo Kluea, Nan
		19	32	38	MYOM	HE036				
		19	32	41	MONT	NZ001				
		19	32	41	KAEW	AK014				
46	12-Dec-2006	17	2	6	MONT	NZ006	18.934	99.245	4.7	Amphoe Doi Saket, Chiang Mai
		17	2	8	KAEW	AK016				
		17	2	9	MYOM	NB001				
		17	2	14	HTUM	UG007				
47	12-Dec-2006	19	49	15	MONT	NZ011	18.965	99.189	3.8	Amphoe Doi Saket, Chiang Mai
		19	49	30	KAEW	AK019				
		19	49	42	HTUM	UG008				
48	12-Dec-2006	22	21	33	MONT	NZ012	19.008	99.144	3.6	Amphoe Doi Saket, Chiang Mai
		22	21	36	KAEW	AK020				
		22	22	2	HTUM	UG009				
49	13-Dec-2006	5	48	41	MONT	NZ014	18.899	99.256	3.9	Amphoe Doi Saket, Chiang Mai
		5	48	56	KAEW	AK022				
		5	48	58	MYOM	NO001				
50	23-Dec-2006	11	48	56	MONT	OA008	18.880	99.638	3.2	Amphoe Chae Hom, Lampang
		11	49	13	KAEW	AK025				
		11	49	15	MYOM	VW001				
51	25-Jan-2007	22	29	37	MONT	OB007	18.824	99.387	3.2	Amphoe Mueang Pan, Lampang
		22	29	43	KAEW	AK032				
		22	29	44	MYOM	XY187				
52	18-Feb-2007	8	52	23	HTUM	UI001	18.555	100.582	3.1	Amphoe Wiaeng Sa, Nan
		8	52	25	MYOM	YB006				
		8	52	28	MONT	OB013				
53	22-Apr-2007	6	17	31	KAEW	AK045	19.427	99.838	4.0	Amphoe Pa Daed, Chiang Rai
		6	17	39	MONT	OD009				
		6	17	42	MYOM	YB139				
		6	17	43	HTUM	UJ004				
54	15-May-2007	14	28	33	KAEW	AK051	20.489	100.579	4.7	Laos
		14	28	37	HTUM	UJ009				
		14	28	54	MONT	OE002				
		14	28	56	MYOM	YC005				
55	16-May-2007	8	55	58	KAEW	AK052(1)	20.646	101.445	6.1	Laos
		8	56	4	HTUM	UJ010(1)				
		8	56	8	MONT	OE003(1)				
		8	56	8	MYOM	YC007(1)				
56	16-May-2007	9	30	49	KAEW	AK063	20.234	100.611	3.8	Laos
		9	31	1	MONT	OE012				
		9	31	19	HTUM	UJ016				
		9	31	31	MYOM	YC011				
57	16-May-2007	10	4	23	KAEW	AK066	21.003	100.514	4.0	Laos
		10	4	30	HTUM	UJ018				
		10	4	35	MONT	OE013				
		10	5	9	MYOM	YC012				

Table 3.6 The 118 KST's epicenters of well-located earthquakes after screening (cont.).

No	Date	Start Time (UTC)			Station	File name	Location		M	Region
		hr	min	sec			Lat	Long		
		10	15	31	KAEW	AK067				
58	16-May-2007	10	15	36	HTUM	UJ019	20.666	100.934	4.0	Laos
		10	15	42	MONT	OE014				
		10	16	10	MYOM	YC013				
		10	25	49	KAEW	AK068				
59	16-May-2007	10	25	55	HTUM	UJ020	20.581	101.070	4.1	Laos
		10	25	58	MONT	OE015				
		11	15	47	KAEW	AK069				
60	16-May-2007	11	15	53	HTUM	UJ021	20.420	101.197	4.2	Laos
		11	15	57	MONT	OE016				
		11	15	59	MYOM	YC014				
		11	35	3	KAEW	AK071				
61	16-May-2007	11	35	9	HTUM	UJ022	20.533	100.822	3.9	Laos
		11	35	15	MONT	OE017				
		11	43	42	KAEW	AK072				
62	16-May-2007	11	43	48	HTUM	UJ023	20.716	101.214	4.1	Laos
		11	43	51	MONT	OE018				
		11	43	57	MYOM	YC015				
		13	17	56	KAEW	AK074				
63	16-May-2007	13	18	2	HTUM	UJ024	20.540	101.051	4.5	Laos
		13	18	6	MONT	OE019				
		13	18	8	MYOM	YC016				
		17	8	43	KAEW	AK078				
64	16-May-2007	17	8	48	HTUM	UJ027	20.309	101.364	4.1	Laos
		17	8	53	MONT	OE021				
		17	8	55	MYOM	YC018				
		3	25	32	KAEW	AK081				
65	17-May-2007	3	25	39	HTUM	UJ029	20.029	101.416	4.1	Laos
		3	25	43	MONT	OE023				
		3	26	11	MYOM	YC019				
		0	1	44	KAEW	AK082				
66	18-May-2007	0	1	49	HTUM	UJ030	20.087	101.254	3.9	Laos
		0	2	21	MONT	OE024				
		0	2	25	MYOM	YC022				
		1	41	3	KAEW	AK083				
67	18-May-2007	1	41	9	HTUM	UJ031	20.253	100.798	3.9	Laos
		1	41	24	MONT	OE025				
		13	5	4	KAEW	AK087				
68	18-May-2007	13	5	11	HTUM	UJ032	20.612	101.232	4.2	Laos
		13	5	16	MONT	OE026				
		1	21	7	KAEW	AK089				
69	20-May-2007	1	21	14	HTUM	UJ033	20.441	100.812	3.9	Laos
		1	21	32	MONT	OE027				
		17	6	15	KAEW	AK096				
70	23-May-2007	17	6	21	HTUM	UJ034	20.434	100.781	4.0	Laos
		18	6	26	MONT	OE030				
		11	15	4	KAEW	AL001				
71	24-May-2007	11	15	10	HTUM	UK002	20.507	100.666	3.9	Laos
		11	15	17	MONT	OF001				
		17	20	54	KAEW	AL007				
72	7-Jun-2007	17	21	0	HTUM	UK011	20.606	100.879	4.7	Laos
		17	21	3	MONT	OF006				
		17	21	6	MYOM	YF002				
		5	6	19	MONT	OF008				
73	19-Jun-2007	5	6	21	KAEW	AL010	18.931	99.178	4.4	Amphoe Doi Saket, Chiang Mai
		5	6	22	MYOM	YF008				
		5	6	29	HTUM	UK013				
		6	53	54	KAEW	AM001				
74	23-Jun-2007	6	54	7	MONT	OG001	19.629	96.758	4.9	Myanmar
		6	54	8	HTUM	UL001				
		6	54	43	MYOM	YG003				

Table 3.6 The 118 KST's epicenters of well-located earthquakes after screening (cont.).

No	Date	Start Time (UTC)			Station	File name	Location		M	Region
		hr	min	sec			Lat	Long		
75	23-Jun-2007	8	17	13	KAEW	AM003	20.887	98.861	5.9	Myanmar
		8	17	21	HTUM	UL003				
		8	17	23	MONT	OG003				
		8	17	24	MYOM	YG005-6				
76	23-Jun-2007	8	27	44	KAEW	AM004	21.461	99.352	5.8	Myanmar
		8	27	51	HTUM	UL004				
		8	27	53	MONT	OG004				
		8	28	1	MYOM	YG007				
77	28-Jul-2007	21	33	45	KAEW	AN005	20.576	100.153	4.3	Laos
		21	33	56	MONT	OI006				
		21	33	58	HTUM	UM003				
78	6-Aug-2007	6	53	40	KAEW	AN010	20.501	100.814	4.1	Laos
		6	53	46	HTUM	UM006				
		6	53	52	MONT	OI013				
		6	54	17	MYOM	YH032				
79	6-Aug-2007	8	50	39	KAEW	AN011	20.327	100.704	3.8	Laos
		8	50	53	MONT	OI014				
		8	51	8	HTUM	UM007				
80	7-Aug-2007	8	53	18	KAEW	AN012	20.490	101.172	4.3	Laos
		8	53	26	HTUM	UM008				
		8	53	29	MONT	OI015				
		8	53	34	MYOM	YH033				
81	8-Aug-2007	9	15	18	KAEW	AO001	20.320	100.441	3.9	Laos
		9	15	25	HTUM	OM009				
		9	15	30	MONT	OJ001				
		9	15	56	MYOM	YI002				
82	19-Aug-2007	11	16	43	KAEW	AO007	19.815	98.775	3.8	Thai-Laos Border
		11	16	49	MONT	OJ006				
		11	17	14	MYOM	YI007				
		11	17	19	HTUM	UN002				
83	8-Sep-2007	7	12	39	KAEW	AP001	20.466	100.783	4.1	Laos
		7	12	44	HTUM	UN001				
		7	12	50	MONT	OJ007				
		7	12	52	MYOM	YI024				
84	16-Oct-2007	2	38	47	MYOM	YJ005	18.661	100.142	2.5	Amphoe Song, Phrae
		2	38	53	MONT	OJ028				
		2	38	54	HTUM	UP003				
85	16-Oct-2007	6	46	42	KAEW	AP011	20.512	100.808	4.5	Laos
		6	46	48	HTUM	UP004				
		6	46	52	MONT	OJ029				
		6	46	54	MYOM	YJ006				
86	1-Nov-2007	19	5	33	KAEW	AR004	20.234	100.460	4.6	Laos
		19	5	39	HTUM	UP006				
		19	5	42	MONT	OJ035				
		19	5	46	MYOM	YJ018				
87	23-Dec-2007	11	18	57	HTUM	UP016	18.652	100.655	3.1	Amphoe Mueang, Nan
		11	19	4	MONT	OJ046				
		11	19	7	MYOM	EF243				
88	2-Mar-2008	3	22	17	MONT	OK016	18.707	100.088	3.1	Amphoe Ngao, Lampang
		3	22	58	MYOM	AJ027				
		3	23	5	HTUM	UQ007				
89	9-Apr-2008	15	47	44	MONT	OM001	19.394	99.620	3.2	Amphoe Wang Nuea, Lampang
		15	49	5	KAEW	AY001				
		15	49	22	MYOM	AL011				
90	10-Jun-2008	21	35	17	MONT	OO004	20.652	100.794	4.8	Laos
		21	37	28	KAEW	BA002				
		21	37	34	HTUM	UU002				
		21	37	39	MYOM	AN006				
91	1-Jul-2008	9	42	45	MONT	OO006	19.420	99.538	3.8	Amphoe Wiaeng Pa Pao, Chiang Rai
		9	45	24	KAEW	BA003				
		9	45	32	MYOM	AN086				
		9	45	34	HTUM	UU005				
92	9-Jul-2008	4	36	22	MONT	OP004	18.701	100.248	2.2	Amphoe Song, Phrae
		4	39	11	MYOM	AO008				
		4	39	19	HTUM	UV003				

Table 3.6. The 118 KST's epicenters of well-located earthquakes after screening (cont.).

No	Date	Start Time (UTC)			Station	File name	Location		M	Region
		hr	min	sec			Lat	Long		
93	25-Nov-2008	8	5	35	MONT	XY013	18.816	100.277	2.6	Amphoe Chiaeng Muan, Phayao
		8	10	18	HTUM	UY009				
		8	10	18	MYOM	AT017				
94	29-Nov-2008	8	1	32	MONT	XY012	20.630	100.890	4.0	Laos
		8	6	12	KAEW	BF004				
		8	6	18	HTUM	UY010				
		8	6	29	MYOM	AT019				
95	31-Dec-2008	7	54	22	MONT	XZ005	18.653	100.650	3.7	Amphoe Mueang, Nan
		7	59	26	HTUM	UZ004				
		7	59	55	KAEW	BG004				
96	31-Dec-2008	7	58	32	MONT	XZ006	18.694	100.642	3.7	Amphoe Mueang, Nan
		8	3	36	HTUM	UZ005				
		8	4	5	KAEW	BG005				
97	29-Jan-2009	23	23	52	MONT	AC006	19.039	100.317	2.8	Amphoe Chiaeng Muan, Phayao
		23	23	57	KAEW	BI002				
		23	23	58	HTUM	VC002				
98	6-Feb-2009	1	38	35	KAEW	BI003	19.505	99.717	2.8	Amphoe Phan, Chiang Rai
		1	38	59	HTUM	VC005				
		1	39	3	MONT	AD001				
99	22-May-2009	7	57	48	KAEW	BL003	20.294	101.086	4.3	Laos
		7	57	57	MONT	AZ005				
		7	58	3	HTUM	VE013				
		7	58	25	MYOM	NO010				
100	22-May-2009	18	50	28	KAEW	BL004	20.984	102.471	5.1	Laos
		18	50	37	MONT	AZ006				
		18	50	40	HTUM	VE016				
		18	50	42	MYOM	NO011				
101	1-Jun-2009	12	43	46	MYOM	NO 015	18.815	100.578	3.1	Amphoe Ban Luang, Nan
		12	43	49	MONT	AZ 013				
		12	43	50	HTUM	VE 021				
		12	44	6	KAEW	BL 009				
102	10-Jun-2009	0	23	14	MYOM	NO017	18.798	100.269	2.7	Amphoe Song, Phrae
		0	23	15	MONT	AZ015				
		0	23	24	HTUM	VE022				
103	10-Jun-2009	0	24	20	MYOM	NO018	18.829	100.277	2.7	Amphoe Chiang Muan, Phayao
		0	24	21	MONT	AZ016				
		0	24	30	HTUM	VE023				
		0	24	33	KAEW	BL011				
104	18-Jun-2009	19	49	31	MYOM	NP006	18.890	100.330	2.6	Amphoe Chiang Muan, Phayao
		19	49	32	MONT	BA004				
		19	49	41	HTUM	VF004				
		19	49	44	KAEW	BM005				
105	16-Aug-2009	17	56	59	MONT	IN004	20.535	100.288	4.2	Loas-Mynmar Border
		17	57	1	MYOM	NR011				
		17	57	4	HTUM	VH010				
106	1-Oct-2009	11	56	31	KAEW	DX001	20.022	103.047	4.1	Loas
		11	56	41	HTUM	VI026				
		11	56	44	MONT	JT018				
107	14-Oct-2009	1	58	30	KAEW	EL001	20.205	102.039	4.8	Loas
		1	58	38	MONT	JV007				
		1	58	41	HTUM	VL001				
		1	59	11	MYOM	PP001				
108	7-Nov-2009	3	55	21	KAEW	FJ001	20.377	101.304	3.9	Loas
		3	55	30	HTUM	WK001				
		3	55	35	MONT	JV036				
109	10-Nov-2009	7	36	45	KAEW	FM002	20.590	102.088	4.8	Loas
		7	36	9	MONT	JW001				
		7	36	18	HTUM	WN002				
		7	37	13	MYOM	QR003				
110	10-Nov-2009	8	2	6	MONT	JW002	20.109	101.440	4.3	Loas
		8	2	9	KAEW	FM003				
		8	2	18	HTUM	WN003				
111	10-Nov-2009	8	40	50	KAEW	FM004	20.276	101.413	4.1	Loas
		8	41	4	HTUM	WN004				
		8	41	2	MONT	JW003				

Table 3.6. The 118 KST's epicenters of well-located earthquakes after screening

No	Date	Start Time (UTC)			Station	File name	Location		M	Region
		hr	min	sec			Lat	Long		
112	2-Dec-2009	7	2	32	KAEW	GJ001	19.310	99.203	3.3	Amphoe Phrao, Chiang Mai
		7	2	32	MONT	JW014				
		7	2	52	MYOM	RN001				
		7	3	7	HTUM	XK001				
113	26-Dec-2009	1	11	31	KAEW	HH001	20.695	99.665	4.0	Myanmar
		1	11	40	MONT	JX008				
		1	12	23	HTUM	YI001				
114	9-Mar-2010	13	3	6	KAEW	KC001	20.508	99.383	4.2	Myanmar
		13	3	15	MONT	KA004				
		13	3	18	MYOM	VP003				
115	26-Jun-2010	2	23	32	KAEW	OI001	20.183	99.524	3.9	Thai-Myanmar Border
		2	24	6	MONT	KC009				
		2	24	13	HTUM	FT002				
116	6-Jul-2010	15	23	25	HTUM	GD001	20.004	99.054	4.1	Thai-Myanmar Border
		15	23	3	KAEW	OS001				
		15	23	16	MONT	KC001				
		15	23	40	MYOM	AH001				
117	18-Jul-2010	12	53	14	HTUM	GP001	20.249	100.978	3.8	Loas
		12	53	18	KAEW	PE001				
		12	53	11	MONT	KD001				
118	29-Aug-2010	8	18	46	HTUM	ID001	19.520	99.540	3.4	Amphoe Mae Suai, Chiang Rai
		8	18	24	KAEW	QU001				
		8	18	33	MONT	KD009				
		8	18	50	MYOM	CO001				

To re-check the well-posted earthquake events that may remain or missed from the previous analysis work. There were 10 well-located earthquakes which remain in these seismograms list (Table 3.7 and Figure 3.30-Figure 3.39) that need to be re-located for the epicenters. Thus from Table 3.6 and Table 3.7 there were a total of 128 well-located earthquakes that can be used to re-locate epicenters, and 20 strong ground-motion earthquakes (Figure 3.18) that can be used to analyze ground motion parameters in the next step.

Table 3. 7 The 10 new well-located earthquakes after interpreting seismograms.

No	Date	Start Time (UTC)			Station	File name	Location		M	Region
		hr	min	sec			Lat	Long		
		6	39	1	MYOM	CP001				
1	29-Jun-1999	6	38	55	KAEW	AY003				
		6	39	9	MONT	CI149				
		17	35	48	KAEW	AY006				
2	15-Jul-1999	17	36	2	MONT	CI175				
		17	36	1	HTUM	CZ010				
		23	15	21	KAEW	AY012				
3	10-Aug-1999	23	15	11	MONT	CI186				
		23	15	15	HTUM	CZ016				
		1	4	18	MONT	WZ002				
		5	36	34	MYOM	GH029				
4	7-Nov-2001	5	36	36	KAEW	VD002				
		5	36	36	MONT	CZ001				
		17	55	16	KAEW	AG015				
5	2-Jul-2002	17	55	24	MONT	HZ116				
		17	55	19	HTUM	EG008				
		4	29	40	MYOM	GO022				
6	15-Mar-2003	4	29	32	KAEW	AG062				
		4	29	37	MONT	WQ001				
		5	15	33	MYOM	HD061				
7	6-Aug-2006	5	15	30	MONT	NW002				
		5	15	42	HTUM	RP002				
		14	16	44	MYOM	YB143				
8	23-Apr-2007	14	16	33	KAEW	AK046				
		14	16	41	MONT	OD010				
		14	16	45	HTUM	UJ005				
		8	29	6	KAEW	AN003				
9	14-Jul-2007	8	29	17	MONT	OH002				
		8	29	12	HTUM	UM001				
		18	5	36	KAEW	BM006				
10	21-Jun-2009	18	5	48	MONT	BA007				
		18	5	57	HTUM	VF005				

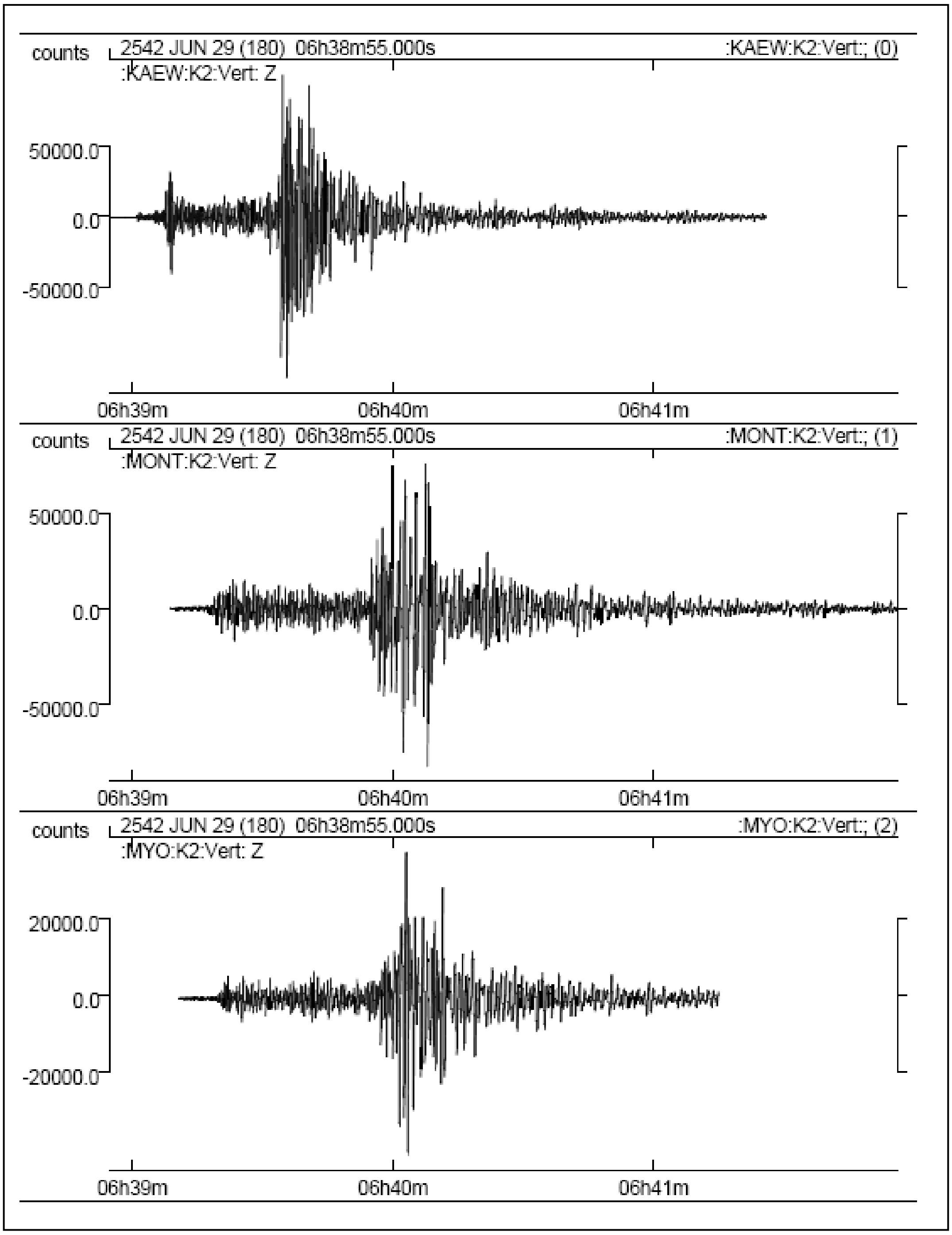


Figure 3. 30. Seismograms of well-located earthquake on June 29, 1999 from seismograph at the KAEW, the MONT and the MYOM stations.

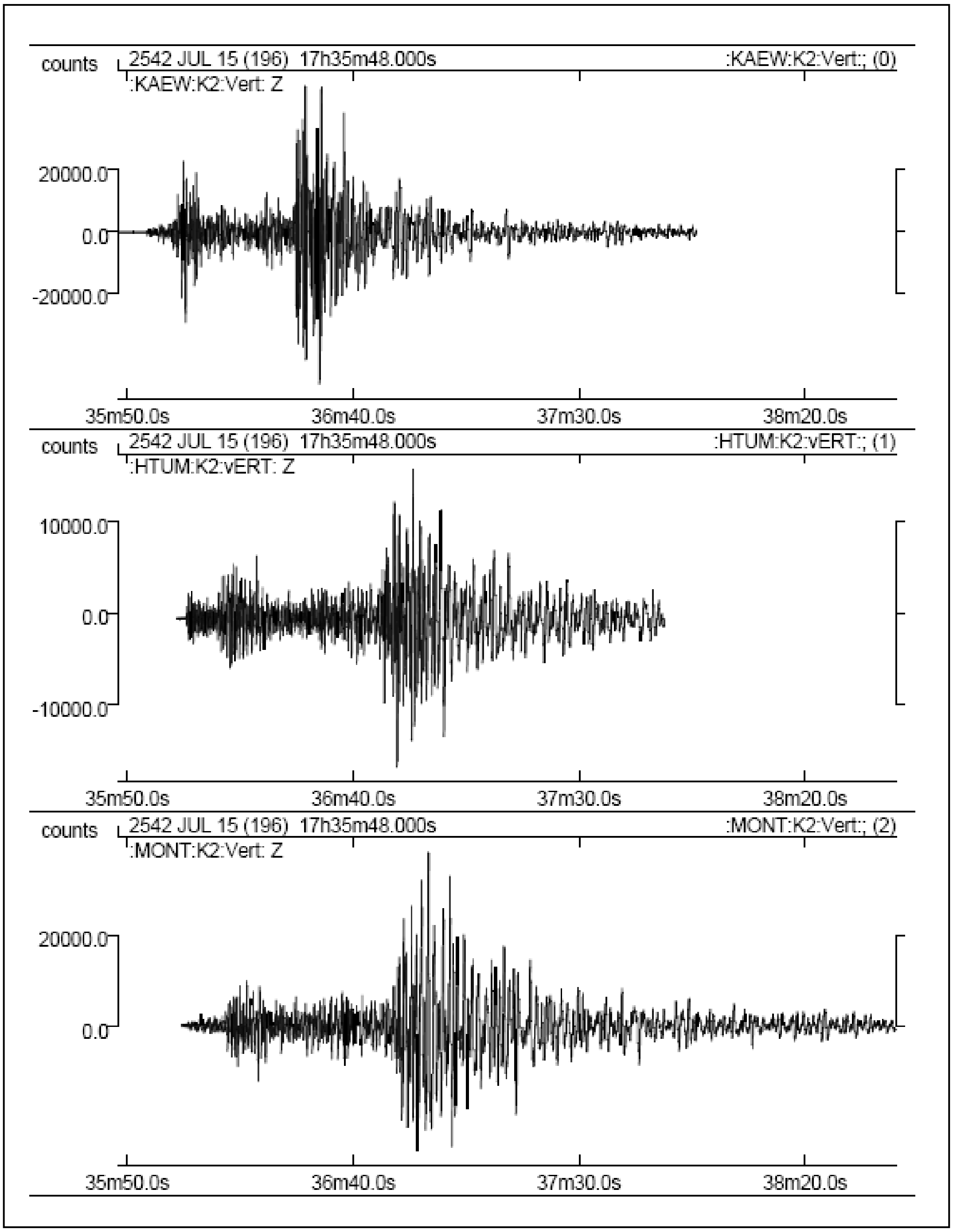


Figure 3. 31. Seismograms of well-located earthquake on July 15, 1999 from seismograph at the KAEW, the HTUM and the MONT stations.

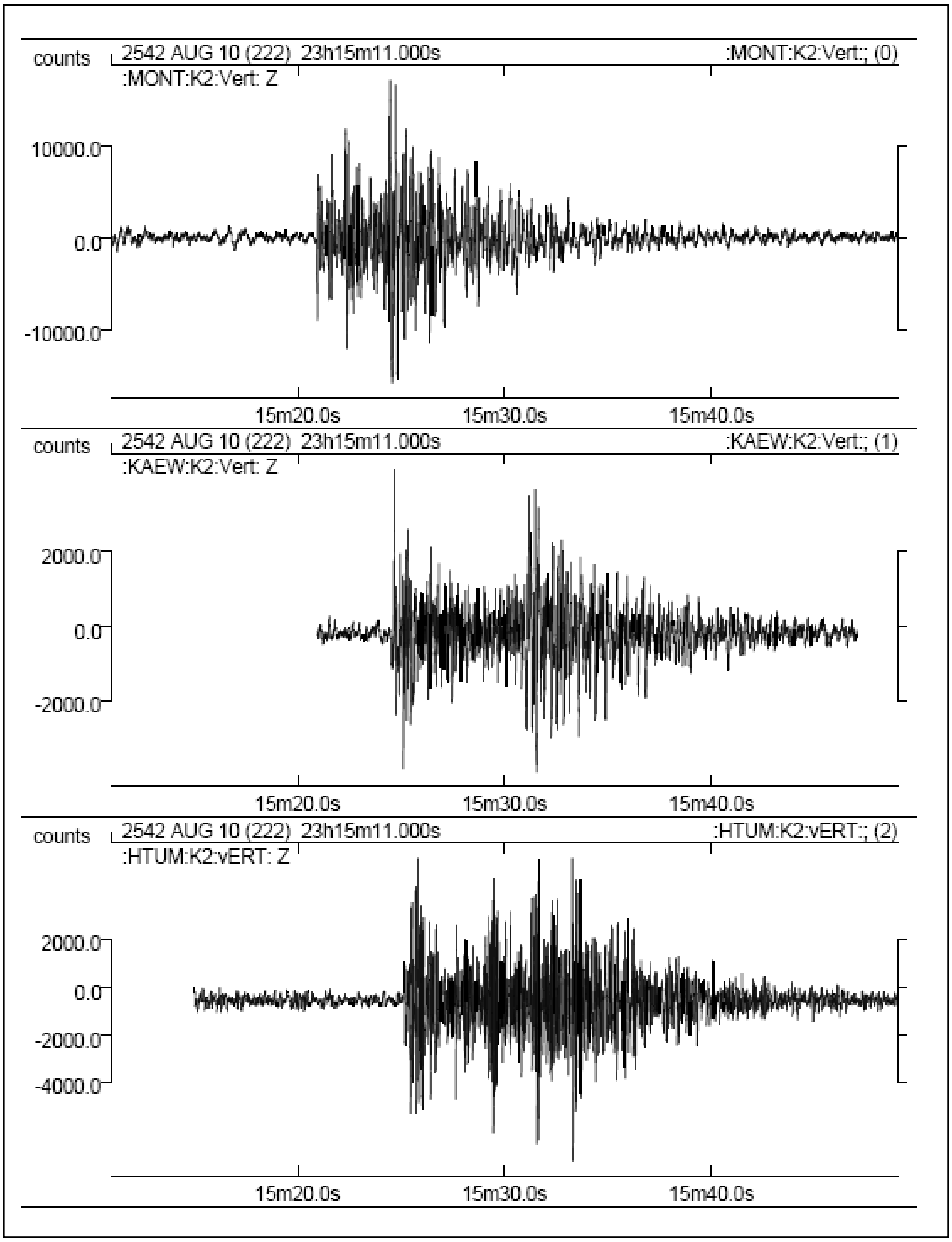


Figure 3. 32. Seismograms of well-located earthquake on August 10, 1999 which can read the arrival time of P and S-wave from 3 stations (the MONT, the KAEW, and the HTUM).

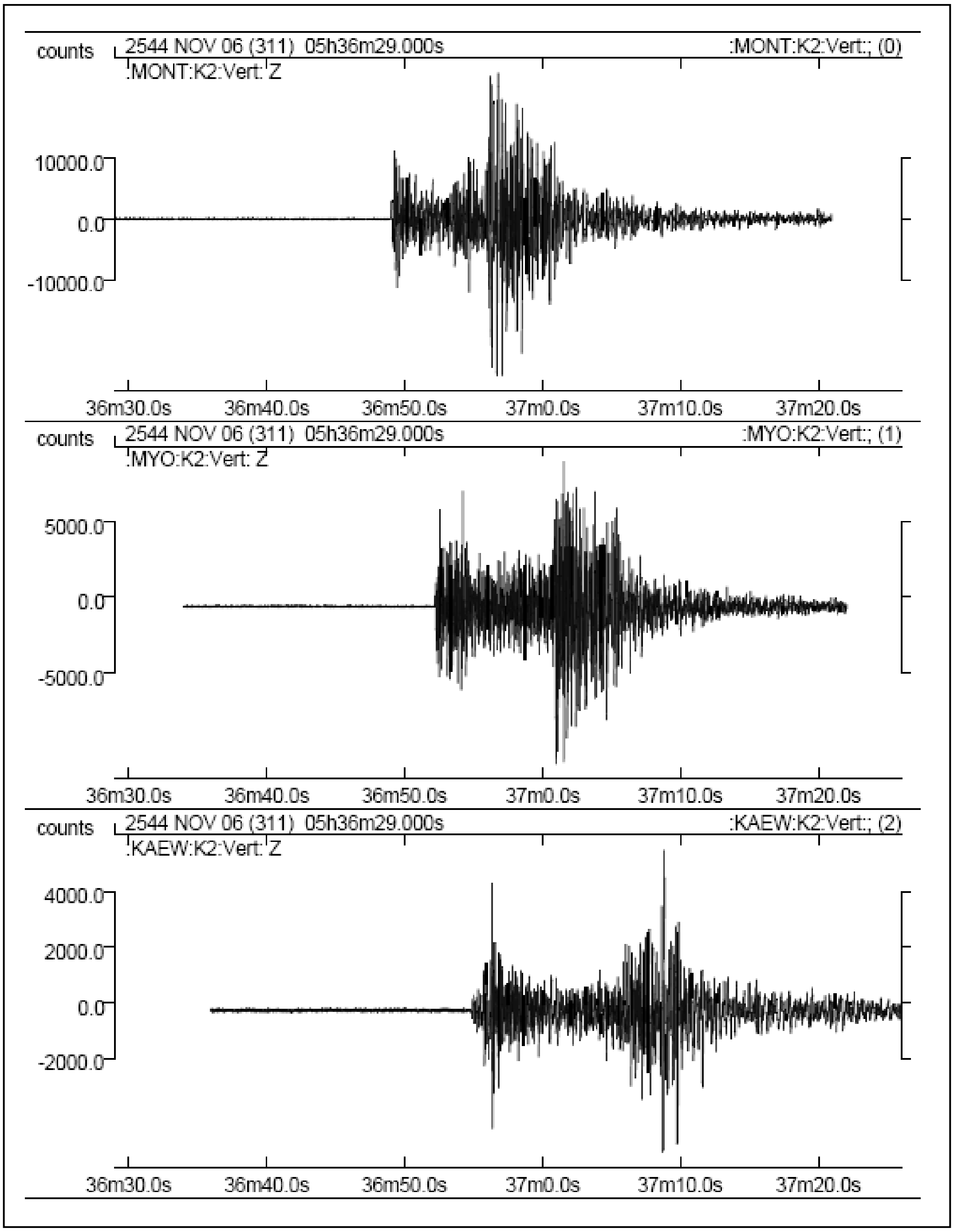


Figure 3. 33. Seismograms of well-located earthquake on November 6, 2001 which can read the arrival time of P and S-wave from 3 stations (the MONT, the MYOM, and the KAEW).

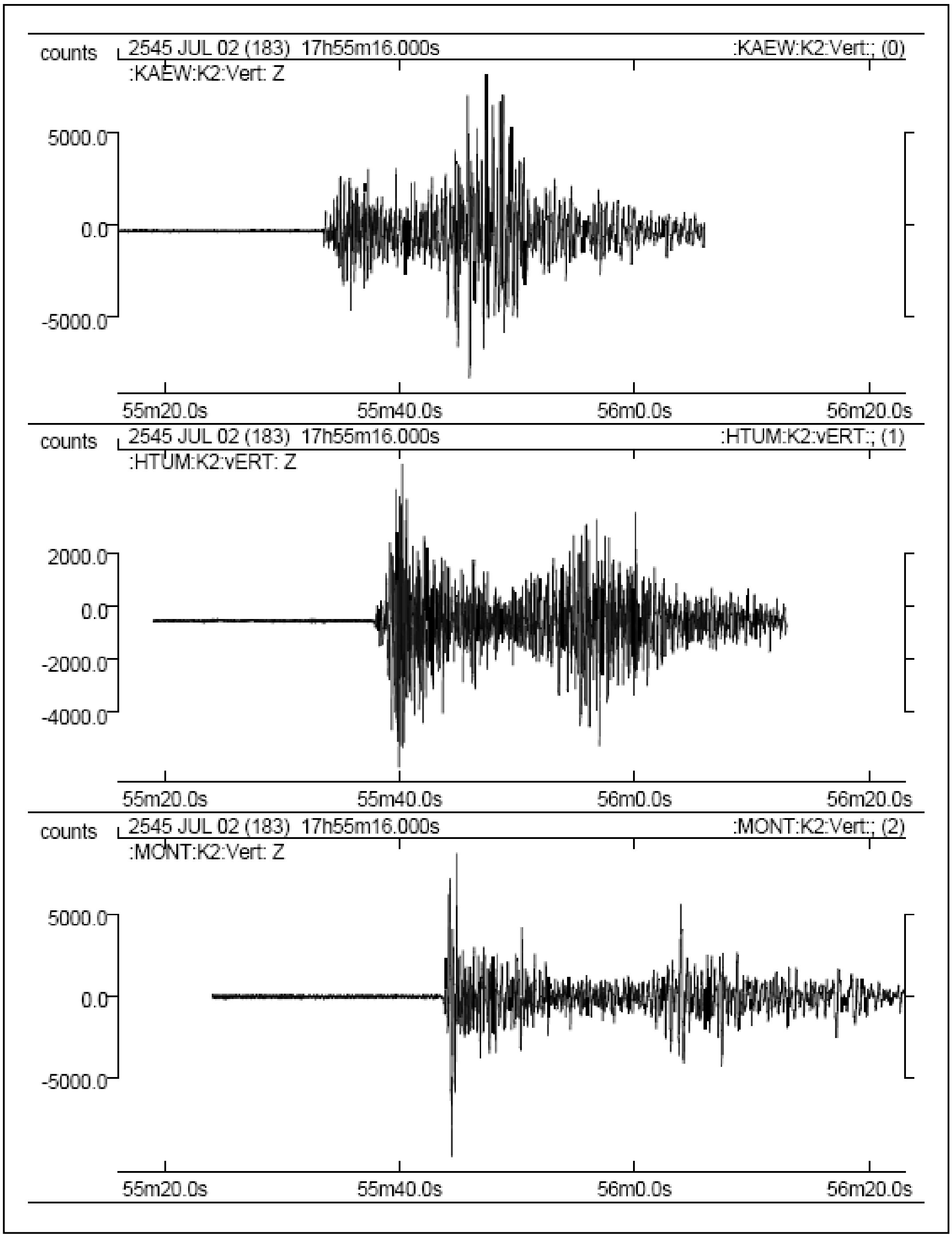


Figure 3. 34. Seismograms of well-located earthquake on July 2, 2002 which can read the arrival time of P and S-wave from 3 stations (the KAEW, the HTUM, and the MONT).

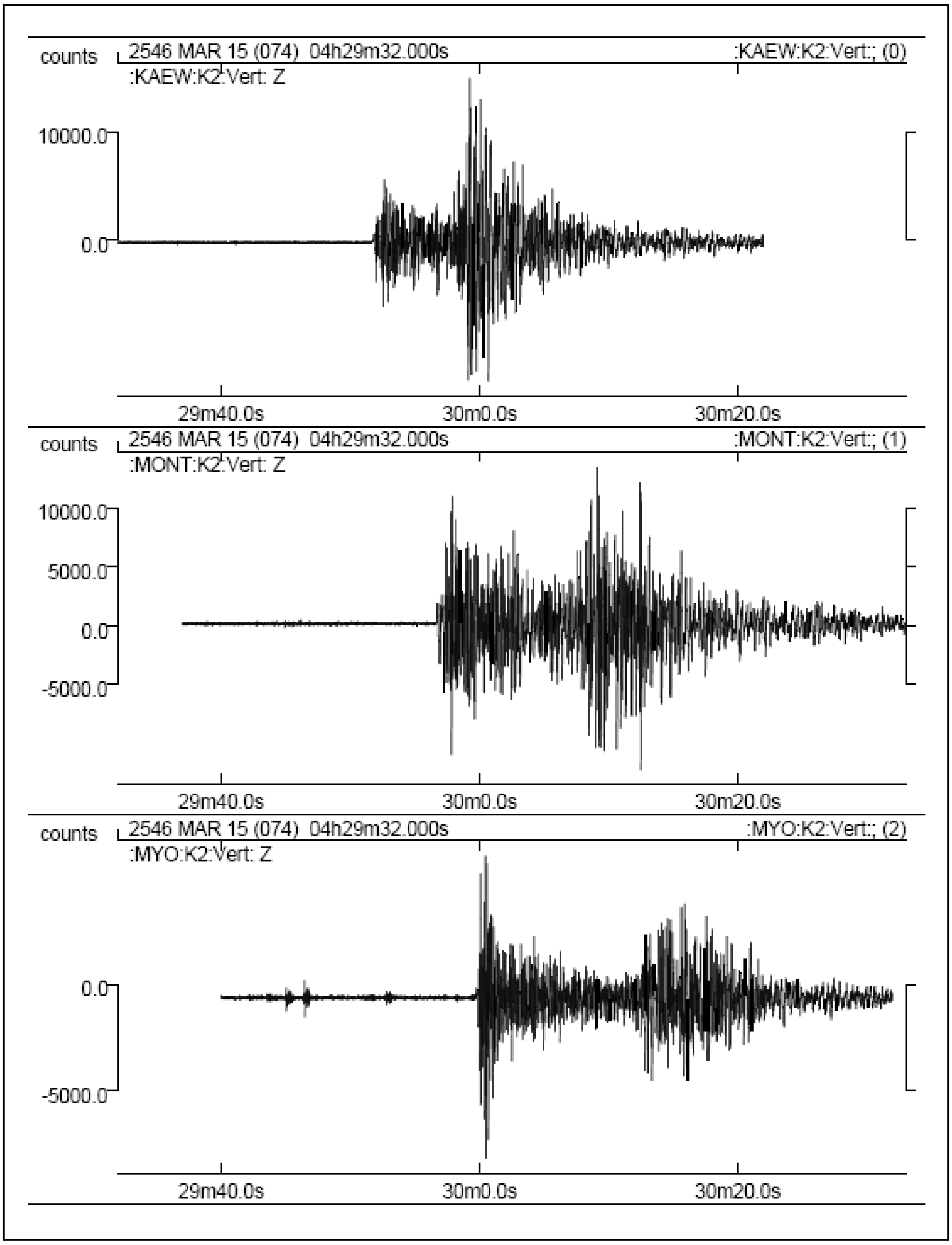


Figure 3. 35. Seismograms of well-located earthquake on March 15, 2003 which can read the arrival time of P and S-wave from 3 stations (the KAEW, the MONT, and the MYOM).

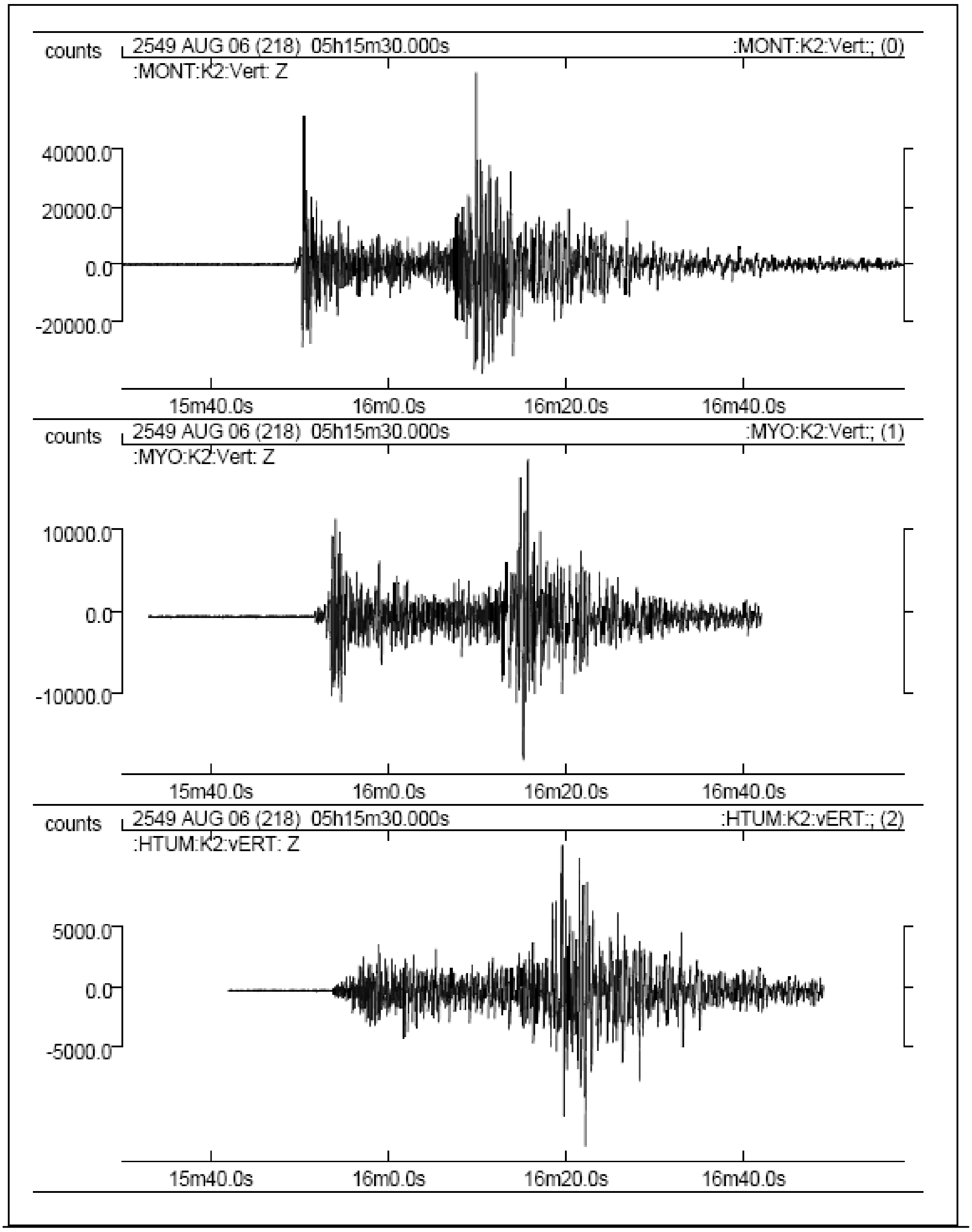


Figure 3. 36. Seismograms of well-located earthquake on August 6, 2006 which can read the arrival time of P and S-wave from 3 stations (the MONT, the MYOM, and the HTUM).

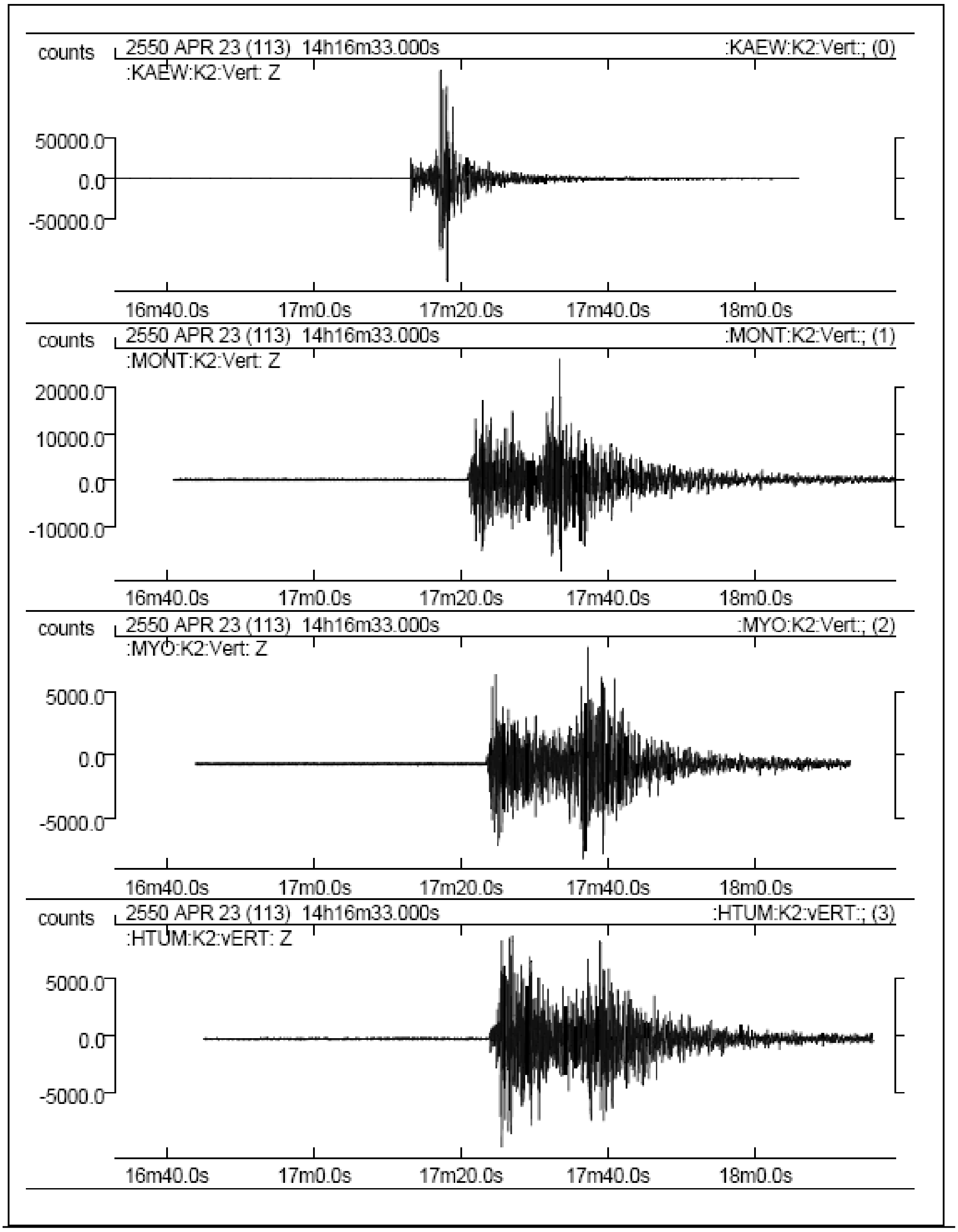


Figure 3. 37. Seismograms of well-located earthquake on April 23, 2007 which can read the arrival time of P and S-wave from 4 stations (the KAEW, the MONT, the MYOM, and the HTUM).

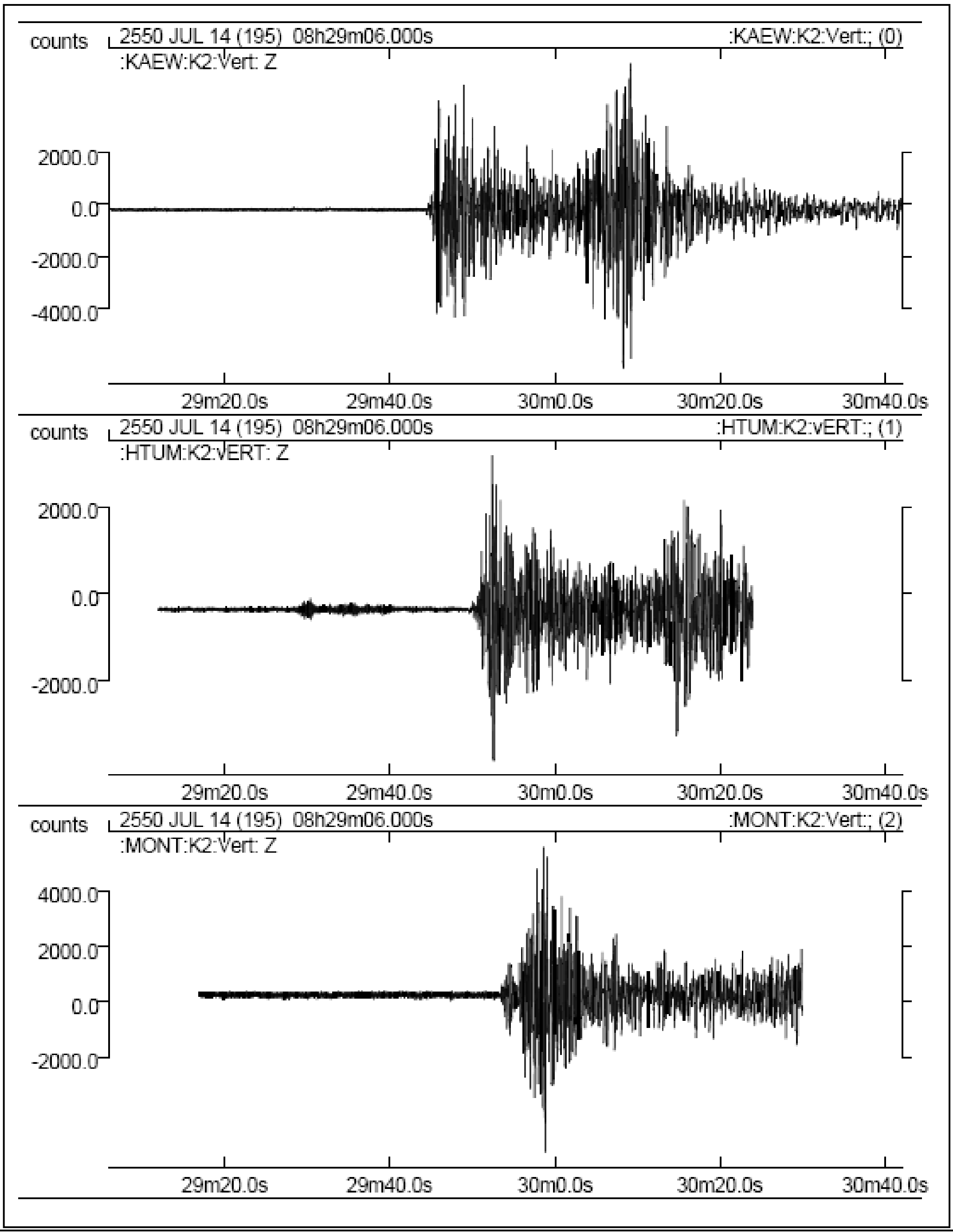


Figure 3. 38. Seismograms of well-located earthquake on July 14, 2007 which can read the arrival time of P and S-wave from 4 stations (the KAEW, the HTUM, and the MONT).

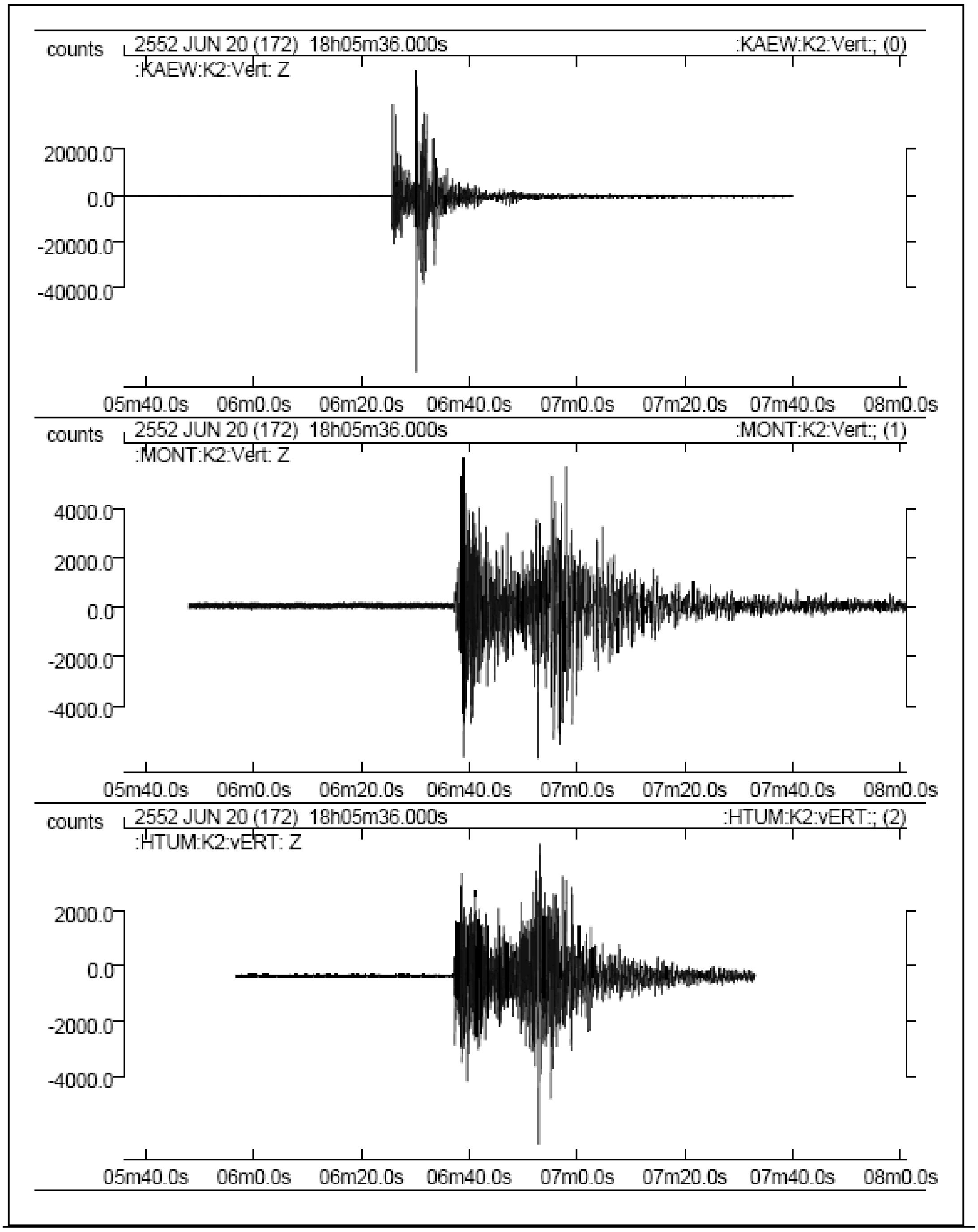


Figure 3. 39. Seismograms of well-located earthquake on June 20, 2009 which can read the arrival time of P and S-wave from 3 stations (the KAEW, the MONT, and the HTUM).

CHAPTER IV
RE-LOCATING EARTHQUAKES

In this chapter the re-locating earthquake is described. It consists of analyzing magnitude and epicenter and depth, calculating origin time, the results of analyzing magnitude and epicenter and depth and origin time, earthquakes catalogue and epicentral map of the KST, frequency and magnitude relation (b value), analyzing ground motion parameters, and the results of analyzing ground motion parameters.

4.1 Analyzing Magnitude and Epicenter and Depth

Magnitude is an estimation of the energy release or the size of an earthquake. The estimates are calculated from the amplitude of wave energy on a seismograph adjusting for the magnification of the seismograph and the distance of the seismograph station from the earthquake. The first magnitude scale was defined by (Richter, 1935) for Southern California. The Richter magnitude is calculated from the amplitude of the largest seismic wave recorded for the earthquake, no matter what type of wave was the strongest. The Richter magnitudes are based on a logarithmic scale (base 10); meaning that for each whole number goes one unit up on the Richter scale, the amplitude of the ground motion recorded by a seismograph goes ten times up. The formula is:

$$ML = \mathrm{Log}\left(\frac{A}{A_o}\right) \qquad (4.1)$$

Where ML is local magnitude

A is the maximum amplitude on a Wood-Anderson seismograph

A_o is the empirical function that depend on the epicentral distance of the stations

The Standard Torsion Seismometer, Ks

$$\text{Ks (magnification)} = \frac{A \text{ (amplitude)}}{D \text{ (ground displacement)}}$$

$$A = KsD$$

From equation 4.1

$$ML = \text{Log}\left(\frac{KsD}{A_o}\right) \qquad (4.2)$$

The Seismometer of Kinematics, K2

$$K2\ (\text{magnification}) = \frac{Vp\text{-}p\ /2\ \ (\text{amplitude})}{D\ \ (\text{ground displacement})}$$

$$D = \frac{Vp\text{-}p\ /2}{K2}$$

From equation 4.2

$$ML = \text{Log}\left(\frac{Ks \times \frac{Vp\text{-}p\ /2}{K2}}{A_o}\right) \qquad (4.3)$$

The magnification of standard torsion seismograph, Ks

$$Ks = V \times \left(\frac{\omega_n^2}{S^2+2h\omega_n S+\omega_n^2}\right)$$

$$= 2{,}800\left(\frac{(2\pi f_n)^2}{(j\omega_n)^2+2 \times h \times 2\pi f_n\ j\omega_n+(2\pi f_n)^2}\right)$$

$$= 2{,}800\left(\frac{(2 \times \pi \times 1.25)^2}{(j\omega_n)^2+2 \times 0.8 \times 2\pi \times 1.25\ j\omega_n+(2\pi \times 1.25)^2}\right)$$

$$= 2{,}800\left(\frac{(2 \times \pi \times 1.25)^2}{-\omega_n^2+(2 \times \pi \times 1.25)^2+ j(2 \times 0.8 \times 2\pi \times 1.25 \times \omega_n)}\right)$$

$$= 2{,}800\left(\frac{(2 \times \pi \times 1.25)^2}{\sqrt{(-\omega_n^2+(2 \times \pi \times 1.25)^2)^2+j(2 \times 0.8 \times 2\pi \times 1.25 \times \omega_n)^2}}\right)$$

$$Ks = 2{,}800\left(TF_1\right)$$

Which; V = displacement sensitivity + 2,800 (Table 4.1)

f_n = natural frequency = 1/To = 1/0.8 = 1.25 H_Z

h = damping ratio = 0.8 (Table 4.1)

j = $\sqrt{-1}$

S = $j\omega$ = Laplace Operator

ω_n = $2\pi f_n$

TF_1 = transfer function

$$= \left(\frac{(2\times\pi\times1.25)^2}{\sqrt{(-\omega^2 + (2\times\pi\times1.25)^2)^2 + j(2\times0.8\times2\pi\times1.25\times\omega)^2}} \right)$$

The magnification of seismometer of Kinemetrics, K2

$$K2 = G_o \times \left(\frac{R_x}{R_x + R_c} \times \omega \right) \times \left(\frac{\omega_n^2}{S^2 + 2h\omega_n S + \omega_n^2} \times G_1 \right)$$

$$= G_L\omega \times TF_2$$

Which; G_o = generator constant (v/m/s) (Table 4.2)

G_1 = amplifier board gain = 1.00

$G_L\omega$ = displacement sensitivity (v/m)

f_n = natural frequency of seismometer K_2 (Table 4.2)

h = damping ratio of seismometer K_2 (Table 4.2)

G_L = velocity sensitivity = $G_o \times \frac{R_x}{R_x + R_c}$ (v/m/s)

TF_2 = transfer function

$$= \left(\frac{(2\times\pi\times f_n)^2}{\sqrt{(-\omega^2 + (2\times\pi\times f_n)^2)^2 + (2\times h\times2\pi\times f_n\times\omega)^2}} \right)$$

From equation 4.3

$$ML = \text{Log} \left(\frac{Vp\text{-}p/2 \times 2{,}800 \times TF_1}{G_L \times \omega \times TF_2 \times A_o} \right) \quad (4.4)$$

Table 4. 1 Logarithms of the amplitude (in millimeters) which the standard torsion seismometer (To = 0.8, V = 2,800, h = 0.8) should register a shock registered at Δ = 100 kilometers with an amplitude 0.01 millimeters (1 micron) (RID, 2000).

Δ (km)	Log Ao	Δ (km)	Log Ao	Δ (km)	Log Ao	Δ (km)	Log Ao
25	-1.90	170	-3.38	315	-4.10	460	-4.64
30	2.10	175	-3.40	320	-4.12	465	-4.66
35	-2.32	180	-3.43	325	-4.15	470	-4.68
40	-2.43	185	-3.45	330	-4.17	475	-4.69
45	-2.54	190	-3.47	335	-4.20	480	-4.70
50	-2.63	195	-3.50	340	-4.22	485	-4.71
55	-2.70	200	-3.53	345	-4.24	490	-4.72
60	-2.77	205	-3.56	350	-4.26	495	-4.73
65	-2.79	210	-3.59	355	-4.28	500	-4.74
70	-2.83	215	-3.62	360	-4.30	505	-4.75
75	-2.87	220	-3.65	365	-4.32	510	-4.76
80	-2.90	225	-3.68	370	-4.34	515	-4.77
85	-2.94	230	-3.70	375	-4.36	520	-4.78
90	-2.96	235	-3.72	380	-4.38	525	-4.79
95	-2.98	240	-3.74	385	-4.40	530	-4.80
100	-3.00	245	-3.77	390	-4.42	535	-4.81
105	-3.03	250	-3.79	395	-4.44	540	-4.82
110	-3.08	255	-3.81	400	-4.46	545	-4.83
115	-3.10	260	-3.83	405	-4.48	550	-4.84
120	-3.12	265	-3.85	410	-4.50	555	-4.85
125	-3.15	270	-3.88	415	-4.51	560	-4.86
130	-3.19	275	-3.92	420	-4.52	565	-4.87
135	-3.21	280	-3.94	425	-4.54	570	-4.88
140	-3.23	285	-3.97	430	-4.56	575	-4.89
145	-3.28	290	-3.98	435	-4.57	580	-4.90
150	-3.29	295	-4.00	440	-4.59	585	-4.91
155	-3.30	300	-4.02	445	-4.61	590	-4.92
160	-3.32	305	-4.05	450	-4.62	595	-4.93
165	-3.35	310	-4.08	455	-4.63	600	-4.94

Table 4. 2. Ranger seismometer model SS-1 of this study (RID, 2000).

Seismograph Stations	R_c (Ohms)	R_s (Ohms)	G_o (V/m/s)	h Damping Ratio	f_n (Hz)	$G_L = G_o \times \frac{R_x}{R_x + R_c}$
MYOM	5708	5466	343.0	0.7	0.984	167.78
KAEW	5751	4640	341.0	0.7	1.014	152.27
MONT	5730	5466	339.0	0.7	0.965	165.50
HTUM	5911	4754	337.8	1.0	0.988	150.57

Which R_c = coil resistance, ohms

R_x = external damping resistance, ohms

G_o = open circuit generator constant in volts/meter/second

H = damping ratio

f_n = natural frequency of the seismometer in Hertz

G_L = generator constant

For example, to calculate earthquake magnitude and epicentral distance (source-to-site the KAEW station) of an earthquake on December 7, 2005.

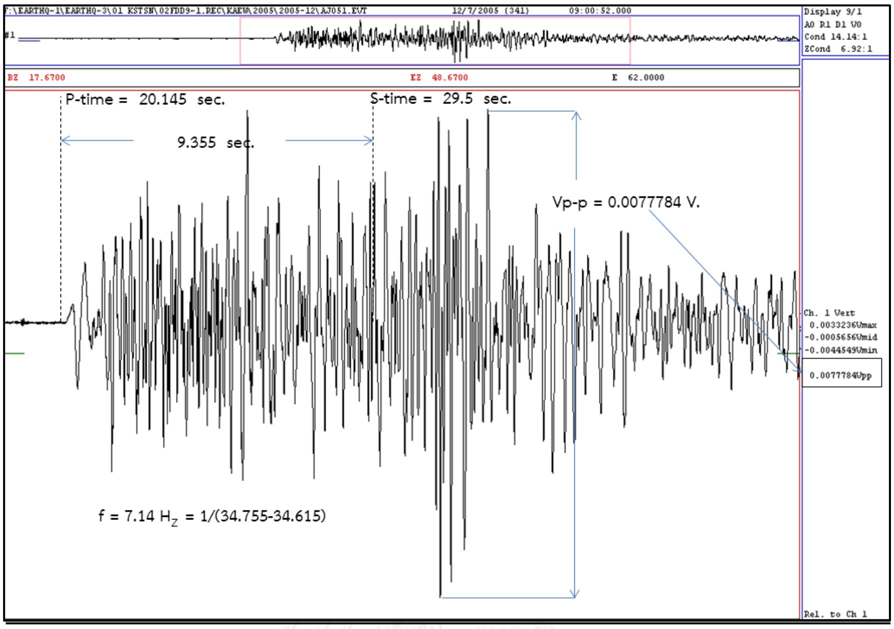


Figure 4. 1. Details of P and S-times, and time difference, and amplitude peak to peak (V p-p), and frequency (f) of an earthquake on December 7, at the KAEW station 2005 (file name AJ051).

The epicentral distance is the distance from the epicenter to the station along the surface of the earth. Generally, the distance can be obtained from the difference in arrival time of two phases, usually P and S, and the distance can be calculated as

$$\Delta = (t_s - t_p) \frac{V_p V_s}{V_p - V_s} \qquad (4.5)$$

where t_p and t_s are the P and S-arrival times (s) respectively,
V_p and V_s are the P and S velocities respectively and
Δ is the epicentral distance (km).

$$\text{or} \quad \Delta = t(S_g - P_g) \times 8 \qquad (4.6)$$

These rules are approximation for a single layer crust with an average P_g-wave velocity of 5.9 km/s and a sub-Moho velocity of 8 km/s and a velocity ratio $V_s/V_p = \sqrt{3}$ (and Sg-wave velocity will be 3.4 km/m).

From equation 4.5 and P-time = 20.145 s, S-times = 29.500 s (Figure 4.1), and Pg-wave velocity = 5.9 km/s, and and Sg-wave velocity = 3.4 km/s, the epicentral distance of an earthquake on December 7, 2005 to the KAEW station is

$$\Delta = (29.5-20.145) \times \frac{(5.9 \times 3.4)}{(5.9-3.4)}$$

$$= (29.5-20.145) \times \frac{20.06}{2.5}$$

$$= (29.5-20.145) \times 8.024$$

$$= 9.355 \times 8.024$$

$$= 75 \text{ km}$$

Magnitude of an earthquake from equation 4.4

$$ML = \text{Log}\left(\frac{Vp\text{-}p/2 \times 2{,}800 \times TF_1}{G_L \times \omega \times TF_2 \times A_o}\right)$$

Where $Vp\text{-}p/2 = 0.0077784/2 = 0.0038892$ V (Figure 4.1)

$f = 1/(34.755-34.615) = 7.14\ H_Z$ (Figure 4.1)

$f_n = 1.014\ H_Z$ (Table 4.2)

$h = 0.7$ (Table 4.2)

$\text{Log}\ A_o = -2.87$ (Table 4.1, where $\Delta = 75$ km)

$A_o = 1.34 \times 10^{-3}$ mm $= 1.34 \times 10^{-6}$ m

$G_L = 152.27$ (Table 4.2)

$\omega = 2\pi f = 2 \times 22/7 \times 7.14 = 44.88$

$$TF_1 = \left(\frac{(2\times\pi\times1.25)^2}{\sqrt{(-\omega^2 + (2\times\pi\times1.25)^2)^2 + (2\times0.8\times2\pi\times1.25\times\omega)^2}}\right)$$

$$= \left(\frac{(2 \times 22/7 \times 1.25)^2}{\sqrt{(-44.88)^2+(2 \times 22/7 \times 1.25)^2)^2+(2 \times 0.8 \times 2 \times 22/7 \times 1.25 \times 44.88)^2}} \right)$$

$$= \left(\frac{61.73}{\sqrt{(2,014.21+61.73)^2+(564.205)^2}} \right)$$

$$= \left(\frac{61.73}{\sqrt{(2,075.94)^2+(564.205)^2}} \right)$$

$$= \left(\frac{61.73}{\sqrt{4,309,526.884+324,148.036}} \right)$$

$$= \frac{61.73}{2,152.60}$$

$$= 0.028$$

$$TF_2 = \left(\frac{(2 \times \pi \times f_n)^2}{\sqrt{(-\omega^2+(2 \times \pi \times fn)^2)^2 + (2 \times h \times 2 \times \pi \times fn \times \omega)^2}} \right)$$

$$= \left(\frac{(2 \times \pi \times 1.014)^2}{\sqrt{(-\omega^2+(2 \times \pi \times 1.014)^2)^2+(2 \times h \times 2 \times \pi \times 1.014 \times \omega)^2}} \right)$$

$$= \left(\frac{40.624}{\sqrt{(2014.21+40.624)^2+(2 \times 0.7 \times 2 \times \pi \times 1.014 \times 44.88)^2}} \right)$$

$$= \left(\frac{40.624}{\sqrt{(2014.21 + 40.624)^2 + (400.473)^2}} \right)$$

$$= \left(\frac{40.624}{\sqrt{(4,222,342.768) + (160,378.624)}} \right)$$

$$= \left(\frac{40.624}{2{,}093.49} \right)$$

$$= 0.019$$

$$ML = \text{Log} \left(\frac{0.0038892 \times 2{,}800 \times 0.028}{152.27 \times 44.88 \times 0.019 \times 1.34 \times 10^{-6}} \right)$$

$$= \text{Log} \left(\frac{0.305}{0.000174} \right)$$

$$= \text{Log}\ (1{,}752.873)$$

$$ML = 3.3$$

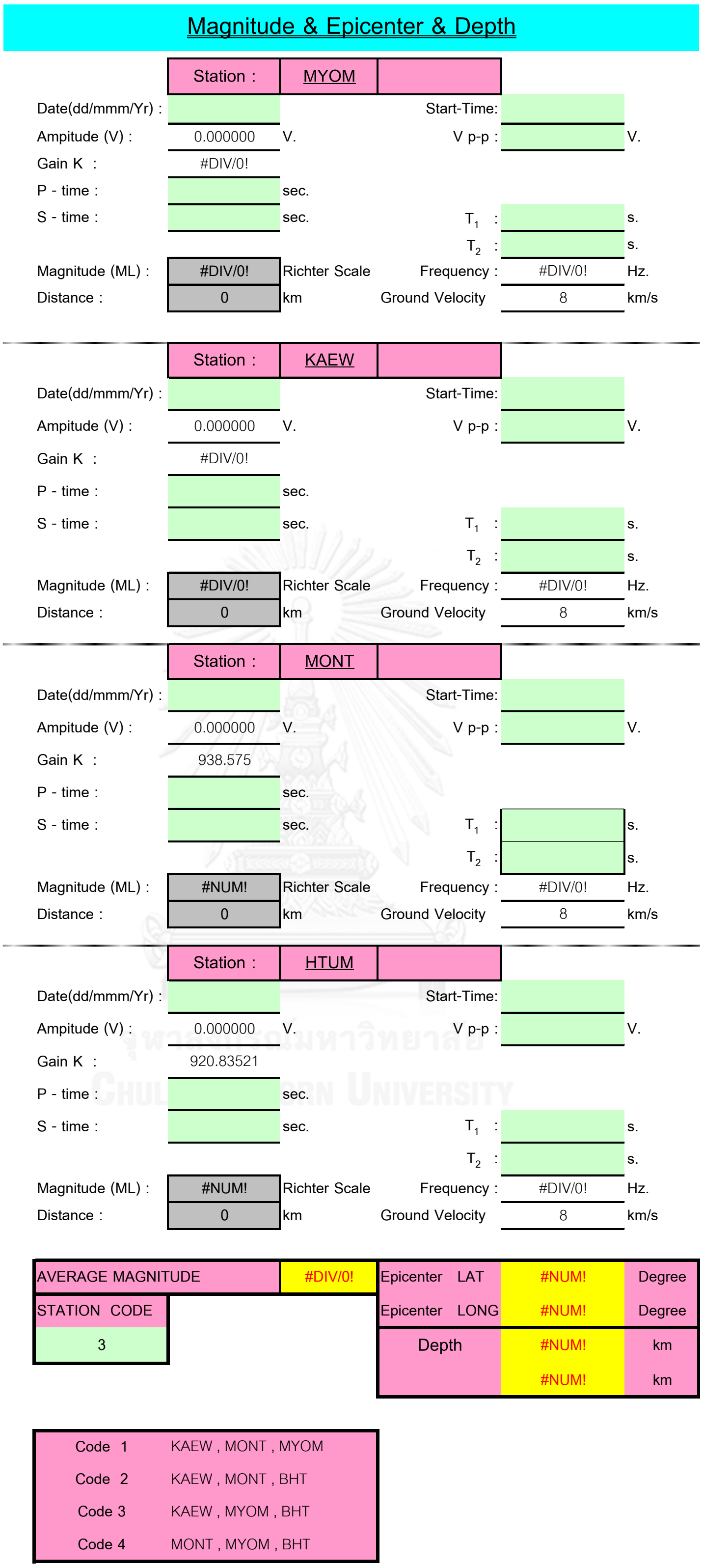
As the earthquake’s magnitude is calculated according to the Richter scale, in case of hand calculation, the procedure would be complex. The KST seismographic network has formulated various calculations on spread sheet programs using the Microsoft Excel, named as the Magnitude and Epicenter and Depth.xls. The software is used to determine the size of the earthquake, and to plot the radial distance between stations, and to identify the location of the earthquake’s epicenter which uses the same basic circle and chord or triangulation method. When drawing a circle on the map around seismograph stations with different radial distance, the points of intersection of the three circles are a focus of an earthquake.

Data file of seismic wave can be opened by the KMI QuickLook software. The file consists of 2 parts of data; the header contains details of events include date, start time, latitude and longitude of seismograph, peak amplitude and etc., the second part is digital data which QuickLook uses to plot the seismogram for analyzing parameters and calculating magnitude, epicenter. In this study QuickLook is used to obtain the arrival time of P-and S-wave, and amplitude of maximum peak.

The analysis assistant program named Magnitude and Epicenter and Depth has an easy and convenient principle of usage as same as Microsoft Excel where in

Magnitude and Epicenter and Depth analysis can be operated by running Microsoft Excel, then open the file named Magnitude and Epicenter and Depth.xls. After that, fill in the time of arrival of the primary waves in the P- time, time of arrival of the secondary wave in the S-time, voltage peak to peak value in the Vp-p, together with the start time of the highest wave in the T1 and the ending time of the highest wave in the T2 which were read from the seismogram (graph of seismic data) recorded at each station, the start time of the recording in the start-time, and date of earthquakes in the date box. After filling in all data from 3 stations, the program will calculate the value of the Magnitude, Distance, and Frequency of each station. Then consider the Code 1-4, putting the code into the Station code box based on the name of seismograph stations seismic data was recorded. Finally, the program will calculate the average magnitude of the earthquake, latitude, longitude, and depth. The output is in the Average Magnitude, Lat, Long, and Depth boxes. Epicenter map is displayed in the work sheet Name Location 2; showing the location of stations on the map along with the radical detect of seismic waves. Points of intersection of the radii from the 3 rings (the intersection point) is the projection of a point on the earth called the earthquake epicenter, where work sheet 1 and 2 are linked together; making it convenient to consider. In the case where the 3 circles do not intersect, or if the program is unable to calculate the average magnitude of the earthquake, latitude, longitude, and depth, make sure to read the time of arrival of a wave of primary and secondary sources of each station again, until the program allows calculation of Average Magnitude, Lat, Long, Depth, which requires a work sheet 1 with the work sheet 2 into consideration simultaneously. The results from the analysis can be printed out by a printer using the print command in the menu bar as usual.

For this project, the above mentioning task was performed in detailed according to Table 3.2 on 118 events and, as indicated in Table 3.3, on addition of 10 events; in all totals of 128 events. Figure 4.3 to Figure 4.21 show an example of the analysis of the earthquake on December 7, 2005.



Magnitude & Epicenter & Depth

	Station :	MYOM			
Date(dd/mmm/Yr) :			Start-Time:		
Ampitude (V) :	0.000000	V.	V p-p :		V.
Gain K :	#DIV/0!				
P - time :		sec.			
S - time :		sec.	T_1 :		s.
			T_2 :		s.
Magnitude (ML) :	#DIV/0!	Richter Scale	Frequency :	#DIV/0!	Hz.
Distance :	0	km	Ground Velocity	8	km/s

	Station :	KAEW			
Date(dd/mmm/Yr) :			Start-Time:		
Ampitude (V) :	0.000000	V.	V p-p :		V.
Gain K :	#DIV/0!				
P - time :		sec.			
S - time :		sec.	T_1 :		s.
			T_2 :		s.
Magnitude (ML) :	#DIV/0!	Richter Scale	Frequency :	#DIV/0!	Hz.
Distance :	0	km	Ground Velocity	8	km/s

	Station :	MONT			
Date(dd/mmm/Yr) :			Start-Time:		
Ampitude (V) :	0.000000	V.	V p-p :		V.
Gain K :	938.575				
P - time :		sec.			
S - time :		sec.	T_1 :		s.
			T_2 :		s.
Magnitude (ML) :	#NUM!	Richter Scale	Frequency :	#DIV/0!	Hz.
Distance :	0	km	Ground Velocity	8	km/s

	Station :	HTUM			
Date(dd/mmm/Yr) :			Start-Time:		
Ampitude (V) :	0.000000	V.	V p-p :		V.
Gain K :	920.83521				
P - time :		sec.			
S - time :		sec.	T_1 :		s.
			T_2 :		s.
Magnitude (ML) :	#NUM!	Richter Scale	Frequency :	#DIV/0!	Hz.
Distance :	0	km	Ground Velocity	8	km/s

AVERAGE MAGNITUDE	#DIV/0!	Epicenter LAT	#NUM!	Degree
STATION CODE		Epicenter LONG	#NUM!	Degree
3		Depth	#NUM!	km
			#NUM!	km

Code 1	KAEW , MONT , MYOM
Code 2	KAEW , MONT , BHT
Code 3	KAEW , MYOM , BHT
Code 4	MONT , MYOM , BHT

Figure 4. 2. The Microsoft Excel which using to analyze Magnitude and Epicenter and Depth in this study.

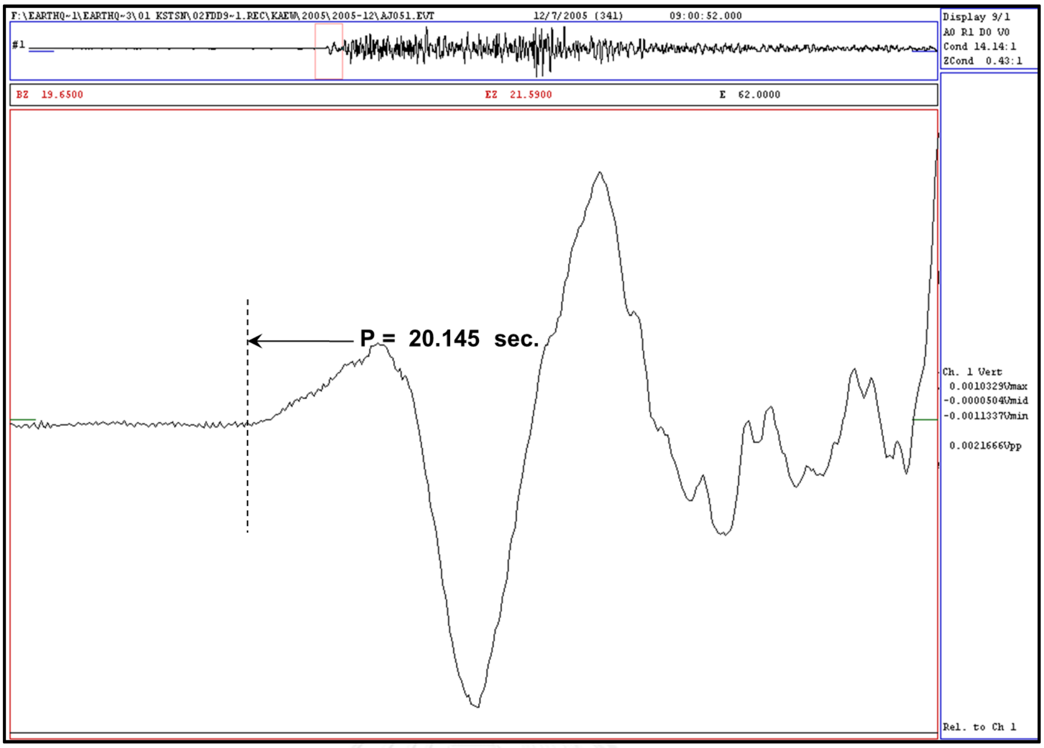


Figure 4. 3. The arrival time of P-wave at the KAEW station is 20.145 sec.

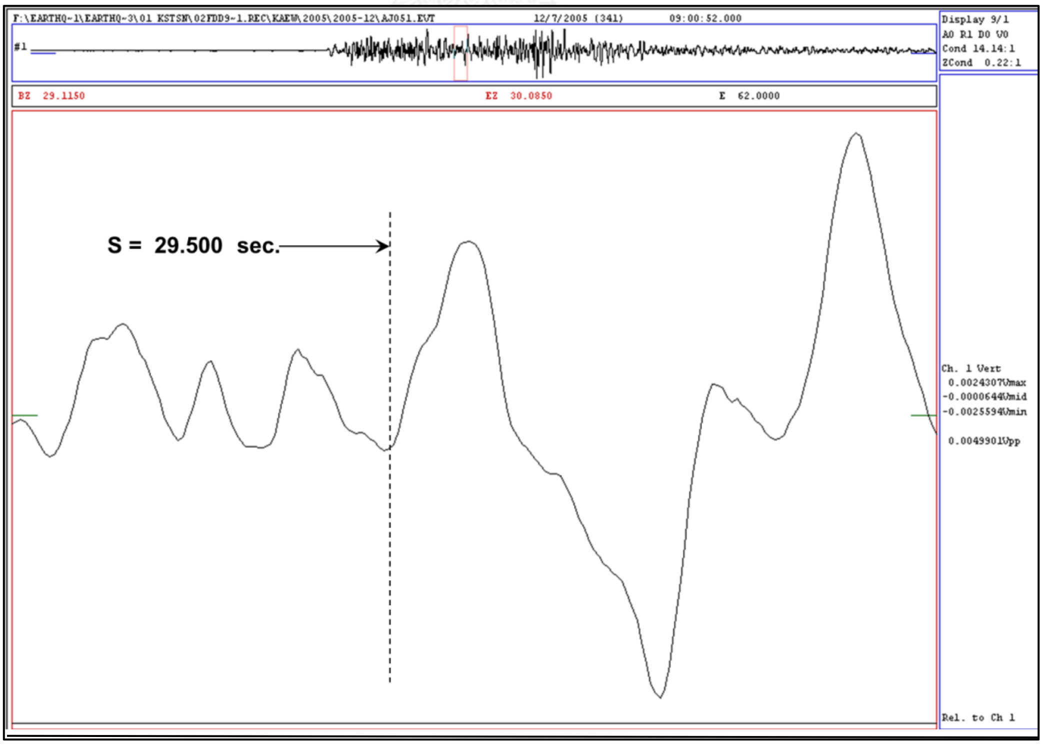


Figure 4. 4. The arrival time of S-wave at the KAEW station is 29.500 sec.

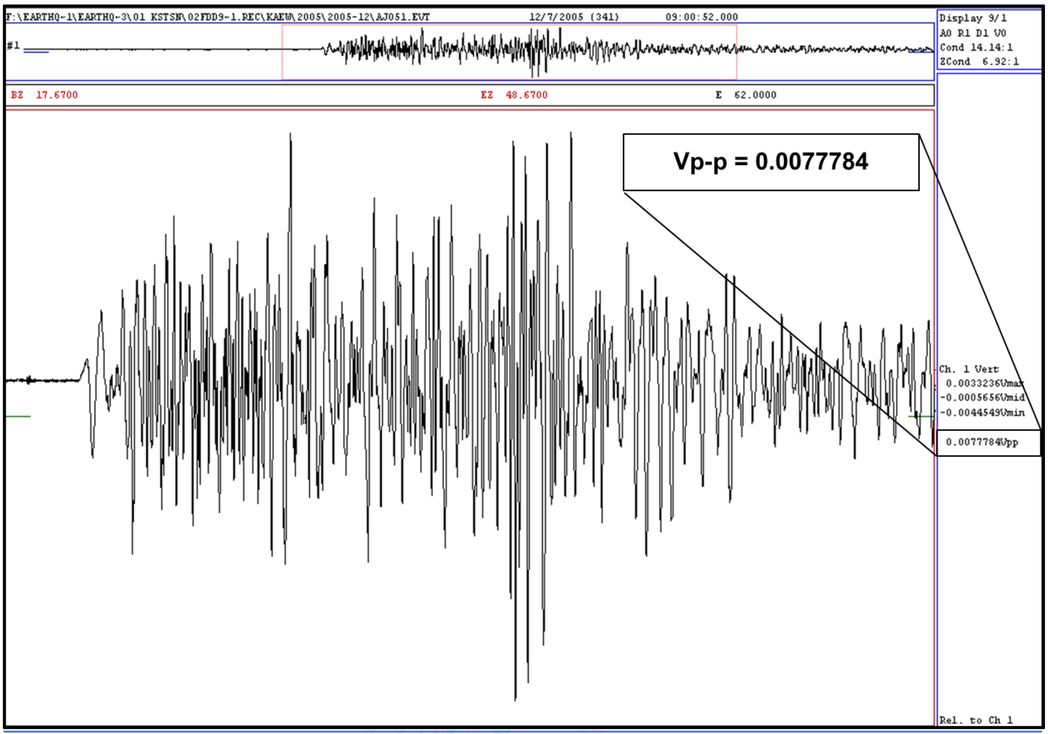


Figure 4. 5. The maximum amplitude of peak to peak at the KAEW station, Vp-p is 0.0077784 V.

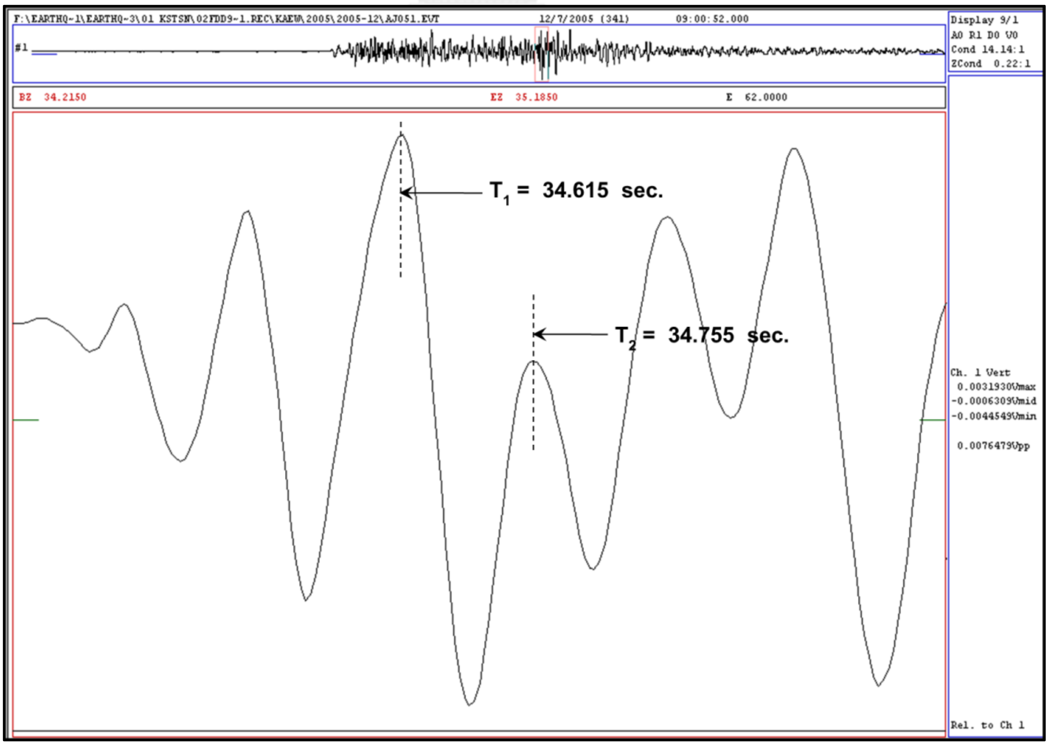


Figure 4. 6. The period of maximum amplitude at the KAEW station, T1 = 34.615 sec, T2 = 34.755 sec.

	Station :	KAEW	AJ051		
Date(dd/mmm/Yr) :	07-Dec-05		Start-Time:	9:00:52	
Ampitude (V) :	0.003889	V.	V p-p :	0.0077784	V.
Gain K :	159.002				
P - time :	20.1450	sec.			
S - time :	29.5000	sec.	T_1 :	34.6150	s.
			T_2 :	34.7550	s.
Magnitude (ML) :	3.2	Richter Scale	Frequency :	7.1429	Hz.
Distance :	75	km	Ground Velocity	8	km/s

Figure 4. 7. The analysis of the results from KAEW station, earthquake magnitude is 3.2, and epicentral distance is 75 km.

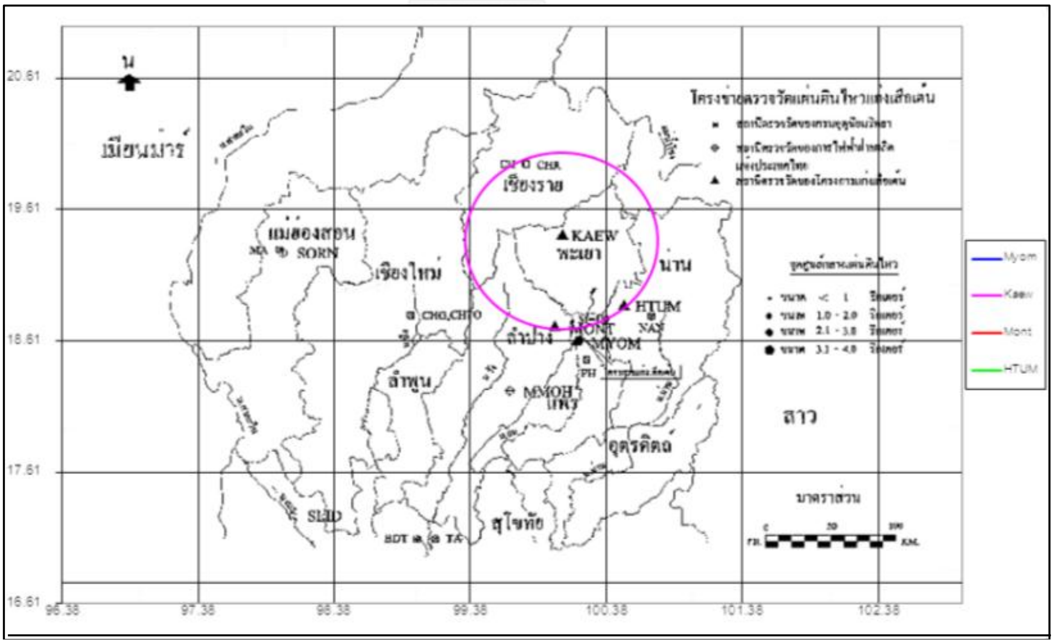


Figure 4. 8. Epicentral map of earthquake on December 7, 2005 from the KAEW station. Note; epicenter is a point on the radius of 75 km (pink circle), but the location and direction were not clear.

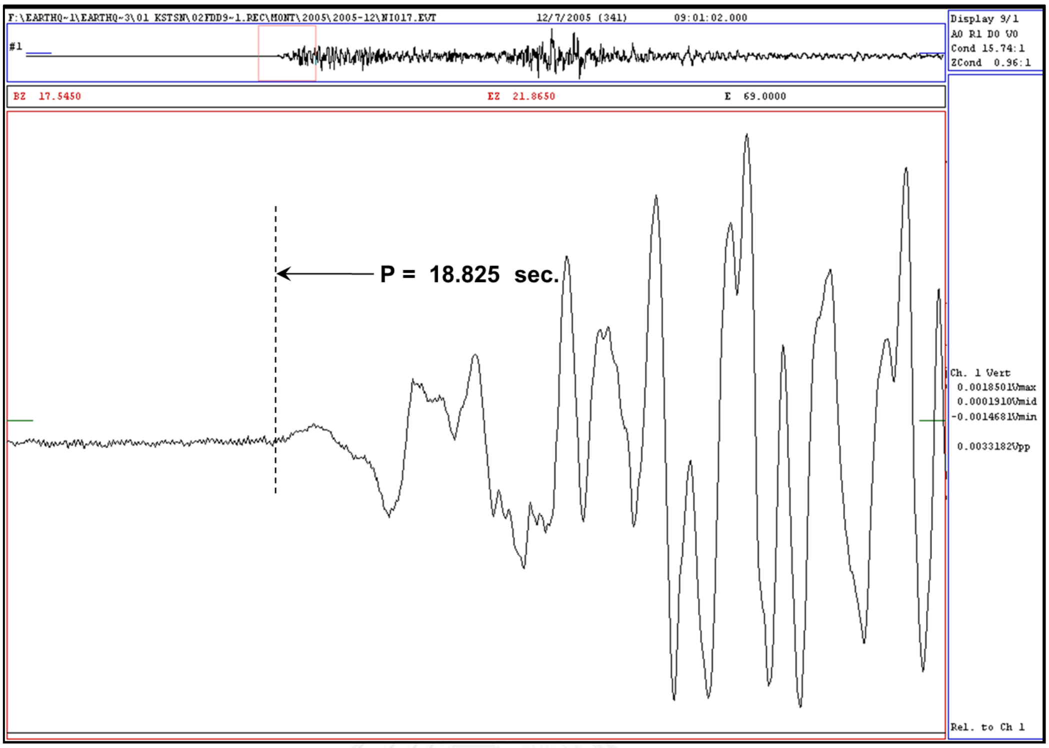


Figure 4. 9. The arrival time of P-wave at the MONT station is 18.825 sec.

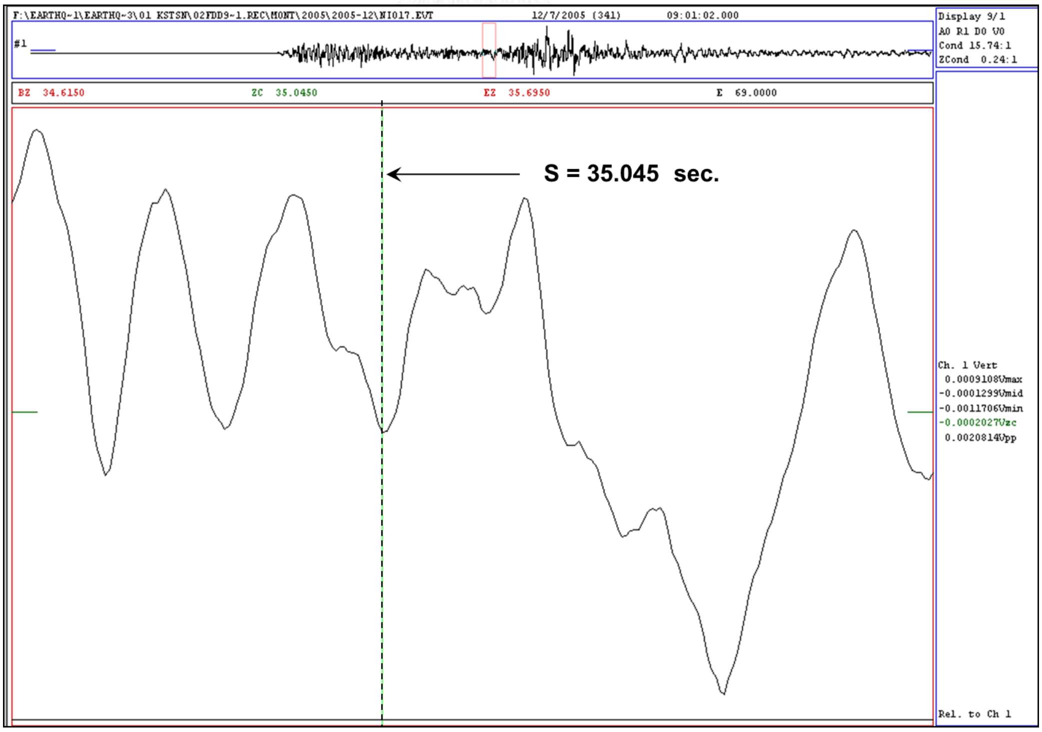


Figure 4. 10. The arrival time of S-wave at the MONT station is 35.045 sec.

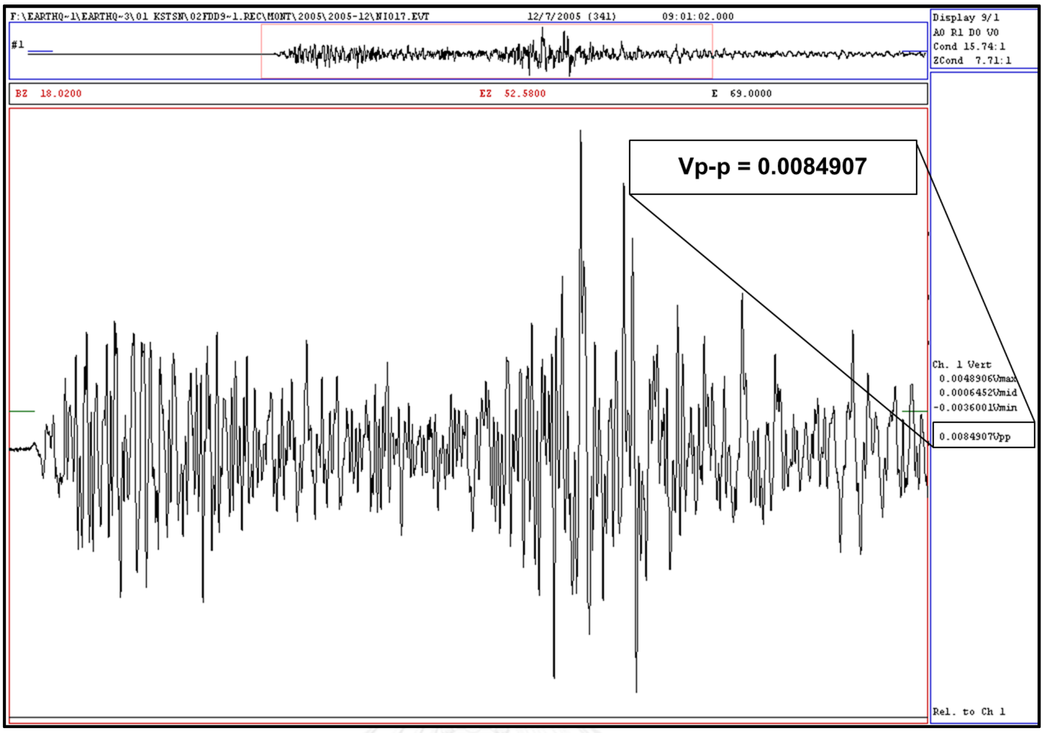


Figure 4. 11. The maximum amplitude of peak to peak at the MONT station, Vp-p is 0.0084907 V.

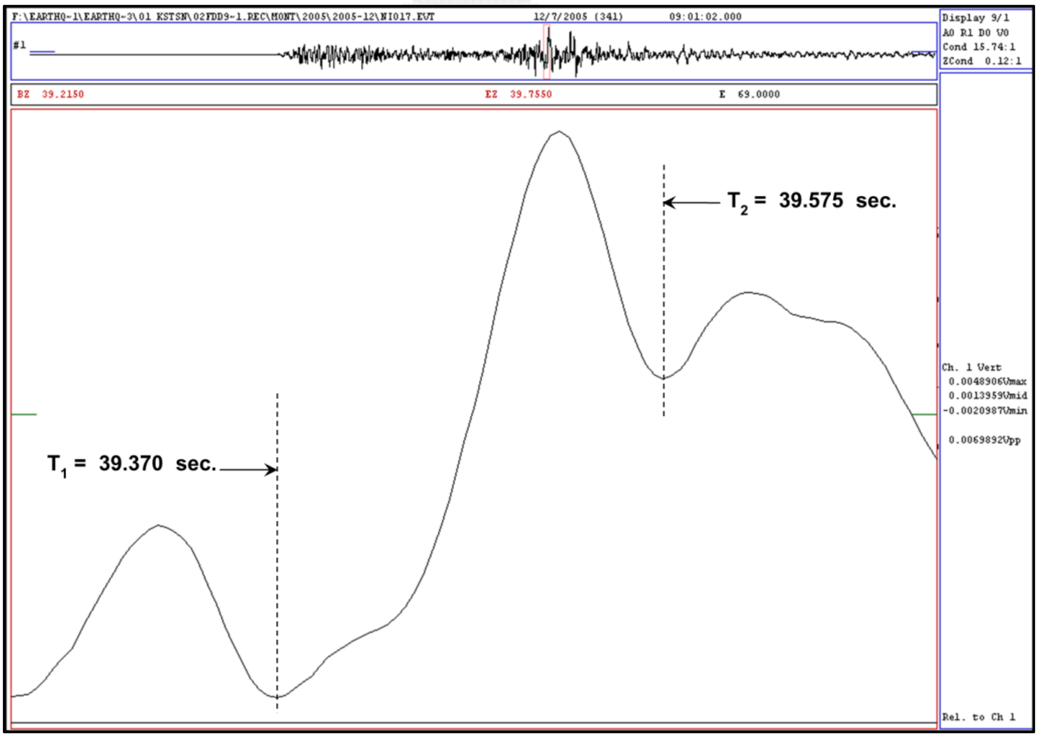


Figure 4. 12. The period of maximum amplitude at the MONT station, T1 = 39.370 sec, T2 = 39.575 sec.

	Station :	MONT	NI017		
Date(dd/mmm/Yr) :	07-Dec-05		Start-Time:	9:01:02	
Amplitude (V) :	0.004245	V.	V p-p :	0.0084907	V.
Gain K :	938.575				
P - time :	18.8250	sec.			
S - time :	35.0450	sec.	T_1 :	39.370	s.
			T_2 :	39.575	s.
Magnitude (ML) :	4.1	Richter Scale	Frequency :	4.8780	Hz.
Distance :	130	km	Ground Velocity	8	km/s

Figure 4. 13. The analysis of the results from MONT station, earthquake magnitude is 4.1, and epicentral distance from. source-to-site is 130 km.

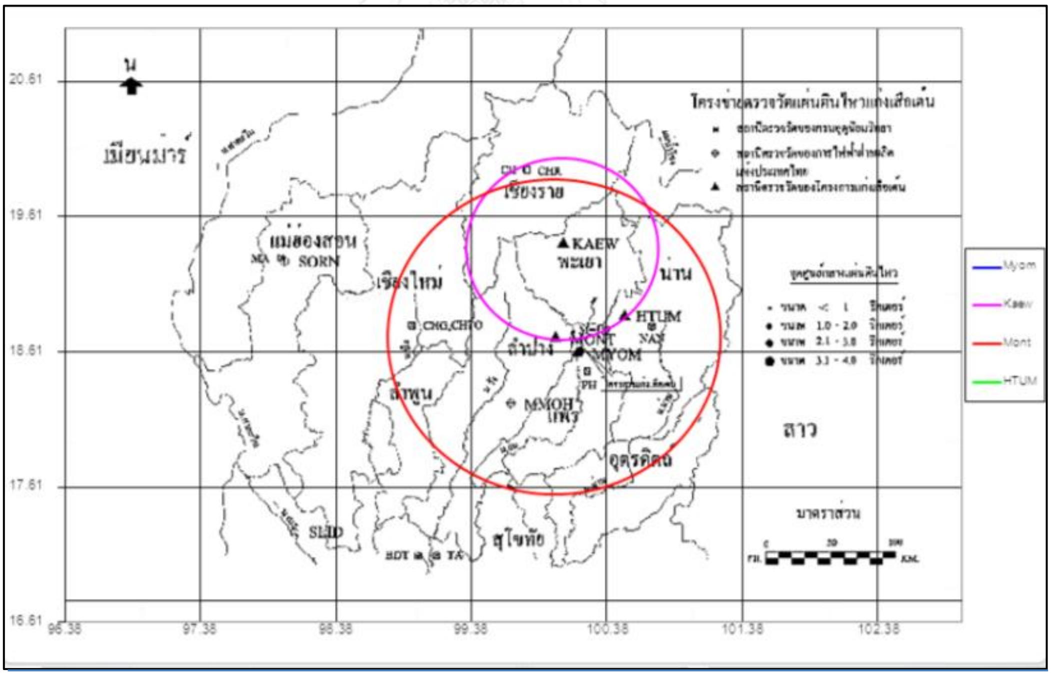


Figure 4. 14. Epicentral map of earthquake on December 7, 2005 from the KAEW and the MONT stations. Note; epicenter is one of the two points on the ray intersects the 75 km radius (pink circle) of 130 km (red circle).

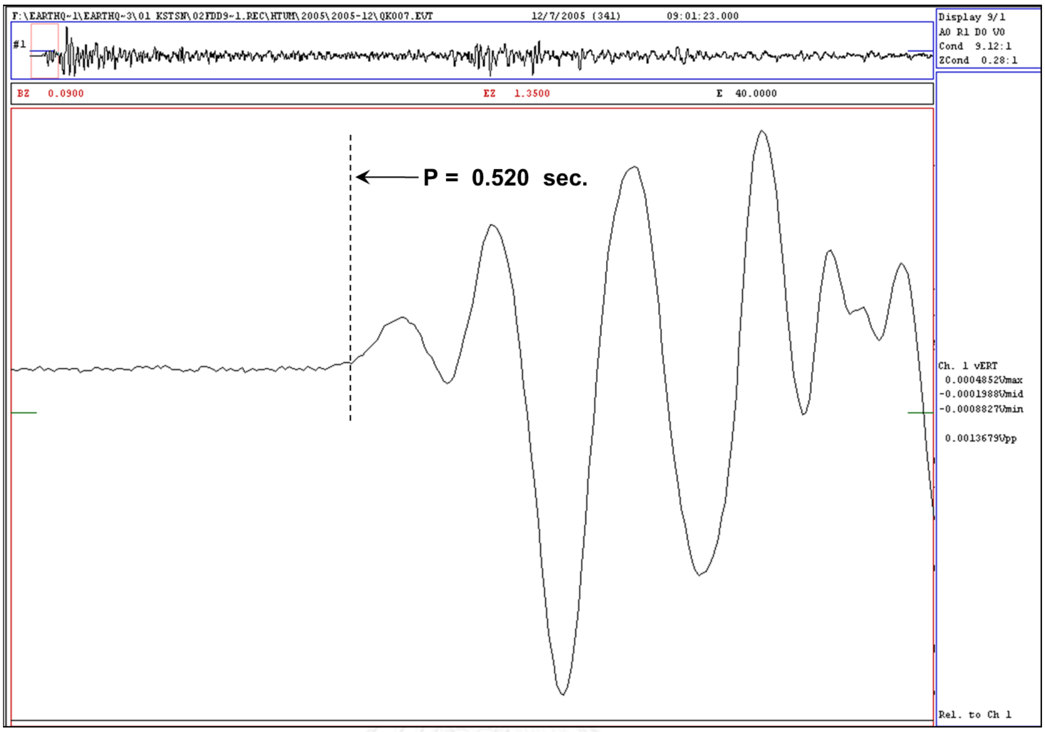


Figure 4. 15. The arrival time of P-wave at the HTUM station is 0.520 sec.

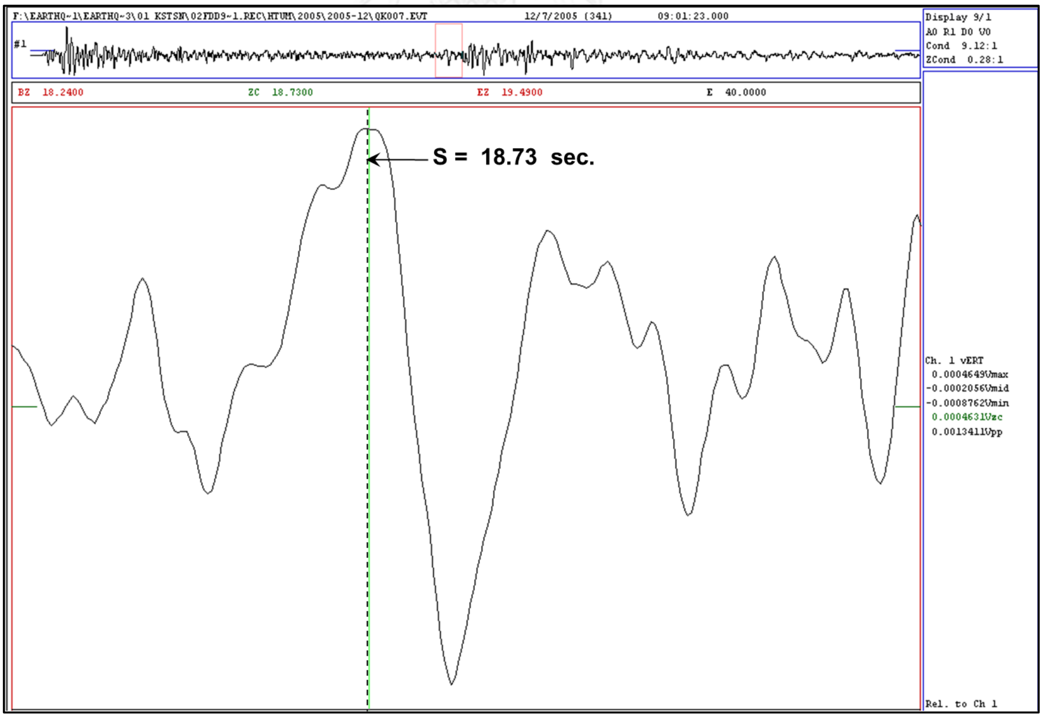


Figure 4. 16. The arrival time of S-wave at the HTUM station is 18.730 sec.

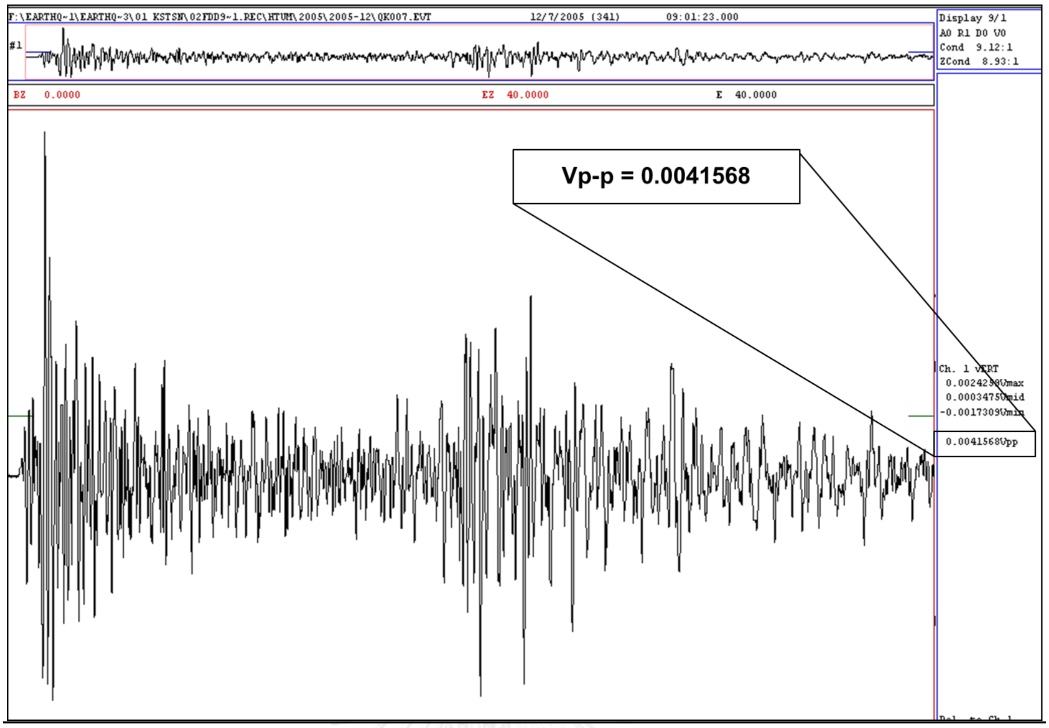


Figure 4. 17. The maximum amplitude of peak to peak at the HTUM station, Vp-p is 0.0041568 V.

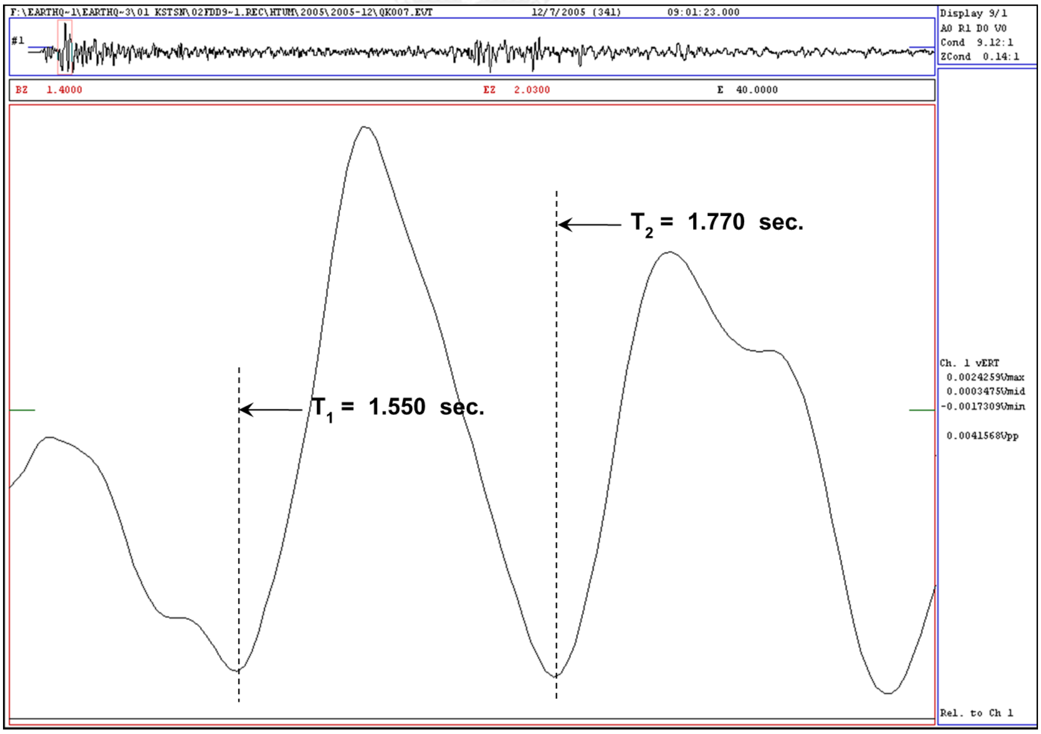


Figure 4. 18. The period of maximum amplitude at the HTUM station, T1 = 1.550 sec, T2 = 1.770 sec.

	Station :	HTUM	QK007		
Date(dd/mmm/Yr) :	07-Dec-05		Start-Time:	9:01:23	
Ampitude (V) :	0.002078	V.	V p-p :	0.0041568	V.
Gain K :	920.835				
P - time :	0.5200	sec.			
S - time :	18.7300	sec.	T_1 :	1.5500	s.
			T_2 :	1.7700	s.
Magnitude (ML) :	3.9	Richter Scale	Frequency :	4.5455	Hz.
Distance :	146	km	Ground Velocity	8	km/s

Figure 4. 19. The analysis of the results from HTUM station, earthquake magnitude is 3.9, and epicentral distance from. source-to-site is 146 km.

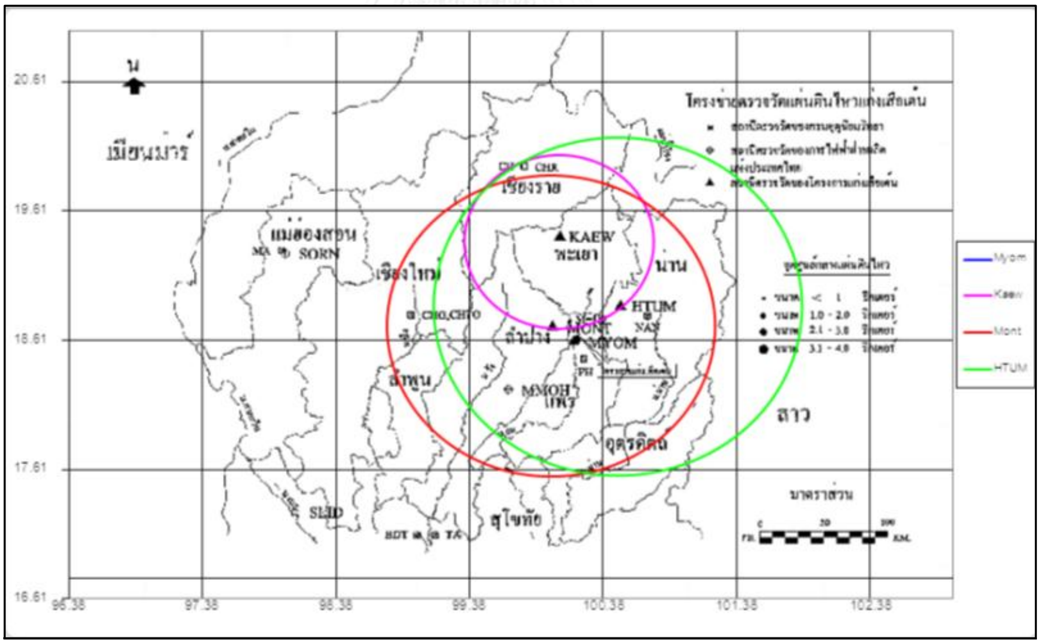


Figure 4. 20. Epicentral map of earthquake on December 7, 2005 from the KAEW, the MONT and the HTUM stations. Note; epicenter is the point of intersection of the radius 75 km (pink circle), 130 km (red crcle) and 146 km radius (green circle).

Magnitude & Epicenter & Depth

	Station :	MYOM			
Date(dd/mmm/Yr) :			Start-Time:		
Ampitude (V) :	0.000000	V.	V p-p :		V.
Gain K :	#DIV/0!				
P - time :		sec.			
S - time :		sec.	T_1 :		s.
			T_2 :		s.
Magnitude (ML) :	0.00	Richter Scale	Frequency :	#DIV/0!	Hz.
Distance :	0	km	Ground Velocity	8	km/s

	Station :	KAEW	AJ051		
Date(dd/mmm/Yr) :	07-Dec-05		Start-Time:	9:00:52	
Ampitude (V) :	0.003889	V.	V p-p :	0.0077784	V.
Gain K :	159.002				
P - time :	20.1450	sec.			
S - time :	29.5000	sec.	T_1 :	34.6150	s.
			T_2 :	34.7550	s.
Magnitude (ML) :	3.2	Richter Scale	Frequency :	7.1429	Hz.
Distance :	75	km	Ground Velocity	8	km/s

	Station :	MONT	NI017		
Date(dd/mmm/Yr) :	07-Dec-05		Start-Time:	9:01:02	
Ampitude (V) :	0.004245	V.	V p-p :	0.0084907	V.
Gain K :	938.575				
P - time :	18.8250	sec.			
S - time :	35.0450	sec.	T_1 :	39.370	s.
			T_2 :	39.575	s.
Magnitude (ML) :	4.1	Richter Scale	Frequency :	4.8780	Hz.
Distance :	130	km	Ground Velocity	8	km/s

	Station :	HTUM	QK007		
Date(dd/mmm/Yr) :	07-Dec-05		Start-Time:	9:01:23	
Ampitude (V) :	0.002078	V.	V p-p :	0.0041568	V.
Gain K :	920.835				
P - time :	0.5200	sec.			
S - time :	18.7300	sec.	T_1 :	1.5500	s.
			T_2 :	1.7700	s.
Magnitude (ML) :	3.9	Richter Scale	Frequency :	4.5455	Hz.
Distance :	146	km	Ground Velocity	8	km/s

AVERAGE MAGNITUDE	3.8	Epicenter LAT	19.734	Degree
STATION CODE		Epicenter LONG	99.544	Degree
2		Depth	108	km
			8	km

Code 1	KAEW , MONT , MYOM
Code 2	KAEW , MONT , HTUM
Code 3	KAEW , MYOM , HTUM
Code 4	MONT , MYOM , HTUM

Figure 4. 21. The results of analyzing earthquake on December 7, 2005 of the KAEW, the MONT and the HTUM stations; average magnitude M3.8, latitude 19.73N, longitude 99.54E, and depth 8 km.

4.2 Calculating Origin Time

Together with re-locating epicenters of the well-located earthquakes the origin time, is calculated for correction and comparison the earthquake events with other organizations such as the TMD. The origin time is the actual time that the earthquake occurred at the source. The origin time can be defined by the formula;

$$O_{time} = P - \left[(S - P) \times 1.37\right] \quad (4.1)$$

When O_{time} is the occurrence time for the earthquake.

P is the arrival time of the primary wave.

S is the arrival time of the secondary wave.

1.37 is the constant value if Poisson’s ratio is assumed equal to 0.25 (Richter, 1958)

An example of calculation of the origin time of earthquake on December 7, 2005

1. The KAEW station has start time of recorded data at 09:00:52 UTC.

   P wave arrival time is 09:01:12.145 UTC (09:00:52 + 20.145 sec)

   S wave arrival time is 09:01:21.50 UTC (09:00:52 + 29.50 sec)

   $S\text{-}P_{time}$ = (29.5-20.145) = 9.355 sec

   = 9.355 x 1.37 = 12.81635 sec

   Subtract of 12.81635 sec from 09:01:12.145 UTC to give origin time

   Origin time = 09:01:12.15 UTC – 12.81635 sec = 09:00:59.32865 UTC

2. The MONT station has start time of recorded data at 09:01:02 UTC.

   P wave arrival time is 09:01:20.825 UTC (09:01:02 + 18.825 sec)

   S wave arrival time is 09:01:37.045 UTC (09:01:02 + 35.045 sec)

   $S\text{-}P_{time}$ = (35.045-18.825) = 16.22 sec

   = 16.22 x 1.37 = 22.2214 sec

   Subtract of 22.2214 sec from 09:01:20.825 UTC to give origin time

   Origin time = 09:01.58.62045 UTC.

3. The HTUM station has start time of recorded data at 09:01:23 UTC.

P wave arrival time is 09:01:23.520 UTC (09:01:23 + 0.520 sec)

S wave arrival time is 09:01:41.730 UTC (09:01:23 + 18.730 sec)

$S\text{-}P_{time}$ = (18.730-0.520) = 18.210 sec

= 18.210 x 1.37 = 24.9477 sec

Subtract of 24.9477 sec from 09:01:23.520 UTC to give origin time

Origin time = 09:01:58.5723 UTC.

The average origin time from 3 stations is = (59.32865 + 58.62045 + 58.5723)/3

= 58.84 sec

= 09:01:58.84 UTC

In this study, Microsoft Excel program is used to assist in the calculation of the origin time (Figure 4.22) which must be considered in conjunction with the Magnitude and Epicenter and Depth. The origin time of the same events when calculate must be fixed the time difference of 3 stations to less than 3 second. If some stations have time difference more than 3 second, the arrival time of P-and S-wave of those stations must go back to read again.

Date	7-Dec-05				Amphoe Mae Suai, Chiang Rai									
Start Time	9	0	52			9	0	62			9	0	83		
Station	KAEW					MONT					HTUM				
P-time				20.145	*72.145*				18.835	*80.835*				0.520	*83.52*
S-time				29.500	*81.5000*				35.045	*97.0450*				18.730	*101.7300*
(S-P)				9.355	*74.84*				16.21	*129.68*				18.210	*145.68*
(S-P) x 1.37				12.816	*5.63*				22.2077	*5.90*				24.948	*5.90*
Origin Time				59.33	*3.30*				58.627	*3.39*				58.57	*3.40*
58.84275	Average Origin Time													

Figure 4. 22. An example of using Microsoft Excel program to calculate the origin time of an earthquake on December 7, 2005. Note: each station has time difference not more than 2 seconds.

4.3 Results of Analysis Magnitude and Epicenter and Depth and Origin Time

4.3.1 Earthquakes Catalogue and Epicentral Map of the KST

The results of analyzing 128 well-located earthquakes are date and time of earthquakes occurrence, magnitude, latitude and longitude, depth, and region of earthquakes which summarized in Table 4.1 and display in epicentral map after re-locating (Figure 4.23) using ArcGIS program with legend of difference magnitude to facilitate the consideration. In Table 4.1, from 128 well-located earthquakes only 99 events of earthquake that occurred in the study area can be extracted, which can be divided into various magnitudes as follows: M2-2.9, 14 events, M3-3.9, 54 events, and M4-4.9, 31 events (Figure 4.24). The earthquakes which mostly occur in the study area are the earthquakes with M3-3.9 and M4-4.9 respectively. They are all shallow earthquakes with depth less than 70 km. There are various depths as follows: below a depth of 0-5 km, 39 events, a depth of 6-10 km, 19 events, a depth of 11-15 km, 19events, a depth of 16-20 km, 5 events, a depth of 21-25 km, 6 events, a depth of 26-30 km, 5 events, a depth of 31-35 km, 4 events, a depth of 36-40 km, 1 event, and a depth of 61 km, 1 events (Figure 4.25). The earthquakes with magnitudes 4-4.9 from this study usually occur in Changwat Chiang Rai and Chiang Mai. It can be concluded that these two areas are the areas of higher seismic risk than others in northern Thailand. The earthquakes occurring within the area of the KST seismographic network or the reservoir area of the KST dam mostly have the magnitudes of 2-3.9, and the nearest earthquake to the KST dam is the earthquake on March 2, 2008 with magnitude of 3.1 and source-to-site is 15 km.

Table 4. 3 The 128 well-located earthquakes during the year 1999 to 2010 after re-locating in this study.

No	Date	Origin Time (UTC)			Location		Depth (km)	M	Region
		hr	min	sec	Lat	Long			
1	22-May-1999	15	23	28	18.919	100.196	-	2.6	Amphoe Chiang Muan, Phayao
2	29-Jun-1999	6	38	16	21.042	98.35	19	5.6	Northern Myanmar
3	15-Jul-1999	17	35	11	21.386	100.529	33	5.2	Northern Laos
4	10-Aug-1999	23	14	34	18.933	99.955	11	3.4	Amphoe Ngao, Lampang
5	10-Aug-1999	23	15	16	18.929	100.087	9	2.9	Amphoe Chiang Muan, Phayao
6	19-Nov-1999	23	21	53	18.791	100.12	-	3.0	Amphoe Ngao, Lampang
7	13-Apr-2000	13	13	52	19.274	100.474	3	3.1	Amphoe Pong, Phayao
8	5-Sep-2000	11	44	28	19.147	100.184	4	3.1	Amphoe Pong, Phayao
9	7-May-2001	1	4	26	18.448	100.484	1	3.1	Amphoe Rong Kwang, Phrae
10	7-Nov-2001	5	36	39	18.775	99.551	5	3.2	Amphoe Mueang Phan, Lampang
11	26-Apr-2002	20	31	41	19.145	99.314	-	4.3	Amphoe Phrao, Chiang Mai
12	2-Jul-2002	3	54	4	19.898	100.6	3	5.0	Northern Laos
13	2-Jul-2002	17	55	17	19.91	100.57	3	3.7	Northern Laos
14	3-Jul-2002	0	17	46	19.902	100.64	2	3.9	Northern Laos
15	21-Jul-2002	22	49	45	19.777	100.837	9	3.9	Northern Laos
16	7-Sep-2002	6	11	44	18.578	100.361	3	3.2	Amphoe Song, Phrae
17	25-Sep-2002	14	27	46	19.296	99.587	8	3.6	Amphoe Wiang Pa Pao, Chiang Rai
18	6-Nov-2002	5	21	21	18.676	99.921	-	2.9	Amphoe Ngao, Lampang
19	18-Dec-2002	13	47	11	19.395	99.196	5	4.7	Amphoe Phrao, Chiang Mai
20	29-Jan-2003	7	14	30	19.729	100.449	7	3.8	Amphoe Thoeng , Chiang Rai
21	15-Mar-2003	4	29	42	19.329	99.566	2	3.2	Amphoe Wiang Pa Pao, Chiang Rai
22	23-Aug-2003	8	57	30	18.849	99.39	8	3.3	Amphoe Mae On, Chiang Mai
23	18-Sep-2003	11	4	15	19.915	100.888	1	4.4	Northern Laos
24	23-Nov-2003	15	8	9	20.405	100.982	19	4.5	Northern Laos
25	14-Mar-2004	5	49	37	19.9	100.563	7	3.9	Northern Laos
26	27-Mar-2004	4	5	35	19.497	99.63	5	3.7	Amphoe Mae Saruai, Chiang Rai
27	17-Aug-2004	18	53	54	17.465	100.819	61	4.1	Amphoe Chat Trakan, Phitsanulok
28	11-Sep-2004	1	31	56	18.787	98.978	7	3.4	Amphoe Mueang, Chiang Mai
29	26-Dec-2004	1	29	28	21.412	98.107	34	6.5	Northern Myanmar
30	30-Dec-2004	23	54	21	21.254	97.761	18	6.3	Northern Myanmar
31	25-Jan-2005	16	30	21	22.608	100.677	23	5.7	Northern Laos
32	1-Apr-2005	7	18	20	19.412	99.421	3	3.7	Amphoe Wiang Pa Pao, Chiang Rai
33	4-Jun-2005	23	1	37	17.909	100.669	34	3.8	Amphoe Tha Pla, Uttaradit
34	9-Jun-2005	21	7	56	18.656	100.249	0	2.3	Amphoe Song, Phrae
35	29-Jun-2005	0	38	52	18.604	99.611	10	3.7	Amphoe Chae Hom, Lampang
36	4-Dec-2005	9	34	32	18.769	98.972	13	3.9	Amphoe Mueang, Chiang Mai
37	7-Dec-2005	9	0	58	19.734	99.544	8	3.8	Amphoe Mae Saruai, Chiang Rai
38	15-Dec-2005	6	48	37	19.553	99.946	11	4.0	Amphoe Pa Daed, Chiang Rai
39	15-Dec-2005	23	13	17	19.492	100.037	8	3.0	Amphoe Pa Daed, Chiang Rai
40	16-Dec-2005	2	13	45	19.601	99.899	15	3.5	Amphoe Phan, Chiang Rai
41	16-Dec-2005	2	15	40	19.564	99.892	11	3.7	Amphoe Phan, Chiang Rai
42	17-Dec-2005	10	59	15	19.639	99.986	22	3.3	Amphoe Pa Daed, Chiang Rai
43	17-Dec-2005	11	48	6	19.505	99.947	4	3.3	Amphoe Pa Daed, Chiang Rai

Table 4.3. The 128 well-located earthquakes during the year 1999 to 2010 after re-locating in this study (cont).

No	Date	Origin Time (UTC)			Location		Depth (km)	M	Region
		hr	min	sec	Lat	Long			
44	24-Jan-2006	13	41	59	20.611	98.418	1	5.6	Northern Myanmar
45	15-Feb-2006	16	54	16	19.132	100.244	8	3.6	Amphoe Pong, Phayao
46	20-Feb-2006	18	34	1	19.129	100.152	1	2.9	Amphoe Dok Kam Tai, Phayao
47	6-Aug-2006	5	15	23	19.641	99.053	3	4.3	Amphoe Chiang Dao, Chiang Mai
48	13-Oct-2006	15	35	28	20.077	100.479	19	3.7	Amphoe Wiang Kaen, Chiang Rai
49	18-Oct-2006	12	1	10	18.95	100.049	4	3.4	Amphoe Dok Kam Tai, Phayao
50	21-Oct-2006	1	58	47	20.32	100.511	22	4.3	Northern Laos
51	16-Nov-2006	18	39	3	19.675	100.023	36	4.0	Amphoe Thoeng , Chiang Rai
52	26-Nov-2006	19	32	57	19.02	101.207	4	3.8	Amphoe Bo Kluea, Nan
53	12-Dec-2006	17	2	29	18.967	99.193	7	4.9	Amphoe Doi Saket, Chiang Mai
54	12-Dec-2006	19	49	37	19.004	99.125	4	3.9	Amphoe Doi Saket, Chiang Mai
55	12-Dec-2006	22	21	55	18.989	99.139	13	3.6	Amphoe Doi Saket, Chiang Mai
56	13-Dec-2006	5	49	4	18.921	99.268	12	3.3	Amphoe Doi Saket, Chiang Mai
57	23-Dec-2006	11	49	17	18.909	99.12	9	3.2	Amphoe Doi Saket, Chiang Mai
58	25-Jan-2007	22	29	47	18.834	99.191	7	3.3	Amphoe Doi Saket, Chiang Mai
59	18-Feb-2007	8	52	55	18.548	100.606	6	3.1	Amphoe Wiang Sa, Nan
60	22-Apr-2007	6	18	3	19.4	99.536	3	4.1	Amphoe Wiang Pa Pao, Chiang Rai
61	23-Apr-2007	14	17	6	19.464	99.769	16	3.7	Amphoe Phan, Chiang Rai
62	15-May-2007	14	35	45	20.622	100.327	3	4.8	Northern Laos
63	16-May-2007	8	56	10	20.657	100.678	24	6.2	Northern Laos
64	16-May-2007	9	31	3	20.232	100.743	29	3.9	Northern Laos
65	16-May-2007	10	5	35	20.621	100.855	23	4.1	Northern Laos
66	16-May-2007	10	15	41	20.548	100.587	24	4.1	Northern Laos
67	16-May-2007	10	26	1	20.488	100.894	15	4.1	Northern Laos
68	16-May-2007	11	15	56	20.458	100.867	13	4.4	Northern Laos
69	16-May-2007	11	35	12	20.53	100.79	19	4.0	Northern Laos
70	16-May-2007	11	43	52	20.4	100.697	29	4.1	Northern Laos
71	16-May-2007	13	18	7	20.495	100.64	33	4.6	Northern Laos
72	16-May-2007	17	8	54	20.547	100.774	10	4.2	Northern Laos
73	17-May-2007	3	25	40	20.652	100.379	36	4.2	Northern Laos
74	18-May-2007	0	1	53	20.42	100.708	25	4.1	Northern Laos
75	18-May-2007	1	40	55	20.458	100.67	20	4.0	Northern Laos
76	18-May-2007	13	5	16	20.465	100.659	17	4.2	Northern Laos
77	20-May-2007	1	21	21	20.268	100.747	24	3.9	Northern Laos
78	23-May-2007	17	6	27	20.399	100.633	32	4.1	Northern Laos
79	24-May-2007	11	15	17	20.31	100.746	24	4.0	Northern Laos
80	7-Jun-2007	17	21	4	20.673	100.73	21	4.8	Northern Laos
81	19-Jun-2007	5	6	42	18.983	99.154	2	4.5	Amphoe Doi Saket, Chiang Mai
82	23-Jun-2007	6	53	45	21.468	99.552	4	5.1	Myanmar
83	23-Jun-2007	8	17	7	21.412	99.32	2	5.9	Myanmar
84	23-Jun-2007	8	27	37	21.324	99.316	12	5.7	Myanmar
85	14-Jul-2007	8	29	18	20.357	100.783	17	3.8	Northern Laos
86	28-Jul-2007	21	33	49	20.651	99.144	17	4.5	Myanmar

Table 4.3. The 128 well-located earthquakes during the year 1999 to 2010 after re-locating in this study (cont).

No	Date	Origin Time (UTC)			Location		Depth (km)	M	Region
		hr	min	sec	Lat	Long			
87	6-Aug-2007	6	53	52	20.475	100.493	25	4.3	Northern Laos
88	6-Aug-2007	8	50	50	20.507	100.573	28	3.9	Northern Laos
89	7-Aug-2007	8	53	23	20.866	100.114	26	4.6	Northern Laos
90	8-Aug-2007	9	15	32	20.408	100.726	26	4.2	Northern Laos
91	19-Aug-2007	11	16	56	19.921	98.93	10	3.9	Myanmar-Thai Border
92	8-Sep-2007	7	12	46	20.59	100.674	29	4.2	Northern Laos
93	16-Oct-2007	2	39	24	18.73	100.246	1	2.4	Amphoe Song, Phrae
94	16-Oct-2007	6	46	53	20.483	100.727	13	4.7	Northern Laos
95	1-Nov-2007	19	5	47	20.374	100.722	25	4.6	Northern Laos
96	23-Dec-2007	11	19	31	18.655	100.654	3	3.2	Amphoe Wiang Sa, Nan
97	2-Mar-2008	3	23	35	18.736	100.113	1	3.1	Amphoe Song, Phrae
98	9-Apr-2008	15	49	24	19.3	99.266	13	3.2	Amphoe Phrao, Chiang Mai
99	10-Jun-2008	21	37	43	20.112	100.858	13	4.7	Northern Laos
100	1-Jul-2008	9	45	51	19.219	99.345	3	3.9	Amphoe Wiang Pa Pao, Chiang Rai
101	9-Jul-2008	4	39	48	18.689	100.253	2	2.2	Amphoe Song, Phrae
102	25-Nov-2008	8	10	52	18.905	100.167	2	2.5	Amphoe Chiang Muan, Phayao
103	29-Nov-2008	8	6	25	20.289	100.658	32	4.0	Northern Laos
104	31-Dec-2008	8	0	1	18.67	100.616	4	3.6	Amphoe Wiang Sa, Nan
105	31-Dec-2008	8	4	11	18.674	100.611	5	3.6	Amphoe Wiang Sa, Nan
106	29-Jan-2009	23	24	33	19.045	100.318	4	2.8	Amphoe Chiang Muan, Phayao
107	6-Feb-2009	1	39	18	19.547	99.759	7	2.8	Amphoe Phan, Chiang Rai
108	22-May-2009	7	58	9	20.464	100.796	12	4.4	Northern Laos
109	22-May-2009	18	50	15	21.318	102.01	8	5.0	Northern Laos
110	1-Jun-2009	12	44	27	18.821	100.707	11	3.1	Amphoe Mueang, Nan
111	10-Jun-2009	0	23	59	18.848	100.286	1	2.6	Amphoe Chiang Muan, Phayao
112	10-Jun-2009	0	25	5	18.899	100.242	0	2.7	Amphoe Chiang Muan, Phayao
113	18-Jun-2009	19	50	16	18.892	100.309	6	2.6	Amphoe Chiang Muan, Phayao
114	21-Jun-2009	18	6	20	19.588	99.977	14	3.6	Amphoe Thoeng, Chiang Rai
115	16-Aug-2009	17	57	11	20.231	100.746	10	4.2	Northern Laos
116	1-Oct-2009	11	56	2	20.836	101.689	4	4.1	Northern Laos
117	14-Oct-2009	1	59	31	20.811	101.498	21	4.8	Northern Laos
118	7-Nov-2009	3	54	55	20.458	101.793	18	3.9	Northern Laos
119	10-Nov-2009	7	36	51	20.815	101.763	31	4.7	Northern Laos
120	10-Nov-2009	8	1	44	20.802	101.243	27	4.2	Northern Laos
121	10-Nov-2009	8	40	23	20.844	101.418	25	4.1	Northern Laos
122	2-Dec-2009	7	3	5	19.232	99.209	14	3.3	Amphoe Phrao, Chiang Mai
123	26-Dec-2009	1	11	49	20.376	98.944	3	4.1	Northern Myanmar
124	9-Mar-2010	13	3	24	20.323	99.168	30	4.2	Northern Myanmar
125	26-Jun-2010	2	23	59	20.354	99.827	10	3.9	Northern Myanmar-Thai
126	6-Jul-2010	15	23	29	20.362	99.614	30	4.1	Northern Myanmar-Thai
127	18-Jul-2010	12	53	19	20.263	101.272	4	3.9	Northern Laos
128	29-Aug-2010	8	19	2	19.516	99.512	6	3.4	Amphoe Mae Suai, Chiang Rai

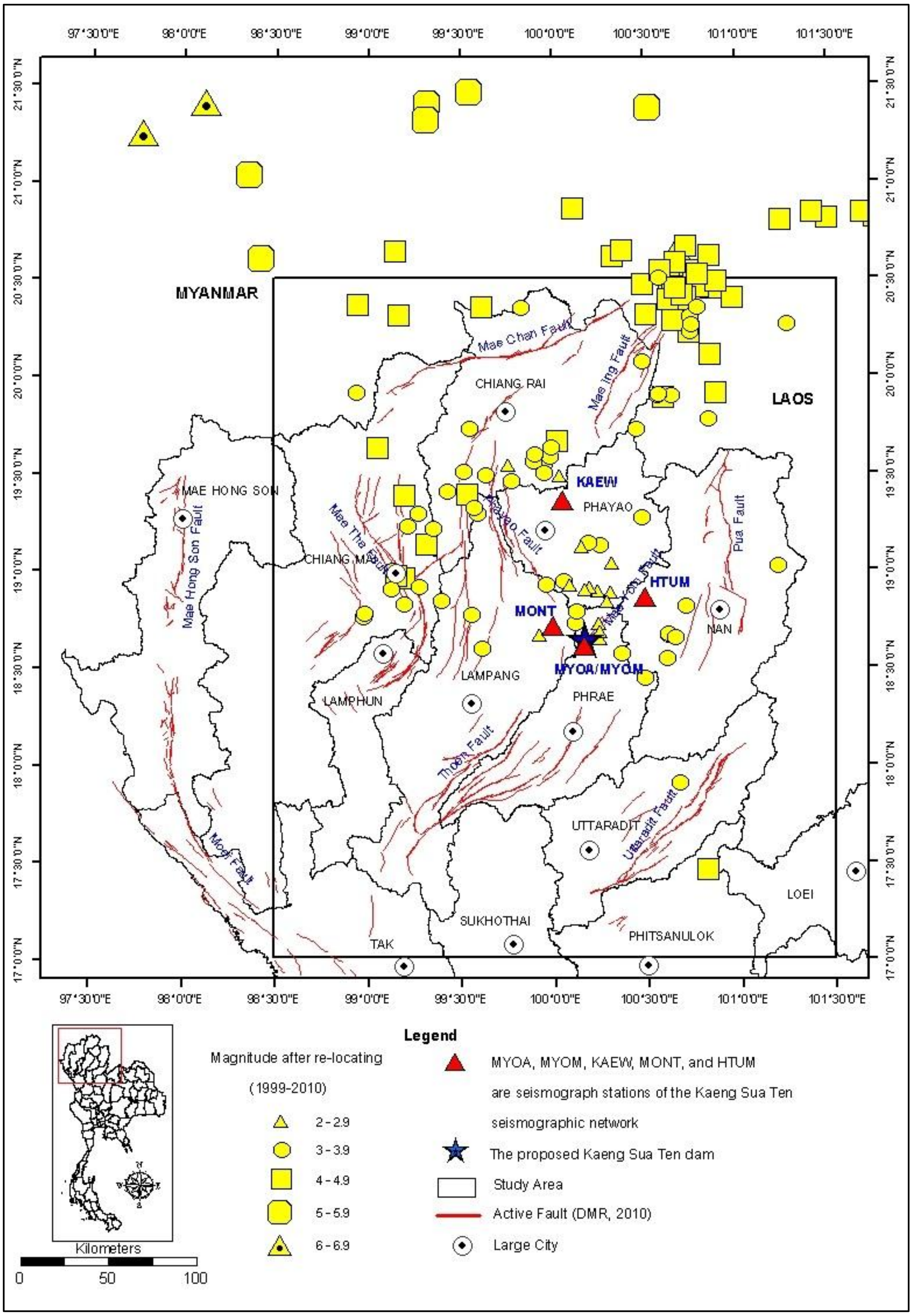


Figure 4. 23. Epicentral map of 128 well-located earthquakes during the year 1999 to 2010 after re-locating.

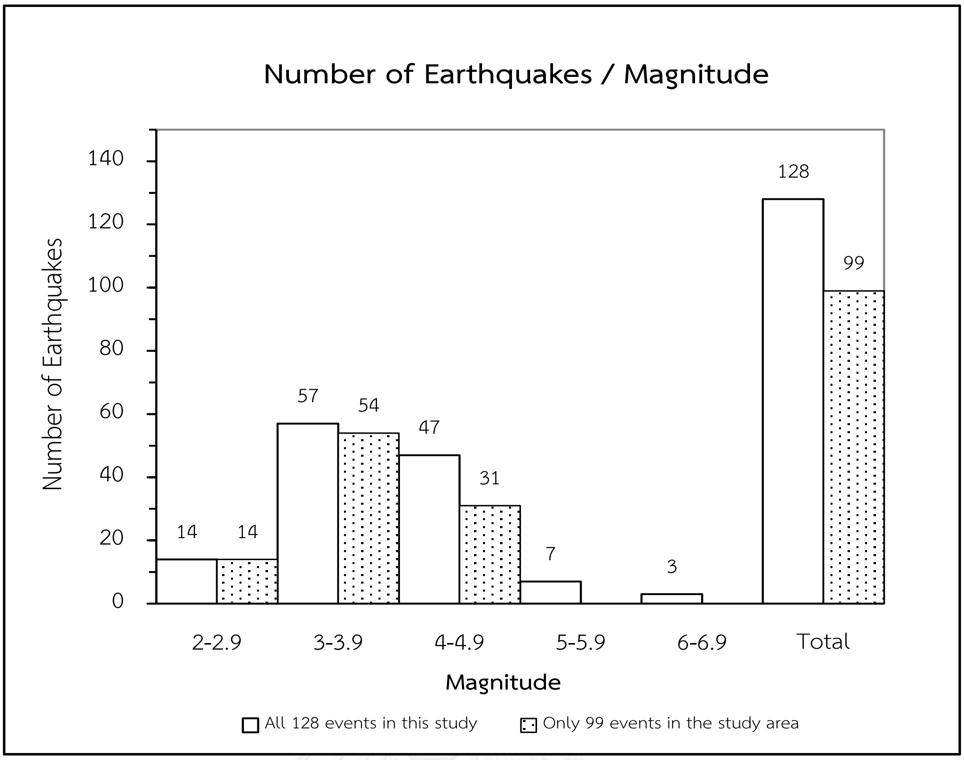


Figure 4. 24. Number of earthquakes and magnitude of the total 128 events in this study, and the only 99 events in the study area.

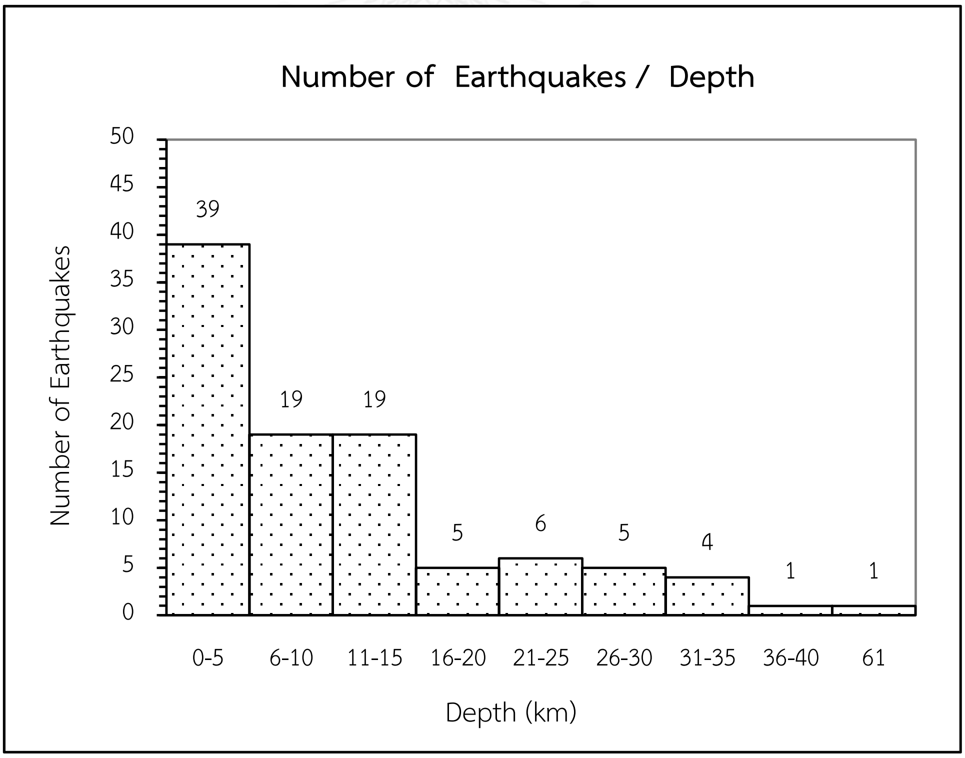


Figure 4. 25. Number of earthquakes and depth of 99 events in the study area.

4.3.2 Frequency and Magnitude Relations (b-value)

Evaluate the frequencies of earthquakes that occur in any specific area is necessary for the seismic hazard analysis that area. It can be calculated from the Gutenberg-Richter's Recurrence Law (Gutenberg & Richter, 1944). This will allow for the studying of the numbers of the opportunity of earthquakes with different magnitudes to be occurred within the specific area.

To obtain the Gutenberg-Richter law (b-value) for this study, the data from Table 4.1, Figure 4.23, and Figure 4.24 must undergo the process of declustering according to the following guidelines, the outcome was shown in Table 4.2:

1) Start date: May 22, 1999; End date: August 29, 2010.
2) Northern Thailand" is defined as that area between latitude 17-20.5 and longitude 98.5-101.5.
3) Only earthquakes of magnitude 2.0 and greater were used, because the earthquake catalogue of the KST is almost certainly incomplete below this magnitude for the area, as outlined above.
4) Preliminary, there are only 69 earthquake events which can be applied to study for the b-value.

Table 4. 4. Earthquake Numbers in Northern Thailand, during the year 1999 to 2010.

Magnitude (M) Range	Count per M Range	Cumulative Total Above Lower M in Range	Annual Rate
2.0 - 2.4	3	69	5.75
2.5 - 2.9	11	66	5.50
3.0 - 3.4	20	55	4.58
3.5 - 3.9	21	35	2.92
4.0 - 4.4	11	14	1.17
4.5 - 4.9	3	3	0.25

By plotting, on a logarithmic scale, the number of earthquakes greater than or equal to a given magnitude in a set period of time against the magnitude, a basic characteristic of the seismicity rate in an area or the b value can be determined.

1. Firstly, choose a simple x-y plot, with magnitude M as the x-axis and number of earthquakes greater than magnitude M as the y-axis. Then plot this data set on a logarithmic-linear graph. In roughly, an approximate linear arrangement of points is shown. Using a straight edge, draw a single line that best represents the set of points that have plotted. That line does not need to run through the center, or even touch, all of the points. There is now a line that represents the data - the numbers of earthquakes with respect to magnitude over 12 years in northern Thailand (1999-2010). The equation for a line on a simple x-y plot is y = bx + a, where a, is the y-intercept and b represents the slope of the line. To keep b positive at all times, think of the above equation as true for positive-sloping lines (going up as when move left-to-right), and the equation y = a – bx as true for negative-sloping lines.

2. The graph has a y-axis that is logarithmic. Thus, a negative-sloping line on this graph would be described as log y = a - bx. Indeed, instead of calling it the y-axis, think of it as a function N of the magnitude, M, which itself can be substituted for x (since the x-axis is magnitude). Make these substitutions in the equation given above. There is now a mathematical expression that represents the Gutenberg-Richter relation, the correlation between the magnitude of earthquakes and their relative numbers. It should look something like

3. Use a ruler to actually measure the slope of the line. Pick any segment of the line and sketch out a right triangle, with the legs parallel to the axes, and the line itself forming the hypotenuse. Measure the height of the vertical side of the triangle and divide this by the length of the horizontal side. The answer will be the slope of the line, otherwise known as the b value.

4. Another way to find the *b* value is to note the value of N(M) at each of two points along the line, exactly one magnitude unit (i.e. in the x-direction) apart. Divide the larger number (the point on the left) by the smaller number (the point on the right), and then take the logarithm of this quotient. That answer is the b value of this line.

Therefore, the b-value of northern Thailand for 12 years from the method that described above is 0.59 (Figure 4.26), if an annual rate is required, calculating by using the number of the cumulative total by 12, the b value obtained is also 0.59 (Figure 4.26). According to the Gutenberg-Richter relation, the b value from this study can be used to assess the seismic hazards such as the opportunity on earthquakes with different magnitudes occurrences within northern Thailand. The results from Figure 4.26 show that the earthquakes with magnitude 3 could occurred at least 4 per year, and the earthquakes with magnitude 3.5 could occurred at least 2.5 per year, and the earthquakes with magnitude 4 could occurred at least 1.5 per year.

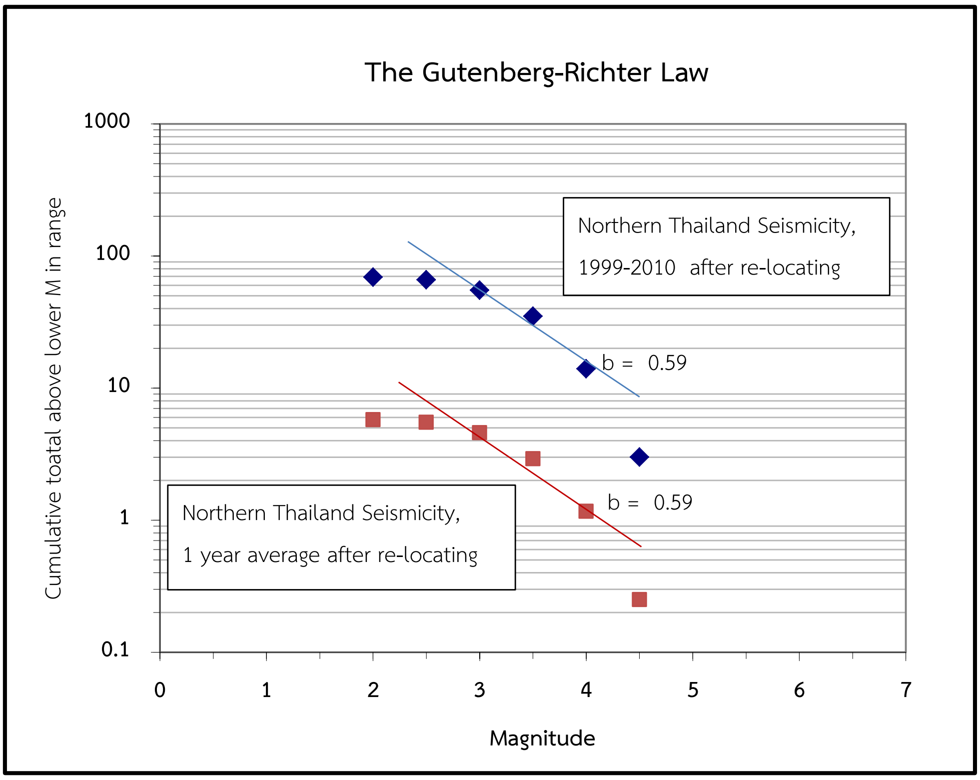


Figure 4. 26. The Gutenberg-Richter law for the northern Thailand seismicity period of 1999 to 2010, and for 1 year average the b value is 0.59.

4.4 Analyzing Ground-motion Parameters

For the earthquake study in northern Thailand, understanding the behavior and characteristics of earthquake ground motion is necessary, which is very useful for design engineers, and for structural design to withstand earthquakes. Ground motion during an earthquake is measured by strong motion seismograph (accelerograph), which records the acceleration of the ground. Since ground motion at particular site due to earthquakes is influenced by source, travel path and local site condition. Strong ground shaking can causes severe damages to man-made structure and unfortunately, sometimes, induce losses of human lives. The characteristics of ground motion that are important in earthquake engineering applications are peak ground motion (peak ground acceleration (PGA), peak ground velocity (PGV), and peak ground displacement (PGD)), and duration of strong motion, and frequency content. Each of these parameters influences the response of structure. Peak ground motion primarily influences the vibration amplitudes. Duration of strong motion has a pronounced effect on the severity of shaking. A ground motion with moderate peak acceleration and a long duration may cause more damage than a ground motion with a larger acceleration and a shorter duration. Frequency content strongly affects the response characteristics of a structure. In a structure, ground motion is amplified the most when the frequency content of the motion and the natural frequencies of the structure are close to each other (Mohraz & Sadek, 2001). Because of the complexity of earthquake ground motions, identification of single parameter that accurately describes all important ground motion characteristics is regarded as impossible (Jennings, 1985; Joyner & Boore, 1988).

4.4.1 Peak Ground Acceleration

The PGA is a measure of earthquake acceleration on the ground and an important input parameter for earthquake engineering. Unlike the Richter magnitude scale, PGA is not a measure of the total size of the earthquake but rather how hard the earth shakes in a given geographic area. Unlike the MMI scale, PGA is measured by instruments, not from personal reports, although PGA generally correlates well with the MMI scale. The PGA can be expressed in g (the acceleration due to Earth's gravity) or in m/s^2 (1 g = 9.81 m/s^2).

In this study, the Kinematics Strong Motion Analyst program is used to analyze the PGA from 20 strong ground-motion earthquakes. This program can use to determine acceleration, velocity, and displacement of ground motion.

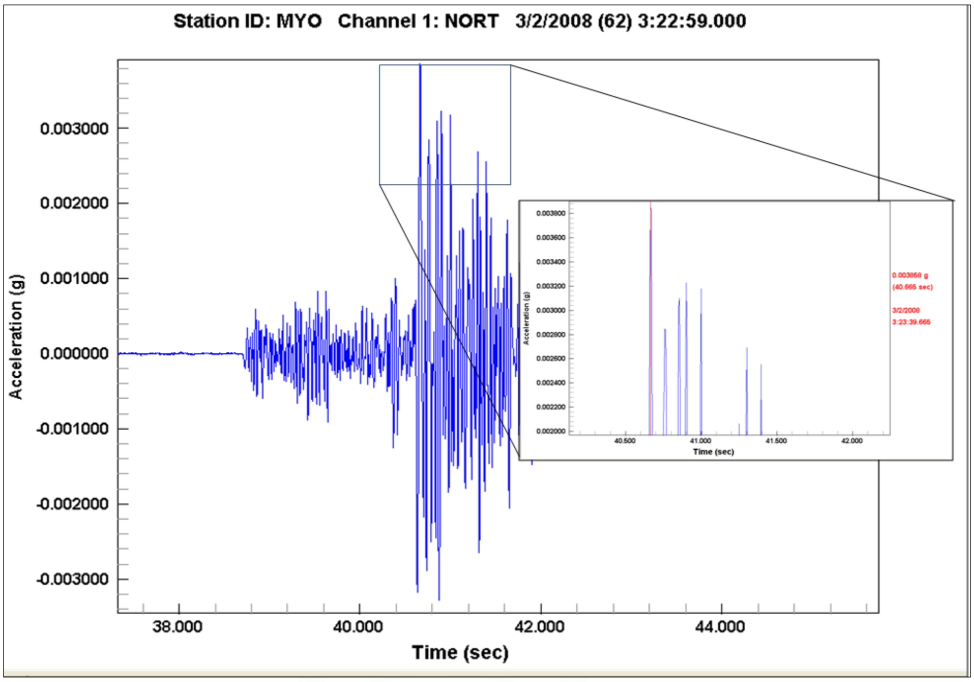


Figure 4. 27. Reading the PGA = 0.003858g at 03:23:39.755 UTC in north-south direction of Amphoe Ngao-Song border earthquake on March 2, 2008, M3.10 and source-to-site the MYOA station 15 km.

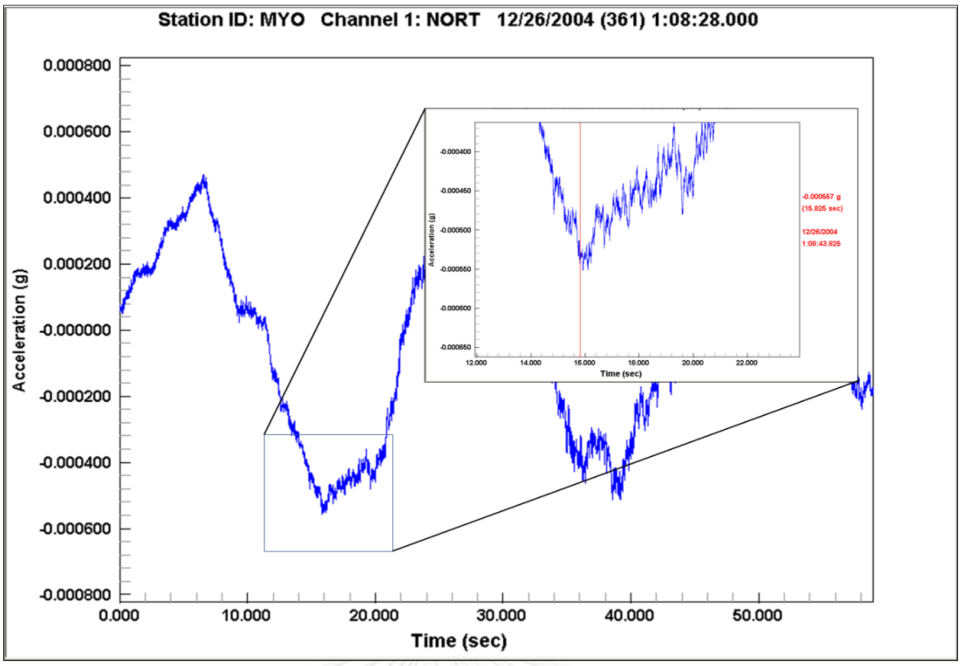


Figure 4. 28. Reading the PGA = 0.000557g at 01:08:43:825 UTC in north-south direction of Sumatra Indonesia earthquake on December 26, 2004, M9.1 and source-to-site the MYOA station >1,500 km.

4.4.2 Duration of Motion

(Kramer, 1996) described that the duration of strong ground motion can have a strong influence on earthquake damage. Many physical processes, such as the degradation of stiffness and strength of certain types of structures and the build-up of pore water pressure in loose, saturated sands, are sensitive to the number of load or stress reversals that occur during an earthquake. A motion of short duration may not produce enough load reversals for damaging response to build up in a structure, even if the amplitude of the motion is high. On the other hand, a motion with moderate amplitude but long duration can produce enough load reversals to cause substantial damage

Due to no standard definition of strong motion duration, the selection of procedure for computing the duration for a certain study depends on the purpose of the intended application. There are different definitions of the duration of strong ground motion.(Bolt, 1969) proposed bracketed duration, which is defined as the time between the first and last exceedance of threshold acceleration (usually 0.05g) (Figure 4.29).

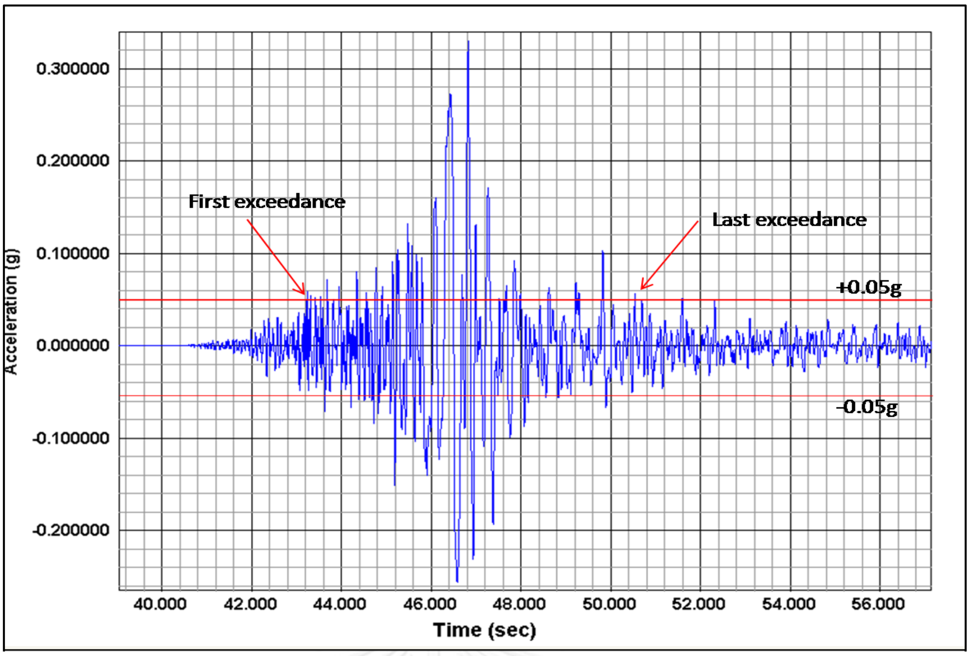


Figure 4. 29. Bracketed duration obtained graphically from the accelerogram based on the threshold acceleration of 0.05g.

4.4.3 Frequency Content

In case of frequency content, (Kramer, 1996) stated the dynamic response of compliant objects, be they buildings, bridge, slopes, or soil deposits, is very sensitive to the frequency at which they are loaded. Earthquakes produce complicated loading with components of motion that span a board range of frequencies. The frequency content describes how the amplitude of ground motion is distributed among different frequencies. Since the frequency content of an earthquake motion will strongly influence the effects of that motion, characterization of the motion cannot be complete without consideration of its frequency content. The frequency content of a ground motion can also be described by a power spectrum or power spectral density function. The power spectral density function can also be used to estimate the statistical properties of a ground motion and to compute stochastic response using random vibration techniques (Clough & Penzien, 1975; Vermarcke, 1976; Yang, 1986). Power spectral density (PSD) function shows the strength of the variations (energy) as a function of frequency. In other words, it shows at which frequencies variations are strong and which frequencies variations are weak.

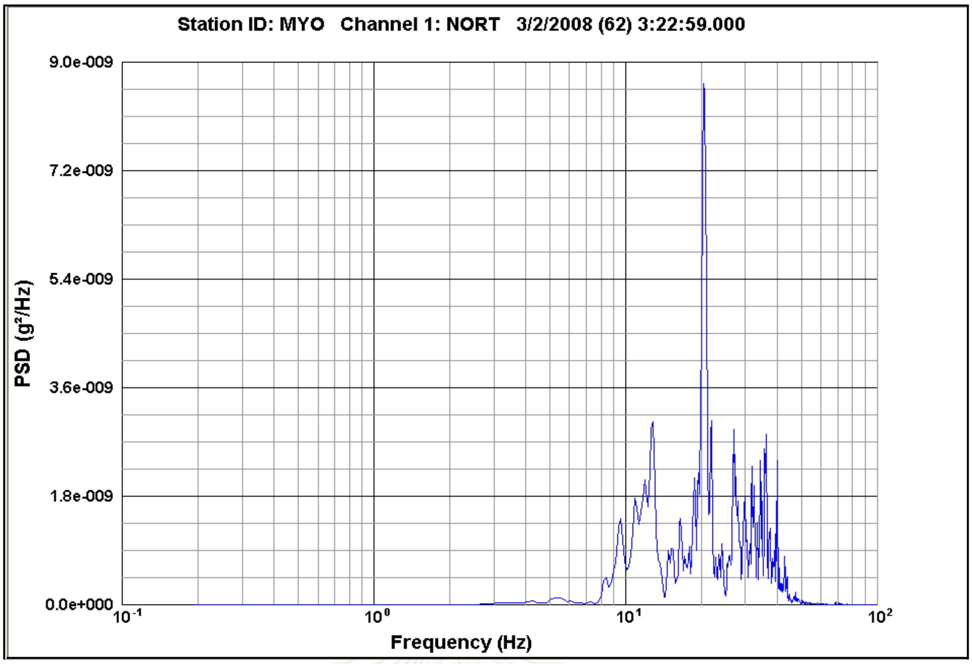


Figure 4. 30. The PSD and frequency content of Amphoe Ngao-Song earthquake on March 2, 2008, M3.10 and source-to-site the MYOA station 15 km.

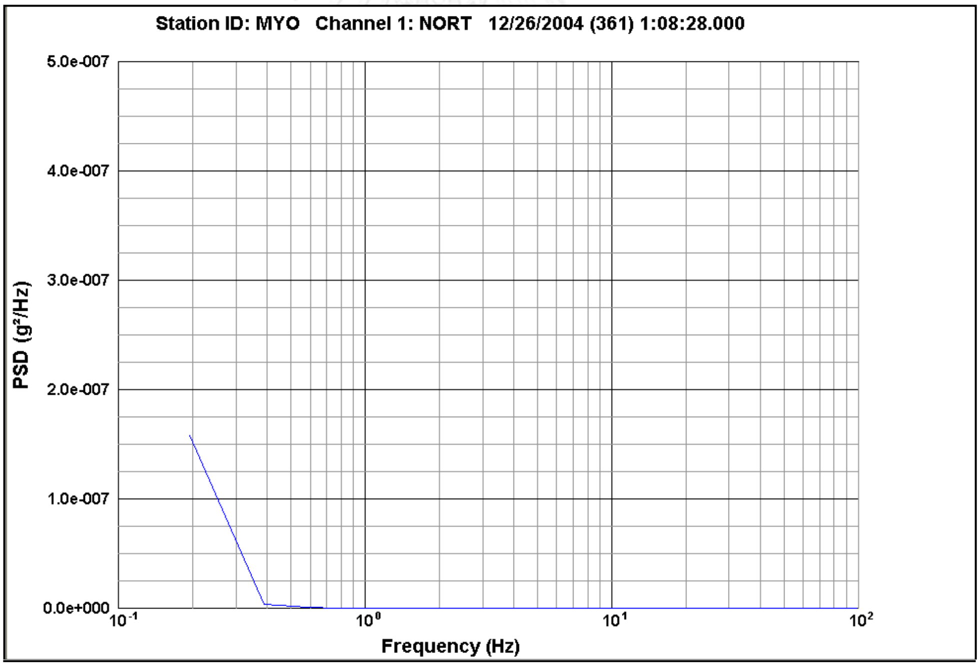


Figure 4. 31. The PSD and frequency content of Sumatra Indonesia earthquake on December 26, 2004, M9.1 and source-to-site the MYOA station >1,500 km.

4.5 Results of Ground Motion Parameters Analysis

The PGA of 20 strong ground-motion earthquakes during the year 1999 to 2010 is summarized in Table 4.4. There are no earthquakes with ground-motion greater than 0.05g at the MYOA station (the proposed KST dam). In case of duration of motion, by using the criteria of bracketed duration (Bolt, 1969), the results of this study showed that there was no earthquakes which have the ground-motion more than 0.05g. The characteristics of earthquake ground motion of northern Thailand from the PGA, duration of motion, and frequency content can be summarized that the PGA value at the site depends on the earthquake's magnitude and the epicentral distance (source-to-site). The earthquakes with smaller magnitude have shorter duration of motion and higher frequency content than the earthquakes with larger magnitude vice versa the earthquakes with larger magnitude have longer duration of motion and lower frequency content than the earthquakes with smaller magnitude.

Table 4. 5. The PGA and frequency content of 20 strong ground-motion earthquakes at the MYOA station during the year 1999 to 2010 in this study.

No	Date	Peak Ground Acceleration (PGA)					Location				
		Component	Time (UTC)	cm/s^2	g	Frency content (Hz)	Lat	Long	M	Region	Distance to the MYOA station (km)
1	10-Aug-1999	N-S	23:14:48.280	0.878847	0.0009	3-50	18.933	99.955	3.42	Amphoe Ngao, Lampang	48
		Vertical	23:14:46.920	0.373286	0.0004	3-50					
		E-W	23:14:48.275	0.657851	0.0007	3-50					
2	19-Nov-1999	N-S	23:22:00.055	1.858995	0.0019	1-50	18.791	100.120	3.03	Amphoe Ngao, Lampang	19
		Vertical	23:21:59.335	0.708568	0.0007	1-60					
		E-W	23:21:59.470	2.530054	0.0026	1-50					
3	26-Apr-2002	N-S	20:32:14.555	0.750442	0.0008	1-30	19.145	99.314	4.32	Amphoe Phrao, Chiang Mai	112
		Vertical	20:32:15.320	0.232761	0.0002	1-30					
		E-W	20:32:14.760	0.440160	0.0004	1-30					
4	2-Jul-2002	N-S	3:54:50.430	0.345154	0.0004	0.2-20	19.898	100.600	4.97	Laos	154
		Vertical	3:54:31.360	0.237727	0.0002	0.2-20					
		E-W	3:54:51.270	0.471349	0.0005	0.2-20					
5	7-Sep-2002	N-S	6:11:52.680	1.055612	0.0011	1-50	18.578	100.361	3.18	Amphoe Song, Phrae	26
		Vertical	6:11:52.740	0.475629	0.0005	1-50					
		E-W	6:11:53.700	0.945668	0.0010	1-50					
6	21-Sep-2003	N-S	18:18:44.980	2.558666	0.0026	0.2-3	19.900	95.730	6.60	Myanmar	430
		Vertical	18:18:47.815	0.932354	0.0010	0.2-4					
		E-W	18:18:41.465	0.928094	0.0009	0.2-5					
7	26-Dec-2004	N-S	1:08:43.825	0.546100	0.0006	0.2-0.6	3.316	95.854	9.10	Sumatra Islands, Indonesia	> 1500
		Vertical	1:08:49.585	0.735392	0.0008	0.2-0.6					
		E-W	1:09:10.700	0.576617	0.0006	0.2-0.6					
8	26-Dec-2004	N-S	1:10:24.055	0.625202	0.0006	0.2-1	3.316	95.854	9.10	Sumatra Islands, Indonesia	> 1500
		Vertical	1:10:02.660	0.803384	0.0008	0.2-1					
		E-W	1:10:46.300	0.523906	0.0005	0.2-1					
9	26-Dec-2004	N-S	1:11:20.830	0.384166	0.0004	0.2-1	3.316	95.854	9.10	Sumatra Islands, Indonesia	> 1500
		Vertical	1:11:47.510	0.362633	0.0004	0.2-1					
		E-W	1:11:32.135	0.422176	0.0004	0.2-1					
10	26-Dec-2004	N-S	1:12:13.760	0.535636	0.0005	0.2-1	3.316	95.854	9.10	Sumatra Islands, Indonesia	> 1500
		Vertical	1:12:19.475	0.860398	0.0009	0.2-1					
		E-W	1:12:51.470	0.857780	0.0009	0.2-1					
11	26-Dec-2004	N-S	1:13:38.515	0.530924	0.0005	0.2-0.6	3.316	95.854	9.10	Sumatra Islands, Indonesia	> 1500
		Vertical	1:13:07.840	0.550147	0.0006	0.2-0.6					
		E-W	1:13:28.205	0.783146	0.0008	0.2-0.6					
12	26-Dec-2004	N-S	1:14:20.180	0.590484	0.0006	0.2-0.6	3.316	95.854	9.10	Sumatra Islands, Indonesia	> 1500
		Vertical	1:14:14.845	0.617070	0.0006	0.2-0.6					
		E-W	1:13:55.970	0.586001	0.0006	0.2-0.6					
13	26-Dec-2004	N-S	1:14:34.455	0.355073	0.0004	0.2-0.6	3.316	95.854	9.10	Sumatra Islands, Indonesia	> 1500
		Vertical	1:15:00.475	0.533855	0.0005	0.2-0.6					
		E-W	1:15:13.780	0.562801	0.0006	0.2-0.6					
14	26-Dec-2004	N-S	1:31:39.040	0.560553	0.0006	0.2-10	21.412	98.107	6.53	Myanmar	306
		Vertical	1:31:38.320	0.486190	0.0005	0.2-10					
		E-W	1:31:33.010	0.486191	0.0005	0.2-10					
15	18-Oct-2006	N-S	12:01:21.965	0.897797	0.0009	1-50	18.950	100.049	3.35	Amphoe Dok Kam Tai, Phayao	36
		Vertical	12:01:21.880	0.464508	0.0005	1-50					
		E-W	12:01:22.555	0.780996	0.0008	1-50					
16	12-Dec-2006	N-S	17:03:05.055	1.288414	0.0013	0.2-40	18.967	99.193	4.86	Amphoe Doi Saket, Chiang Mai	117
		Vertical	17:03:04.375	0.446271	0.0005	0.2-40					
		E-W	17:03:05.995	0.763968	0.0008	0.2-40					
17	16-May-2007	N-S	8:57:31.770	1.023331	0.0010	0.2-10	20.540	100.350	6.21	Laos	225
		Vertical	8:57:22.295	1.118008	0.0011	0.2-10					
		E-W	8:57:26.980	1.412541	0.0014	0.2-10					
18	19-Jun-2007	N-S	5:07:16.470	0.862205	0.0009	0.2-40	18.950	99.190	4.44	Amphoe Doi Saket, Chiang Mai	112
		Vertical	5:07:17.535	0.281525	0.0003	0.2-40					
		E-W	5:07:18.010	0.612953	0.0006	0.2-40					

Table 4.5. The PGA and frequency content of 20 strong ground-motion earthquakes at the MYOA station during the year 1999 to 2010 in this study (cont).

No	Date	Peak Ground Acceleration (PGA)					Location				
		Component	Time (UTC)	cm/s^2	g	Frency content (Hz)	Lat	Long	M	Region	Distance to the MYOA station (km)
19	2-Mar-2008	N-S	3:29:39.665	3.783707	0.0039	3-50	18.740	100.110	3.10	Amphoe Ngao-Song, Lampang-Phrae	15
		Vertical	3:23:39.665	2.208710	0.0023	3-50					
		E-W	3:23:39.755	3.848810	0.0039	3-50					
20	1-Jun-2009	N-S	12:44:43.505	0.374622	0.0004	0.2-80	18.806	100.593	3.10	Amphoe Wiang Sa, Nan	53
		Vertical	12:44:36.850	0.179374	0.0002	0.2-80					
		E-W	12:44:36.915	0.253605	0.0003	0.2-80					

CHAPTER V

COMPARISON OF DATA FROM BEFORE AND AFTER RE-LOCATING

These steps consist of comparison of data from before and after re-locating well-located earthquakes such as the epicenter of earthquakes, the frequency and magnitude relation (b-value), the relationship of earthquakes with geological structures, and the correlation of the KST's epicenters with the TMD.

5.1 Epicenter of Earthquakes before and after Re-locating

The comparison of KST's epicenters before and after re-locating can be summarized as follows:

Before relocating, the KST network has 118 events with magnitude 2.0-6.6 (Table 3.2) that can be categorized in northern Thailand, 62 events with magnitude 2.0-5.0 and in neighboring countries, 56 events with magnitude 3.9-6.6, and mostly scattered between Lat.18.5- 20.0 N Long.99.0-101.5 E (Figure 5.2). After relocating, the KST network has 128 well-located earthquakes with magnitude 2.2-6.5 (Table 4.1). 67 events are categorized to be in northern Thailand with magnitude range of 2.2-4.9 and in the neighboring countries 61 events with magnitude 3.9-6.5 (additional of 10 events are added, with 2 events of magnitude 3-3.9, and with 7 events of magnitude 4-4.9, and 1 event at magnitude 6-6.9 (Table 3.2 and Table 4.1)). The epicenters are mostly scattered along the Lat.18.0-20.5 N and Long.99.0-100.5 E (Figure 5.2). The depths of earthquakes are shallow with focal depth less than 70 km (Figure 4.25).

There are earthquakes with magnitudes 2-3.9 occurred near the reservoir area and around the seismographic stations of the KST network but no earthquakes occurred at the proposed KST dam in Phrae (Figure 5.3). The earthquake that occurred nearest the proposed KST dam is at Amphoe Song in Phrae on June 9, 2005 with magnitude 2.34, with epicenter at Lat.18.656 N and Long. 100.249 E, about 11.2 km to the northeast from the proposed KST dam (Figure 5.3 and Table 4.1).

The regions where the earthquakes with magnitude 4-4.9 mostly occur are in Chiang Mai and Chiang Rai. They were found in Amphoe Doi Saket (near the Mae

Kuang dam), Amphoe Phrao, and Amphoe Chiang Dao in Chiang Mai (Figure 5.4, Figure 5.5, and Table 4.1), and Amphoe Thoeng, Amphoe Wiang Pa Pao in Chiang Rai (Figure 5.6 and Table 4.1).

The earthquakes before and after re-locating have difference in the magnitude about $\pm$0.00-0.57 unit and the location about $\pm$2.0-125 km (Table 5.1). The original pre-relocating earthquake epicenters do not have any relation with existing geologic structure. This may be due to the manually analysis, not automatic, which did not have uniform standard procedure in the analysis. It was depended on the operator judgment to pick the phase of P or S-wave. However, the epicenters of 128 events after re-locating based on the criteria that were used in this study are more reliable and have better accuracy than before the re-locating, owing to the new epicenters were obtained from the intersection of 3 circles from at least 3 epicentral distances (Figure 5.7 - Figure 5.10). Together all events' origin times have been revised, as the difference in occurrence time from each station have been fixed to be less than 2 seconds error.

Figure 5.7 is the examples compares earthquake's locations from before and after re-locating on July 2, 2002. Before re-locating the location is at Amphoe Mae Suai Changwat Chiang Rai (Figure 5.7a) but after re-locating the location is in Northern Laos (Figure 5.7b). Figure 5.8 is the earthquake's locations from before and after re-locating which occurred on July 3 2002. Before re-locating, the location is at Amphoe Kun Tan Changwat Chiang Rai (Figure 5.8a) but after re-locating, the location is in Northern Laos (Figure 5.8b). Figure 5.9 is the earthquake's locations from before and after re-locating for September 18, 2003. Before re-locating, the location is in Myanmar (Figure 5.9a) but after re-locating the location is moved to Northern Laos (Figure 5.9b). Figure 5.10 is the earthquake's locations from before and after re-locating for March 14, 2004. Before re-locating, the location is in Amphoe Mae Chan, Changwat Chiang Rai (Figure 5.10a) but after re-locating the location is in Northern Laos (Figure 5.10b).

Table 5. 1. The KST's epicenters before and after re-locating.

No.	Date	Start Time (UTC)		before re-locating			No.	Date	Origin Time (UTC)			after re-locating		
		hr	min	Lat	Long	M			hr	min	sec	Lat	Long	M
1	22-May-1999	15	23	18.900	100.200	2.0	1	22-May-1999	15	23	28	18.919	100.196	2.6
							2	29-Jun-1999	6	38	16	21.042	98.35	5.6
							3	15-Jul-1999	17	35	11	21.386	100.529	5.2
2	10-Aug-1999	23	14	18.950	100.040	3.1	4	10-Aug-1999	23	14	34	18.933	99.955	3.4
							5	10-Aug-1999	23	15	16	18.929	100.087	2.9
3	19-Nov-1999	23	21	19.790	100.110	2.9	6	19-Nov-1999	23	21	53	18.791	100.12	3.0
4	13-Apr-2000	13	13	19.310	100.480	3.0	7	13-Apr-2000	13	13	52	19.274	100.474	3.1
5	5-Sep-2000	11	44	19.129	100.110	3.2	8	5-Sep-2000	11	44	28	19.147	100.184	3.1
6	7-May-2001	1	4	18.310	100.440	3.3	9	7-May-2001	1	4	26	18.448	100.484	3.1
							10	7-Nov-2001	5	36	39	18.775	99.551	3.2
7	26-Apr-2002	20	31	18.910	99.080	4.5	11	26-Apr-2002	20	31	41	19.145	99.314	4.3
8	2-Jul-2002	3	54	19.668	99.432	5.0	12	2-Jul-2002	3	54	4	19.898	100.6	5.0
							13	2-Jul-2002	17	55	17	19.91	100.57	3.7
9	3-Jul-2002	0	17	19.860	100.280	3.7	14	3-Jul-2002	0	17	46	19.902	100.64	3.9
10	21-Jul-2002	22	49	19.920	100.900	4.1	15	21-Jul-2002	22	49	45	19.777	100.837	3.9
11	7-Sep-2002	6	11	18.580	100.320	3.5	16	7-Sep-2002	6	11	44	18.578	100.361	3.2
12	25-Sep-2002	14	27	19.390	99.350	3.6	17	25-Sep-2002	14	27	46	19.296	99.587	3.6
13	6-Nov-2002	5	21	18.670	99.980	2.9	18	6-Nov-2002	5	21	21	18.676	99.921	2.9
14	18-Dec-2002	13	47	19.390	98.800	4.9	19	18-Dec-2002	13	47	11	19.395	99.196	4.7
15	29-Jan-2003	7	14	19.750	100.566	3.9	20	29-Jan-2003	7	14	30	19.729	100.449	3.8
							21	15-Mar-2003	4	29	42	19.329	99.566	3.2
16	23-Aug-2003	8	57	18.599	99.216	3.5	22	23-Aug-2003	8	57	30	18.849	99.39	3.3
17	18-Sep-2003	11	4	20.407	100.129	4.5	23	18-Sep-2003	11	4	15	19.915	100.888	4.4
18	23-Nov-2003	15	8	20.320	101.206	4.5	24	23-Nov-2003	15	8	9	20.405	100.982	4.5
19	14-Mar-2004	5	49	20.174	100.044	3.9	25	14-Mar-2004	5	49	37	19.9	100.563	3.9
20	27-Mar-2004	4	5	19.466	99.583	3.6	26	27-Mar-2004	4	5	35	19.497	99.63	3.7
21	17-Aug-2004	18	54	17.353	100.553	4.1	27	17-Aug-2004	18	54	54	17.465	100.819	4.1
22	11-Sep-2004	1	31	18.812	98.844	3.6	28	11-Sep-2004	1	31	56	18.787	98.978	3.4
23	26-Dec-2004	1	30	21.627	103.341	6.6	29	26-Dec-2004	1	30	28	21.412	98.107	6.5
24	30-Dec-2004	23	55	21.335	100.377	6.4	30	30-Dec-2004	23	55	21	21.254	97.761	6.3
25	25-Jan-2005	16	31	23.507	99.749	6.0	31	25-Jan-2005	16	31	21	22.608	100.677	5.7
26	1-Apr-2005	7	18	19.386	99.431	3.7	32	1-Apr-2005	7	18	20	19.412	99.421	3.7
27	4-Jun-2005	23	1	17.859	100.676	3.8	33	4-Jun-2005	23	1	37	17.909	100.669	3.8
28	9-Jun-2005	21	7	18.575	100.240	2.3	34	9-Jun-2005	21	7	56	18.656	100.249	2.3
29	29-Jun-2005	0	38	18.815	99.504	3.1	35	29-Jun-2005	0	38	52	18.604	99.611	3.7
30	4-Dec-2005	9	34	18.773	98.992	4.2	36	4-Dec-2005	9	34	32	18.769	98.972	3.9
31	7-Dec-2005	9	0	19.722	99.478	3.6	37	7-Dec-2005	9	0	58	19.734	99.544	3.8
32	15-Dec-2005	6	48	19.452	100.269	4.1	38	15-Dec-2005	6	48	37	19.553	99.946	4.0
33	15-Dec-2005	23	13	19.490	99.922	3.0	39	15-Dec-2005	23	13	17	19.492	100.037	3.0
34	16-Dec-2005	2	13	19.488	99.826	3.6	40	16-Dec-2005	2	13	45	19.601	99.899	3.5
35	16-Dec-2005	2	15	19.494	99.927	3.7	41	16-Dec-2005	2	15	40	19.564	99.892	3.7
36	17-Dec-2005	10	59	19.608	100.147	3.2	42	17-Dec-2005	10	59	15	19.639	99.986	3.3
37	17-Dec-2005	11	47	19.466	100.011	3.3	43	17-Dec-2005	11	47	6	19.505	99.947	3.3
38	24-Jan-2006	13	42	20.898	98.464	5.5	44	24-Jan-2006	13	42	59	20.611	98.418	5.6
39	15-Feb-2006	16	54	19.134	100.207	3.4	45	15-Feb-2006	16	54	16	19.132	100.244	3.6
40	20-Feb-2006	18	33	19.138	100.221	2.8	46	20-Feb-2006	18	33	1	19.129	100.152	2.9
							47	6-Aug-2006	5	15	23	19.641	99.053	4.3
41	13-Oct-2006	15	35	20.229	100.157	3.7	48	13-Oct-2006	15	35	28	20.077	100.479	3.7
42	18-Oct-2006	12	0	18.945	100.116	3.2	49	18-Oct-2006	12	0	10	18.95	100.049	3.4
43	21-Oct-2006	1	58	20.325	100.846	4.2	50	21-Oct-2006	1	58	47	20.32	100.511	4.3
44	16-Nov-2006	18	38	19.540	99.999	3.7	51	16-Nov-2006	18	38	3	19.675	100.023	4.0
45	26-Nov-2006	19	32	19.069	101.239	3.8	52	26-Nov-2006	19	32	57	19.02	101.207	3.8
46	12-Dec-2006	17	2	18.934	99.245	4.7	53	12-Dec-2006	17	2	29	18.967	99.193	4.9
47	12-Dec-2006	19	49	18.965	99.189	3.8	54	12-Dec-2006	19	49	37	19.004	99.125	3.9
48	12-Dec-2006	22	21	19.008	99.144	3.6	55	12-Dec-2006	22	21	55	18.989	99.139	3.6
49	13-Dec-2006	5	48	18.899	99.256	3.1	56	13-Dec-2006	5	48	4	18.921	99.268	3.3

Table 5.1. The KST's epicenters before and after re-locating (cont).

No.	Date	Start Time (UTC)		before re-locating			No.	Date	Origin Time (UTC)			after re-locating		
		hr	min	Lat	Long	M			hr	min	sec	Lat	Long	M
50	23-Dec-2006	11	48	18.880	99.638	3.2	57	23-Dec-2006	11	48	17	18.909	99.12	3.2
51	25-Jan-2007	22	29	18.824	99.387	3.2	58	25-Jan-2007	22	29	47	18.834	99.191	3.3
52	18-Feb-2007	8	52	18.555	100.582	3.1	59	18-Feb-2007	8	52	55	18.548	100.606	3.1
53	22-Apr-2007	6	17	19.427	99.838	4.0	60	22-Apr-2007	6	18	3	19.4	99.536	4.1
							61	23-Apr-2007	14	17	6	19.464	99.769	3.7
							62	15-May-2007	14	35	45	20.622	100.327	4.8
54	16-May-2007	8	56	20.646	101.445	6.1	63	16-May-2007	8	56	10	20.657	100.678	6.2
55	16-May-2007	9	10	20.421	101.440	3.9								
56	16-May-2007	9	31	20.234	100.611	3.8	64	16-May-2007	9	31	3	20.232	100.743	3.9
57	16-May-2007	10	4	21.003	100.514	4.0	65	16-May-2007	10	5	35	20.621	100.855	4.1
58	16-May-2007	10	15	20.666	100.934	4.0	66	16-May-2007	10	15	41	20.548	100.587	4.1
59	16-May-2007	10	25	20.581	101.070	4.1	67	16-May-2007	10	26	1	20.488	100.894	4.1
60	16-May-2007	11	15	20.420	101.197	4.2	68	16-May-2007	11	15	56	20.458	100.867	4.4
61	16-May-2007	11	35	20.533	100.822	3.9	69	16-May-2007	11	35	12	20.53	100.79	4.0
62	16-May-2007	11	43	20.716	101.214	4.1	70	16-May-2007	11	43	52	20.4	100.697	4.1
63	16-May-2007	13	18	20.540	101.051	4.5	71	16-May-2007	13	18	7	20.495	100.64	4.6
64	16-May-2007	17	8	20.309	101.364	4.1	72	16-May-2007	17	8	54	20.547	100.774	4.2
65	17-May-2007	3	25	20.029	101.416	4.1	73	17-May-2007	3	25	40	20.652	100.379	4.2
66	18-May-2007	0	1	20.087	101.254	3.9	74	18-May-2007	0	1	53	20.42	100.708	4.1
67	18-May-2007	1	41	20.253	100.798	3.9	75	18-May-2007	1	40	55	20.458	100.67	4.0
68	18-May-2007	13	5	20.612	101.232	4.2	76	18-May-2007	13	5	16	20.465	100.659	4.2
69	20-May-2007	1	21	20.441	100.812	3.9	77	20-May-2007	1	21	21	20.268	100.747	3.9
70	23-May-2007	17	6	20.434	100.781	4.0	78	23-May-2007	17	6	27	20.399	100.633	4.1
71	24-May-2007	11	15	20.507	100.666	3.9	79	24-May-2007	11	15	17	20.31	100.746	4.0
72	7-Jun-2007	17	21	20.606	100.879	4.7	80	7-Jun-2007	17	21	4	20.673	100.73	4.8
73	19-Jun-2007	5	6	18.931	99.178	4.4	81	19-Jun-2007	5	6	42	18.983	99.154	4.5
74	23-Jun-2007	6	54	19.629	96.758	4.9	82	23-Jun-2007	6	53	45	21.468	99.552	5.1
75	23-Jun-2007	8	17	20.887	98.861	5.9	83	23-Jun-2007	8	17	7	21.412	99.32	5.9
76	23-Jun-2007	8	27	21.461	99.352	5.8	84	23-Jun-2007	8	27	37	21.324	99.316	5.7
							85	14-Jul-2007	8	29	18	20.357	100.783	3.8
77	28-Jul-2007	21	33	20.578	100.153	4.3	86	28-Jul-2007	21	33	49	20.651	99.144	4.5
78	6-Aug-2007	6	53	20.501	100.814	4.1	87	6-Aug-2007	6	53	52	20.475	100.493	4.3
79	6-Aug-2007	8	50	20.327	100.704	3.8	88	6-Aug-2007	8	50	50	20.507	100.573	3.9
80	7-Aug-2007	8	53	20.490	101.172	4.3	89	7-Aug-2007	8	53	23	20.866	100.114	4.6
81	8-Aug-2007	9	15	20.320	100.441	3.9	90	8-Aug-2007	9	15	32	20.408	100.726	4.2
82	19-Aug-2007	11	16	19.815	98.775	3.8	91	19-Aug-2007	11	16	56	19.921	98.93	3.9
83	8-Sep-2007	7	12	20.466	100.783	4.1	92	8-Sep-2007	7	12	46	20.59	100.674	4.2
84	16-Oct-2007	2	38	18.661	100.142	2.5	93	16-Oct-2007	2	39	24	18.73	100.246	2.4
85	16-Oct-2007	6	46	20.512	100.808	4.5	94	16-Oct-2007	6	46	53	20.483	100.727	4.7
86	1-Nov-2007	19	5	20.234	100.460	4.6	95	1-Nov-2007	19	5	47	20.374	100.722	4.6
87	23-Dec-2007	11	19	18.652	100.655	3.1	96	23-Dec-2007	11	19	31	18.655	100.654	3.2
88	2-Mar-2008	3	22	18.707	100.088	3.1	97	2-Mar-2008	3	23	35	18.736	100.113	3.1
89	9-Apr-2008	15	47	19.394	99.620	3.2	98	9-Apr-2008	15	49	24	19.3	99.266	3.2
90	10-Jun-2008	21	37	20.652	100.794	4.8	99	10-Jun-2008	21	37	43	20.112	100.858	4.7
91	1-Jul-2008	9	45	19.420	99.538	3.8	100	1-Jul-2008	9	45	51	19.219	99.345	3.9
92	9-Jul-2008	4	39	18.701	100.248	2.2	101	9-Jul-2008	4	39	48	18.689	100.253	2.2
93	25-Nov-2008	8	10	18.816	100.277	2.6	102	25-Nov-2008	8	10	52	18.905	100.167	2.5
94	29-Nov-2008	8	6	20.630	100.890	4.0	103	29-Nov-2008	8	6	25	20.289	100.658	4.0
95	31-Dec-2008	7	59	18.653	100.650	3.7	104	31-Dec-2008	8	0	1	18.67	100.616	3.6
96	31-Dec-2008	8	4	18.694	100.642	3.7	105	31-Dec-2008	8	4	11	18.674	100.611	3.6
97	29-Jan-2009	23	23	19.039	100.317	2.8	106	29-Jan-2009	23	24	33	19.045	100.318	2.8
98	6-Feb-2009	1	39	19.505	99.717	2.8	107	6-Feb-2009	1	39	18	19.547	99.759	2.8
99	22-May-2009	7	58	20.294	101.086	4.3	108	22-May-2009	7	58	9	20.464	100.796	4.4
100	22-May-2009	18	50	20.984	102.471	5.1	109	22-May-2009	18	50	15	21.318	102.01	5.0
101	1-Jun-2009	12	43	18.815	100.578	3.1	110	1-Jun-2009	12	44	27	18.821	100.707	3.1
102	10-Jun-2009	0	23	18.798	100.269	2.7	111	10-Jun-2009	0	23	59	18.848	100.286	2.6

Table 5.1. The KST's epicenters before and after re-locating (cont).

No.	Date	Start Time (UTC)		before re-locating			No.	Date	Origin Time (UTC)			after re-locating		
		hr	min	Lat	Long	M			hr	min	sec	Lat	Long	M
103	10-Jun-2009	0	24	18.829	100.277	2.7	112	10-Jun-2009	0	25	5	18.899	100.242	2.7
104	18-Jun-2009	19	49	18.890	100.330	2.6	113	18-Jun-2009	19	50	16	18.892	100.309	2.6
							114	21-Jun-2009	18	6	20	19.588	99.977	3.6
105	16-Aug-2009	17	57	20.535	100.288	4.2	115	16-Aug-2009	17	57	11	20.231	100.746	4.2
106	1-Oct-2009	11	56	20.022	103.047	4.1	116	1-Oct-2009	11	56	2	20.836	101.689	4.1
107	14-Oct-2009	1	58	20.205	102.039	4.8	117	14-Oct-2009	1	59	31	20.811	101.498	4.8
108	7-Nov-2009	3	55	20.377	101.304	3.9	118	7-Nov-2009	3	54	55	20.458	101.793	3.9
109	10-Nov-2009	7	36	20.590	102.088	4.8	119	10-Nov-2009	7	36	51	20.815	101.763	4.7
110	10-Nov-2009	8	2	20.109	101.440	4.3	120	10-Nov-2009	8	1	44	20.802	101.243	4.2
111	10-Nov-2009	8	40	20.276	101.413	4.1	121	10-Nov-2009	8	40	23	20.844	101.418	4.1
112	2-Dec-2009	7	2	19.310	99.203	3.3	122	2-Dec-2009	7	3	5	19.232	99.209	3.3
113	26-Dec-2009	1	11	20.695	99.665	4.0	123	26-Dec-2009	1	11	49	20.376	98.944	4.1
114	9-Mar-2010	13	3	20.508	99.383	4.2	124	9-Mar-2010	13	3	24	20.323	99.168	4.2
115	26-Jun-2010	2	24	20.183	99.524	3.9	125	26-Jun-2010	2	23	59	20.354	99.827	3.9
116	6-Jul-2010	15	23	20.004	99.054	4.1	126	6-Jul-2010	15	23	29	20.362	99.614	4.1
117	18-Jul-2010	12	53	20.249	100.978	3.8	127	18-Jul-2010	12	53	19	20.263	101.272	3.9
118	29-Aug-2010	8	18	19.520	99.540	3.4	128	29-Aug-2010	8	19	2	19.516	99.512	3.4

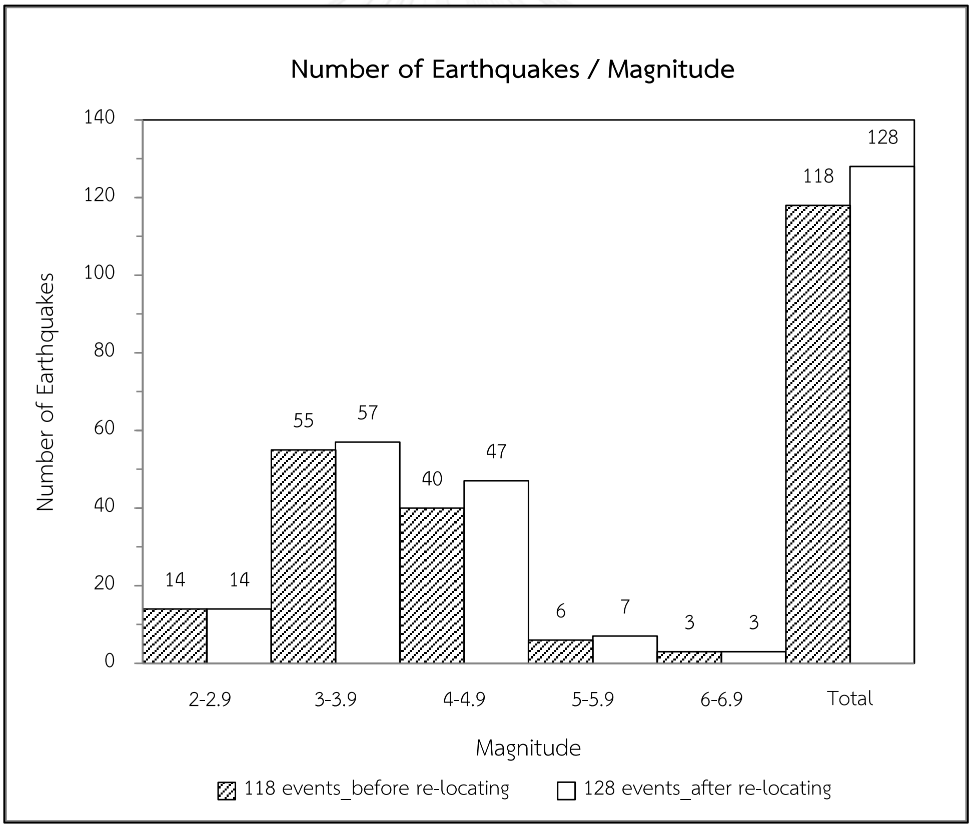


Figure 5. 1. Number of earthquakes and magnitude before and after re-locating.

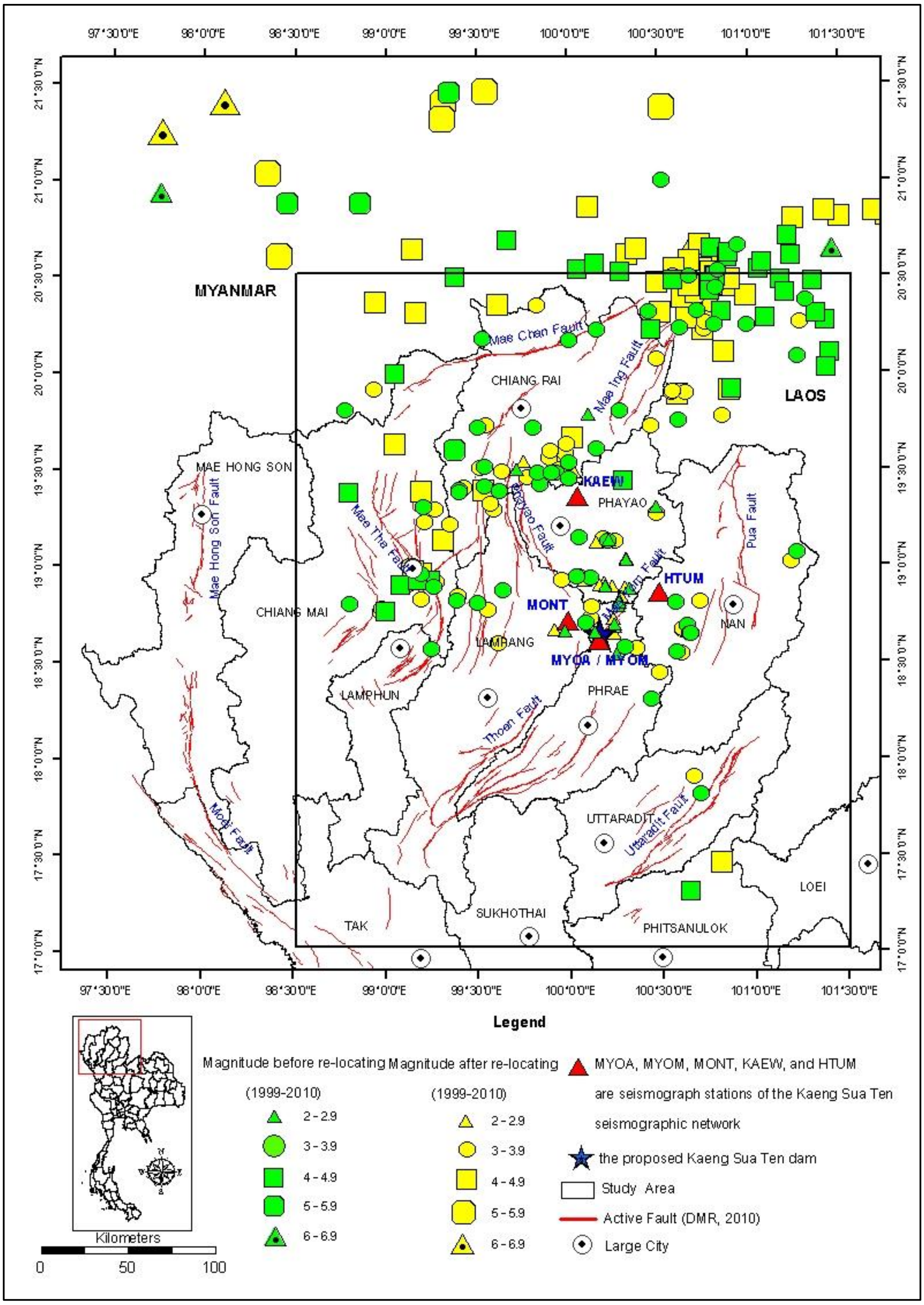


Figure 5. 2. Epicentral map before and after re-locating of this study.

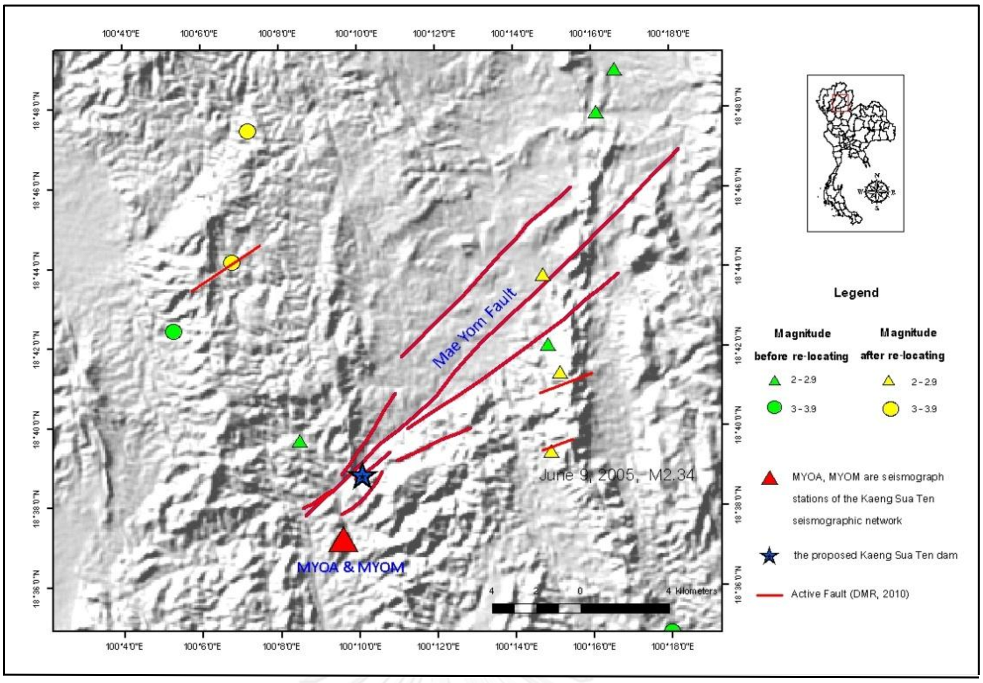


Figure 5. 3. DEM map shows the epicenters before and after re-locating with magnitudes 2-3.9 near the proposed KST dam in Phrae and the epicenters on June 9, 2005 with M2.34 and source-to-site the MYOA and the MYOM stations 15 km.

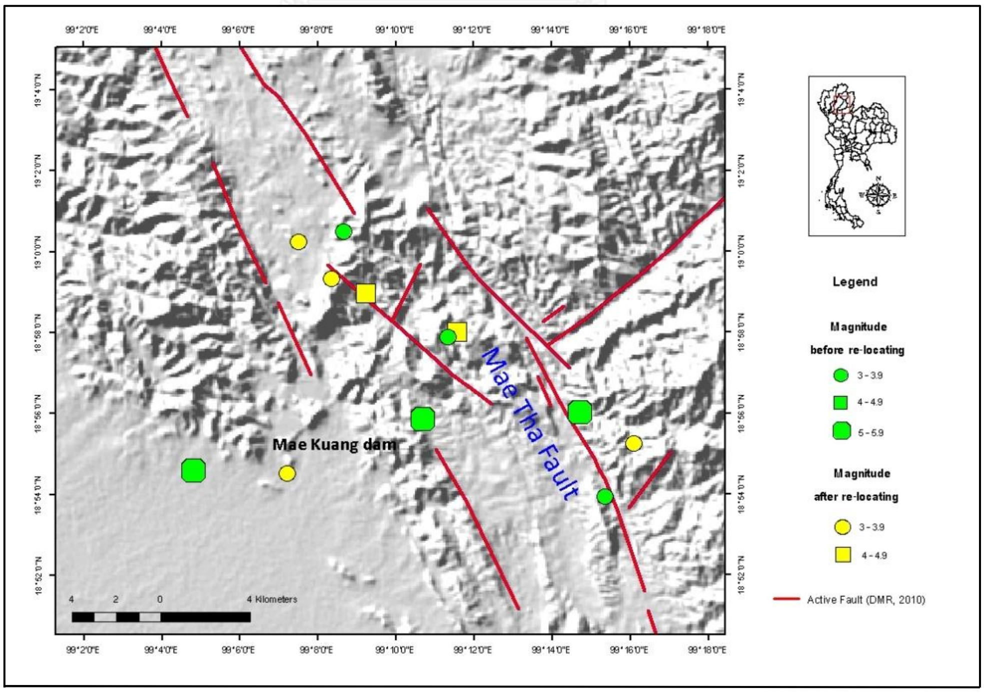


Figure 5. 4. DEM map shows the epicenters before and after re-locating with magnitudes 3-5.9 near the Mae Kuang dam in Chiang Mai.

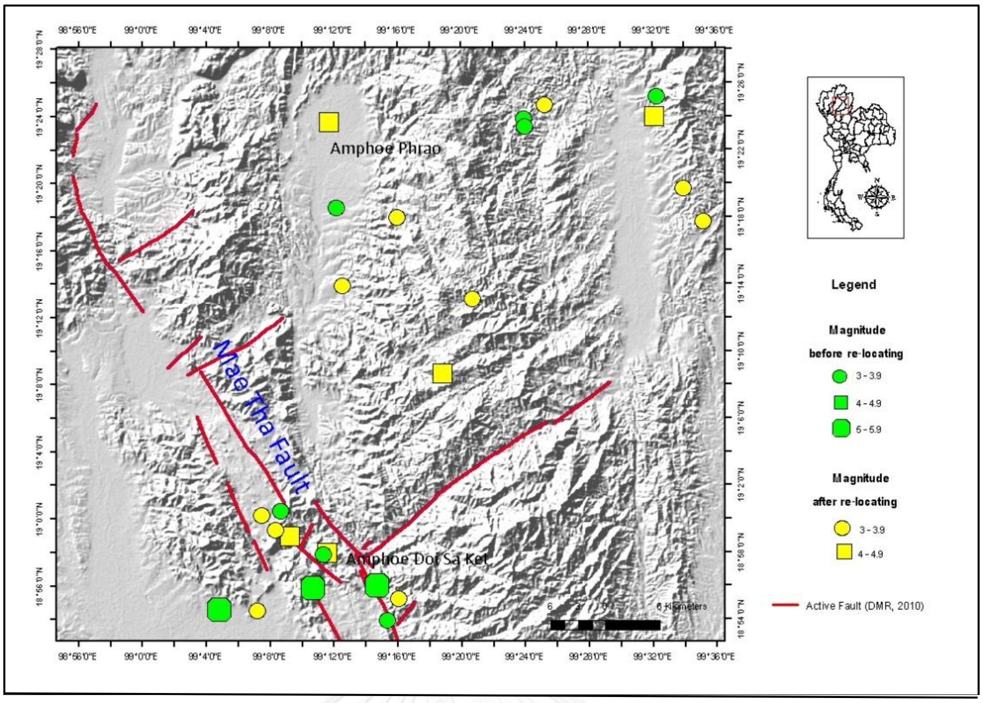


Figure 5. 5. DEM map shows the epicenters before and after re-locating with magnitudes 3-5.9 in Amphoe Doi Sa ket and Amphoe Phrao, Chiang Mai.

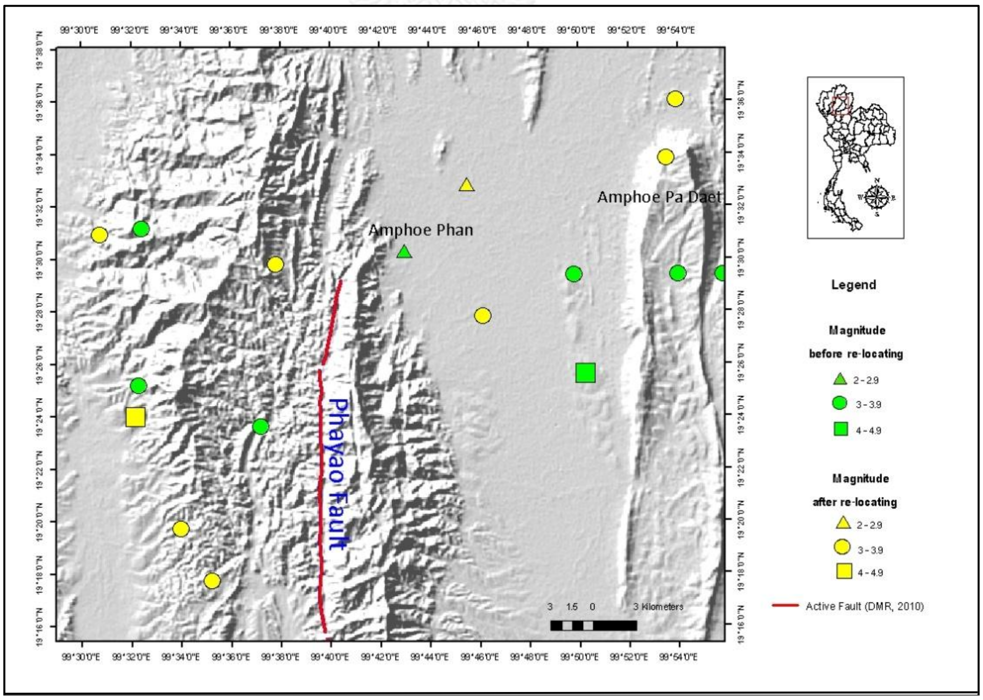
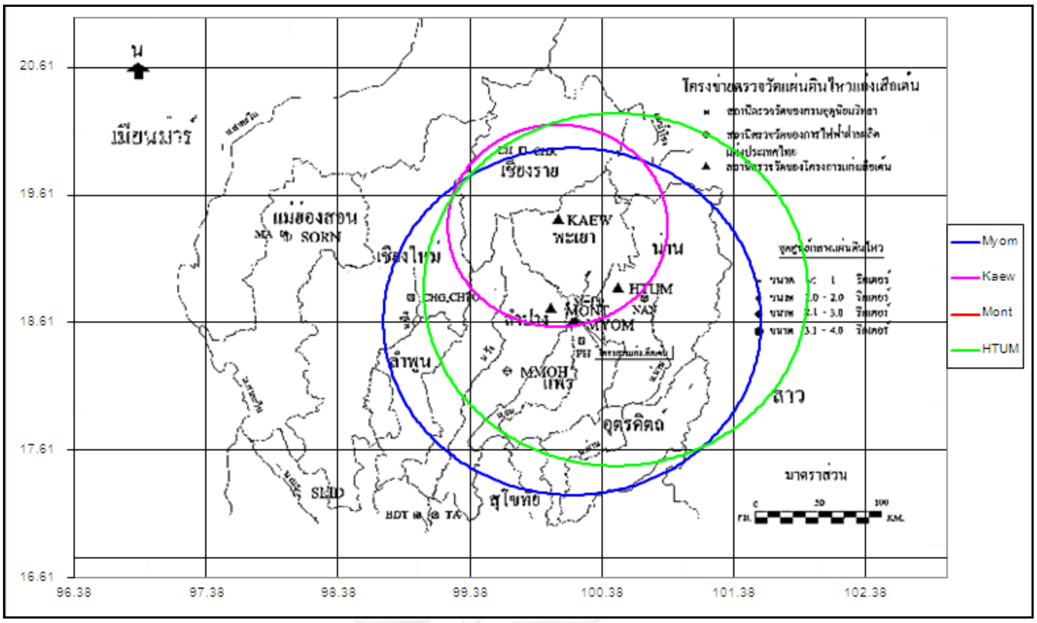
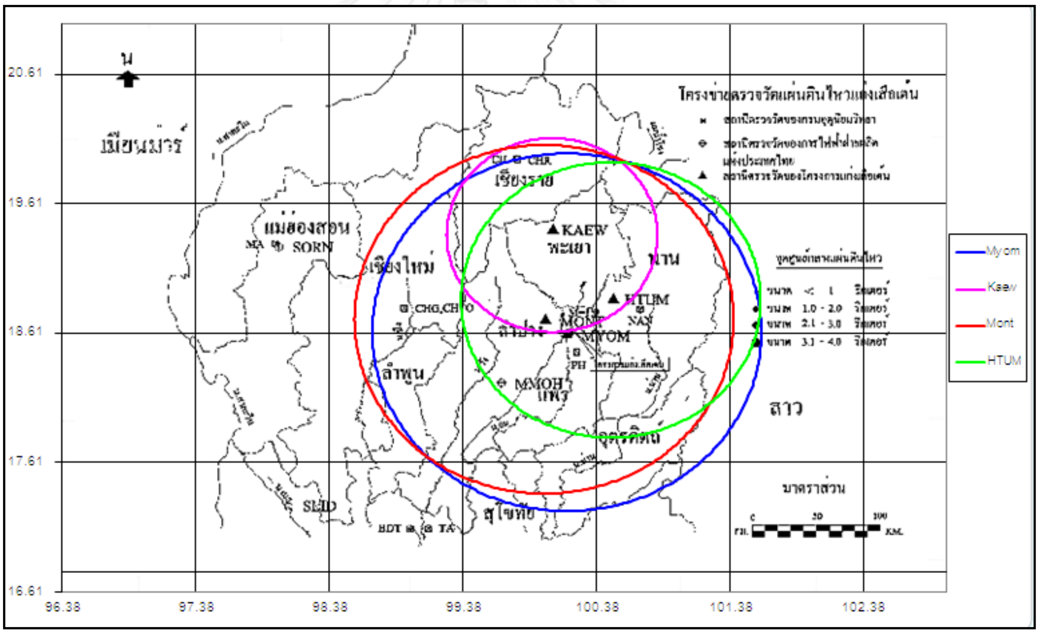


Figure 5. 6. DEM map shows the epicenters before and after re-locating with magnitudes 2-4.9 in Amphoe Phan and Amphoe Pa Daet, Chiang Rai.

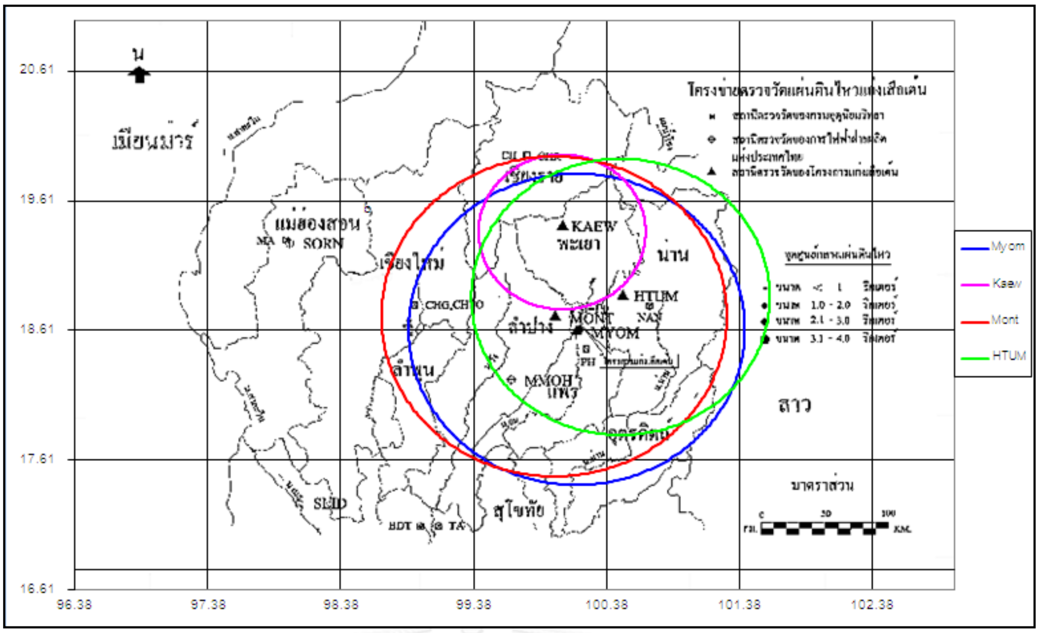


(a)

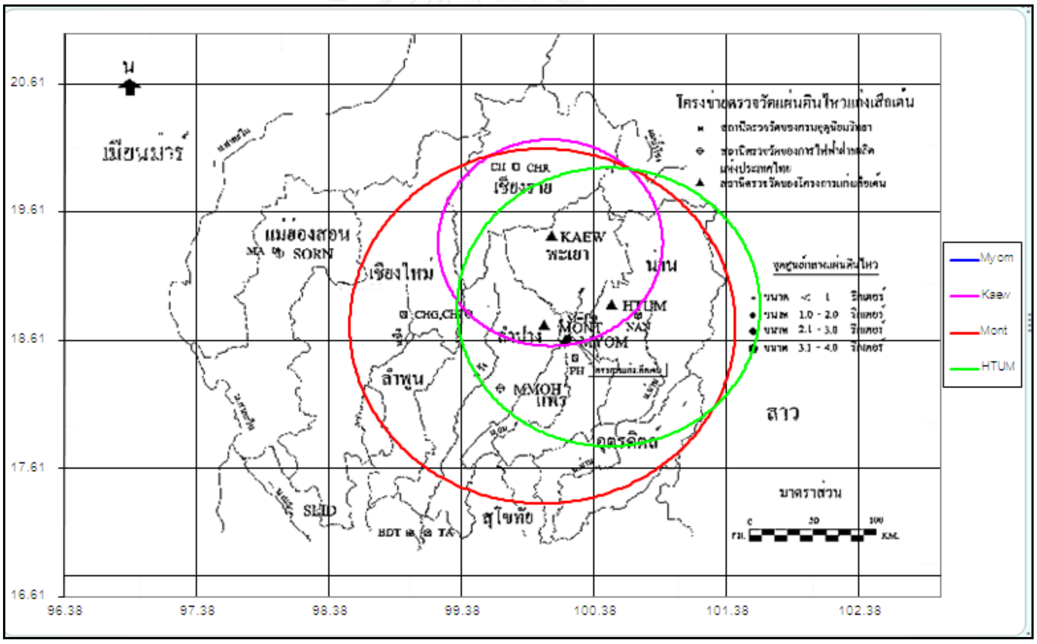


(b)

Figure 5. 7. Location of an earthquake with a magnitude of 5.0 on July 2, 2002 (a) before re-locating; Amphoe Mae Suai Changwat Chiang Rai (b) after re-locating; Northern Laos, based on data of KST network.

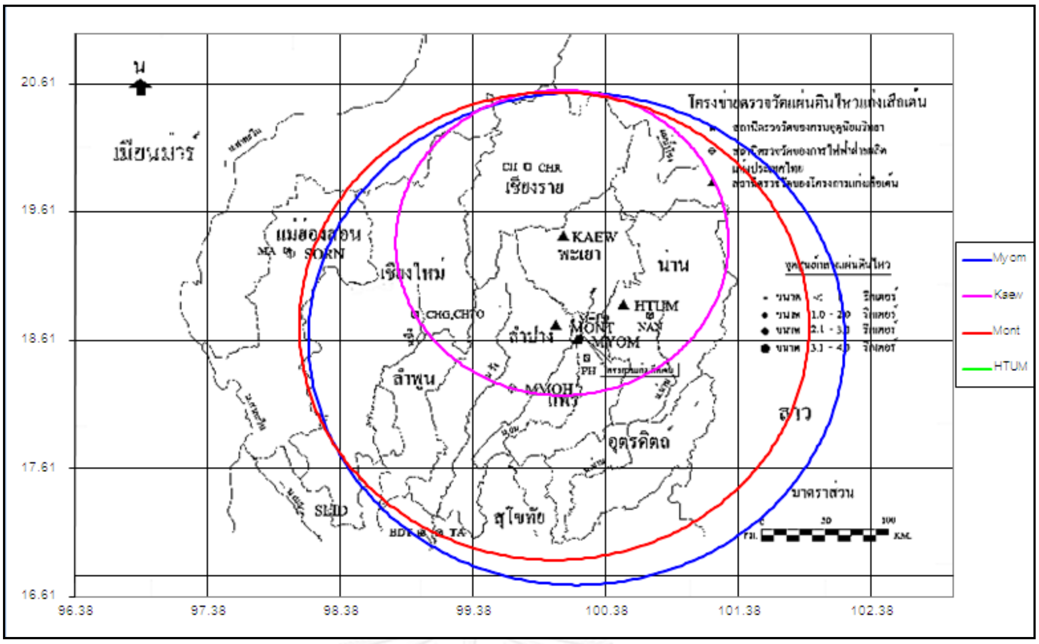


(a)

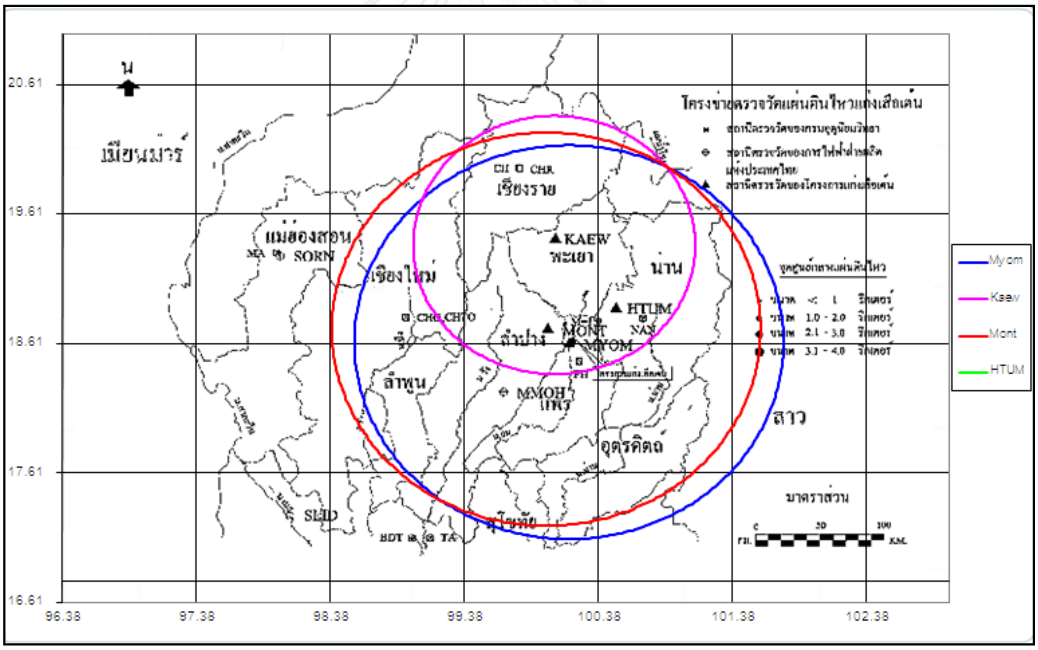


(b)

Figure 5. 8. Location of an earthquake with a magnitude of 3.9 on July 3 2002 (a) before re-locating; Amphoe Kun Tan Changwat Chiang Rai (b) after re-locating; Northern Laos, based on data of KST network.

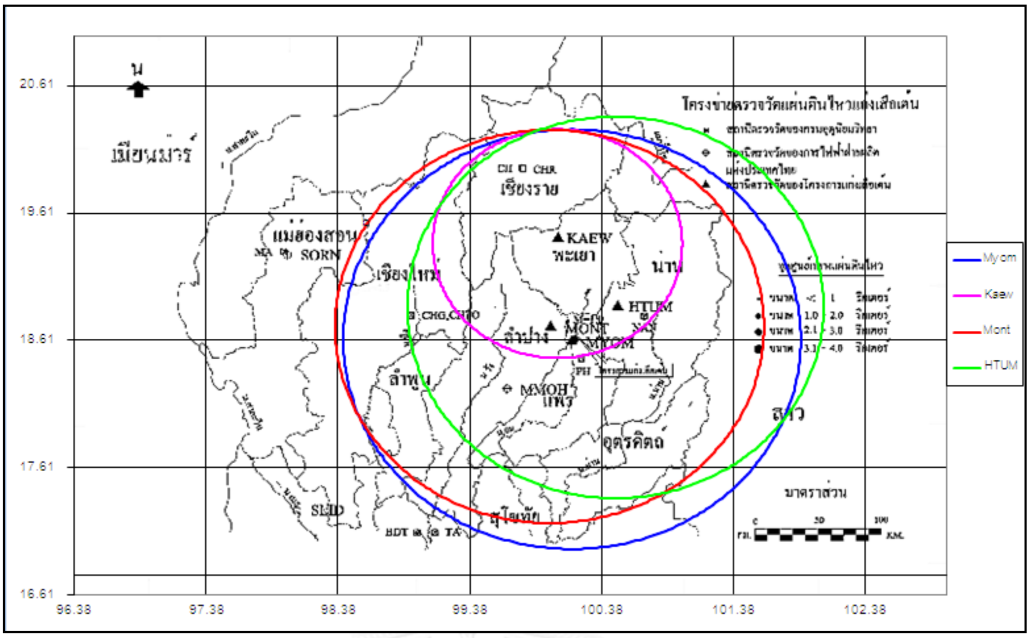


(a)

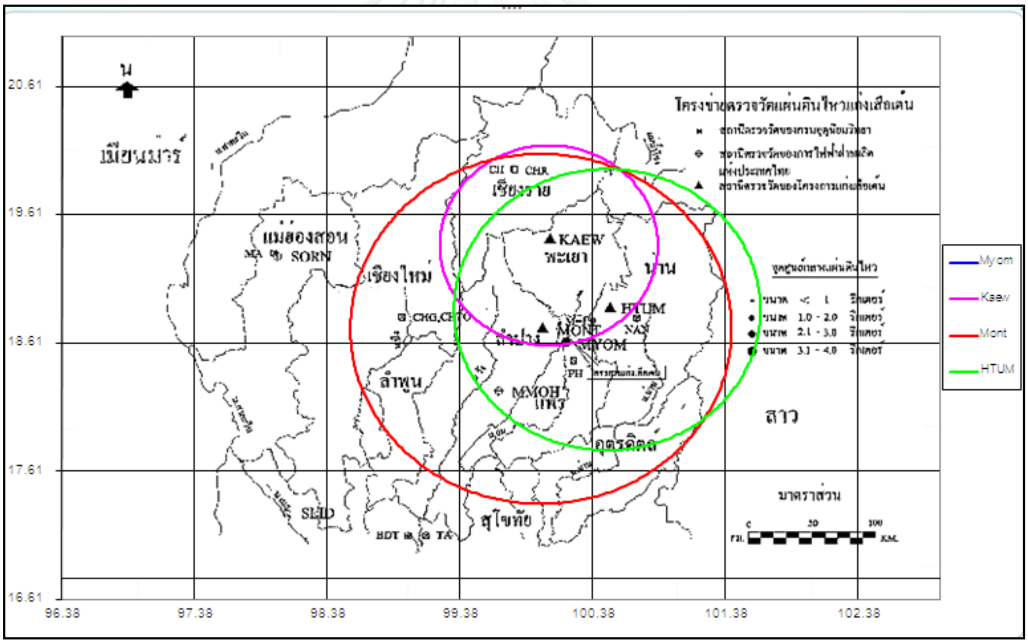


(b)

Figure 5. 9. Location of an earthquake with a magnitude of 4.4 on September 18 2003 (a) before re-locating; Myanmar (b) after re-locating; Northern Laos, based on data of KST network.



(a)



(b)

Figure 5. 10. Location of an earthquake with a magnitude of 3.9 on March 14 2004 (a) before re-locating; Amphoe Mae Chan Changwat Chiang Rai (b) after re-locating; Northern Laos, based on data of KST network.

5.2 Frequency and Magnitude Relation (b-value) before and after re-locating

The relationship between the frequency and magnitude of earthquakes before re-locating the b-value is 0.52 (Figure 5.11), and after re-locating the b-value is 0.59 (Figure 5.12). The b-value has a little difference as the number of earthquakes before and after re-locating which were used in this study is different. Table 5.2 shows the earthquake numbers in northern Thailand during the year 1999 to 2010. Before re-locating, the cumulative earthquake above lower M in range of the earthquake magnitude 2.0-2.4 is 74, magnitude 2.5-2.9 is 70, magnitude 3.0-3.4 is 60, magnitude 3.5-3.9 is 40, magnitude 4.0-4.9 is 18, and magnitude 4.5-4.9 is 7. Table 5.3 shows the earthquake numbers in northern Thailand during the year 1999 to 2010 after re-locating, the cumulative earthquake above lower M in range of the earthquake magnitude 2.0-2.4 is 69, magnitude 2.5-2.9 is 66, magnitude 3.0-3.4 is 55, magnitude 3.5-3.9 is 35, magnitude 4.0-4.9 is 14, and magnitude 4.5-4.9 is 3.

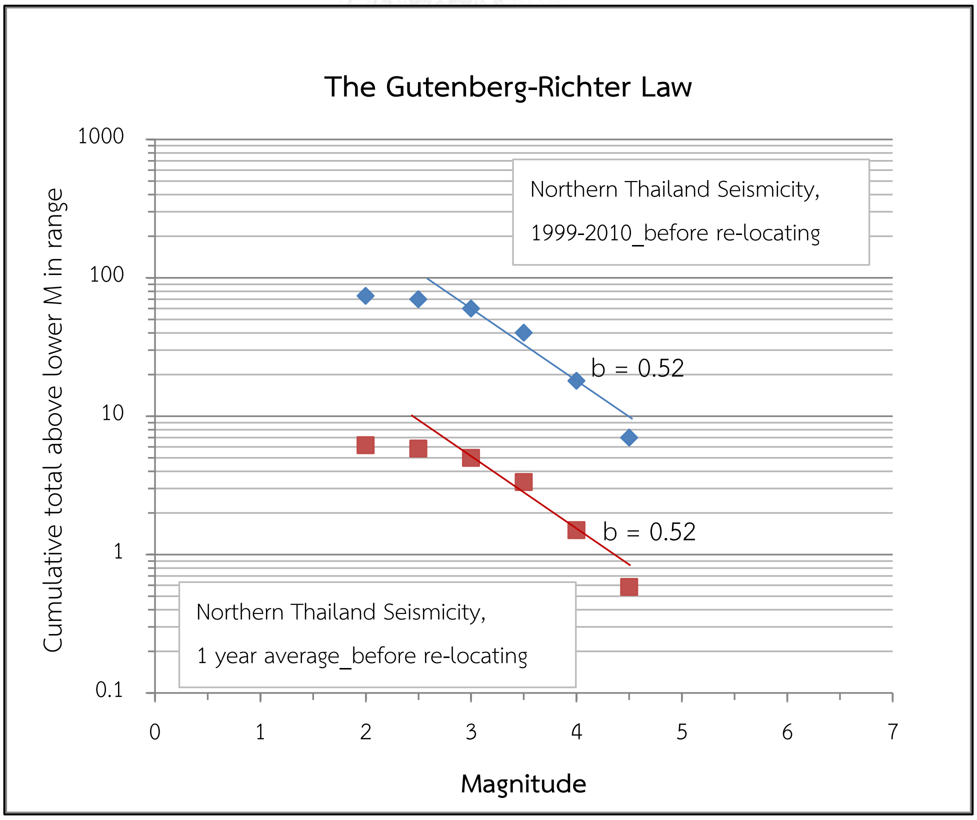


Figure 5. 11. Northern Thailand seismicity during the year 1999 to 2010 before re-locating, b-value = 0.52.

Table 5. 2. Earthquake Numbers in Northern Thailand, during the year 1999 to 2010 before re-locating.

Magnitude (M) Range	Count per M Range	Cumulative Total Above Lower M in Range	Annual Rate
2.0 - 2.4	4	74	6.2
2.5 - 2.9	10	70	5.8
3.0 - 3.4	20	60	5.0
3.5 - 3.9	22	40	3.3
4.0 - 4.4	11	18	1.5
4.5 - 4.9	6	7	0.6
5.0 - 5.4	1		

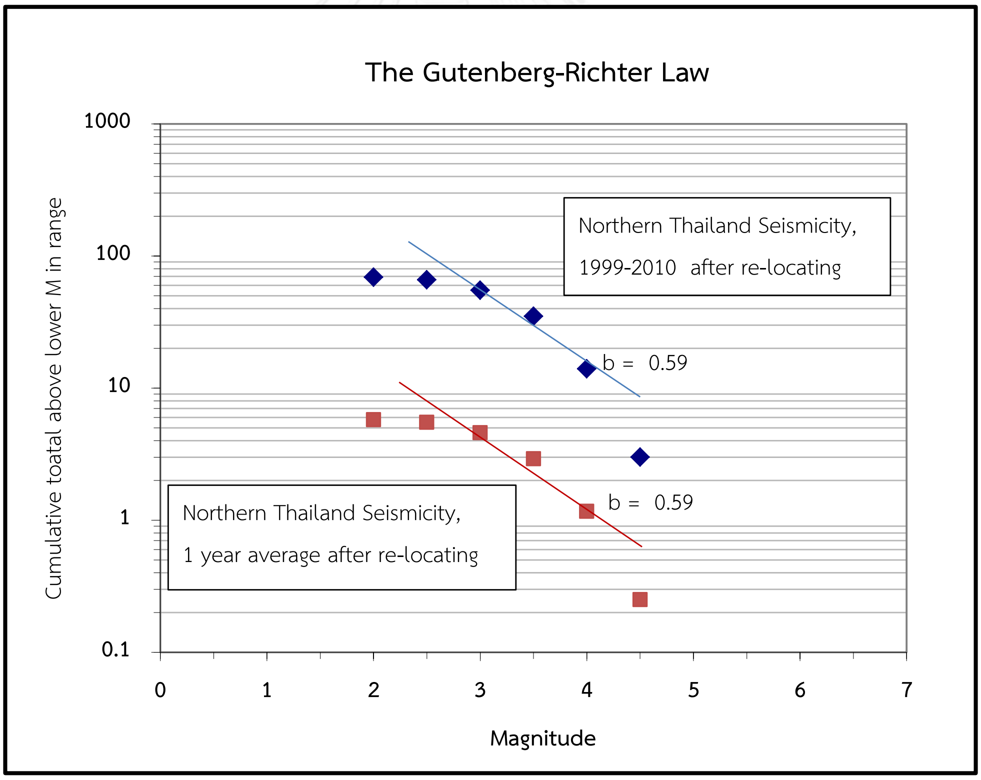


Figure 5. 12. Northern Thailand seismicity during the year 1999 to 2010 after re-locating, b-value = 0.59.

Table 5. 3. Earthquake Numbers in Northern Thailand, during the year 1999 to 2010 after re-locating.

Magnitude (M) Range	Count per M Range	Cumulative Total Above Lower M in Range	Annual Rate
2.0 - 2.4	3	69	5.75
2.5 - 2.9	11	66	5.50
3.0 - 3.4	20	55	4.58
3.5 - 3.9	21	35	2.92
4.0 - 4.4	11	14	1.17
4.5 - 4.9	3	3	0.25

5.3 Relationship of Earthquakes with Geological Structures

In the interpretation part, detailed geomorphology was used to identify geologic features those are associated with active tectonic landforms for strike-slip faulting (Keller & Pinter, 1996). There were several features of each tectonic landform associated with active fault as explained below (Figure 5.13).

(1) Linear valleys was generated from a transform faulting (strike-slip fault), which controls the flow of stream channels in a straight form.

(2) Shutter ridge is a long and narrow mound that obstructs stream flow. The shutter ridge effected the hill ridge by cutting through it and gave the appearance that the ridge moved out from the originally mountain line. This is common evident for strike-slip fault.

(3) Offset stream which was a result of strike-slip fault cutting through the stream. It cut and displaced the stream channel, which originally was flowing in straight line. The distance of movement from the originally stream line can be referred to displacement of fault movement.

(4) Beheaded stream, one of the causes of strike-slip fault, affecting the form of stream. The originally straight-continuous stream was cut by fault displacement and the new stream upper end shows no connection with the main stream.

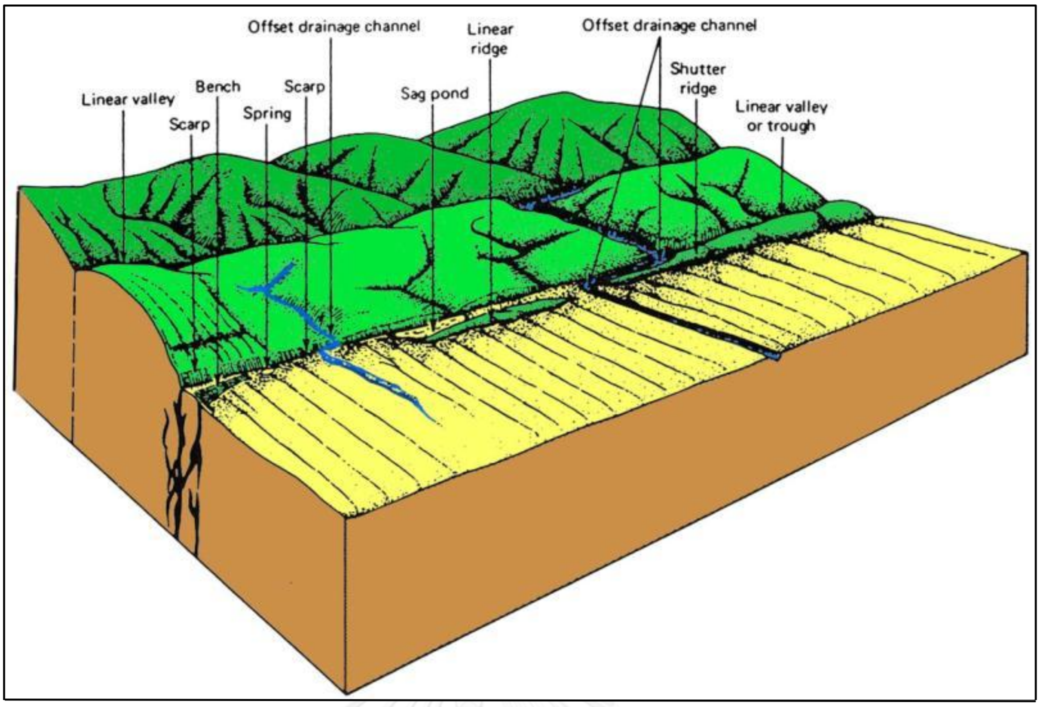


Figure 5. 13. Assemblage of landforms associated with active tectonic strike – slip faulting (Keller & Pinter, 1996).

(5) Fault scarp, the characterized slanting cliff, was caused by fault cutting through the area. This may be caused by both normal fault and strike-slip fault. It is commonly appear in the topography that showed steep cliff next to the basin and indicated distinctly by rows of fault trace movement.

(6) Sag pond, which was effected by strike-slip fault and caused the subsidence of the land in the area. Water is ponding in the fault-developed basin. Both normal fault and strike-slip fault can be caused of this.

(7) Spring and hot spring are fault generated open gap of fracture in the subsurface rock and consequently underground water in that area flows out from subsurface. Hot spring is related to hydrothermal activity in the subsurface rock.

(8) Triangular facet is the result of vertical movement of normal fault. After faulting it was affected by surface erosion until it has the triangle cliff character.

(9) Bench is the topography landform that was developed as a consequent of triangular facet landform. The normal fault causes this step-like feature.

(10) Wine glass canyon is the affected from normal fault, which cut through a stream channel and continue with vertical erosion that is faster than its horizontal erosion, resulted into a valley that is resemble to wine glass, that is to say, the top of the valley is rather wide and the lower part is narrow and deep.

In this study, the Digital Elevation Models (DEM) which created from SRTM was used to create contour line to study the relationship between earthquake's epicenters with geological structures. DEMs are gray scale images wherein the pixel values are actually elevation numbers. The pixels are also coordinated to world space (longitude and latitude), and each pixel represents some variable amount of that space (foot, meter, mile, etc.) depending on the purpose of the model and land area involved. They produced using elevation data derived from existing contour maps, digitized elevations and photogrammetric stereo-models based on aerial photographs and satellite remote sensing images.

The results of this study (Figure 5.3-Figure 5.6 and Figure 5.14-Figure 5.16) found that some epicenters after re-locating were associated with mapped faults with surficial expression, but some epicenters were not. However, (Bott et al., 1997) mentioned that northern Thailand is similar to the Basin and Range province in the western United States of America in term of earthquake processes and tectonics. In the Basin and Range province background earthquakes as large as M6-6.5 can occur on buried faults with no surface expression or apparent geological association (dePolo, 1994). Therefore some epicenters probably associated with faults which have no surficial expression might be background earthquakes.

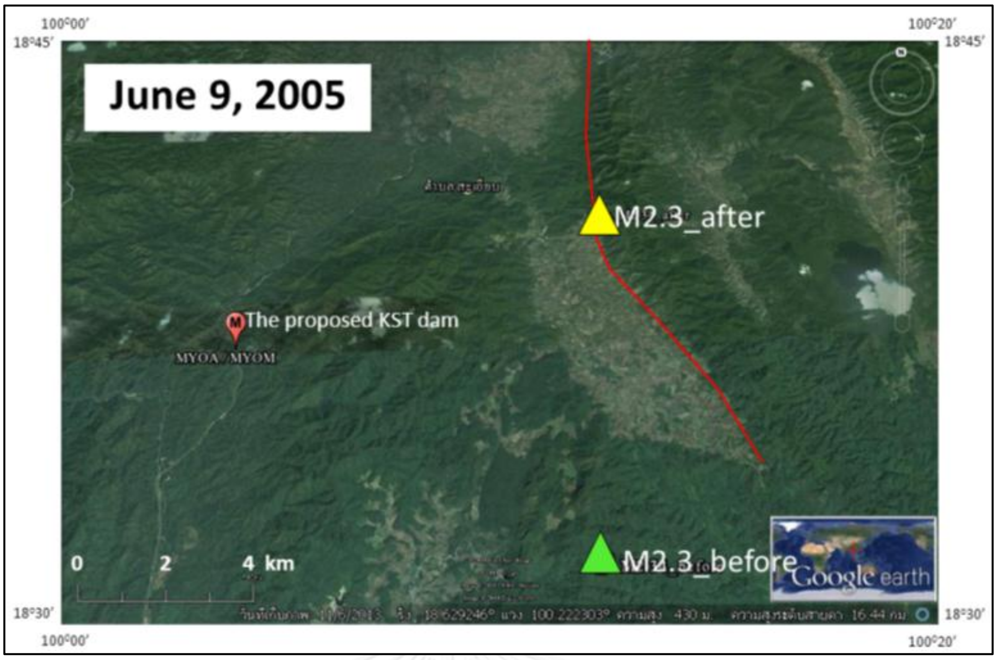


Figure 5. 14. Epicenters of earthquake on June 9, 2005, before (green triangle) and after (yellow triangle) re-locating, plotting in Google map. Note: epicenter after re-locating on fault scarp.

Figure 5. 15. Epicenters of earthquake on October 16, 2007, before (green triangle) and after (yellow triangle) re-locating, plotting in Google map. Note: epicenter after re-locating on fault scarp.

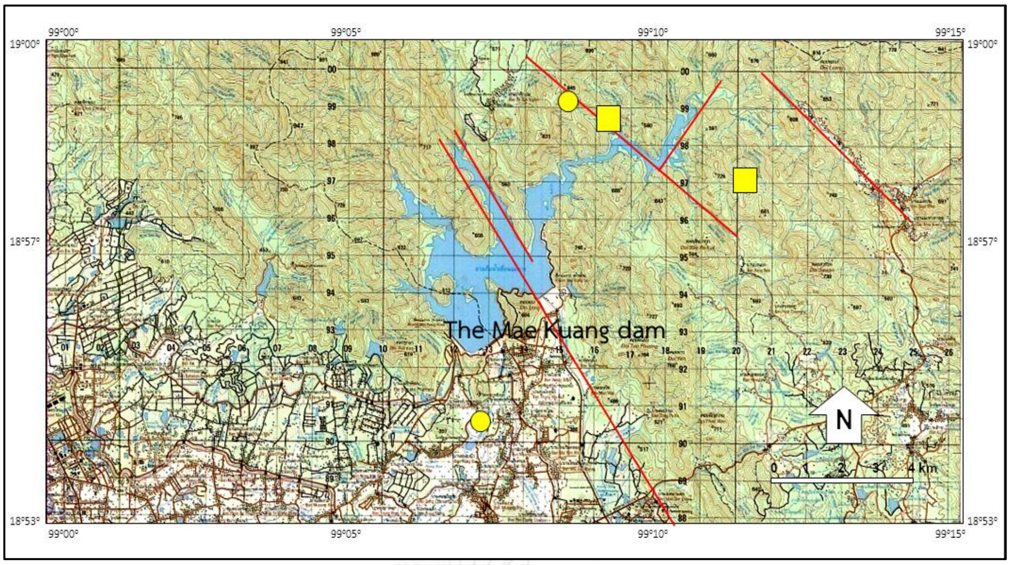


Figure 5. 16. Topographic map shows the epicenters of earthquakes after re-locating (yellow circles and squares) near the Mae Kuang dam site. Note: epicenters associated with and closely to mapped fault.

5.4 Correlation of the KST's Epicenters with the TMD

In earthquake study, it is necessary to recheck the KST's events with the TMD recorded events, such as when and where the earthquakes have occurred, and to check the accuracy of the events. The information of the TMD's epicenters in this study mostly comes from the catalogue and the website of the TMD (http://www.seismology.tmd.go.th/home.html).

The first seismograph station of the TMD was set up in 1963 in Chiang Mai, northern Thailand. At first, this station is the participation of the Worldwide Standardized Seismograph Network: WWSSN, and thereafter has transferred to participate with the Incorporated Institution of Seismology: IRIS. Later the TMD has set up more seismograph stations in many provinces cover all parts of Thailand as listed in Table 5.4.

Comparing the KST's epicenters of this study with the TMD's epicenters was rather difficult due to the lack of local earthquakes reported in TMD bulletin. Since TMD stations is regional stations, they were sparse and reported only large to medium earthquakes with some small local events. There were only 45 events or 35 percent of the KST's events (Table 5.5) to compare with. In conclusion, the epicenters of the two networks show not the same location and magnitude (Figure 5.17), which may be due to the instrument types (shot period and broadband), the operators, and the computer program that used in the analyses.

However, in the study, it has been tried to compare the KST's epicenters with the TMD's epicenters for the recorded during the year 1978 to 1998 (Table 5.6) or the year before the set-up of the KST network, and the epicenter of earthquake with magnitude 6.3 on May 5, 2014, in order to identify the area of high seismicity from the past, and present earthquakes. The results from past and present earthquakes of this study indicates that the earthquakes with magnitudes 4-4.9 frequently occurred in Chiang Mai, and Chiang Rai between latitude 18.75-19.75 and longitude 98.75-99.75 (Figure 5.18 and Figure 5.19).

Table 5. 4. Details of the TMD's seismic stations all part of Thailand.

Seismic Station List	Network Code	Station Code	Lat	Long	Elevation (m)	Sensor	Digitizer
Kirithan Dam, Chanthaburi	TM	CHBT	102.33	12.7526	4	Trillium 120 sec	taurus, trident
Doi Suthep, Chiang Mai	TM	CMMT	98.95	18.8128	399.7	Trillium 120 sec	taurus, trident
Wachiralongkorn Dam, Kanchanaburi	TM	KHLT	98.5893	14.7970	164	Trillium 40 sec	taurus, trident
Lumpraplueng Dam, Nakhonratchasima	TM	KRDT	104.8442	14.5905	266	Trillium 40 sec	taurus, trident
The Immigration Checkpoint, Mae Hong Son	TM	MHIT	97.9632	19.3148	270	Trillium 120 sec	taurus, trident
Sariang Meteorological Station, Mae Hong Son	TM	MHMT	97.931	18.1764	164	Trillium 40 sec	taurus, trident
Khao Kho, Phetchabun	TM	PBKT	100.9687	16.5733	8	Trillium 120 sec	taurus, trident
Bangwaad Dam, Phuket	TM	PKDT	98.335	7.8920	53	Trillium 40 sec	taurus, trident
Ranong	TM	RNNT	98.4778	9.3904	38	Trillium 40 sec	taurus, trident
Songkhla	TM	SKLT	100.6188	7.1735	14.5	Trillium 120 sec	taurus, trident
Srinakarintara Dam, Kanchanaburi	TM	SRDT	98.1212	14.3945	122	Trillium 40 sec	taurus, trident
Ratchaprapa Dam, Surat Thani	TM	SURT	98.795	8.9577	26	Trillium 40 sec	taurus, trident
Pak Mun Dam, Ubon Ratchathani	TM	UBPT	105.4695	15.2773	120	Trillium 120 sec	taurus, trident
Nampoong, Sakon Nakhon	TM	SKNT	103.9815	16.9742	254	Trillium 40 sec	taurus, trident
Tha Ngiu Dam, Trang	TM	TRTT	99.6912	7.8362	71	Trillium 40 sec	taurus, trident
Kwae-noi Dam,Phitsanulok	TMD	PHIT	100.416499	17.189269	113.5	SP -S13-1HZ	smart24
Huai Tha Phrae Reservoir, Sukhothai	TMD	SUKH	99.631013	17.482143	58.0294	SP -S13-1HZ	smart24
Sirikit Dam, Uttaradit	TMD	UTTA	100.554083	17.744258	62.61	SP -S13-1HZ	smart24
Namsong Reservoir, Phrae	TMD	PHRA	100.229325	18.498912	186.83564	BB KS2000M 120 sec	smart24
Kiewlom Dam, Lampang	TMD	LAMP	99.632246	18.522614	246.655	SP -S13-1HZ	smart24
Namkorn Dam, Nan	TMD	NAN	100.911631	19.283535	261.711992	SP -S13-1HZ	smart24
Mae Puem Reservoir, Phayao	TMD	PAYA	99.869172	19.360284	408.264	SP -S13-1HZ	smart24
Huai Chang Reservoir	TMD	CRAI	100.373434	20.228927	356.746966	BB KS2000M 120 sec	smart24
Doi Ang Khang Meteorological Station, Chiang Mai	TMD	CMAI	99.04526	19.932477	1502.668207	BB KS2000M 120 sec	smart24
Umphang Meteorological Station, Tak	TMD	UMPA	98.86035	16.20572	403.234	BB KS2000M 120 sec	smart24
Pranburi Dam, Prachuap Khiri Khan District	TMD	PRAC	99.79288	12.47263	53.63791	BB KS2000M 120 sec	smart24
Thap Salao Dam, Uthaithani	TMD	UTHA	99.445133	15.558565	128.607	SP -S13-1HZ	smart24
Kaeng-Krachan Reservoir, Phetchaburi	TMD	PHET	99.62675	12.91331	100.6704	SP -S13-1HZ	smart24
Pattaya Meteorological Station, Chon Buri	TMD	PATY	100.865694	12.923188	39.190244	SP -S13-1HZ	smart24
Klong Din Daeng Reservoir, Nakhon Si Thammarat	TMD	SRIT	99.60196	8.59549	58.4626	BB KS2000M 120 sec	smart24
Tha-Thong Dam, Surat-Thani	TMD	SURA	99.62945	9.16634	-5.54492	BB KS2000M 120 sec	smart24
Choraka Reservoir, Chaiyaphum	TMD	CHAI	101.9864	15.9018	198.9548	SP -S13-1HZ	smart24
Huai Plew Nguek Reservoir, Nong Khai	TMD	NONG	103.1457	18.06346	140.47	BB KS2000M 120 sec	smart24
Huai Khan Reservoir, Nakhon Phanom	TMD	PANO	104.6122	17.1476	135.5955	BB KS2000M 120 sec	smart24
Tha-Phra Agricultural weather station, Khon Kaen	TMD	KHON	102.823	16.33778	134.6877	SP -S13-1HZ	smart24
Khlong Tha Dan Reservoir, Nakhon Nayok	TMD	NAYO	101.3209	14.31523	106.293	BB KS2000M 120 sec	smart24
Um-Puem Reservoir, Surin	TMD	SURI	103.5529	14.7688	125.908	SP -S13-1HZ	smart24
Huai Yang Reservoir, Sa-Kaew	TMD	SRAK	102.0425	14.012	96.90778	SP -S13-1HZ	smart24
Huai Nam Man Reservoir, Loei	TMD	LOEI	101.2644	17.50928	305.5835	BB KS2000M 120 sec	smart24
Bang-Kamprud Reservoir, Krabi	TMD	KRAB	99.631013	17.482143	58.0294	SP -S13-1HZ	smart24

Table 5. 5. Correlation of the KST's epicenters with the TMD.

No.	Earthquake Data of the KST							No.	Earthquake Data of the TMD						
	Date	Origin Time (UTC)			Location		M		Date	Origin Time (Local, UTC+7)			Location		M
		hr	min	sec	Lat	Long				hr	min	sec	Lat	Long	
1	22-May-1999	15	23	28	18.919	100.196	2.6								
2	29-Jun-1999	6	38	16	21.042	98.35	5.6								
3	15-Jul-1999	17	35	11	21.386	100.529	5.2								
4	10-Aug-1999	23	14	34	18.933	99.955	3.4								
5	10-Aug-1999	23	15	16	18.929	100.087	2.9								
6	19-Nov-1999	23	21	53	18.791	100.12	3.0								
7	13-Apr-2000	13	13	52	19.274	100.474	3.1								
8	5-Sep-2000	11	44	28	19.147	100.184	3.1								
9	7-May-2001	1	4	26	18.448	100.484	3.1								
10	7-Nov-2001	5	36	39	18.775	99.551	3.2								
11	26-Apr-2002	20	31	41	19.145	99.314	4.3	1	26-Apr-2002	20	31	40	18.80	99.20	5.3
12	2-Jul-2002	3	54	4	19.898	100.6	5.0	2	2-Jul-2002	3	54	5	20.18	100.17	5.1
13	2-Jul-2002	17	55	17	19.91	100.57	3.7	3	2-Jul-2002	17	55	20	19.83	100.65	3.1
14	3-Jul-2002	0	17	46	19.902	100.64	3.9	4	3-Jul-2002	0	17	49	19.83	100.69	3.3
15	21-Jul-2002	22	49	45	19.777	100.837	3.9	5	21-Jul-2002	22	49	50	19.72	100.61	3.9
16	7-Sep-2002	6	11	44	18.578	100.361	3.2	6	7-Sep-2002	6	11	42	17.89	100.04	3.3
17	25-Sep-2002	14	27	46	19.296	99.587	3.6								
18	6-Nov-2002	5	21	21	18.676	99.921	2.9								
19	18-Dec-2002	13	47	11	19.395	99.196	4.7	7	18-Dec-2002	13	47	15	19.06	98.95	4.3
20	29-Jan-2003	7	14	30	19.729	100.449	3.8								
21	15-Mar-2003	4	29	42	19.329	99.566	3.2								
22	23-Aug-2003	8	57	30	18.849	99.39	3.3	8	23-Aug-2003	15	57		19.00	99.20	2.5
23	18-Sep-2003	11	4	15	19.915	100.888	4.4	9	18-Sep-2003	18	4		20.50	100.90	5.5
24	23-Nov-2003	15	8	9	20.405	100.982	4.5								
25	14-Mar-2004	5	49	37	19.9	100.563	3.9								
26	27-Mar-2004	4	5	35	19.497	99.63	3.7	10	27-Mar-2004	3	0		19.43	99.46	3.4
27	17-Aug-2004	18	54	54	17.465	100.819	4.1								
28	11-Sep-2004	1	31	56	18.787	98.978	3.4	11	11-Sep-2004	8	30		18.70	98.70	3.7
29	26-Dec-2004	1	30	28	21.412	98.107	6.5	12	26-Dec-2004	8	30		20.70	98.00	6.4
30	30-Dec-2004	23	55	21	21.254	97.761	6.3								
31	25-Jan-2005	16	31	21	22.608	100.677	5.7								
32	1-Apr-2005	7	18	20	19.412	99.421	3.7								
33	4-Jun-2005	23	1	37	17.909	100.669	3.8	13	5-Jun-2005	6	17		17.80	100.60	3.8
34	9-Jun-2005	21	7	56	18.656	100.249	2.3								
35	29-Jun-2005	0	38	52	18.604	99.611	3.7								
36	4-Dec-2005	9	34	32	18.769	98.972	3.9	14	4-Dec-2005	16	34		18.70	98.50	4.1
37	7-Dec-2005	9	0	58	19.734	99.544	3.8	15	7-Dec-2005	16	2		19.70	99.60	3.9
38	15-Dec-2005	6	48	37	19.553	99.946	4.0	16	15-Dec-2005	13	48		19.43	100.18	4.1
39	15-Dec-2005	23	13	17	19.492	100.037	3.0								
40	16-Dec-2005	2	13	45	19.601	99.899	3.5	17	16-Dec-2005	9	13		19.43	99.96	3.8
41	16-Dec-2005	2	15	40	19.564	99.892	3.7	18	16-Dec-2005	9	14		19.43	99.96	3.9
42	17-Dec-2005	10	59	15	19.639	99.986	3.3								
43	17-Dec-2005	11	47	6	19.505	99.947	3.3								
44	24-Jan-2006	13	42	59	20.611	98.418	5.6	19	24-Jan-2006	20	42		20.53	98.69	5.7
45	15-Feb-2006	16	54	16	19.132	100.244	3.6								
46	20-Feb-2006	18	33	1	19.129	100.152	2.9								
47	6-Aug-2006	5	15	23	19.641	99.053	4.3	20	6-Aug-2006	12	15		19.15	98.92	3.4
48	13-Oct-2006	15	35	28	20.077	100.479	3.7								
49	18-Oct-2006	12	0	10	18.95	100.049	3.4								
50	21-Oct-2006	1	58	47	20.32	100.511	4.3								
51	16-Nov-2006	18	38	3	19.675	100.023	4.0	21	17-Nov-2006	1	39		19.50	99.60	4.4
52	26-Nov-2006	19	32	57	19.02	101.207	3.8								
53	12-Dec-2006	17	2	29	18.967	99.193	4.9	22	13-Dec-2006	0	2		18.93	98.97	5.1
54	12-Dec-2006	19	49	37	19.004	99.125	3.9								
55	12-Dec-2006	22	21	55	18.989	99.139	3.6								
56	13-Dec-2006	5	48	4	18.921	99.268	3.3								
57	23-Dec-2006	11	48	17	18.909	99.12	3.2	23	23-Dec-2006	18	51		19.00	99.00	3.6
58	25-Jan-2007	22	29	47	18.834	99.191	3.3								

Table 5.5. Correlation of the KST's epicenters with the TMD (cont).

No.	Earthquake Data of the KST							No.	Earthquake Data of the TMD						
	Date	Origin Time (UTC)			Location		M		Date	Origin Time (Local, UTC+7)			Location		M
		hr	min	sec	Lat	Long				hr	min	sec	Lat	Long	
59	18-Feb-2007	8	52	55	18.548	100.606	3.1								
60	22-Apr-2007	6	18	3	19.4	99.536	4.1	24	22-Apr-2007	13	18	0	19.40	99.36	4.5
61	23-Apr-2007	14	17	6	19.464	99.769	3.7	25	23-Apr-2007	21	18	0	19.60	99.20	4.0
62	15-May-2007	14	35	45	20.622	100.327	4.8								
63	16-May-2007	8	56	10	20.657	100.678	6.2								
64	16-May-2007	9	31	3	20.232	100.743	3.9								
65	16-May-2007	10	5	35	20.621	100.855	4.1	26	16-May-2007	17	4	0	21.00	100.50	4.7
66	16-May-2007	10	15	41	20.548	100.587	4.1								
67	16-May-2007	10	26	1	20.488	100.894	4.1								
68	16-May-2007	11	15	56	20.458	100.867	4.4								
69	16-May-2007	11	35	12	20.53	100.79	4.0								
70	16-May-2007	11	43	52	20.4	100.697	4.1								
71	16-May-2007	13	18	7	20.495	100.64	4.6								
72	16-May-2007	17	8	54	20.547	100.774	4.2								
73	17-May-2007	3	25	40	20.652	100.379	4.2								
74	18-May-2007	0	1	53	20.42	100.708	4.1								
75	18-May-2007	1	40	55	20.458	100.67	4.0								
76	18-May-2007	13	5	16	20.465	100.659	4.2								
77	20-May-2007	1	21	21	20.268	100.747	3.9								
78	23-May-2007	17	6	27	20.399	100.633	4.1								
79	24-May-2007	11	15	17	20.31	100.746	4.0								
80	7-Jun-2007	17	21	4	20.673	100.73	4.8								
81	19-Jun-2007	5	6	42	18.983	99.154	4.5	27	19-Jun-2007	12	6	0	18.90	99.00	4.5
82	23-Jun-2007	6	53	45	21.468	99.552	5.1								
83	23-Jun-2007	8	17	7	21.412	99.32	5.9	28	23-Jun-2007	15	17	0	21.27	99.82	5.0
84	23-Jun-2007	8	27	37	21.324	99.316	5.7								
85	14-Jul-2007	8	29	18	20.357	100.783	3.8								
86	28-Jul-2007	21	33	49	20.651	99.144	4.5								
87	6-Aug-2007	6	53	52	20.475	100.493	4.3								
88	6-Aug-2007	8	50	50	20.507	100.573	3.9								
89	7-Aug-2007	8	53	23	20.866	100.114	4.6								
90	8-Aug-2007	9	15	32	20.408	100.726	4.2								
91	19-Aug-2007	11	16	56	19.921	98.93	3.9								
92	8-Sep-2007	7	12	46	20.59	100.674	4.2								
93	16-Oct-2007	2	39	24	18.73	100.246	2.4								
94	16-Oct-2007	6	46	53	20.483	100.727	4.7	29	16-Oct-2007	13	47	0	20.80	100.93	5.0
95	1-Nov-2007	19	5	47	20.374	100.722	4.6	30	2-Nov-2007	2	5	0	21.57	100.92	5.7
96	23-Dec-2007	11	19	31	18.655	100.654	3.2								
97	2-Mar-2008	3	23	35	18.736	100.113	3.1	31	2-Mar-2008	10	23	0	18.99	99.97	2.5
98	9-Apr-2008	15	49	24	19.3	99.266	3.2								
99	10-Jun-2008	21	37	43	20.112	100.858	4.7	32	10-Jun-2008	4	38	0	20.67	97.44	5.1
100	1-Jul-2008	9	45	51	19.219	99.345	3.9								
101	9-Jul-2008	4	39	48	18.689	100.253	2.2								
102	25-Nov-2008	8	10	52	18.905	100.167	2.5								
103	29-Nov-2008	8	6	25	20.289	100.658	4.0	33	29-Nov-2008	15	6	15	21.25	101.41	4.5
104	31-Dec-2008	8	0	1	18.67	100.616	3.6								
105	31-Dec-2008	8	4	11	18.674	100.611	3.6								
106	29-Jan-2009	23	24	33	19.045	100.318	2.8								
107	6-Feb-2009	1	39	18	19.547	99.759	2.8								
108	22-May-2009	7	58	9	20.464	100.796	4.4	34	22-May-2009	14	58	14	20.64	100.60	4.5
109	22-May-2009	18	50	15	21.318	102.01	5.0	35	23-May-2009	1	50	24	21.37	102.00	5.1
110	1-Jun-2009	12	44	27	18.821	100.707	3.1								
111	10-Jun-2009	0	23	59	18.848	100.286	2.6								
112	10-Jun-2009	0	25	5	18.899	100.242	2.7								
113	18-Jun-2009	19	50	16	18.892	100.309	2.6								
114	21-Jun-2009	18	6	20	19.588	99.977	3.6	36	22-Jun-2009	1	6	19	19.67	100.04	3.6
115	16-Aug-2009	17	57	11	20.231	100.746	4.2	37	17-Aug-2009	0	57	13	20.57	100.85	4.7
116	1-Oct-2009	11	56	2	20.836	101.689	4.1								
117	14-Oct-2009	1	59	31	20.811	101.498	4.8								

Table 5.5. Correlation of the KST's epicenters with the TMD (cont).

No.	Earthquake Data of the KST							No.	Earthquake Data of the TMD						
	Date	Origin Time (UTC)			Location		M		Date	Origin Time (Local, UTC+7)			Location		M
		hr	min	sec	Lat	Long				hr	min	sec	Lat	Long	
118	7-Nov-2009	3	54	55	20.458	101.793	3.9	38	7-Nov-2009	10	55	9	20.63	101.54	3.9
119	10-Nov-2009	7	36	51	20.815	101.763	4.7								
120	10-Nov-2009	8	1	44	20.802	101.243	4.2								
121	10-Nov-2009	8	40	23	20.844	101.418	4.1								
122	2-Dec-2009	7	3	5	19.232	99.209	3.3	39	2-Dec-2009	14	3	4	19.26	99.18	3.3
123	26-Dec-2009	1	11	49	20.376	98.944	4.1	40	26-Dec-2009	8	11	52	20.56	99.12	4.2
124	9-Mar-2010	13	3	24	20.323	99.168	4.2	41	9-Mar-2010	20	3	29	20.33	98.95	4.4
125	26-Jun-2010	2	23	59	20.354	99.827	3.9	42	26-Jun-2010	9	24	2	20.37	99.77	4.0
126	6-Jul-2010	15	23	29	20.362	99.614	4.1	43	6-Jul-2010	22	23	32	20.42	99.83	4.5
127	18-Jul-2010	12	53	19	20.263	101.272	3.9	44	18-Jul-2010	19	53	13	21.30	101.27	4.5
128	29-Aug-2010	8	19	2	19.516	99.512	3.4	45	29-Aug-2010	15	19	4	19.57	99.63	3.3

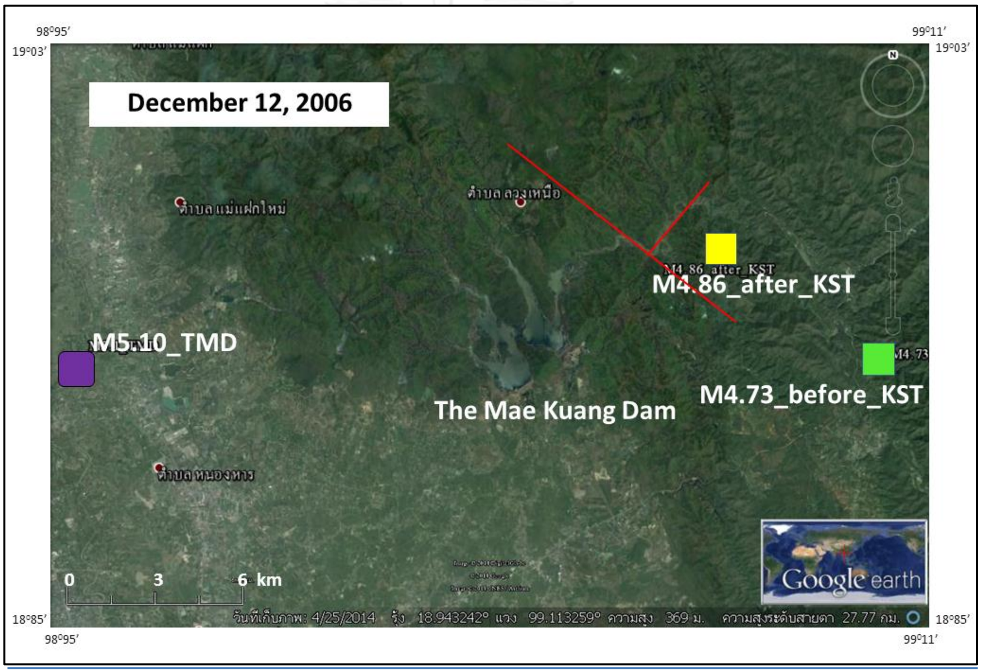


Figure 5. 17. Epicenters of the KST before (green square) and after (yellow square) re-locating and the TMD's epicenter (purple square) of earthquake on December 12, 2006, plotting in Google map. They are all difference in magnitudes and locations of earthquakes.

Table 5. 6. Details of the TMD's epicenters with magnitude greater than 4 during the year 1978 to 1998.

No	Date	Lat	Long	M	Region
1	26-May-1978	19.27	99.06	4.8	Amphoe Phrao, Chiang Mai
2	10-Feb-1980	19.35	99.23	4.2	Chiang Mai
3	20-Jun-1982	18.92	99.18	4.3	Chiang Mai
4	19-Feb-1988	18.87	99.17	4.2	Chiang Mai
5	8-May-1994	18.3	99.2	4.5	Chiang Mai
6	11-Sep-1994	19.46	99.6	5.1	Amphoe Mae Suai, Chiang Rai
7	5-Nov-1995	19.8	98.8	4.0	Amphoe Fang, Chiang Mai
8	9-Dec-1995	18.2	99.8	5.1	Amphoe Rong Kwang, Phrae
9	21-Dec-1995	19.7	99	5.2	Amphoe Phrao, Chiang Mai
10	2-Feb-1997	18.4	99.9	4.0	Amphoe Song, Phrae
11	13-Jul-1998	19.7	99.1	4.1	Amphoe Fang, Chiang Mai

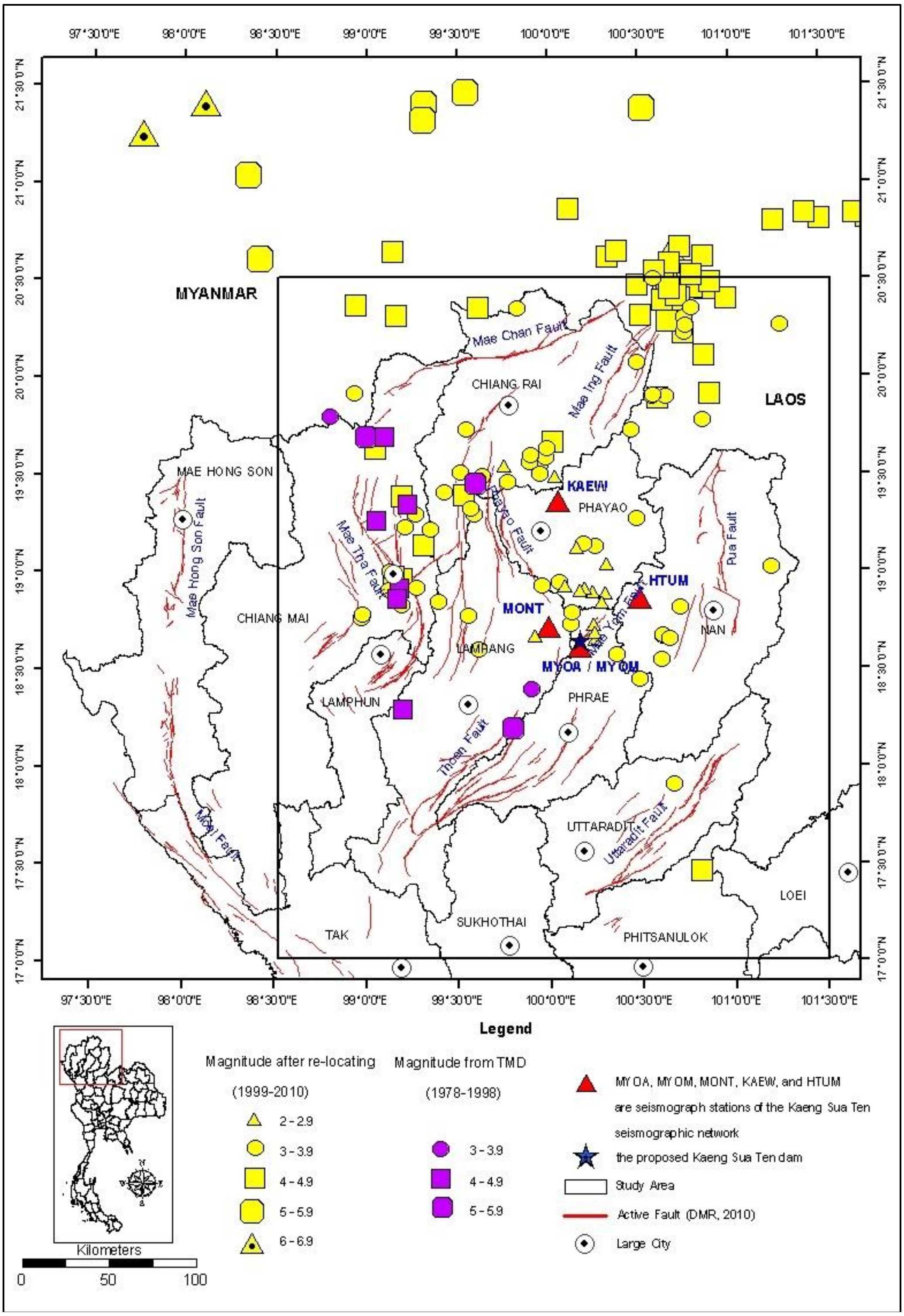


Figure 5. 18. Correlation of the KST's epicenters (yellow) of this study to the TMD's epicenters (purple) during the year 1978 to 1998.

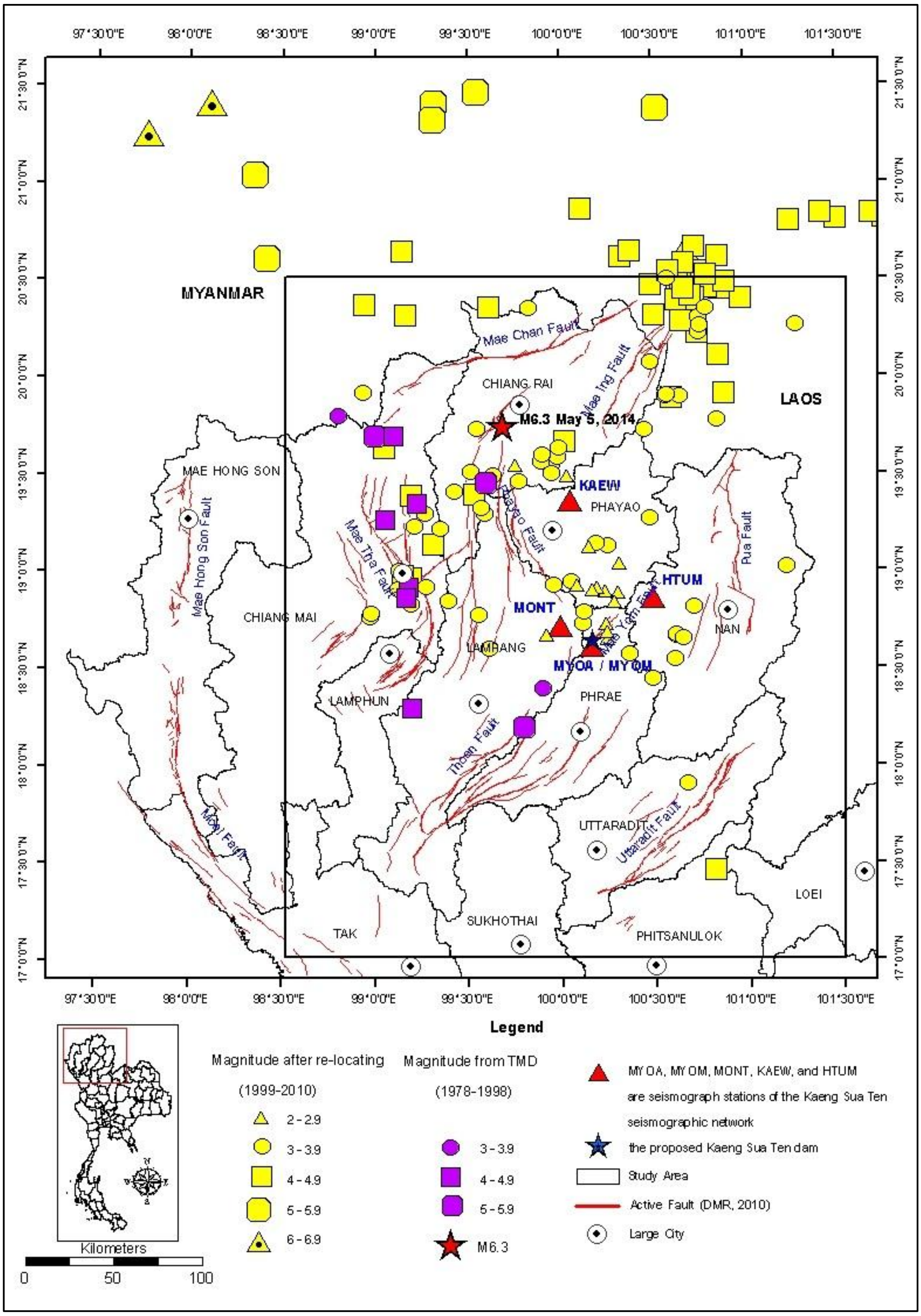


Figure 5. 19. Correlation of the KST's epicenters (yellow) of this study to the TMD's epicenters (purple) during the year 1978 to 1998 and the M6.3 (red star) earthquake on May 5, 2014.

CHAPTER VI
DISCUSSION

In this chapter, a main point is described for the discussion related to the results from location of earthquakes after re-locating along with the previous works. The discussion comprised of characteristics of seismicity in northern Thailand, and frequency and magnitude distribution.

6.1 Characteristics of Seismicity in Northern Thailand

The newly located earthquake location of earthquakes of the size ranging from M2.2-6.2 (Table 4.1) during 1999-2010, recorded by the KST network, a local seismograph network in this study, confirms that the earthquake in the study area consist of minor to light magnitude ranges between M3-4.9 (Figure 4.23 and Figure 4.24) local earthquake. They are shallow earthquakes with depth less than 70 kilometer (Table 4.1 and Figure 4.25). The earthquake's locations are clearly and significantly have some epicenters after re-locating, were associated with mapped faults with surficial expression, but some epicenters were not (Figure 5.3- Figure 5.6).

Upon reviewing the result of this study with that of (Bott et al., 1997), there is both consistence and inconsistence issues. The consistence is that the seismicity is of low to moderate level. The obvious significantly inconsistence conclusion by (Bott et al., 1997), is that the relation of some earthquake hypocenter with mapped faults of the site. The data source used by (Bott et al., 1997) in their review and this study are different. This study used data obtain from local seismograph network. It consists of shot period seismometer which is appropriated to study small local earthquake. The distance between stations is 20-80 kilometer. However, (Bott et al., 1997), utilized earthquake achieve from global seismograph network maintains by the TMD. The network may not be appropriated for monitoring the local-small earthquake. This achieve might not be completed for small earthquake occurred in the northern Thailand. The error in reading of phase times may lead to incorrectly determination of earthquake location. Also the magnitude that has been used may be of different scale, leading to the inconsistent in magnitude conversion. All of these factors made it difficult to come up with the correlation of earthquake location with structural geology of northern Thailand.

Because of the highly uncertainty in the earthquake location determination which is clearly mention by (Bott et al., 1997), the type of the network and instrument is therefore important for the determination of earthquake. This study is strongly supplemented of the work by (Bott et al., 1997). It complements the study of small local earthquake data such as M3-3.9 and M4-4.9, with data from more suitable seismograph. To study small local earthquake magnitude smaller than M3 to understand the earthquake pattern in northern Thailand, it is necessary to install more of short period seismograph with separation distance between stations at not more than 50 kilometer, so that more of the smaller earthquake epicenter can be detected and be located correctly.

Macroseismic survey should also be carried out whenever an earthquake of M3 or greater occur. Macroseismic study can provide an accurate result for earthquake such that relationship to the geological structure can be determined e.g. (Harnpattanapanich, 2006c) which was used to study the December 7, 2005, Mae Suai, Chiang Rai earthquake. With the help of epicenter determined from the KST local network, the intensity map, in MMI scale obtained from macroseismic survey from population around the epicenter, GPS located and displayed on 1:50,000 scale topographic map, showed the good correlation of Isoseismal line and the drawn Meizoseismal area to the geologic formations and structure of the area.

One of the most important factor that cause the differing in the epicenter location determination among the agency or network is the error from the operators themselves i.e. the error in reading phases time. When these data are different the located earthquake epicenter would be in error. When more data are available rereading of the phases data or using other earth velocity model in the analysis can help verifying the correct epicenter. In order to explain the characteristic and relation of earthquakes, it is necessary for the seismologist to correctly determine the earthquake location.

From this research, it can be observed that the evaluation of small local earthquake recorded by a local network such as the KST network, at a rather short period of only 12 years, however, the characteristic of earthquakes in the area can be identified and correlated well with distribution of earthquake of M4 to M5.2 between 1978-1998 (Table 5.6) obtained from the TMD network and the earthquake of M6.3 at Amphoe Mae Lao, Chiang Rai on May 5, 2014 and with active fault zone in map produced by the DMR. The result can be used to delineate high risk zone for earthquake hazard in Amphoe Mae Suai, Chiang Rai, and Amphoe Phrao, Chiang Mai where major active fault i.e. the Phayao fault and the Mae Tha fault are located. The area is covered by latitudes 18.75-19.75N and longitudes 98.75-99.75E (Figure 6.1). It can be identified that the Mae Suai dam, the Mae Kuang dam and the Mae Ngad dam are all located in the high earthquake hazard zone. The study for the effect of earthquake to these dams should be a priority for the RID.

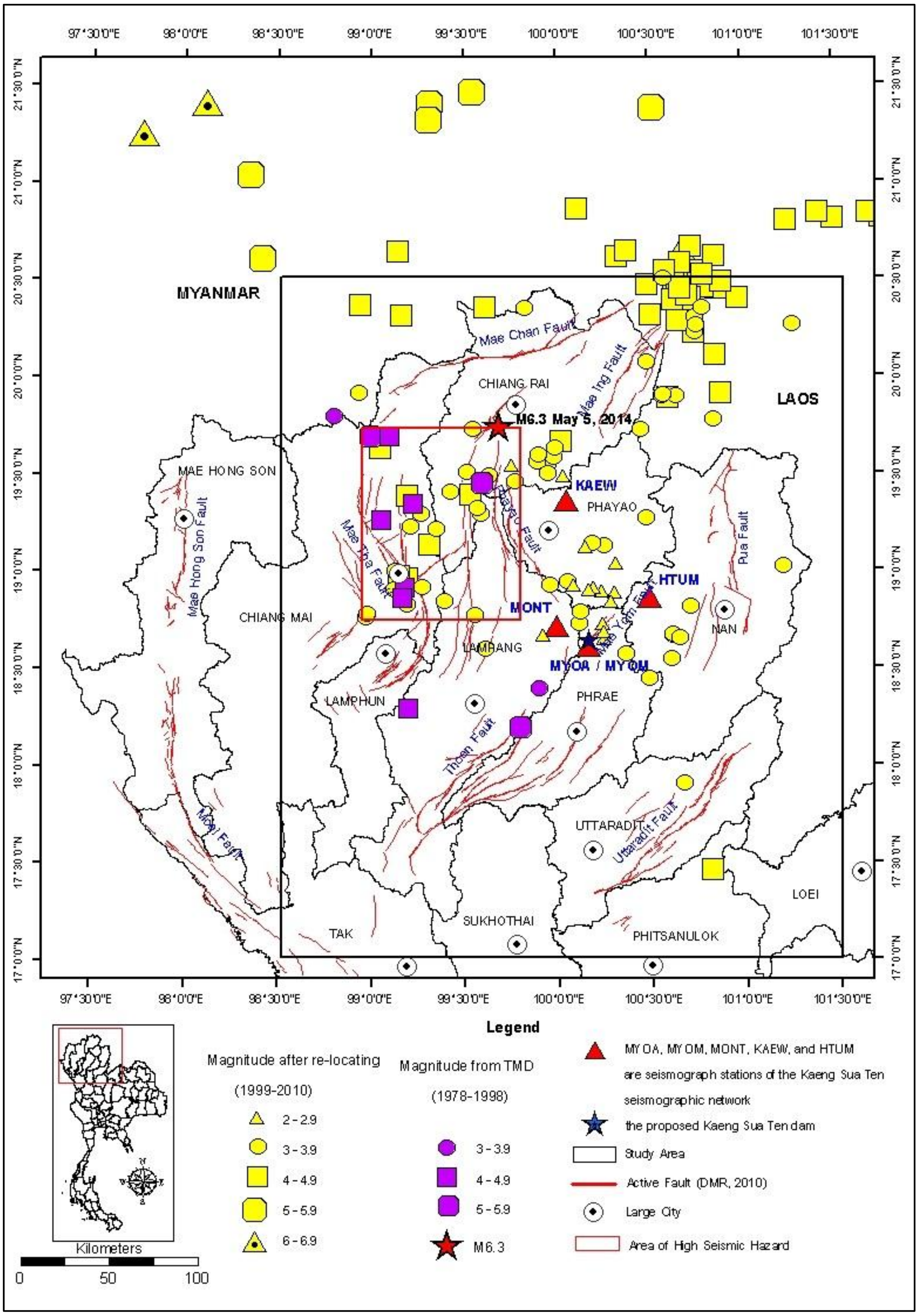


Figure 6. 1. Epicentral map shows the area of high seismic hazard between Lat 18.75-19.75 Long 98.75-99.75 estimated from present and historical seismicity.

6.2 Frequency and Magnitude Distribution

Gutenberg-Richter Recurrence Law is used for the estimation of earthquake hazard level of the study area. The new b-value from this study, covered the period 1999-2010, is 0.59 (Figure 6.2) where average earthquake occurrence for M3 is 4 per year, M3.5 is 2.5 per year and M4 is 1.5 per year. This statistic help identify the number and size of future small earthquake. The information can support the work by WCFS (1996) in the evaluation of earthquake risk to the KST dam.

With the available of higher intensity, more damages medium size earthquake e.g. M5-6.5, the data set is used to compare with (WCFS, 1996) result. B value from (WCFS, 1996) is -0.92 ± 0.12, where average earthquake recurrence for M5 is 7 year, M5.5 is 20 year, M6 is 56 year and M6.5 is 163 year. When included the earthquake of M6.3 at Amphoe Mae Lao, Chiang Rai on May 5, 2014 in the data set, the event is the largest ever for the period of 163 year and is the largest ever recorded by instrument for Thailand. The maximum intensity at the epicenter, reported by the DMR is VIII on MMI scale. The accelerograph recorded at the MYOA station for the KST dam at 130 km from the epicenter gave maximum ground acceleration of 0.0052g. However, the strong motion recorded study by (Khamkom, 2014) obtained from the instrument at the MSAC station, located at the right abutment of the Mae Suai dam, which is only 15 km from the epicenter, gave maximum ground acceleration of 0.33g. This is the highest value ever recorded in Thailand. There was continuous strong ground vibration (more than 0.05g) for more than 7 second. It is likely that the strong vibration from main shock and the aftershocks are the causes of damages affected more than 10,000 houses and buildings situated in the Mae Lao flood plain. The results show that the size and the distance from the epicenter of earthquakes affecting the level of violence or damage to occur. Due to the statistic of earthquakes with magnitudes 3.5 are likely to occur in the study area average 2.5 per year, and may cause the structure to damage. If it happened near the community such as the impact of earthquake on March 27, 2005 with M3.73 to the Mae Suai dam, the report of (Harnpattanapanich, 2005) stated that found crack of lift joint at upstream left gallery about 12 meter long. Hazard evaluation from Gutenberg-Richter

Law obtained in this study and the study by WCFS, 1996 will help clarifying and complementing the statistics analyses of earthquake study in northern Thailand.

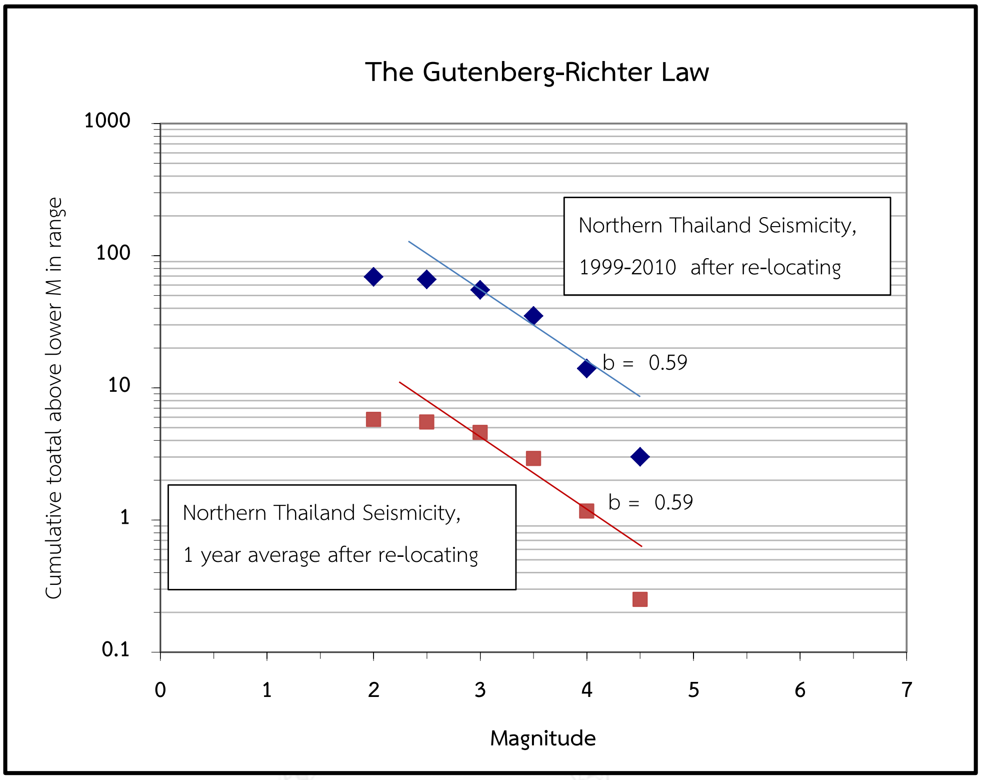


Figure 6. 2. Northern Thailand seismicity during the year 1999 to 2010 and for 1 year average b-value = 0.59.

Table 6. 1. Recurrence intervals for earthquakes in the KST project (WCFS, 1996).

M	Intervals (yrs)*
5	7 (2 - 27)
5.5	20 (4 - 89)
6	56 (11 - 296)
6.5	163 (27 - 979)

* Range of interval when incorporating the standard error of b-value

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of re-locating the KST's epicenters during the year 1999 to 2010 by using the arrival times of P-and S- waves and triangulation method, calculating the origin time, determining the result and summarizing from the study with other previous studies, for examples, the magnitudes, the focal depths, the relationship with geological structures, the b value, and the characteristics of earthquake ground motion, the conclusions can be drawn below.

1. Before relocating, the KST network has 118 events with magnitude 2.0-6.6 that can be categorized in northern Thailand, 62 events with magnitude 2.0-5.0 and in neighboring countries, 56 events with magnitude 3.9-6.6, and mostly scattered between latitudes 18.5- 20.0N longitudes 99.0-101.5E. After relocating, the KST network has 128 well-located earthquakes with magnitude 2.2-6.5. The 67 events are categorized to be in northern Thailand with magnitude range of 2.2-4.9 and in the neighboring countries 61 events with magnitude 3.9-6.5. The epicenters are mostly scattered along the latitudes 18.0-20.5N and longitudes 99.0-100.5E. The depths of earthquakes are shallow with focal depth less than 70 km.
2. The epicenters of 128 events after re-locating based on the criteria that were used in this study are more reliable and have better accuracy than before the re-locating, owing to the new epicenters were obtained from the intersection of 3 circles from at least 3 epicentral distances. Together all events' origin times have been revised, as the difference in occurrence time from each station have been fixed to be less than 2 seconds error.
3. The earthquakes before and after re-locating have difference in the magnitude about $\pm$0.00-0.57 unit and the location about $\pm$2.0-125 km. This may be due to the manually analysis, not automatic, which did not have uniform standard procedure in the analysis. It was depended on the operator judgment to pick the phase of P or S-wave.

4. There are earthquakes with magnitudes 2-3.9 occurred near the reservoir area and around the seismograph stations of the KST network, but no earthquakes occurred at the proposed KST dam in Phrae. The earthquake that occurred nearest the proposed KST dam is at Amphoe Song in Phrae on June 9, 2005 with magnitude 2.34, with epicenter at latitudes 18.656N and longitudes 100.249E, about 11.2 km to the northeast from the proposed KST dam.
5. There are no earthquakes with ground-motion greater than 0.05g at the proposed KST dam (the MYOA station). The characteristics of earthquake ground motion of this study from the PGA, duration of motion, and frequency content can be summarized that the PGA value at the site depends on the earthquake's magnitude and the epicentral distance (source-to-site).
6. The regions where the earthquakes with magnitude 4-4.9 mostly occur are in Chiang Mai and Chiang Rai. They were found in Amphoe Doi Saket (near the Mae Kuang dam), Amphoe Phrao, and Amphoe Chiang Dao in Chiang Mai, and Amphoe Thoeng, Amphoe Wiang Pa Pao in Chiang Rai.
7. The correlation of the KST's epicenters with the TMD's epicenters for the recorded during the year 1978 to 1998 or the year before the set-up of the KST network, and the epicenter of earthquake with magnitude 6.3 on May 5, 2014, in order to identify the area of high seismicity from the past, and present earthquakes. The result from past and present earthquakes of this study indicates that the earthquakes with magnitudes 4-4.9 frequently occurred in Chiang Mai, and Chiang Rai between latitudes 18.75-19.75N and longitudes 98.75-99.75E.
8. The results of the KST's epicenters of this study show that some epicenters after re-locating were associated with mapped faults with surficial expression, but some epicenters were not. However, (Bott et al., 1997) mentioned that northern Thailand is similar to the Basin and Range province in the western United States of America in term of earthquake processes and tectonics. In the Basin and Range province background

earthquakes as large as M6-6.5 can occur on buried faults with no surface expression or apparent geological association (dePolo, 1994). Therefore some epicenters probably associated with faults which have no surficial expression might be background earthquakes.

9. The epicenters of the KST and the TMD networks are not plotted in the same location and with varying magnitudes. This may be due to the instrument types (shot period and broadband), the operators, and the computer program that used in the analyses.
10. The b-value before re-locating is 0.52, and after re-locating the b-value is 0.59. The b-value has a little difference as the number of earthquakes before and after re-locating which were used in this study is different.

Recommendations

To study small local earthquake magnitude smaller than M3 to understand the earthquake pattern in northern Thailand, it is necessary to install more of short period seismograph with separation distance between stations at not more than 50 kilometer, so that more of the smaller earthquake epicenters can be detected and be located correctly.

There should be a detailed study on the intensity of the earthquakes using macroseismic method. So, in the case, the earthquakes with the magnitudes >3 on the Richter scale need to be corrected and relocated in order to emphasize the importance of that active-fault segment.

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http://www.sci.tsu.ac.th. The point on the fault that first ruptures is the focus. The point on the Earth's surface directly above the focus is the epicenter

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http://www.usgs.gov/.

http://www.yorku.ca/. Seismometer recording horizontal and vertical ground -motion

https://sites.google.com. The point where the three circles intersect is the epicenter of the earthquake. This technique is called triangulation

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APPENDIX

ความเร่งพื้นดินสูงสุด ความเร็วพื้นดินสูงสุด ระยะเวลาการสั่นไหว และช่วงค่าความถี่จากการสั่นไหวของแผ่นดินไหวหลัก ขนาด 6.3 อำเภอพาน จังหวัดเชียงราย และแผ่นดินไหวตาม ขนาด 5-6 และขนาด 4-5

PEAK GROUND ACCELERATION, PEAK GROUND VELOCITY, DURATION OF MOTION, FREQUENCY CONTENT OF MAIN SHOCK M6.3 AT PHAN DISTRICT, CHIANG RAI PROVINCE AND AFTERSHOCKS M5-6 AND M4-5

วัฒนา คำคม
นักธรณีวิทยาชำนาญการพิเศษ หัวหน้ากลุ่มงานวิชาการวิศวกรรมธรณี ส่วนวิศวกรรมธรณี สำนักสำรวจด้านวิศวกรรมและธรณีวิทยา
กรมชลประทาน

Watana Khamkom
Senior Professional Geologist, Chief of Technical Engineering Geology Group, Engineering Geology Division,
Office of Engineering Topographical and Geotechnical Survey, the Royal Irrigation Department

บทคัดย่อ

การศึกษาความเร่งพื้นดินสูงสุด ความเร็วพื้นดินสูงสุด ระยะเวลาการสั่นไหว และช่วงค่าความถี่จากการสั่นไหวของแผ่นดินไหวหลัก ขนาด 6.3 และแผ่นดินไหวตาม ขนาด 5-6 และขนาด 4-5 มีวัตถุประสงค์เพื่ออธิบายลักษณะการสั่นไหวของพื้นดินที่รุนแรง และเพื่อประเมินผลกระทบของแผ่นดินไหวที่มีต่อเขื่อนแม่สรวย จากค่าพารามิเตอร์ของการสั่นไหวที่มากกว่าหนึ่งพารามิเตอร์ เนื่องจากการใช้ค่าความเร่งพื้นดินสูงสุดเพียงอย่างเดียวไม่สามารถที่จะอธิบายได้อย่างชัดเจน โดยค่าความเร่งพื้นดินสูงสุด ณ บริเวณที่ตั้งเขื่อนแม่สรวยของแผ่นดินไหวหลัก ขนาด 6.3 เมื่อวันที่ 5 พฤษภาคม 2557 มีค่าเท่ากับ 0.33 g ในแนวตะวันออก-ตะวันตก ซึ่งเป็นค่าที่มากที่สุดตั้งแต่มีการตรวจวัดแรงกระทำของแผ่นดินไหวได้ด้วยเครื่องมือในประเทศไทย แต่เขื่อนแม่สรวยได้รับการออกแบบเพื่อต้านทานแรงแผ่นดินไหว ด้วยวิธี pseudo static ค่าสัมประสิทธิ์ของการสั่นสะเทือน เท่ากับ 0.10 จึงทำให้เกิดคำถามและความวิตกกังวลในเรื่องความมั่นคง และปลอดภัยของตัวเขื่อนแม่สรวย การอธิบายลักษณะการสั่นไหวของพื้นดินที่รุนแรงเพื่อให้เกิดความเข้าใจและชัดเจน จึงจำเป็นต้องใช้ค่าพารามิเตอร์ของการสั่นไหวอย่างน้อย 2 พารามิเตอร์

คำสำคัญ: พารามิเตอร์การสั่นไหวของพื้นดิน ความเร่งพื้นดินสูงสุด ความเร็วพื้นดินสูงสุด ระยะเวลาการสั่นไหว ช่วงค่าความถี่ของการสั่นไหว สเปคตรัมตอบสนอง ผลกระทบในท้องถิ่น

ABSTRACT

The study of peak ground acceleration, peak ground velocity, duration of motion, and frequency content of main shock with M6.3 and aftershocks with M5-6 and M4-5 has the purpose to describe the characteristics of strong ground motion and to evaluate the seismic hazard of the Mae Suai dam by using more than one ground motion parameters since using of only the peak ground acceleration is unable to describe clearly. The peak ground acceleration at the Mae Suai dam site of main shock with M6.3 on May 5, 2014 is 0.33 g in the East-West component which is the highest value from the instrumental data that have been recorded in Thailand. However the Mae Suai dam has been designed to withstand earthquake force by the pseudo static method with seismic coefficient of 0.10 that raises the questions of concern about stability and safety of the Mae Suai dam. In order to describe the characteristics of strong ground motion thoroughly and clearly, the necessity to use at least two ground motion parameters is applied.

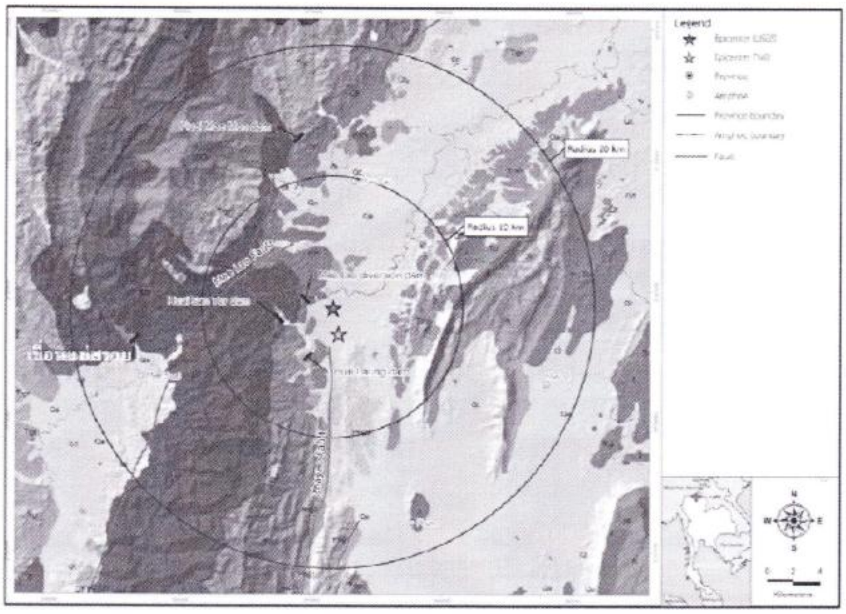
KEYWORDS: ground motion parameters, peak ground acceleration, peak ground velocity, duration of motion, frequency content, response spectrum, local site effect

1. บทนำ

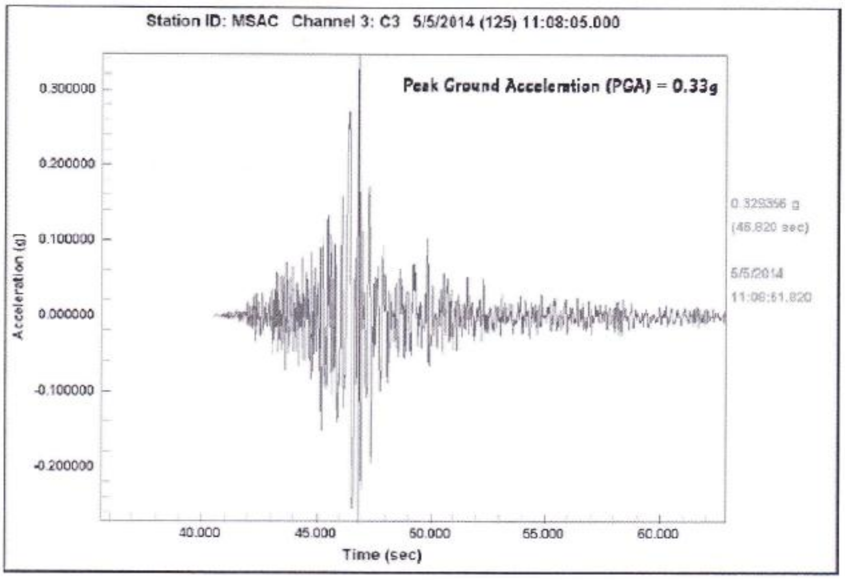
ตามที่ได้เกิดแผ่นดินไหว ขนาด 6.3 เมื่อวันที่ 5 พฤษภาคม 2557 เวลา 18:08:42 น. ความรุนแรงของแผ่นดินไหวส่งผลกระทบต่อผู้คนและทำความเสียหายให้กับโครงสร้างอาคารเป็นบริเวณกว้าง โดยเขื่อนแม่สรวย จังหวัดเชียงราย เป็นเขื่อนหนึ่งที่ได้รับการคาดว่าจะได้รับผลกระทบที่รุนแรงจากการสั่นไหว เนื่องจากอยู่ใกล้ศูนย์กลางแผ่นดินไหว ประมาณ 15 กิโลเมตร จากการตรวจสอบสภาพเขื่อนภายหลังการเกิดแผ่นดินไหวทางกายภาพด้วยสายตา [1] ของเจ้าหน้าที่ผู้เกี่ยวข้อง ไม่พบว่ามีความเสียหายที่รุนแรงจากการสั่นไหวของแผ่นดินไหว แต่เมื่อตรวจสอบข้อมูลที่ได้จากเครื่องมือตรวจวัดพฤติกรรมเขื่อน พบว่ามีการเปลี่ยนแปลงค่าของข้อมูลในช่วงที่เกิดเหตุการณ์แผ่นดินไหวหลัก และแผ่นดินไหวตาม หลายครั้ง [2] โดยค่าความเร่งพื้นดินสูงสุด ที่บันทึกได้จากเครื่องมือวัดค่าความเร่ง (accelerograph) ที่ติดตั้งอยู่ที่สถานี MSAC บริเวณฐานยันฝั่งขวาของเขื่อนแม่สรวย มีค่าเท่ากับ 0.33 g (ในแนวตะวันออก-ตะวันตก) ซึ่งถือว่าเป็นค่าที่มากที่สุด ตั้งแต่มีการตรวจวัดแรงกระทำของแผ่นดินไหวได้ในประเทศไทย เขื่อนแม่สรวยและเขื่อนของกรมชลประทานส่วนใหญ่ได้รับการออกแบบเพื่อต้านทานแรงแผ่นดินไหว ด้วยวิธี pseudo static กำหนดค่าสัมประสิทธิ์ของการสั่นสะเทือน เท่ากับ 0.10 ดังนั้นสัดส่วนค่าสัมประสิทธิ์ของการสั่นสะเทือนที่ใช้ในการออกแบบต่อค่าความเร่งพื้นดินสูงสุดที่ตรวจวัดได้จากแรงกระทำของแผ่นดินไหวในครั้งนี้ จึงมีค่า ประมาณ 1:3 เท่า ทำให้เกิดคำถามและความวิตกกังวลในเรื่องความมั่นคงและปลอดภัยของเขื่อนแม่สรวย ทั้งจากผู้บริหารและเจ้าหน้าที่ผู้เกี่ยวข้องของกรมชลประทาน ตลอดจนประชาชนที่อยู่บริเวณท้ายน้ำของเขื่อนแม่สรวย เขื่อนแม่สรวยได้รับการสำรวจ และออกแบบโดยบริษัท COYNE ET BELLIER Bureau d'Ingenieurs Conseils และบริษัท ทีม คอนซัลติ้ง เอ็นจิเนียริ่ง แอนด์ แมเนจเมนท์ จำกัด เป็นเขื่อนคอนกรีตบดอัดผสมกับเขื่อนดิน เขื่อนสูง 59 เมตร สภาพธรณีวิทยาฐานรากบริเวณที่ตั้งเขื่อนเป็นหินยุคไซลูเลียน-ดีโวเนียน (รูปที่ 1) ดำเนินการก่อสร้างโดย กิจการร่วมค้า SC ประกอบด้วยบริษัท สี่แสงการโยธา (1979) จำกัด ร่วมกับ China National Water Resources and Hydropower Engineering Corporationมีที่ปรึกษาควบคุมงานก่อสร้าง ประกอบด้วย บริษัท COYNE ET BELLIER Bureau d'Ingenieurs Conseils และ บริษัท ทีม คอนซัลติ้ง เอ็นจิเนียริ่ง แอนด์ แมเนจเมนท์ จำกัด ในลักษณะอำนวยการก่อสร้างเต็มรูปแบบ (Full Supervision) ก่อสร้างแล้วเสร็จเมื่อปีพ.ศ. 2546 การศึกษานี้มีวัตถุประสงค์เพื่อศึกษาลักษณะการสั่นไหวของพื้นดินของแผ่นดินไหวหลัก ขนาด 6.3 และแผ่นดินไหวตามขนาด 5-6 และขนาด 4-5 จากค่าพารามิเตอร์ของการสั่นไหว ประกอบด้วย ความเร่งพื้นดินสูงสุด ความเร็วพื้นดินสูงสุด ระยะเวลาการสั่นไหว และช่วงค่าความถี่จากการสั่นไหวที่รุนแรง เพื่อประเมินผลกระทบของแผ่นดินไหวที่มีต่อเขื่อนแม่สรวย

2. การสั่นไหวที่รุนแรงของพื้นดิน

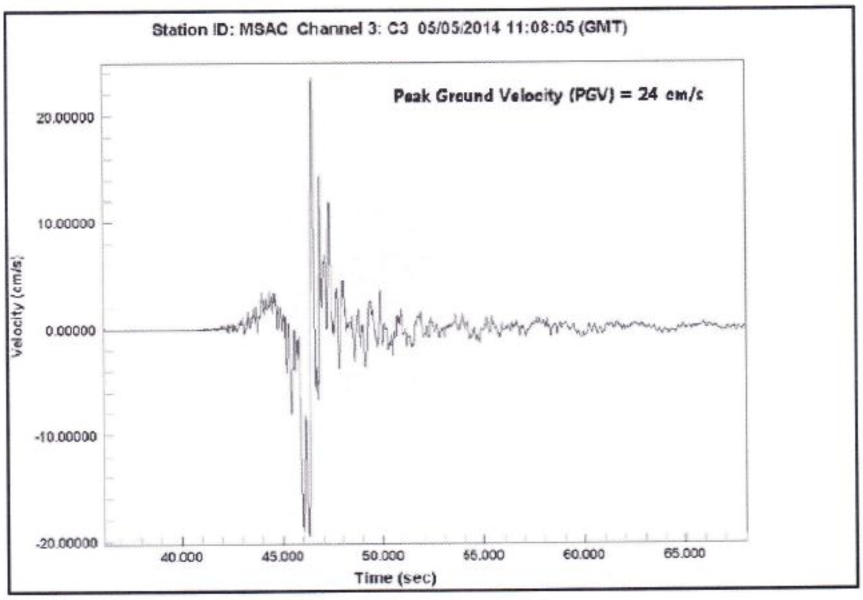
การศึกษาแรงกระทำของแผ่นดินไหวที่มีต่อเขื่อนแม่สรวยหรือโครงสร้างต่างๆ มีคุ่พารามิเตอร์ของการสั่นไหวที่สำคัญสำหรับงานทางด้านวิศวกรรมแผ่นดินไหวที่ต้องนำมาพิจารณาประกอบกัน 3 ประการ คือ (1) ขนาดของแรงที่กระทำ (ความเร่งพื้นดินสูงสุด, ความเร็วพื้นดินสูงสุด, การเคลื่อนที่พื้นดินสูงสุด) (2) ช่วงค่าความถี่ของการสั่นไหวที่รุนแรง (3) ระยะเวลาของการสั่นไหวที่รุนแรง[3,4] ซึ่งในการอธิบายลักษณะการสั่นไหวที่รุนแรงของพื้นดินให้ชัดเจนจะต้องใช้อย่างน้อย 2 พารามิเตอร์ ในการศึกษานี้ได้ใช้ข้อมูลแผ่นดินไหวที่บันทึกได้จากเครื่องมือตรวจวัดค่าความเร่งพื้นดินที่สถานี MSAC ยี่ห้อ Kinemetrics รุ่น Basalt, FBA-2g ซึ่งเป็นสถานีตรวจวัดแผ่นดินไหวของกรมชลประทาน ที่ได้ดำเนินการติดตั้งเครื่องมือและตรวจวัดค่าความเร่งพื้นดินตั้งแต่เดือนธันวาคม 2555 ในช่วงที่เกิดเหตุการณ์แผ่นดินไหว เฉพาะเดือนพฤษภาคม 2557 สามารถตรวจวัดค่าความเร่งพื้นดินได้มากกว่า 1,000 ครั้ง แต่พบว่ามีปัญหาเครื่องมือตรวจวัดดับ 2 ครั้ง คือ ช่วงวันที่ 5-7 พฤษภาคม 2557 และวันที่ 13 มิถุนายน-26 กรกฎาคม 2557 ทำให้ข้อมูลบางส่วนไม่สมบูรณ์ และไม่มีข้อมูลในช่วงนี้ ส่วนข้อมูลจุดศูนย์กลางแผ่นดินไหว อ้างอิงข้อมูลจากกรมอุตุนิยมวิทยา และกรมอุทกศาสตร์ กองทัพเรือ ในการวิเคราะห์ค่าความเร่งพื้นดินสูงสุด ความเร็วพื้นดินสูงสุด และระยะเวลาของการสั่นไหว ใช้โปรแกรม Kinemetrics Strong Motion Analyst โดยระยะเวลาของการสั่นไหวที่รุนแรง ได้เลือกใช้ค่า bracketed duration [5,6] ซึ่งได้อธิบายถึงช่วงระหว่างเวลาเริ่มต้นและเวลาสุดท้ายที่มีค่าเกินค่าความเร่งเกณฑ์ที่กำหนด (โดยทั่วไป เท่ากับ 0.05g) เนื่องจากใช้งานได้ง่ายที่สุด และขึ้นอยู่กับคุณสมบัติของค่าความเร่งที่บันทึกได้โดยตรง ส่วนการวิเคราะห์ช่วงค่าความถี่ของการสั่นไหว ได้ใช้โปรแกรมKMI Power Spectral Density โดยทั้ง 2 โปรแกรม เป็นของ บริษัท Kinemetrics ประเทศสหรัฐอเมริกาผลการวิเคราะห์ค่าพารามิเตอร์จากการสั่นไหวของแผ่นดินไหวหลัก ขนาด 6.3 พบว่าค่าความเร่งพื้นดินสูงสุด มีค่ามากที่สุดในแนวตะวันออก-ตะวันตก เท่ากับ 0.329356 g (รูปที่ 2) แต่เป็นค่า ณ เวลา 11:08:51.820 UTC ค่าความเร็วพื้นดินสูงสุด เท่ากับ 24เซนติเมตร/วินาที (รูปที่ 3) ณ เวลา 11:08:51.8 UTC ระยะเวลาของการสั่นไหวที่รุนแรงที่มีค่าเกิน 0.05 g เท่ากับ 7 วินาที (รูปที่ 4)ช่วงค่าความถี่จากการสั่นไหวที่รุนแรงพบว่ามีค่ามากที่สุดที่ความถี่ 2.5 เฮิรตซ์ (รูปที่ 5) ในกรณีของแผ่นดินไหวตาม ขนาด 5-6 และขนาด 4-5 (ตารางที่ 1) พบว่าแผ่นดินไหวที่จะมีผลกระทบต่อเขื่อนแม่สรวย คือ แผ่นดินไหวที่มีขนาดตั้งแต่ 4 ตามมาตราริกเตอร์ ขึ้นไป และต้องมีจุดศูนย์กลางอยู่ห่างจากที่ตั้งเขื่อนแม่สรวยไม่เกิน 10 กิโลเมตร



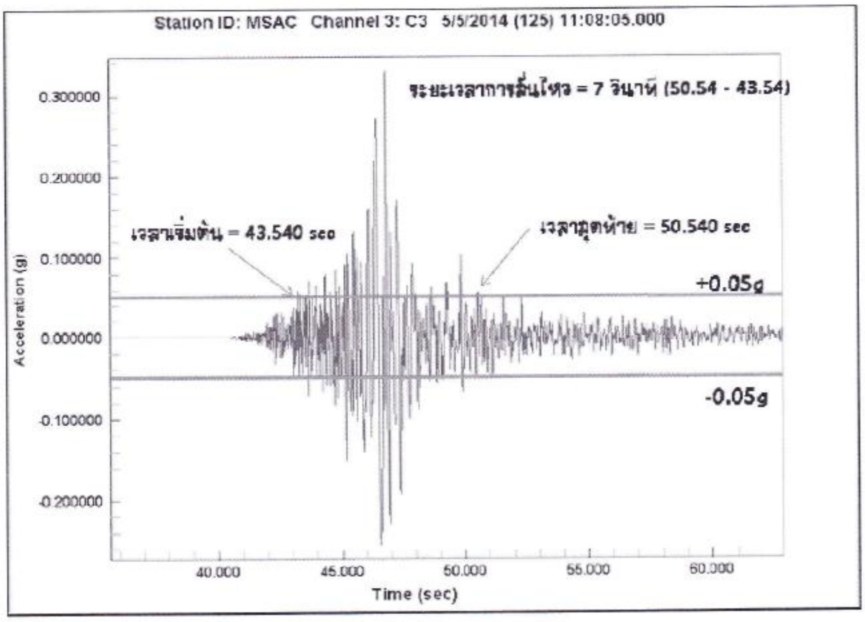
รูปที่ 1 สภาพธรณีวิทยาบริเวณที่ตั้งเขื่อนแม่สรวย และเขื่อนของกรมชลประทาน ศูนย์กลางแผ่นดินไหว ขนาด 6.3 วันที่ 5 พฤษภาคม 2557 กรมอุตุนิยมวิทยา และ USGS และรอยเลื่อนมีพลัง กรมทรัพยากรธรณี



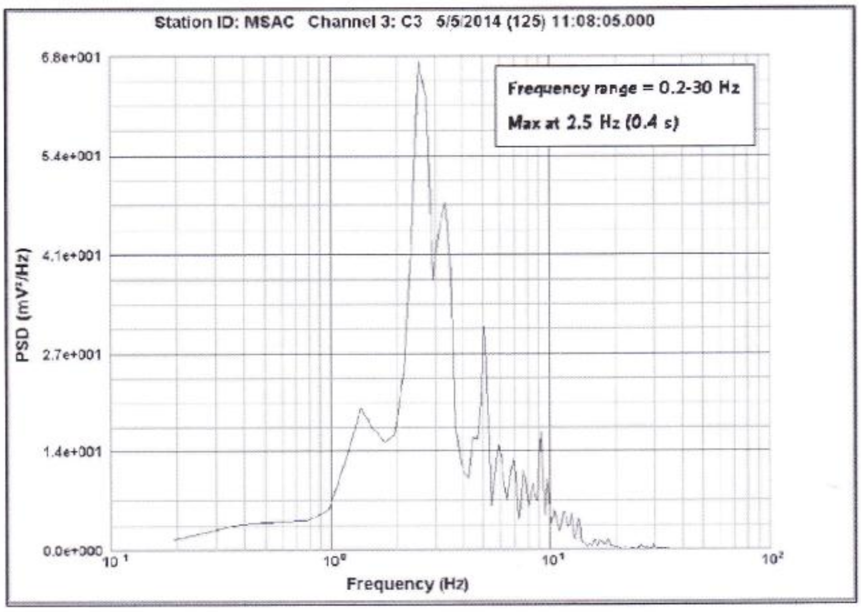
รูปที่ 2 ความเร่งพื้นดินสูงสุด เท่ากับ 0.329356g ที่เวลา 11:08:51.820 UTC (18:08:51.820 น.) ในแนวตะวันออก-ตะวันตก (C3)



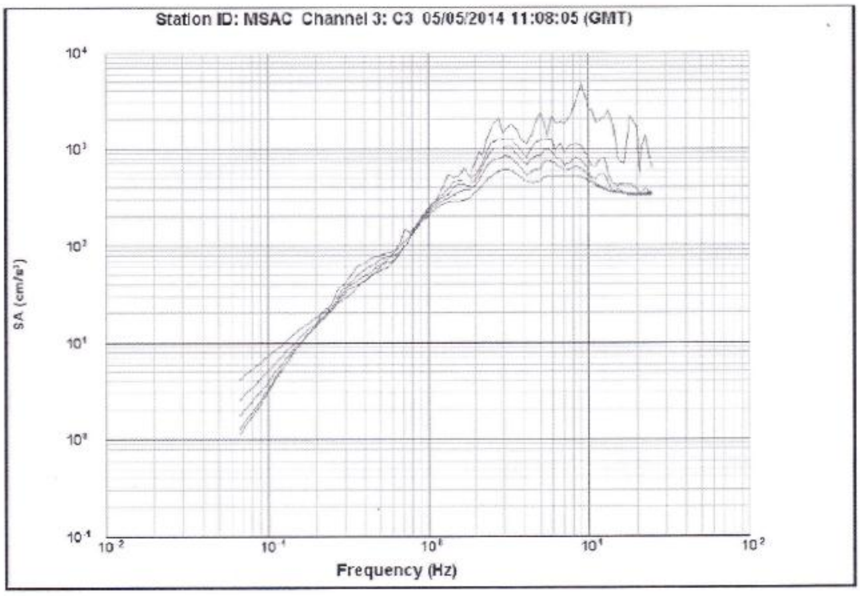
รูปที่ 3 ความเร็วพื้นดินสูงสุด เท่ากับ 24 เซนติเมตร/วินาที ที่เวลา 11:08:51.8 UTC (ในแนวตะวันออก-ตะวันตก)



รูปที่ 4 ระยะเวลาการสั่นไหวที่รุนแรง เท่ากับ 7 วินาที (ในแนวตะวันออก-ตะวันตก)



รูปที่ 5 ค่าความถี่ของการสั่นไหวที่รุนแรงที่สุด เท่ากับ 2.5 เฮิรตซ์ (ในแนวตะวันออก-ตะวันตก)



รูปที่ 6 สเปคตรัมความเร่งตอบสนองในแนวตะวันออก-ตะวันตก (damping ratio 0,2,5,10 และ 20%)

ตารางที่ 1 ค่าความเร่งพื้นดินสูงสุด ของแผ่นดินไหวหลัก ขนาด 6.3 และแผ่นดินไหวตาม ขนาด 5-6 และขนาด 4-5

ที่	วันที่	เวลา	ขนาด	ละติจูด	ลองจิจูด	ความลึก	บริเวณ	Component	PGA (g) ที่ สถานี MSAC (เขื่อนแม่สรวย)	เวลา (UTC)
1	5/5/2014 5/5/2014	18:08:42 น. 11:08:42 UTC	6.3	19.68	99.69	7	อำเภอพาน จังหวัดเชียงราย	Vertical	**-0.215158**	11:08:50.740
								N-S	**0.271973**	11:08:51.600
								E-W	**0.329356**	11:08:51.820
2	5/5/2014 5/5/2014	18:12:37 น. 11:12:37 UTC	5	19.68	99.43		อำเภอแม่สรวย จังหวัดเชียงราย	Vertical	**-0.132732**	11:12:37.100
								N-S	**-0.150293**	11:12:37.185
								E-W	**-0.172878**	11:12:37.325
3	5/5/2014	18:13:36 น.						Vertical	-0.042319	11:13:36.850
								N-S	-0.034268	11:13:36.440
								E-W	-0.039301	11:13:36.640
4	5/5/2014 5/5/2014	18:14:32 น. 11:14:32 UTC	4.8	19.64	99.65		อำเภอพาน จังหวัดเชียงราย	Vertical	-0.031970	11:14:34.050
								N-S	-0.033858	11:14:34.030
								E-W	**-0.069984**	11:14:34.035
5	5/5/2014	18:15:40 น.						Vertical	0.047155	11:15:42.170
								N-S	-0.038218	11:15:42.015
								E-W	**0.054985**	11:15:42.175
6	5/5/2014 5/5/2014	18:19:37 น. 11:19:37 UTC	5.1	19.71	99.71	5	อำเภอพาน จังหวัดเชียงราย	Vertical	0.020066	11:19:41.825
								N-S	0.024459	11:19:41.780
								E-W	0.029538	11:19:42.275
7	5/5/2014	18:20:20 น.						Vertical	-0.039684	11:20:20.225
								N-S	0.039146	11:20:20.180
								E-W	**0.057750**	11:20:20.295
8	5/5/2014 5/5/2014	18:22:18 น. 11:22:18 UTC	4.6	19.73	99.65	6	อำเภอแม่ลาว จังหวัดเชียงราย	Vertical	-0.021581	11:22:22.545
								N-S	0.022630	11:22:22.775
								E-W	0.024013	11:22:22.370
9	5/5/2014 5/5/2014	19:06:19 น. 12:06:19 UTC	5.1	19.70	99.62	5	อำเภอแม่สรวย จังหวัดเชียงราย	Vertical	0.035268	12:06:25.615
								N-S	-0.026977	12:06:26.035
								E-W	**-0.059189**	12:06:25.545
10	5/5/2014 5/5/2014	19:20:57 น. 12:20:57 UTC	5.2	19.86	99.68	-	อำเภอเมือง จังหวัดเชียงราย	Vertical	0.024966	12:20:20.950
								N-S	0.035148	12:20:20.925
								E-W	-0.046885	12:20:20.770
11	5/5/2014 5/5/2014	19:20:59 น. 12:20:59 UTC	5.1	19.78	99.74	-	อำเภอแม่ลาว จังหวัดเชียงราย	Vertical	-0.027308	12:21:05.355
								N-S	0.027586	12:21:05.170
								E-W	0.032721	12:21:05.265
12	5/5/2014 5/5/2014	19:25:05 น. 12:25:05 UTC	4.4	19.72	99.6	6	อำเภอแม่สรวย จังหวัดเชียงราย	Vertical	-0.009630	12:25:09.505
								N-S	0.013675	12:25:09.095
								E-W	-0.015384	12:25:09.480
13	5/5/2014 5/5/2014	19:40:09 น. 12:40:09 UTC	4	19.86	99.7	5	อำเภอเมือง จังหวัดเชียงราย	Vertical	0.004459	12:40:17.115
								N-S	0.003834	12:40:17.090
								E-W	0.007086	12:40:16.900
14	5/5/2014 5/5/2014	19:49:23 น. 12:49:23 UTC	4.2	19.72	99.71	8	อำเภอแม่ลาว จังหวัดเชียงราย	Vertical	0.025386	12:49:26.430
								N-S	-0.018200	12:49:28.815
								E-W	0.018100	12:49:26.665
15	5/5/2014 5/5/2014	20:04:45 น. 13:04:45 UTC	4.5	19.67	99.74	7	อำเภอพาน จังหวัดเชียงราย	Vertical	0.015621	13:04:49.775
								N-S	-0.013582	13:04:49.660
								E-W	-0.019103	13:04:49.720
16	5/5/2014 5/5/2014	20:18:02 น. 13:18:02 UTC	4.3	19.7	99.73	7	อำเภอพาน จังหวัดเชียงราย	Vertical	0.009553	13:18:08.880
								N-S	-0.011311	13:18:08.525
								E-W	-0.010990	13:18:08.795

หมายเหตุ: * เครื่องดับ

ตารางที่ 1 ค่าความเร่งพื้นดินสูงสุด ของแผ่นดินไหวหลัก ขนาด 6.3 และแผ่นดินไหวตาม ขนาด 5-6 และขนาด 4-5 (ต่อ)

ที่	วันที่	เวลา	ขนาด	ละติจูด	ลองจิจูด	ความลึก	บริเวณ	Component	PGA (g) ที่ สถานี MSAC (เขื่อนแม่สรวย)	เวลา (UTC)
17	5/5/2014 5/5/2014	20:34:29 น. 13:34:29 UTC	4.7	19.69	99.65	6	อาเภอพาน จังหวัดเชียงราย	Vertical N-S E-W	-0.020795 -0.023411 0.021037	13:34:33.650 13:34:33.450 13:34:33.645
18	5/5/2014 5/5/2014	21:26:52 น. 14:26:52 UTC	4.4	19.67	99.65	7	อาเภอพาน จงหวัดเชียงราย	Vertical N-S E-W	0.009300 -0.006469 0.009746	14:26:53.825 14:26:55.830 14:27:48.210
19	5/5/2014 5/5/2014	21:51:02 น. 14:51:02 UTC	4	19.83	99.59	6	อาเภอเมือง จังหวัดเชียงราย	Vertical N-S E-W	0.003857 -0.005495 -0.003424	14:51:08.015 14:51:08.205 14:51:08.305
20*	5/5/2014 5/5/2014	22:34:20 น. 15:34:20 UTC	4	19.7	99.63	6	อำเภอแม่สรวย จังหวัดเชียงราย	Vertical N-S E-W		
21*	5/5/2014 5/5/2014	23:03:06 น. 16:03:06 UTC	4	19.67	99.72	-	อำเภอพาน จงหวัดเชียงราย	Vertical N-S E-W		
22*	5/5/2014 5/5/2014	23:07:25 น. 16:07:25 UTC	4.5	19.6	99.62	-	อำเภอแม่สรวย จังหวัดเชียงราย	Vertical N-S E-W		
23*	5/5/2014 5/5/2014	23:20:17 น. 16:20:17 UTC	4.5	19.69	99.69	5	อำเภอพาน จังหวัดเชียงราย	Vertical N-S E-W		
24*	6/5/2014 5/5/2014	0:12:51 น. 17:12:51 UTC	4	19.68	99.57	6	อำเภอแม่สรวย จังหวัดเชียงราย	Vertical N-S E-W		
25*	6/5/2014 5/5/2014	0:35:28 น. 17:35:28 UTC	4.8	19.72	99.71	4	อำเภอแม่ลาว จังหวัดเชียงราย	Vertical N-S E-W		
26*	6/5/2014 5/5/2014	0:38:12 น. 17:38:12 UTC	4.1	19.78	99.62	2	อำเภอเมือง จังหวัดเชียงราย	Vertical N-S E-W		
27*	6/5/2014 5/5/2014	0:58:30 น. 17:58:30 UTC	4.1	19.66	99.64	14	อำเภอพาน จังหวัดเชียงราย	Vertical N-S E-W		
28*	6/5/2014 5/5/2014	1:02:33 น. 18:02:33 UTC	4.1	19.64	99.73	-	อำเภอพาน จังหวัดเชียงราย	Vertical N-S E-W		
29*	6/5/2014 5/5/2014	2:12:04 น. 19:12:04 UTC	4.7	19.82	99.71	6	อำเภอแม่ลาว จังหวัดเชียงราย	Vertical N-S E-W		
30*	6/5/2014 5/5/2014	3:05:25 น. 20:05:25 UTC	4.4	19.61	99.62	10	อำเภอแม่สรวย จังหวัดเชียงราย	Vertical N-S E-W		
31*	6/5/2014 5/5/2014	4:17:05 น. 21:17:05 UTC	5.1	19.65	99.66	23	อำเภอพาน จังหวัดเชียงราย	Vertical N-S E-W		
32*	6/5/2014 5/5/2014	5:10:56 น. 22:10:56 UTC	4.1	19.68	99.66	7	อำเภอพาน จังหวัดเชียงราย	Vertical N-S E-W		

หมายเหตุ: * เครื่องดับ

ตารางที่ 1 ค่าความเร่งพื้นดินสูงสุด ของแผ่นดินไหวหลัก ขนาด 6.3 และแผ่นดินไหวตาม ขนาด 5-6 และขนาด 4-5 (ต่อ)

ที่	วันที่ เวลา	ขนาด	ละติจูด	ลองจิจูด	ความลึก	บริเวณ	Component	PGA (g) ที่ สถานี MSAC (เขื่อนแม่สรวย)	เวลา (UTC)
33*	6/5/2014 6:04:55 น. 5/5/2014 23:04:55 UTC	5.2	19.70	99.62	7	อำเภอแม่สรวย จังหวัดเชียงราย	Vertical N-S E-W		
34*	6/5/2014 7:50:16 น. 6/5/2014 00:50:16 UTC	5.9	19.73	99.69	20	อำเภอแม่ลาว จังหวัดเชียงราย	Vertical N-S E-W		
35*	6/5/2014 7:58:19 น. 6/5/2014 00:58:19 UTC	5.6	19.70	99.53	2	อำเภอแม่สรวย จังหวัดเชียงราย	Vertical N-S E-W		
36*	6/5/2014 11:45:14 น. 6/5/2014 04:45:14 UTC	4.3	19.66	99.65	-	อำเภอพาน จังหวัดเชียงราย	Vertical N-S E-W		
37*	6/5/2014 16:20:35 น. 6/5/2014 09:20:35 UTC	4.2	19.77	99.64	-	อำเภอแม่ลาว จังหวัดเชียงราย	Vertical N-S E-W		
38*	6/5/2014 19:42:12 น. 6/5/2014 12:42:12 UTC	4.7	19.63	99.62	4	อำเภอพาน จังหวัดเชียงราย	Vertical N-S E-W		
39*	6/5/2014 20:47:01 น. 6/5/2014 13:47:01 UTC	4.7	19.75	99.7	6	อำเภอแม่ลาว จังหวัดเชียงราย	Vertical N-S E-W		
40*	6/5/2014 21:50:12 น. 6/5/2014 14:50:12 UTC	4.9	19.74	99.59	1	อำเภอแม่สรวย จังหวัดเชียงราย	Vertical N-S E-W		
41*	6/5/2014 22:57:32 น. 6/5/2014 15:57:32 UTC	4.6	19.67	99.67	9	อำเภอพาน จังหวัดเชียงราย	Vertical N-S E-W		
42*	7/5/2014 1:29:39 น. 6/5/2014 18:29:39 UTC	4.2	19.73	99.62	12	อำเภอแม่ลาว จังหวัดเชียงราย	Vertical N-S E-W		
43*	7/5/2014 3:52:26 น. 6/5/2014 20:52:26 UTC	4.8	19.7	99.59	7	อำเภอแม่สรวย จังหวัดเชียงราย	Vertical N-S E-W		
44	8/5/2014 1:37:35 น. 7/5/2014 18:37:35 UTC	4	19.64	99.62	7	อาเภอพาน จังหวัดเชียงราย	Vertical N-S E-W	0.008975 0.006552 0.011565	18:37:38.815 18:37:39.110 18:37:38.680
45	9/5/2014 3:43:38 น. 8/5/2014 20:43:38 UTC	4.7	19.69	99.63	2	อำเภอแม่สรวย จงหวัดเชียงราย	Vertical N-S E-W	0.03504 0.030308 **0.065275**	20:43:42.420 20:43:42.325 20:43:42.435
46	9/5/2014 9:48:24 น. 9/5/2014 02:48:24 UTC	4.1	19.64	99.74	5	อาเภอพาน จังหวัดเชียงราย	Vertical N-S E-W	0.007223 -0.008155 -0.009507	02:48:29.170 02:48:29.405 02:48:28.980
47	9/5/2014 14:12:31 น. 9/5/2014 07:12:31 UTC	4.7	19.62	99.57	7	อำเภอแม่สรวย จังหวัดเชียงราย	Vertical N-S E-W	**0.065254** **-0.113121** **-0.112382**	07:12:32.130 07:12:32.290 07:12:32.300
48	10/5/2014 12:56:47 น. 10/5/2014 05:56:47 UTC	4	19.65	99.58	2	อาเภอแม่สรวย จงหวัดเชียงราย	Vertical N-S E-W	-0.013294 0.018143 -0.023815	05:56:47.485 05:56:48.485 05:56:48.460

หมายเหตุ: * เครื่องดับ

ตารางที่ 1 ค่าความเร่งพื้นดินสูงสุด ของแผ่นดินไหวหลัก ขนาด 6.3 และแผ่นดินไหวตาม ขนาด 5-6 และขนาด 4-5 (ต่อ)

ที่	วันที่	เวลา	ขนาด	ละติจูด	ลองจิจูด	ความลึก	บริเวณ	Component	PGA (g) ที่ สถานี MSAC (เขื่อนแม่สรวย)	เวลา (UTC)
49	12/5/2014	9:47:27 น.	4	19.6	99.71	5	อาเภอพาน จังหวัดเชียงราย	Vertical	0.000663	02:27:31.910
	12/5/2014	02:47:27 UTC						N-S	0.000479	02:27:33.060
								E-W	0.000797	02:27:32.795
50	12/5/2014	18:05:29 น.	5	19.80	99.72	8	อำเภอแม่ลาว จงหวัดเชียงราย	Vertical	0.025988	11:05:36.350
	12/5/2014	11:05:29 UTC						N-S	0.016686	11:05:37.225
								E-W	0.043418	11:05:36.226
51	15/5/2014	0:23:57 น.	4.4	19.57	99.67	9	อาเภอพาน จังหวัดเชียงราย	Vertical	-0.015910	17:24:00.220
	14/5/2014	17:23:57 UTC						N-S	-0.015525	17:24:00.380
								E-W	0.019685	17:24:00.620
52	16/5/2014	11:31:34 น.	4.8	19.66	99.63	1	อาเภอพาน จงหวัดเชียงราย	Vertical	-0.017894	04:31:34.510
	16/5/2014	04:31:34 UTC						N-S	-0.015344	04:31:34.835
								E-W	0.016873	04:31:36.296
53	21/5/2014	17:19:49 น.	4.1	19.64	99.7	7	อาเภอพาน จังหวัดเชียงราย	Vertical	-0.002002	10:19:56.255
	21/5/2014	10:19:49 UTC						N-S	0.002418	10:19:55.865
								E-W	-0.002191	10:19:56.270
54	27/5/2014	19:22:16 น.	4.6	19.89	99.72	4	อาเภอเมือง จังหวัดเชียงราย	Vertical	-0.034109	12:22:23.110
	27/5/2014	12:22:16 UTC						N-S	-0.024143	12:22:23.160
								E-W	-0.030852	12:22:22.705
55*	26/6/2014	14:29:35 น.	4.5	19.71	99.67		อำเภอแม่ลาว จังหวัดเชียงราย	Vertical		
	26/6/2014	7:29:35 UTC						N-S		
								E-W		
56*	15/7/2014	20:30:53 น.	4.3	19.7	99.7		อำเภอพาน จังหวัดเชียงราย	Vertical		
	15/7/2014	13:30:53 UTC						N-S		
								E-W		
57	16/8/2014	14:03:18 น.	3.8	19.69	19.6		อำเภอแม่สรวย จังหวัดเชียงราย	Vertical	-0.066798	07:03:20.335
	16/8/2014	07:03:18 UTC						N-S	0.027879	07:03:20.415
								E-W	0.140529	07:03:20.375
58	16/8/2014	15:25:25 น.	4.1	19.68	99.61		อำเภอแม่สรวย จังหวัดเชียงราย	Vertical	0.059734	08:25:26.100
	16/8/2014	08:25:25 UTC						N-S	-0.053289	08:25:26.140
								E-W	-0.128819	08:25:26.040
59	25/8/2014	05:32:45 น.	4.8	19.71	99.55		อำเภอแม่สรวย จังหวัดเชียงราย	Vertical	0.147961	22:32:47.340
	24/8/2014	22:32:45 UTC						N-S	0.216523	22:32:47.340
								E-W	-0.212339	22:32:47.865

หมายเหตุ: * เครื่องดับ

3. สรุป

จากการศึกษาค่าพารามิเตอร์ของการสั่นไหวที่รุนแรงของแผ่นดินไหวหลักขนาด 6.3 พบว่าค่าความเร่งพื้นดินสูงสุด มีค่ามากที่สุดในแนวตะวันออก-ตะวันตก เท่ากับ 0.329356 g แต่เป็นค่า ณ เวลา 11:08:51.820 UTC เท่านั้น ค่าความเร็วพื้นดินสูงสุด เท่ากับ 24 เซนติเมตร/วินาที ณ เวลา 11:08:51.8 UTC เช่นเดียวกัน ระยะเวลาของการสั่นไหวที่รุนแรงที่มีค่าเกิน 0.05 g เท่ากับ 7 วินาที ช่วงค่าความถี่จากการสั่นไหวที่รุนแรง มีค่ามากที่สุดที่ความถี่ 2.5 เฮิรตซ์ และจากการศึกษาค่าพารามิเตอร์ของการสั่นไหวที่รุนแรงของแผ่นดินไหวตาม ขนาด 5-6 และขนาด 4-5 สามารถสรุปได้ว่าแผ่นดินไหวที่จะมีผลกระทบต่อเขื่อนแม่สรวย เมื่อพิจารณาจากค่าความเร่งพื้นดินสูงสุดที่มากกว่า 0.05 g ระยะเวลาของการสั่นไหว และช่วงค่าความถี่จากการสั่นไหวที่รุนแรง คือ แผ่นดินไหวที่มีขนาดตั้งแต่ 4 ตามมาตราริกเตอร์ ขึ้นไป และต้องมีจุดศูนย์กลางอยู่ห่างจากที่ตั้งเขื่อนแม่สรวยไม่เกิน 10 กิโลเมตร เนื่องจากว่ามีการเปลี่ยนแปลงค่าของข้อมูลที่ได้จากเครื่องมือตรวจวัดพฤติกรรมเขื่อน จากการตรวจสอบเขื่อนแม่สรวยภายหลังการเกิดแผ่นดินไหวทางกายภาพด้วยสายตา ไม่พบว่าเขื่อนได้รับความเสียหายที่รุนแรงจากแผ่นดินไหว ซึ่งอาจมีความเป็นไปได้ว่าเนื่องจากเขื่อนแม่สรวยได้รับการออกแบบเพื่อต้านทานแรงกระทำของแผ่นดินไหว ด้วยวิธี pseudo static ค่าสัมประสิทธิ์ของการสั่นสะเทือน เท่ากับ 0.10 และเขื่อนแม่สรวยตั้งอยู่บนสภาพธรณีวิทยาฐานรากที่เป็นหินยุคไซลูเลียน-ดีโวเนียน ซึ่งในทางธรณีวิทยาจัดเป็นพื้นที่ที่ค่อนข้างเสถียรมาก

ระยะเวลาการสั่นไหวของพื้นดินที่รุนแรง ค่อนข้างสั้นกว่าเมื่อเปรียบเทียบกับบริเวณที่เป็นที่ตั้งของชุมชนที่อยู่ทางด้านท้ายน้ำของเขื่อนแม่สรวยและชุมชนที่ตั้งอยู่ตามที่ราบลุ่มน้ำแม่ลาว ซึ่งส่วนใหญ่เป็นตะกอนดินยุคปัจจุบันที่ยังไม่แข็งตัว ทำให้บริเวณที่เป็นที่ตั้งของชุมชนได้รับความเสียหายมากทั้งจากแผ่นดินไหวหลัก และแผ่นดินไหวตาม เนื่องจากถูกสั่นไหวอย่างต่อเนื่องและยาวนานกว่า ประการสุดท้ายที่สำคัญ คือ ค่าความถี่ธรรมชาติในการสั่นไหวของเขื่อนแม่สรวยอาจจะไม่สอดคล้องกับค่าความถี่จากการสั่นไหวที่รุนแรงของแผ่นดินไหว ซึ่งต้องมีการศึกษาอย่างละเอียดอีกครั้งหนึ่ง แต่เพื่อสร้างความเชื่อมั่นในเรื่องความปลอดภัย เพื่อคืนความสุขให้กับราษฎรหรือชุมชนที่อยู่บริเวณท้ายเขื่อนแม่สรวย และเพื่อเพิ่มประสิทธิภาพในการศึกษาวิเคราะห์ผลกระทบของแผ่นดินไหวที่มีต่อเขื่อนแม่สรวยให้ดียิ่งขึ้น จึงได้เสนอให้มีการติดตั้งเครื่องมือตรวจวัดความเร่งพื้นดินเพิ่มเติม บริเวณตีนเขื่อนแม่สรวย อีก 2 ชุด คือ บนฐานรากที่เป็นหิน 1 ชุด และฐานรากที่เป็นดิน 1 ชุด เนื่องจากค่าความเร่งพื้นดินที่ตรวจวัดได้จาก สถานี MSAC อาจเป็นค่าที่มีการขยายไปจากความเป็นจริง ประมาณ 1-3 เท่า อันเป็นผลเนื่องมาจากสภาพภูมิประเทศบริเวณที่ตั้งเครื่องมือตรวจวัด ซึ่งตั้งอยู่บนสันเขื่อนแม่สรวยที่สูงประมาณ 59 เมตร

กิตติกรรมประกาศ

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เอกสารอ้างอิง

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VITA

Mrs. Watana Khamkom was born on January 13, 1962 in Buriram, northeastern Thailand. She studied at Baan Krasang primary school from grade one to grade seven, and graduated at high school level from Burirampittayakom school, Buriram, in 1980. In 1984, she received a B.Sc. degree in Geology from the Department of Geology, Faculty of Science, Khon Kaen University, Thailand. After her graduation, she started to work as a research assistant at the Department of Geology, Faculty of Science, Khon Kaen University, Thailand. From 1987 to 1989, she worked as a government employee at the Regional Irrigation Office 4 (former), Khon Kaen. Hereafter, she has moved to work as a government official at the Engineering Geology Group, Geotechnical Division, the Royal Irrigation Department and has been employed until present at the Engineering Geology Division, Office of Engineering Topographical and Geotechnical Survey. She enrolled as a graduate student of Geology program at Graduate School, Chulalongkorn University, Bangkok, Thailand in 2006 and again in 2010.