CHAPTER II
GROUND MOTION RECORDS

One of the most vital stages in the derivation or selection of attenuation model for a certain region is the choice of earthquake records to include in the analysis. The manner in which strong motion records are collated for this study is described in subsequent sections.

2.1 Seismic Network in Thailand

The seismic monitoring system in Thailand commenced when U.S. Geological Survey installed two World Wide Standardized Seismographic Network (WWSSN) seismographs at Chiang Mai and Songkhla in March 1963 and October 1965 respectively. Afterwhich, Thai Meteorological Department (TMD) has expanded the network by setting up analog and digital seismic stations. The analog stations are equipped with short period vertical component seismographs. On the other hand, the digital stations make use of three-component short period (SP) seismometers (L-4C3D Mark Products) as well as three-component broadband (BB) seismometers (Guralp CMG-40T). Furthermore, another station in Chiang Mai under the Global Seismic Network (GSN) system of Incorporated Research Institutions for Seismology (IRIS) is capable of data transmission in real time basis. The TMD digital seismic stations have been in operation since 1998. The recorded seismic data from eight of the digital acquisition systems produced by Refraction Technology Inc. (Reftek 72A-08) is transmitted to the central office in Bangkok through VSAT as shown in Figure 2.1. Tables 2.1 and 2.2 provide a summary of the description of TMD's digital seismic stations and instruments. Other agencies that operate seismic stations in Thailand include Electricity Generating Authority of Thailand (EGAT) and Naval Hydrographic Department (NHD) (Saringkarnphasit *et al.*, 2006).

Table 2.1 Description of TMD's seismic instruments

Instruments	Sensor	Gain	Sensitivity (volt/(m/s))	Digitizer Reftek 72A-08 (volt/count)
Seismometer (SP)	L-4C3D	32	171	$1.907x10^{-6}$
Seismometer (BB)	CMG-40T	1	800	$1.907x10^{-6}$
Accelerograph	SSA-320	1	-	$4.477x10^{-7}$

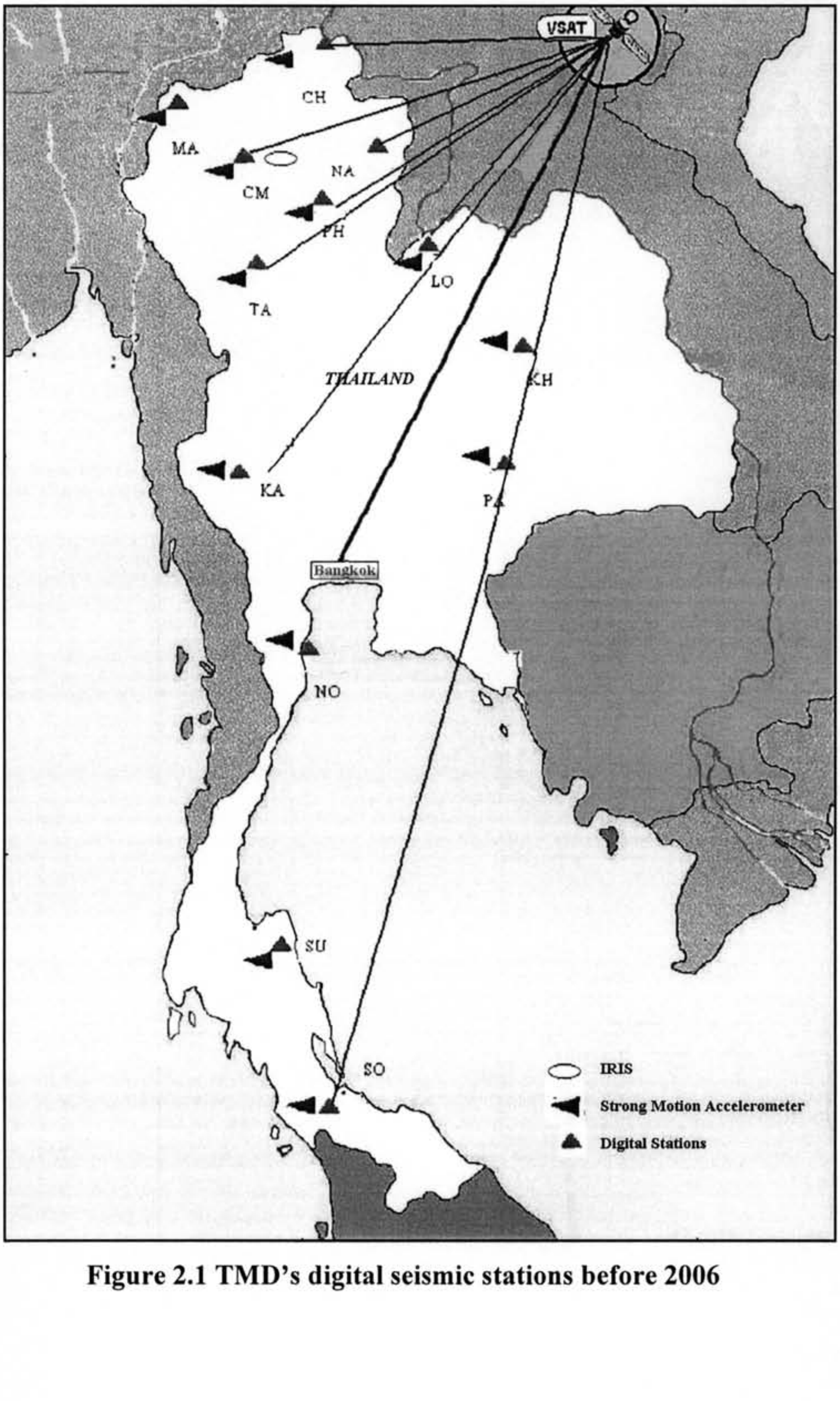

Figure 2.1 TMD's digital seismic stations before 2006

Table 2.2 TMD's digital seismic stations before 2006

Code	Station	Latitude (N°)	Longitude (E°)	Type of Sensors	Period of Operation
CHTO	Chiangmai	18.49	98.57	IRIS	March 1963
CM	Chiangmai*	18.49	98.57	L-4C3D, SSA-320	1994
CH	Chiangrai*	19.88	99.77	L-4C3D, SSA-320	May 1998
KA	Kanchanaburi*	14.39	99.12	CMG-40T, SSA-320	May 1998
KH	Khonkaen	16.34	102.82	CMG-40T, SSA-320	May, 1978-2002
LO	Loei*	17.41	101.73	L-4C3D, SSA-320	May 1998
MA	Maehongson	19.27	97.97	L-4C3D, SSA-320	May 1978-2002
NA	Nan*	18.8	100.7	L-4C3D, SSA-320	1994
NO	Nong Plub	12.59	99.73	L-4C3D, SSA-320	May 1978-2002
PA	Pakchong	14.64	101.32	L-4C3D, SSA-320	May 1978-2002
PH	Phrae*	18.50	100.23	CMG-40T, SSA-320	May 1998
SO	Songkhla*	7.18	100.62	CMG-40T, SSA-320	May 1998
SU	Surathani	9.14	99.63	L-4C3D, SSA-320	May 1978-2002
TA	Tak*	17.24	99.00	L-4C3D, SSA-320	May 1998

* VSAT Transmission

The calibration factors for the velocity and acceleration monitoring systems are represented by Equations 2.1 and 2.2, respectively.

$$V = \frac{C \text{ x } CF \text{ x } 100}{Gain \text{ x } G} \quad (2.1)$$

where

V = ground velocity in cm/sec;

C = amplitude in counts;

CF = A/D conversion factor in volt/count = $1.907 \text{x} 10^{-6}$;

Gain = pre-amplification gain which is equals to 1 for broadband (BB) and 32 for short-period (SP) instruments; and

G = sensor sensitivity in volt/(m/sec) (BB=800; SP=171).

$$Acc = \frac{C \text{ x } CF}{Gain \text{ x } G} \quad (2.2)$$

where

Acc = ground acceleration in cm/sec^2;

C = amplitude in counts;

CF = A/D conversion factor in volt/count = $4.477x10^{-7}$; and

Gain x G = 2.5 volt/(980 cm/sec^2).

The occurrence of tsunami on 26th of December, 2004 has led TMD to continuously expand and improve the seismic monitoring system of the country. Fifteen new digital stations have been installed in 2006. The new seismic network consists of 8 short period seismometers and 7 broadband seismometers. Atlas version 1.2 is used to estimate the epicenter of the earthquake as well as to store the recorded seismograms. The navigation interface of this software allows the user to view multiple events at the same time as shown in Figure 2.2.

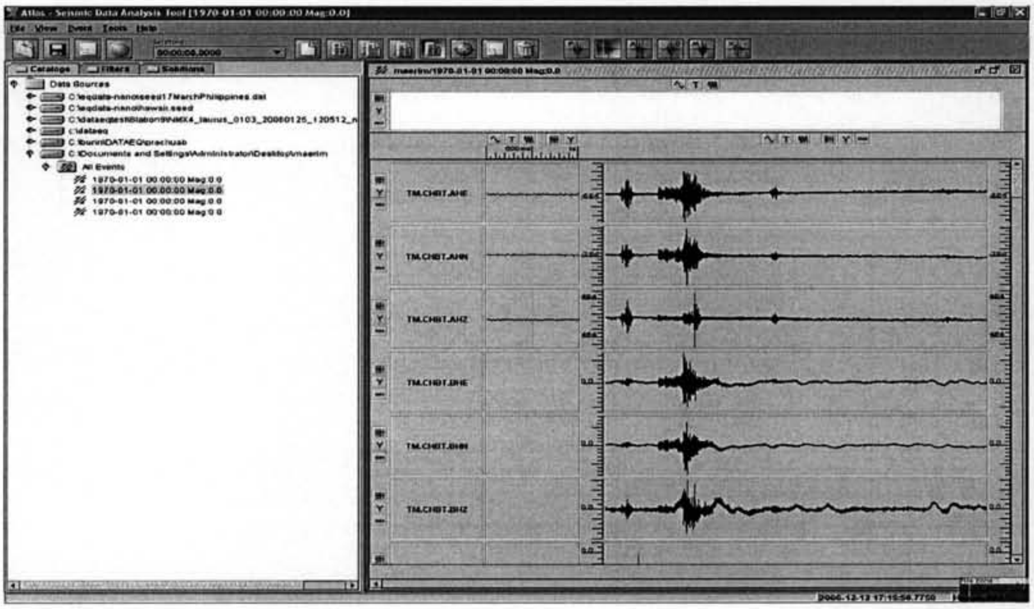

Figure 2.2 Atlas' navigation interface

The new seismic network started its operation in October of 2006. Through internet and satellites, real time data are transmitted to the central office in Bangkok. Both short-period and broadband stations are equipped with Taurus data acquisition system. Moreover, tri-axial seismic accelerometers (Nanometrics TSA100S) are also installed at all these stations. A list of the newly installed digital seismic stations is summarized in Table 2.3. Figure 2.3 shows the distribution of these stations all over the country.

Equations 2.3, 2.4a and 2.4b specify the digitizer and sensor sensitivities for acceleration and velocity monitoring systems, respectively.

For acceleration monitoring system:

System sensitivity (Taurus+TSA100S) = (8,388,608 count/20volt) x (0.51 volt/(m/s^2))

$$= 213{,}909.504 \text{ count/(m/s}^2\text{)} \quad (2.3)$$

For velocity monitoring system:

System sensitivity (Taurus + Trillium40)= (8,388,608 count/8volt) x (1500 volt/(m/s))

$$= 1.572864 \times 10^9 \text{ count/(m/s)} \quad (2.4a)$$

System sensitivity(Taurus+Trillium120)=(8,388,608 count/20volt) x (1200 volt/(m/s))

$$= 503{,}316{,}480 \text{ count/(m/s)} \quad (2.4b)$$

Table 2.3 TMD's new digital seismic stations (in operation since 2006)

Code	**Station**	**Latitude (N°)**	**Longitude (E°)**	**Elevation (m)**
Short-period seismic stations (Nanometrics Trillium 40)				
KHLT	Khao Laem Dam	14.7970	98.5893	164
MHMT	Maesariang	18.1764	97.9310	164
KRDT	Nakonrachasima	14.5905	101.8442	266
PKDT	Phuket	7.8920	98.3350	53
RNTT	Ranong	9.3904	98.4778	38
SKNT	Sakonnakorn	16.9742	103.9815	254
SURT	Surathani	8.6582	98.4098	20
TRTT	Trang	7.8362	99.6912	71
Broadband seismic stations (Nanometrics Trillium 120)				
CHBT	Chantaburi	12.7526	102.3297	4
CMMT	Chiangmai	18.8128	98.9476	400
SRDT	Kanchanaburi	14.3945	99.1212	122
MHTT	Maehongson	19.3148	97.9632	270
PBKT	Petchaboon	16.5733	100.9687	8
SKLT	Songkhla	7.1735	100.6188	145
UBDT	Ubolrachatani	15.2773	105.4695	120

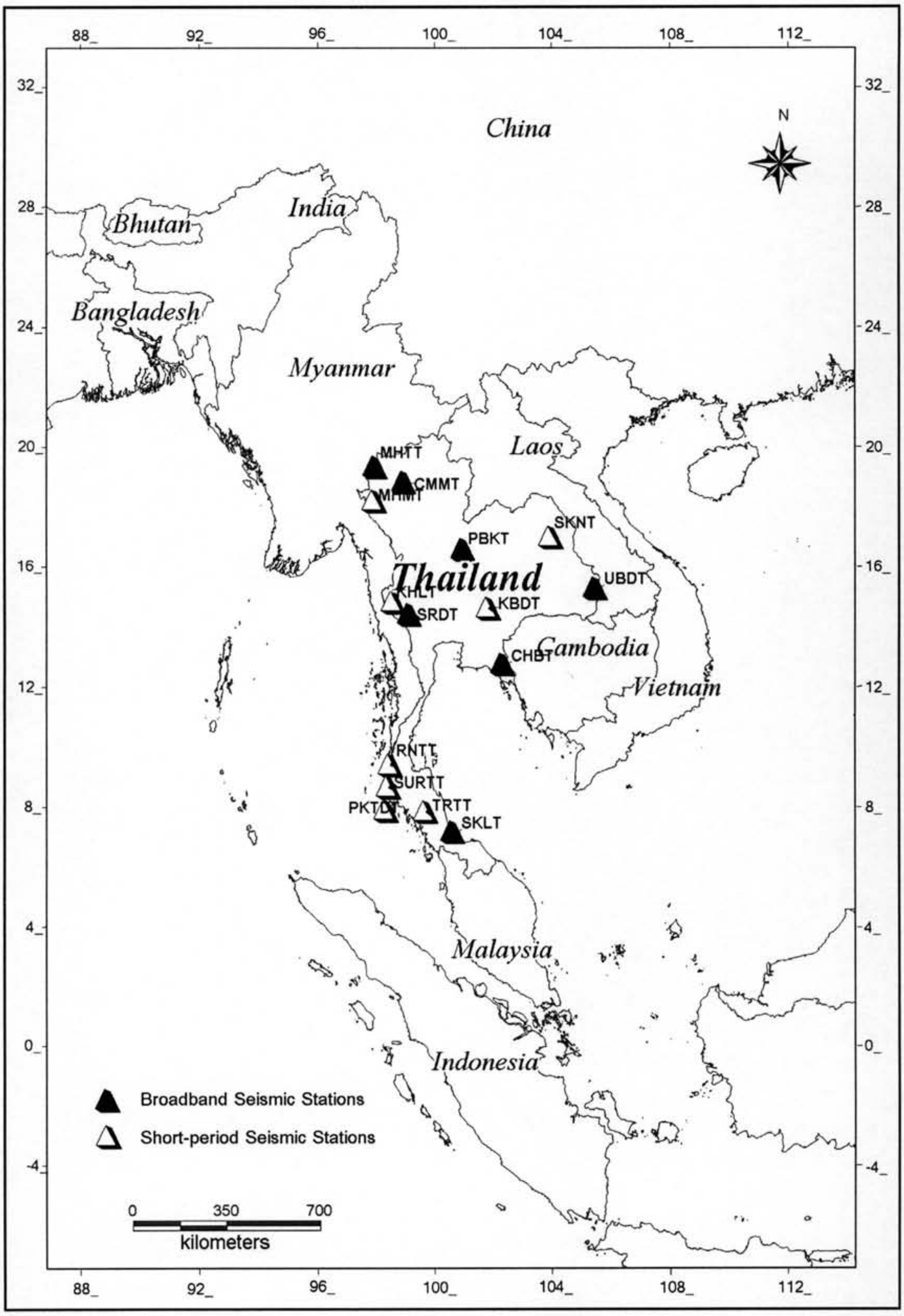

Figure 2.3 TMD's new digital seismic stations (2006 system)

To enhance ability in detecting earthquakes, a budget has been allotted to continuously upgrade and increase the number of seismic stations. From 2006 to 2008, more digital seismic stations will be added to the current network. This upgrade includes 25 seismic stations with 10 broadband and 15 short period instruments, 20 acceleration stations, 4 Global Positioning System (GPS) stations, 9 tide gauge stations and two borehole stations. The latter will consists of accelerometer and broadband instruments installed to study site amplification of soft soil underneath Bangkok. VSAT, IPSTAR and ADSL telecommunications will be used to transmit seismic data recorded from the stations to Bangkok (Saringkarnphasit and Prachuab, 2006).

2.2 Data Processing and Conversion

Ground motion records in this study are principally based on TMD's earthquake catalog (1912-2002), TMD's list of selected earthquakes (1912-2006), TMD's ground motion time histories (2000-2006) and Harvard Central Moment Tensor (CMT) catalog (2000-2006). TMD's catalog is a compilation of earthquake events in Thailand and adjacent areas. It contains information about epicenter, magnitude, focal depth and time of earthquake given in Coordinated Universal Time (UTC). It also incorporates information from other network sources such as International Seismological Centre (ISC), Institute of Physics of the Earth, Moscow, Russia (MOS), United States Geological Survey (USGS), Peking, China (PEK), Norsar, Norway (NAO) and State Seismological Bureau, Beijing, China (BJI). A partial listing of earthquake events that have been felt in Thailand is also provided by TMD. On the other hand, ground motion time histories include the actual earthquake records measured by eight of the TMD's digital seismic stations before the 2006 system.

In order to maximize the use of available TMD time history records, events listed in Harvard CMT Catalog (also known as Global CMT database) are also considered. The Harvard Catalog is preferable because it provides the moment magnitude (M_w) which is the magnitude scale adopted in this study. Since most of the earthquakes felt in Thailand occurred along the boundaries of the neighboring countries, the scope of events considered in this study is widened to cover such areas where earthquakes are prevalent. By considering this catalog, a set of events at higher magnitudes large enough to affect Bangkok is taken into account.

The interface of Harvard CMT database, which is available online, is shown in Figure 2.4. The location constraints specified in the Harvard's search form include coordinates ranging from latitudes -8° to 32° N and longitudes 90° to 108° E within M_w ranging from 3.5 to 9.5. Based on these particular search fields, 1,104 events from 2000 to 2006 have been downloaded.

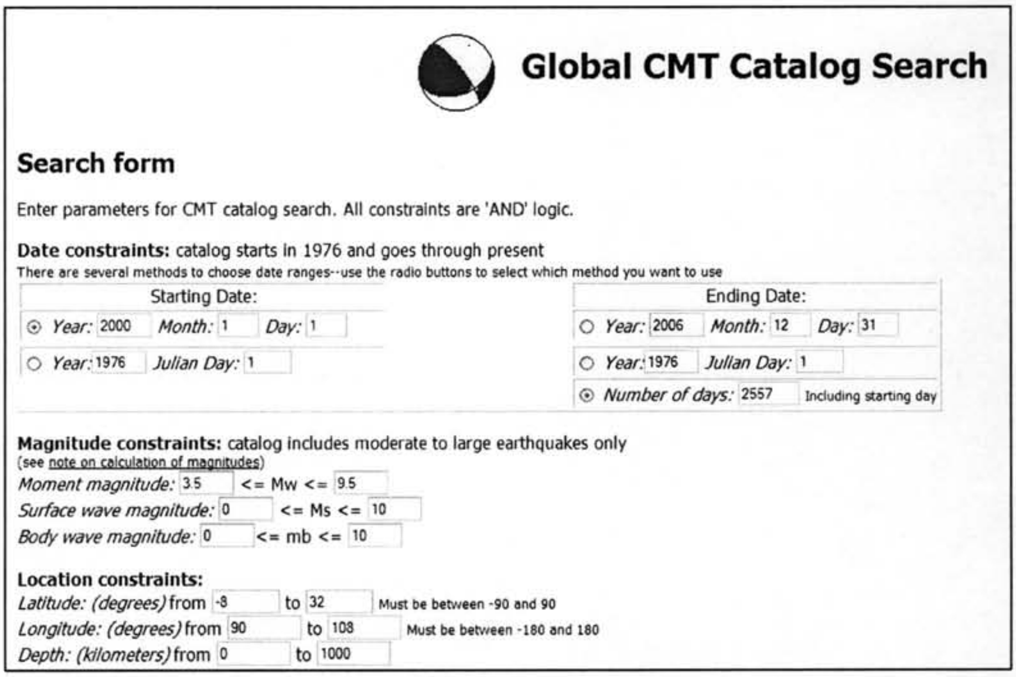

Figure 2.4 Harvard CMT earthquake catalog interface

Events listed in TMD's earthquake catalog as well as in partial listing are accounted for to include local earthquakes. Although TMD's earthquake catalog includes events determined by other agencies, this study considers only events that were calculated by TMD's central office (denoted by BKK in the catalog). A total of 326 entries are obtained. The final data set is a combination of Harvard and TMD's earthquake catalogs containing 1,377 earthquake events that transpired during 2000 to 2006 of which 53 events are common to both catalogs.

Each velocity time history recording is then evaluated individually through the usable bandwidth. The corresponding acceleration and displacement time histories are estimated by applying numerical differentiation using Central Difference method and numerical integration using Trapezoidal Rule respectively. Then, the bandpass filter was applied. These are incorporated in a Matlab program.

The routine in the program involves filtering of the combined catalog list by comparing the date and time of the event with the date and time of the recording as abovementioned. The program creates a folder for each event containing the raw data recorded from the seismic station, the converted text file of the raw data and the time-history plots of acceleration, velocity and displacement. Other text files placed outside of the event folder are also generated which basically provide a summary of all events that occurred within the duration of recorded time-histories with information about the duration of the recording, peak values of time-history plots, filename of raw data and event reference number.

The filtered time-history is plotted to check if values are realistic as shown in Figure 2.5. Through these plots, it is ensured that the time of the event occurred within the duration of recording. Also, each plot was checked such that the event occurred prior to the peak values in the time-history to make certain that an event is correctly paired to the available time-history records. The peak values for acceleration, velocity and distance time histories are encircled. The three directions, in which seismic waves propagate, such as East-West (EW) and North-South (NS) for horizontal directions and another for vertical (Z) direction, are also shown in the figure. A sample of the converted text file of raw data in the two-column format is shown in Figure 2.6.

Out of 1,377 events from the combined catalogs, only 430 events have corresponding time histories. From TMD's database, 557 time history records match the aforementioned criteria. The programs developed for data processing and conversion are available in the Appendix A.

- **November 19, 2005 Event (2:10:18pm UTC)**
  M_w=6.3
  Filename: 437F2FD9.SO2

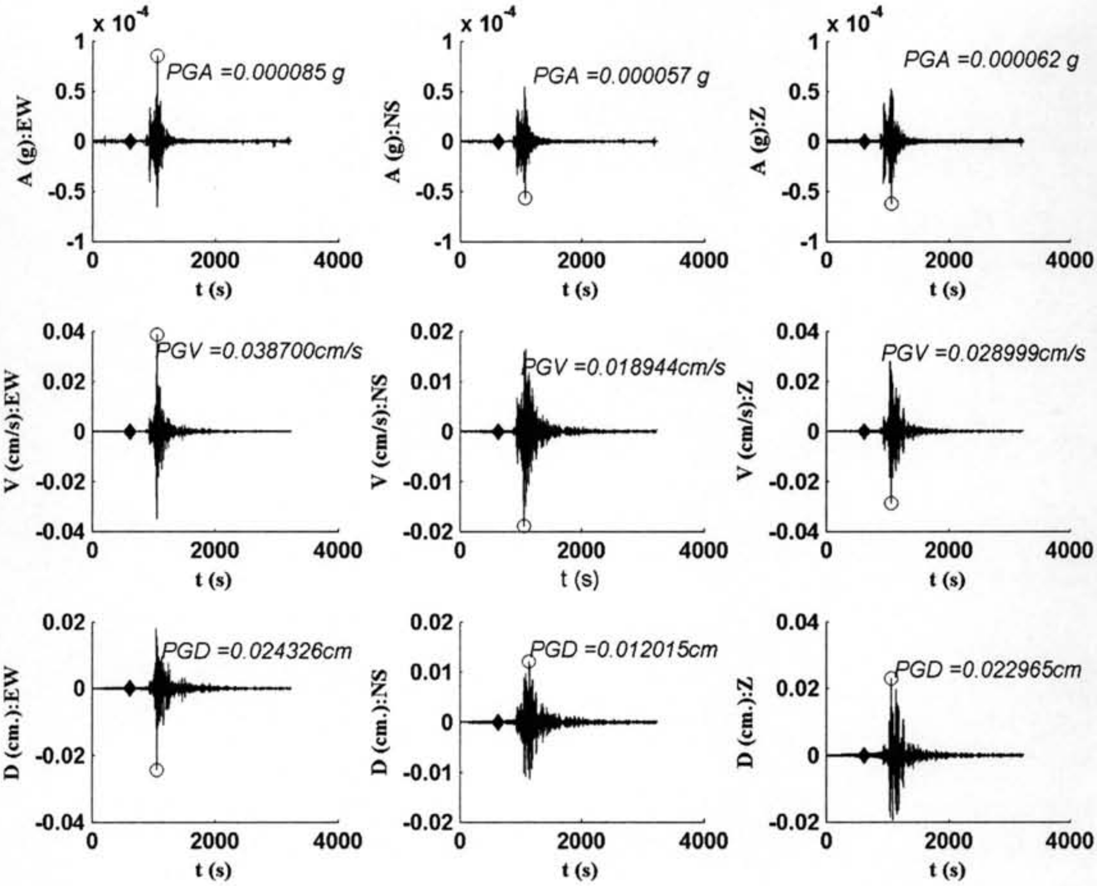

Figure 2.5 Acceleration, velocity and displacement time histories for ground motions recorded at Songkhla station

For the purpose of classifying the dataset whether events are mainshock, aftershock or foreshock, Gardner and Knopoff's (1974) window algorithm is incorporated in a program. In the algorithm, a computational routine is recommended by interpolating a set of values including duration *T*, magnitude *M* and distance *L* taken from selected Southern California earthquakes.

Based on linear interpolation in logarithmic values of L and T, the entire catalog is scanned using the spatial and temporal criteria specified in Equations 2.5, 2.6a and 2.6b. Equation 2.5 determines the extent of the aftershock zone by utilizing the magnitude-length data from the fault traces observations of Southern California earthquakes. On the other hand, equations 2.6a and 2.6b represent the time lapse after the mainshock that aftershocks may occur.

Using the above criteria, the 430 events are classified as 85 mainshocks, 317 aftershocks and 28 foreshocks, and there are 117, 404, and 36 records corresponding to each group respectively. Regardless of these three types of events, all event types are considered in the assessment of attenuation models.

$$\log L=0.124M+0.983 \qquad (2.5)$$

$$\log T=0.662M+2.511 \qquad \text{for } M > 6.4 \qquad (2.6a)$$

$$\log T=0.556M-0.603 \qquad \text{for } M \leq 6.4 \qquad (2.6b)$$

```
;SUD2ASC - Version 2.60
;Input file:  C:\!!!TOB~1\2005\1249\437F2FD9.SO2
;Output file: C:\!!!TOB~1\2005\1249\437F2FD9.TXT
;Converted @  03/01/07 01:11:26.380
;Dateform:    Month/Day
;No Data:     FALSE

$ 5 0 ; StationComp structure
unk                          ; network
SO24                         ; station name
_                            ; component
0                            ; instrument type
-32767                       ; component azimuth
-32767                       ; component incidence
-32767.000000                ; latitude
-32767.000000                ; longitude
-32767.000000                ; elevation, meters
_                            ; enclosure
0                            ; annotated comment
r                            ; recorder type
_                            ; rock class
0                            ; rock type
-                            ; site condition
_                            ; sensor type
2                            ; data type
d                            ; data units
n                            ; polarity
0                            ; status
8192.000000                  ; maximum gain
8388607.000000               ; clipping value
0.001907                     ; conversion to mvolts
4                            ; channel
1                            ; atod gain
11/19/05 13:59:53.000000     ; effective date
+0.000000                    ; clock correction
+0.000000                    ; station delay

$ 31 0 ; Instrument structure
unk                          ; network
SO24                         ; station name
_                            ; component
0                            ; instrument type
938                          ; inst. serial number
-32767                       ; number of components
4                            ; channel number
_                            ; sensor type
2                            ; data type
-8388608                     ; void sample value
524288.000000                ; digitizing constant
20.000000                    ; AAF corner freq. (Hz)
41.666599                    ; AAF poles
-32767.000000                ; trans natural freq. (Hz)
-32767.000000                ; trans damping coeff.
-32767.000000                ; trans motion constant
0.000000                     ; amplifier gain (dB)
-32767.000000                ; local X coord. (meters)
-32767.000000                ; local Y coord. (meters)
-32767.000000                ; local Z coord. (meters)
11/19/05 13:59:53.000000     ; effective time
0.000000                     ; pre-event memory (secs)
1043                         ; trigger number
                             ; study ID
-32767                       ; sensor serial number

$ 7 646384 ; DescripTrace structure
unk                          ; network
SO24                         ; station name
_                            ; component
0                            ; instrument type
11/19/05 13:59:53.305000     ; initial sample time
-32767                       ; local time diff
2                            ; data type
_                            ; data descriptor
0                            ; digitized by
0                            ; processed by
161596                       ; number of samples
50.000000                    ; samples per second
-8388607.000000              ; minimum data value
8388607.000000               ; maximum data value
0.000000                     ; average noise
-32767                       ; num clipped samples
+0.000000                    ; time correction
+0.000000                    ; rate correction
```

Figure 2.6 Sample of converted raw ASCII data

2.3 Characterization of Source, Path and Site Conditions

The process on how the data is converted produced a database that is limited to PGA, moment magnitude, site-to-source distance and site category. These parameters are assumed to sufficiently characterize the source, path and site conditions of selected earthquake events. In the process, data was filtered the best way possible to come up with a listing that covers adequate range of magnitude and distance. No distinction of the focal mechanism type is made since the available information of the selected recordings is not adequate to carry out this particular evaluation.

2.3.1 Peak Ground Acceleration (PGA)

Geometric mean of PGA in two horizontal components are calculated for each ground motion as most of the attenuation models selected for this study employed this definition for ground motion estimation. The conversion factor of the instruments is taken into account to obtain ground velocity from digital count depending on the type of sensor and monitoring system used at each station. Acceleration is obtained by numerically differentiating velocity.

In the first data set, only the recordings from the velocity monitoring system of the digital stations before the 2006 system are utilized since it covers a wider range of period providing more time-history records of digital instruments. The second data set consists of recordings from the acceleration monitoring system installed in 2006 and is presented in detail in Sections 2.5.

2.3.2 Magnitude

Moment magnitude (M_w) is used to define the size of earthquake in this study. M_w is directly associated to the ruptured fault area and average slip, unlike other magnitude scales which are based on the measurement of the amplitude of the seismic wave at different periods. Since M_w prevents saturation at large seismic moments, hence, it is considered as a better representation of the true earthquake size (Idriss and Archuleta, 2005). Furthermore, M_w is the preferred magnitude type for this study since most of the candidate attenuation models use this scale.

As mentioned earlier, the listing of earthquake events from 2000 to 2006 is summarized using the information from TMD and downloaded data from Harvard's Catalog. The latter is selected from many other available catalogs because it provides moment magnitude (M_w) of earthquake events. In the case that a certain event listed in TMD is not included in Harvard's Catalog, the local magnitude (M_L) of TMD is used instead with the assumption that M_L is equivalent to M_w up to M=6.

This assumption is based on the correlation of magnitude scales with M_w presented by Heaton *et al.* in 1982 and cited by Idriss and Archuleta in 2005. It is depicted in Figure 2.7.

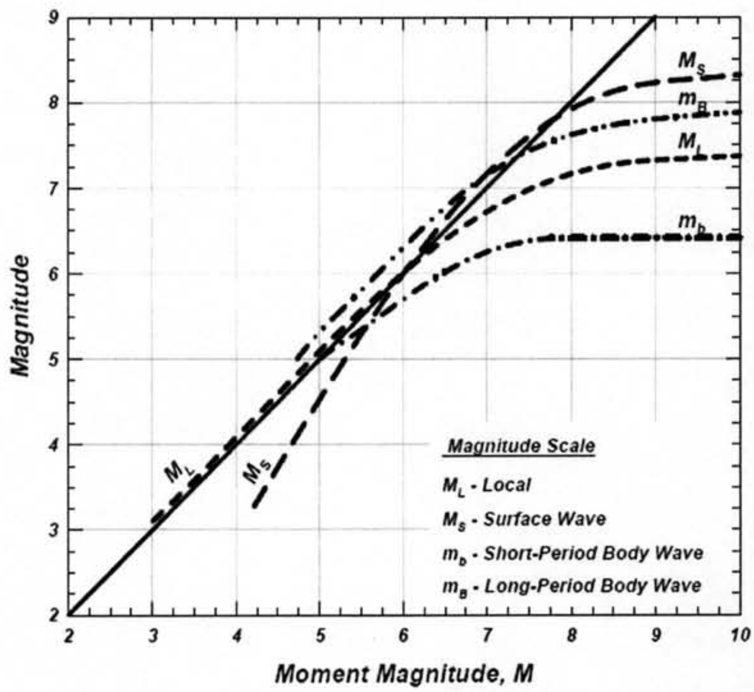

Figure 2.7 Relationship between moment magnitude and various magnitude scales (cited in Idriss and Archuleta, 2005)

To further support this assumption, the 53 earthquake events common to Harvard and TMD catalogs are summarized to compare how well M_L determined by TMD corresponds to M_w from Harvard's Catalog. Figure 2.8 illustrates that although slight deviation from the linear relationship exists for some data points, in general, TMD's M_L is approximately equal to Harvard's M_w. To this end, TMD's M_L is regarded as a good estimate of M_w for those events not listed in Harvard Catalog.

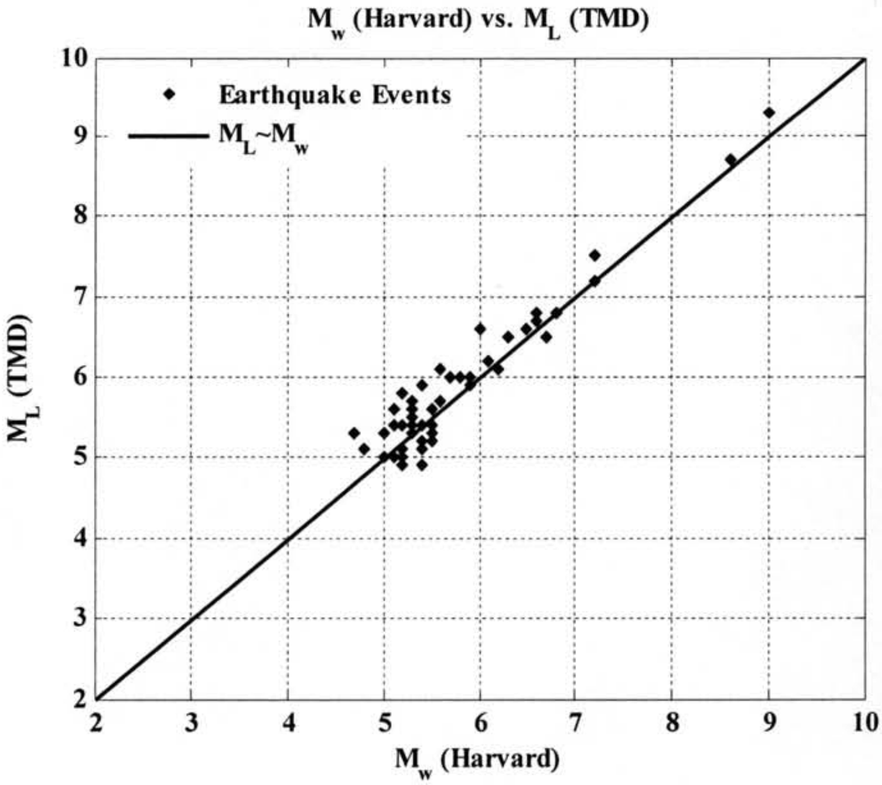

Figure 2.8 Relationship between Harvard's M_w and TMD's M_L

2.3.3 Site-to-Source Distance

The definition of distance applied in this study is the horizontal distance between the epicenter of the earthquake and the site of the recording instrument. Since most of the earthquake events in the data set consist of long-distance events, the difference among other several distance definitions would not be significant. Hence, epicentral distance is utilized. In addition, there is no available information with regards to other distance definitions. Also, computations using assumed values for focal depth or using empirical formulas could be a source of uncertainty.

The site-to-source distance is computed for each event using the great circle distance formula represented by Equation 2.7.

$$d = \left\{\cos^{-1}\left[\sin(A)\sin(B)+\cos(A)\cos(B)\cos(|\Delta_{long}|)\right]\right\}*111.23 \qquad (2.7)$$

where

d = site-to-source distance in km;

A = $Station_{Latitude}*(\pi/180)$;

B = $Epicenter_{Latitude}*(\pi/180)$;

Δ_{long} = $(Station_{Longitude} - Epicenter_{Longitude})*(\pi/180)$; and

111.23 km = 1° at the equator.

To check the computed values of site-to-source distances for every earthquake event, the software MapInfo Professional is used to plot the epicenters of the earthquake events together with TMD's seismic stations. Using the feature of this software, site-to-source distance is computed by drawing a line from the epicenter of the event under consideration to the recording station. Through this procedure, site-to-source distances computed using Equation 2.7 and the distance measured from the generated map shown in Figure 2.9 are found to be equal.

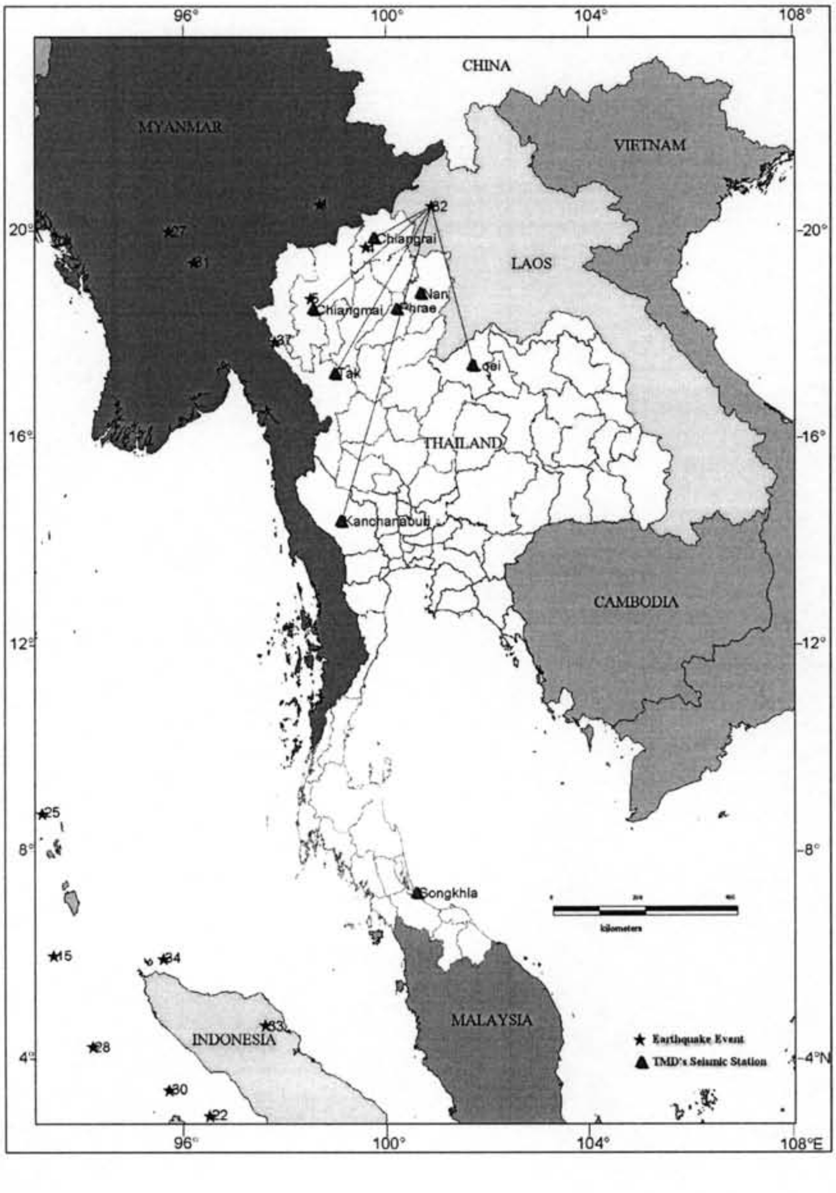

Figure 2.9 Site-to-source distance checking

2.3.4 Site Category

Seismic stations operated by TMD are categorized into rock and soil site classes. Due to time and financial constraints, seismic stations are not evaluated in an in depth manner through site investigations or borehole logs. However, valuable descriptions regarding seismic stations have been obtained which include available borehole logs taken within the vicinity of the site, geological map published by DMR and soil profiles from EGAT. These are the best available data used in order to describe the sites where the seismic stations are located up to a level of detail required in the analysis.

Borehole measurements nearest to the recording sites are obtained from the website of the Department of Public Woks and Town and Country Planning, Interior Ministry for five TMD seismic stations at Loei, Chiang Rai, Songkhla, Phrae and Nan. Using these borehole logs, shear wave velocities (V_s) in each layer are estimated by empirical equations correlating N-values of standard penetration test (SPT) to V_s. The correlations utilized to estimate V_s in m/s for sand layer are

Dickenson (1994) : $V_s = 88.392(N+1)^{0.3}$ (2.8a)

Seed, Idriss and Arango (1983) : $V_s = 56.388N^{0.5}$ (2.8b)

Sykora and Stokoe (1983) : $V_s = 100.584N^{0.29}$ (2.8c)

To approximate the velocity of shear wave for clay layer, the following equations are used:

Imai and Tonouchi (1982) : $V_s = 96.926N^{0.314}$ (2.9a)

Ohsaki and Iwasaki (1973) : $V_s = 81.686N^{0.39}$ (2.9b)

Ohta and Goto (1978) : $V_s = 85.344N^{0.341}$ (2.9c)

These empirical relations are specified in the study conducted by Ashford *et al.* in 2000 about soil amplification in Bangkok. After computing V_s for each relationship, the average values are calculated within each layer. Afterwhich, the average shear wave velocity ($\overline{V}_{S,30}$) for the top 30m layer of soil, as suggested in the provisions specified by Dash and Jain (2006), is estimated by

$$\overline{V}_{S,30} = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{V_{si}}} \tag{2.10}$$

where

$\overline{V}_{S,30}$	= normalized shear wave velocity for top 30 m soil;
n	= number of layers in top 30 m soil;
d_i	= thickness of the i^{th} layer between top 30 m soil; and
V_{si}	= shear wave velocity in i^{th} layer.

The site classification stipulated on the seismic code provisions of National Earthquake Hazards Reduction Program (NEHRP) which is based on the shear wave velocity averaged over the upper 30 meters $\overline{V}_{S,30}$ is considered in this research. The classification was incorporated into the 1994 edition of the NEHRP provisions (BSSC, 1994). Recording sites are grouped into two geologic categories based on NEHRP's soil classification (Table 2.4). Local site conditions of stations are categorized based on the estimated values of $\overline{V}_{S,30}$ whenever available.

Table 2.4 NEHRP's Classification of soil at site

Site Class	Soil Type	Shear Wave Velocity (m/s)
A	Hard rock	$\overline{V}_{S,30} > 1{,}500$
B	Rock	$760 < \overline{V}_{S,30} \leq 1{,}500$
C	Very dense soil and soft rock	$360 < \overline{V}_{S,30} \leq 760$
D	Stiff soil	$180 < \overline{V}_{S,30} \leq 360$
E	Soft soil	$\overline{V}_{S,30} < 180$

In general, the soil profiles considered for the seismic stations provide information to a depth of 15 meters only. In order to arrive at a plausible estimate of $\overline{V}_{S,30}$, it was assumed that the shear wave velocity of layer at depth between about 15 m to 30 m is the same as V_s at the depth of 15 m. This may lead to $\overline{V}_{S,30}$ that is lower than the actual value. Based on the computed $\overline{V}_{S,30}$ values given in Table 2.5 (see Appendix C), the soil type of the five seismic stations of TMD falls under NEHRP site class C and D. The downloaded and processed soil profiles as well as a sample computation of $\overline{V}_{S,30}$ are provided in Appendix C.

Table 2.5 Site category of seismic stations based on $\overline{V}_{S,30}$

Station	$\overline{V}_{S,30}$ **(m/s)**	**NEHRP's Site Class**
Chiangrai	293	D
Phrae	347	D
Loei	355	D
Songkhla	340	D
Nan	428	C

On the other hand, site-specific data for Kanchanaburi and Tak stations are obtained from EGAT. Based on geologic section profiles of Srinagarin and Bhumibol dams where these stations are situated respectively, the sites are categorized under rock site class. For Chiangmai station, site visit was conducted and based on the observation of the geologic setting within the area, it is classified under rock site category. It is worthwhile to note that this station is founded on granite and underlain by rock as mentioned in the environmental impact assessment report concerning the Kaeng Sua Ten dam site (Woodward-Clyde Federal Services, 1996).

In the following study, we will refer to stations on NEHRP site class C as on rock sites and site class D as on soil sites. Therefore, the stations on rock sites are Chiang Mai, Tak, Nan and Kanchanaburi and stations on soil sites are Chiang Rai, Loei, Phrae and Songkhla. Figures 2.10 and 2.11 show the distribution of selected ground motion recordings at each station, which are sorted based on the type of event whether mainshock, aftershock, or foreshock. 255 of the 557 recordings in the data set are recorded at rock sites, while the rest are from stations located at soil sites.

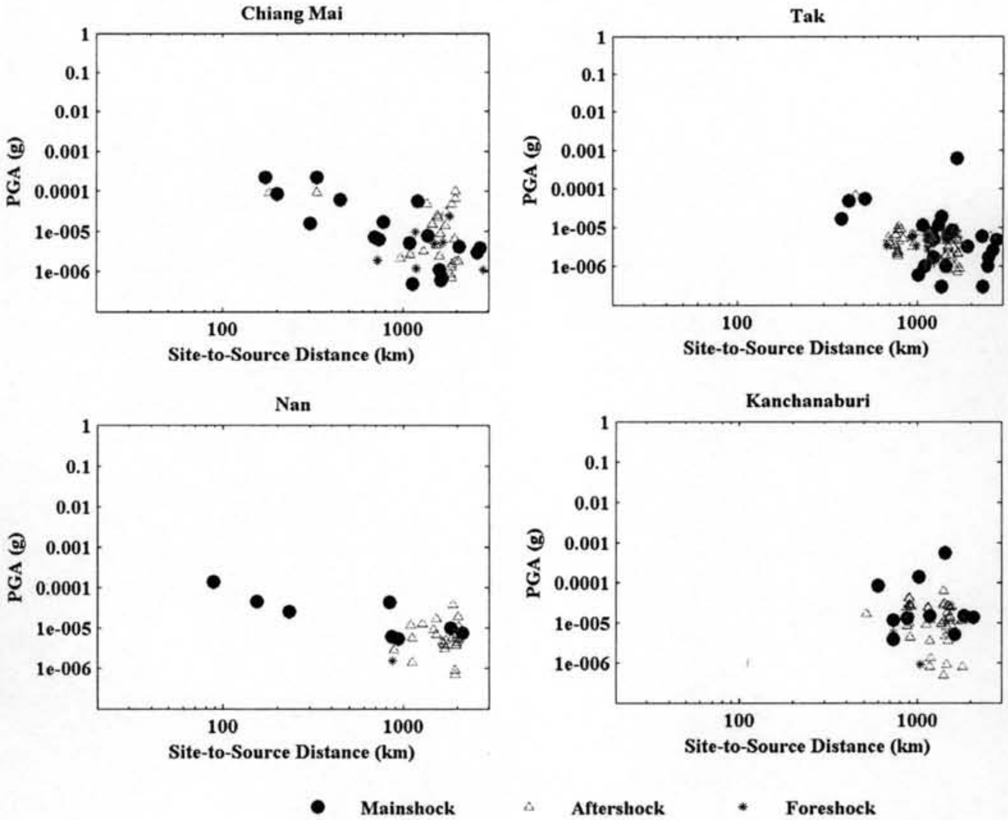

Figure 2.10 Distribution of data used from rock sites

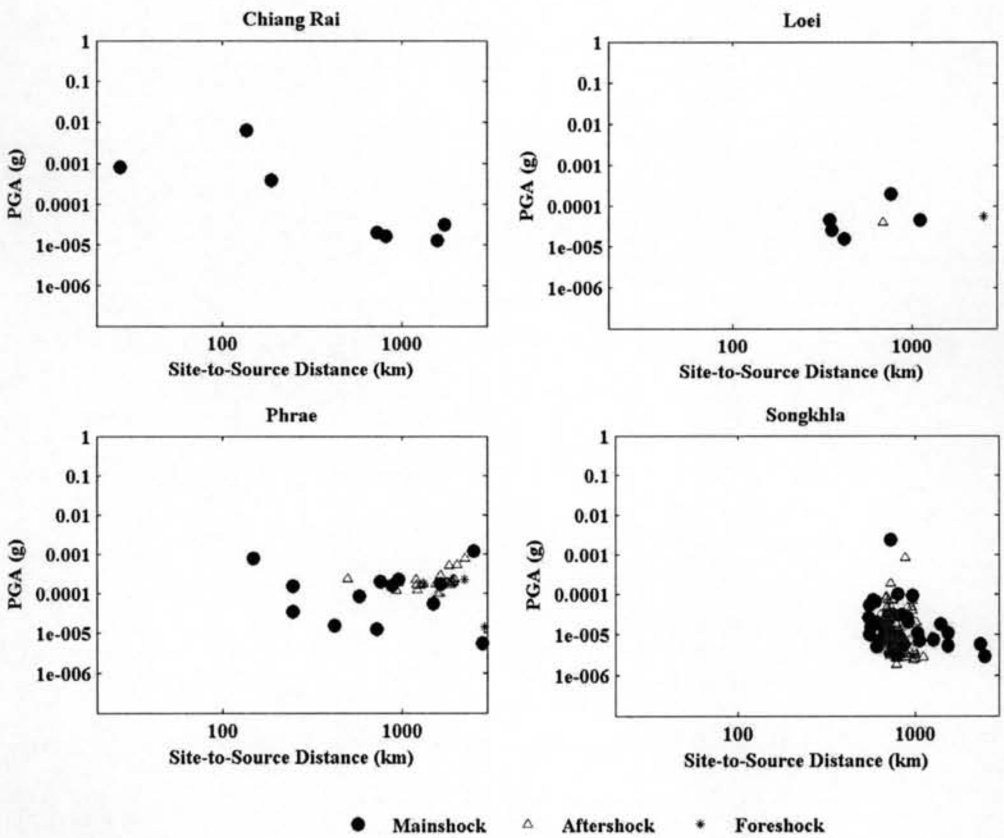

Figure 2.11 Distribution of data used from soil sites

2.4 Summary of Database

In total, 430 earthquake events consisting of 557 recordings measured from eight of TMD's digital seismic stations (in operation before the 2006 seismic system) comprise the first database used in this study. Few of these records are considered as strong-motion data because most of earthquakes that have been felt in the country are small to moderate in global standard. Strong earthquakes usually occur along the borders between Thailand and nearby countries.

The distribution of the selected records with respect to magnitude and site-to-source distance is shown in Figure 2.12. It conveys that there is a lack of data from large earthquakes with M_w greater than 7.0 as expected for a region of low seismicity. As for distance range, there are few events that represent local earthquakes. Higher proportion of data is clustered at long distances as most events have epicenter located in Sumatra and Myanmar.

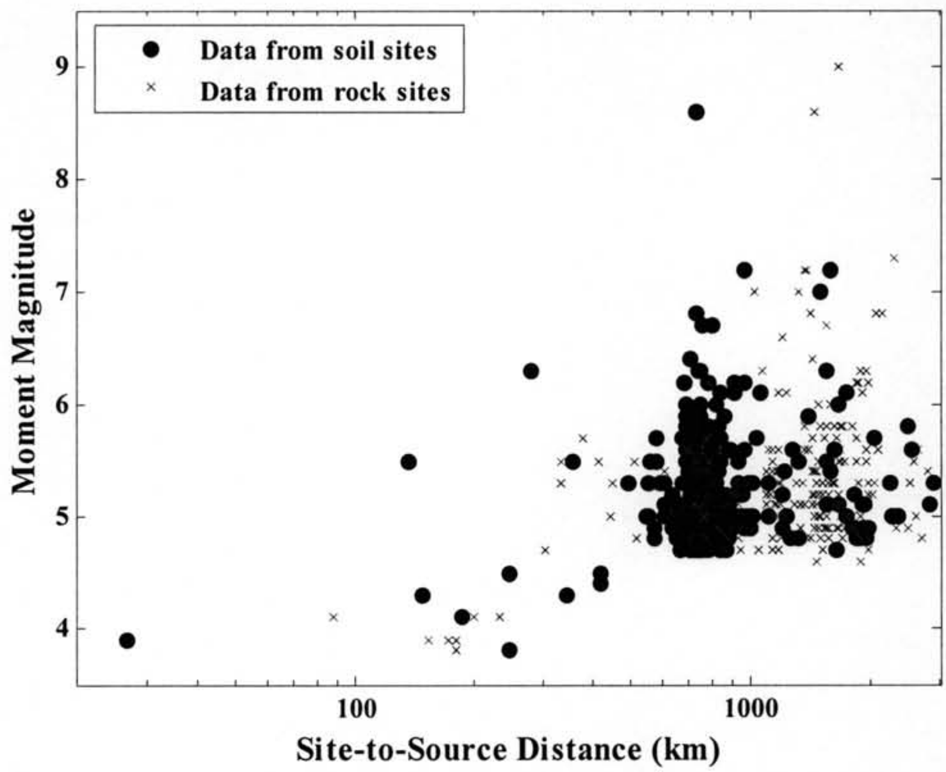

Figure 2.12 Distribution of data used in terms of magnitude and distance

Figure 2.13 illustrates the variation of PGA values with distance. Fifty-four percent of the PGA records were taken from soil sites while the rest were measured at rock sites as abovementioned. As expected, rock ground motions tend to be weaker than soil ground motions.

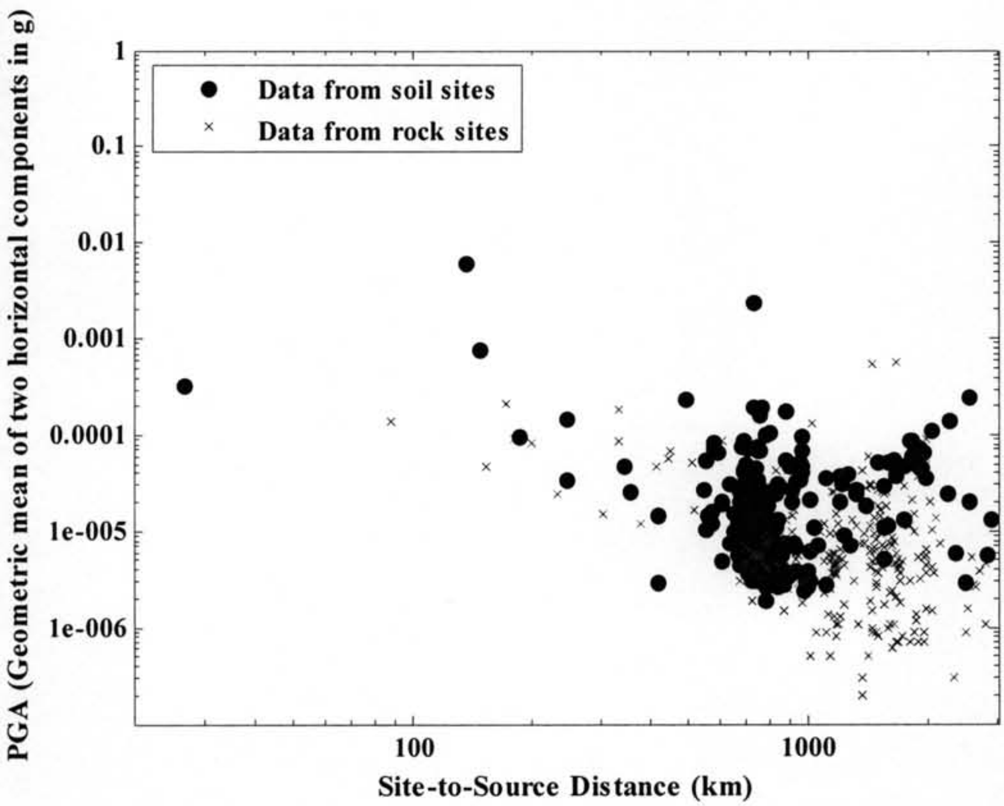

Figure 2.13 Distribution of data used in terms of PGA and distance

About 90% of the earthquake events are categorized as subduction zone earthquakes while the remaining 10% are classified as shallow crustal earthquakes. Such distribution of earthquake events is shown in Figure 2.14. On the other hand, Figure 2.15 describes the distribution of earthquake events with respect to magnitude. Record count within a bin of 0.5 magnitude is provided in the map. Table 2.6 provides the ranges of PGA and independent variables compiled for this study. Other pertinent details regarding the database of this research are outlined in Appendix B.

Table 2.6 Properties of seismic parameters in the 1st data set

Parameter	Range of Values
PGA (g)	0.0000002-0.0060631
Moment magnitude	3.8-9.0
Site-to-source distance (km)	27-2,895
Focal depth (km)	12-600

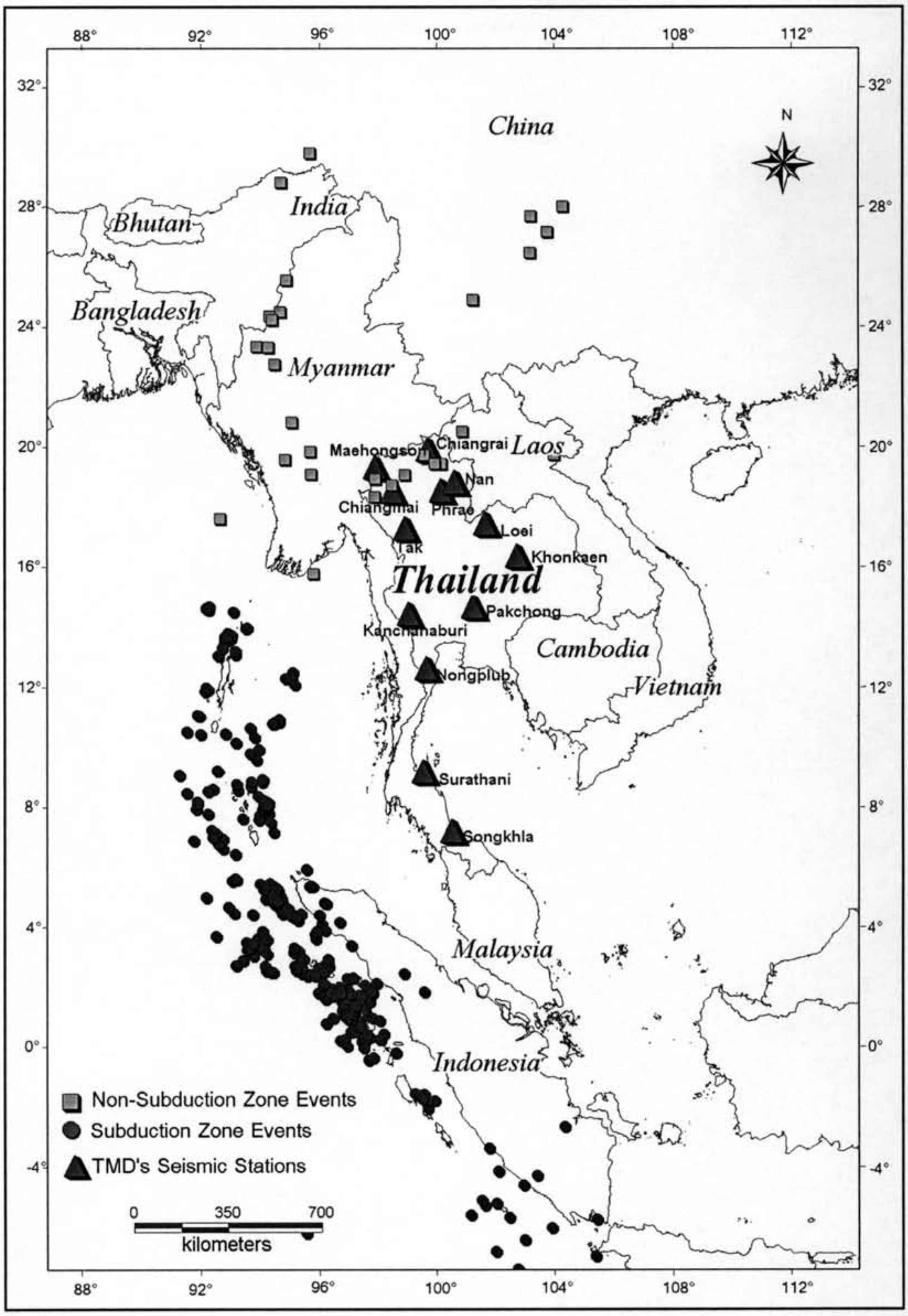

Figure 2.14 Distribution of data used according to event type

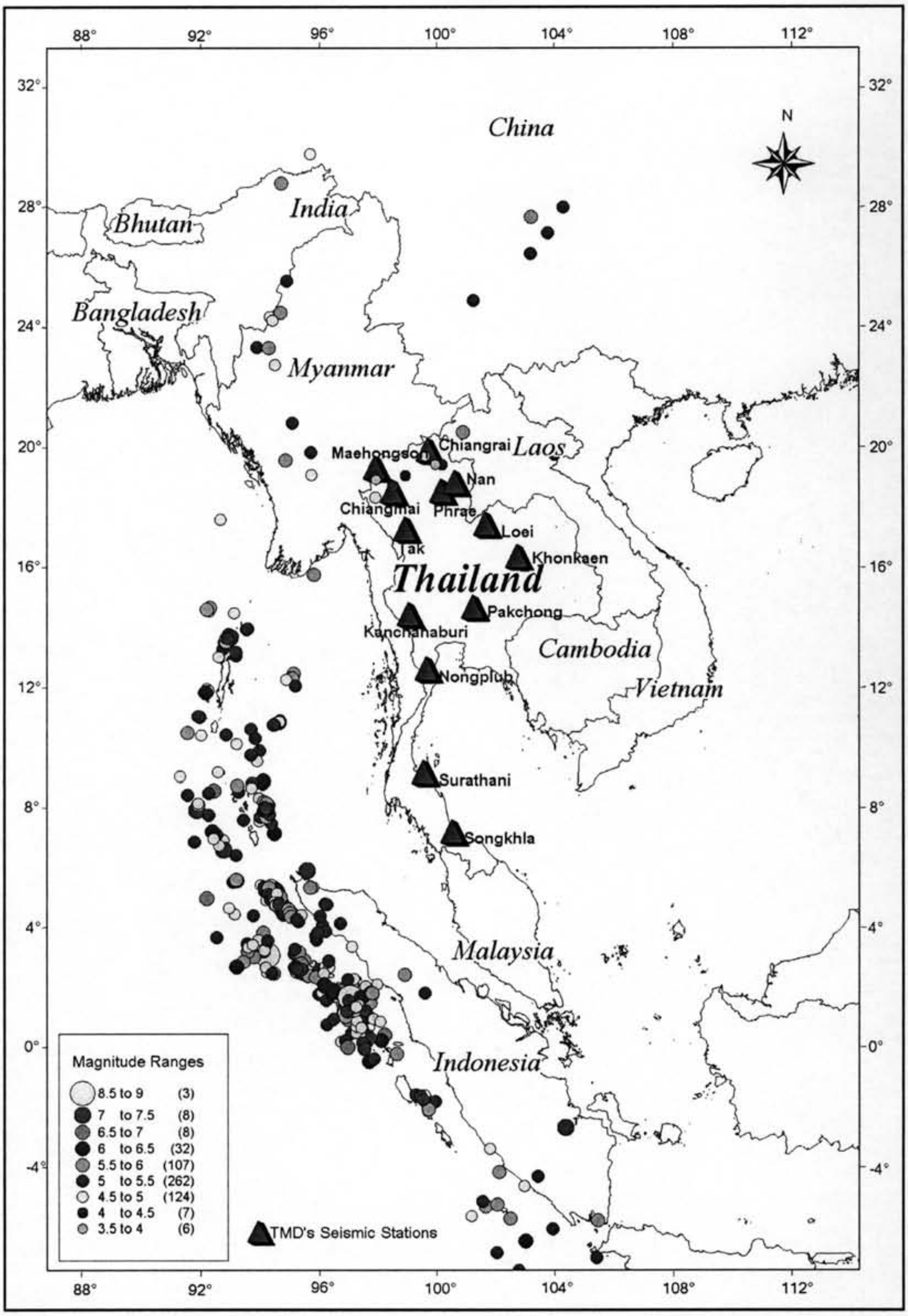

Figure 2.15 Distribution of data used according to magnitude

TMD has ventured into developing the seismic monitoring system of the country. From this newly installed set of equipment, a number of recordings have been measured since the stations started its operation on October of 2006. In as much as the reliability of the gathered data in old seismic stations is tested, this section provides more information of the attenuation characteristic of Thailand by studying another set of data obtained from the new digital seismic stations. Table 2.7 provides the information for this data set. Figure 2.16 shows the epicenters of these two earthquake events together with the locations of the seismic stations.

Table 2.7 Field records from TMD's new digital seismic stations

Data No.	Event No.	Date	M_L	Epicenter		Station	Station		Site-to-Source Distance	PGA (Geometric mean of two horizontal components)
				(°N)	(°E)		(°N)	(°E)	(km)	(g)
1	1	8 October 2006 (Prachubkhirikhun)	5.6	12.02	99.17	Petchaboon	16.5733	100.9690	542	0.0000358
2				12.02	99.17	Kanchanaburi	14.3945	99.1212	264	0.0001725
3				12.02	99.17	Maesariang	18.1764	97.9310	698	0.0000014
4	2	13 December 2006 (Mae Rim, Chiang Mai)	5.1	18.93	98.97	Chiangmai	18.8128	98.9476	13	0.0106178
5				18.93	98.97	Maesariang	18.1764	97.9310	138	0.0019752
6				18.93	98.97	Petchaboon	16.5733	100.9690	337	0.0001170
7				18.93	98.97	Nakonrachasima	14.5905	101.8440	572	0.0000088
8				18.93	98.97	Khao Laem Dam	14.7970	98.5893	461	0.0000419
9				18.93	98.97	Kanchanaburi	14.3945	99.1212	505	0.0000182
10				18.93	98.97	Chantaburi	12.7526	102.3300	775	0.0000164
11				18.93	98.97	Sakonnakorn	16.9742	103.9820	573	0.0000073

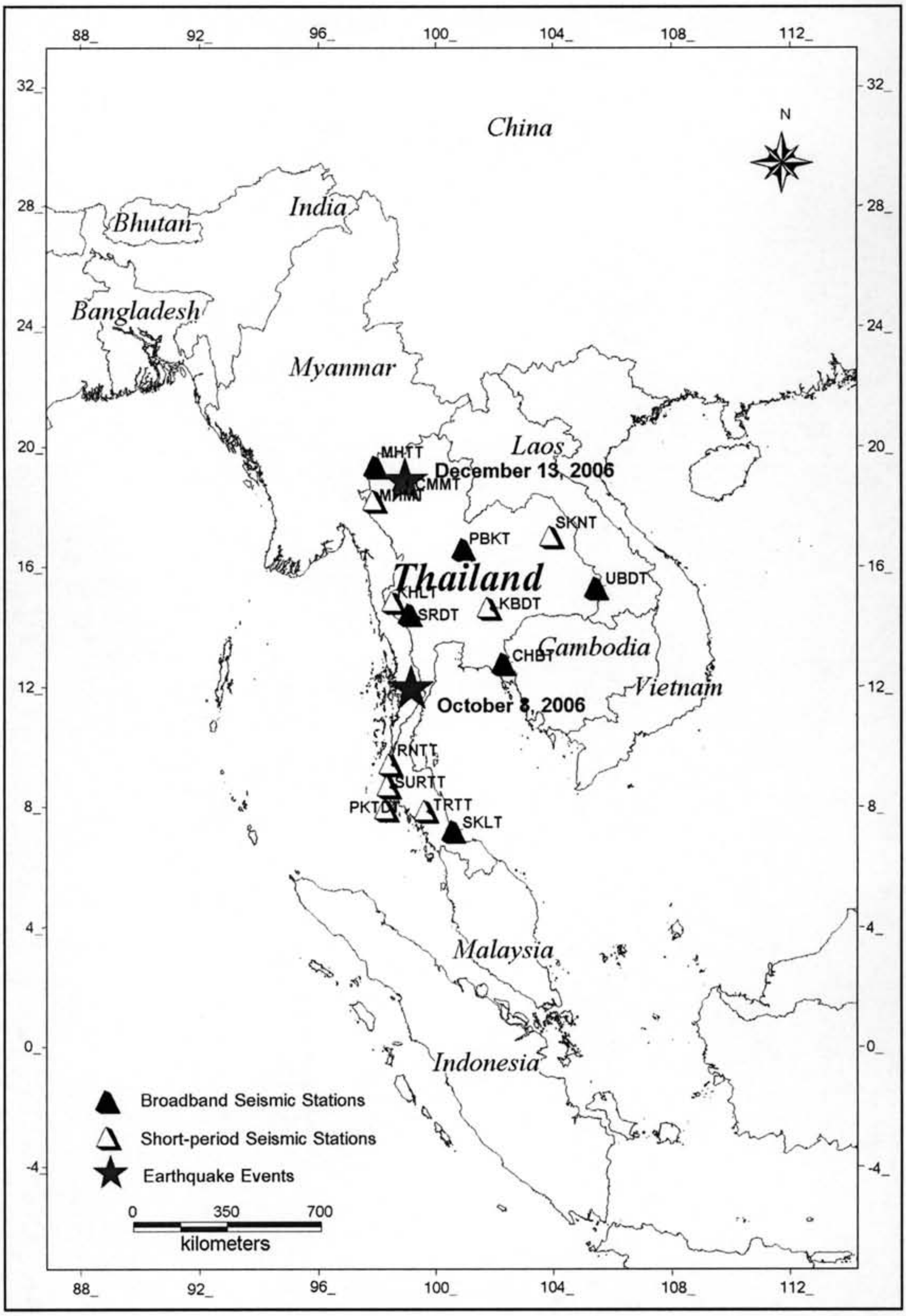

Figure 2.16 TMD's new digital seismic stations (in operation since 2006) and the epicenters of October and December 2006 earthquakes