REPORT #7 on the Chi-Chi (Taiwan) Earthquake:

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Data from CWB, Taipei

A Preliminary Report on the 1999 Chi-Chi (Taiwan) Earthquake

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INTRODUCTION

A major earthquake (M_w =7.6) occurred near the town of Chi-Chi in Nantou county, central Taiwan, on 1:47 a.m., September 21, 1999, local time (UTC is 17:47, September 20, 1999), about 150 km south of Taipei. As of October 13, 1999, the Taiwan's Interior Department record shows that the death toll is 2,333 and 10,002 people were injured. Thousands of houses collapsed making more than 100,000 people homeless. This disastrous earthquake provided a wealth of modern digital data for seismology and earthquake engineering because an extensive six-year, seismic instrumentation program for Taiwan was successfully implemented three years ago by the Central Weather Bureau (CWB). This program was guided by the CWB Advisory Committee and benefited from co-operative projects with the U.S. Geological Survey and with the Southern California Earthquake Center.

INSTRUMENTATION IN OPERATION BY CWB

The Seismology Center of the Central Weather Bureau (CWB) has the official responsibility to monitor earthquakes in and near Taiwan. An extensive seismic instrumentation program, especially for the urban areas of Taiwan, with mostly strong-motion instruments was completed in 1996. At present, the following instruments are in operation:

(1) a realtime digitally telemetered seismic network of 80 three-component, short-period stations,
(2) a rapid earthquake information release system based on 61 realtime telemetered digital accelerographs (also record on site in trigger mode),
(3) about 700 modern digital accelerographs in free-field sites (all record in trigger mode; 61 sites are also continuously telemetered to the CWB Headquarters in Taipei for (2) above; and some sites have more than one accelerographs), and
(4) fifty-six realtime strong-motion arrays (up to 60 uni-axial accelerometers in each array and include one 3-component accelerometer outside the structure whenever possible) in buildings and bridges.

Taiwan is a small island of about 35,000 square kilometers (about 9% of the area of California or Japan). More than half of the area of Taiwan is the high Central Mountain Ranges (up to nearly 4,000 meters); population is concentrated in the northern and western plains and along the narrow Longitudinal Valley between the Central Mountain Ranges and the Coastal Ranges in the east. With the above instrumentation (see Figures 1, 2, 3, and 4), CWB operates the densest network of digital strong-motion instruments in the world. For comparison, station spacing of the free-field accelerographs in Taiwan is about 3 km in the metropolitan areas (vs a 25-km uniform spacing of K-Net in Japan). The rapid earthquake information release system and the realtime strong-motion array systems are based on a simple hardware/software design first introduced by Lee et al. (1989). These systems are subsequently improved and refined (Lee, 1994; Lee et al., 1996; Shin et al., 1996; Lee and Shin, 1997; Teng et al., 1997; Wu et al., 1997; Wu et al., 1999).

The accelerometer sensors used have a flat response from DC to 50 Hz. Signals are digitized at 200 samples per second or higher and at 16-bit or higher resolution. Most accelerometer sensors are ± 2 g full scale. These digital accelerographs at the free-field sites are operated in trigger mode with a 20-second pre-event memory and are usually set to record an extra 5 seconds after the signal drops below a preset threshold. About half of these digital accelerographs are capable of outputting a continuous digital data stream, making telemetry very easy. All digital accelerographs are capable of being dialed in via a telephone modem.

PARAMETERS FOR THE MAINSHOCK

At the time of the earthquake, the Taiwan Rapid Earthquake Information Release System (RTD) automatically determined the location and magnitude for the mainshock and prepared a shake map within 102 seconds after the earthquake's origin time. This information was then sent out by a pager-telephone system, by an e-mail server, and by fax (Wu et al., 1999).

CWB also operates a digital short-period telemetered seismic network (S13), which is the primary tool used for routine earthquake monitoring. The following table compares the results from these two systems, as well as that from the solution by USGS using global digital stations around the world and a refined solution by one of the authors using a few near-field strong-motion records.

RTD:	23.87^{o} N	120.75^{o} E	10 km	M_L=7.3	results in 102 sec.
S13:	23.85^{o} N	120.81^{o} E	7 km		results in ~30 min.
USGS:	23.8^{o} N	121.1^{o} E	normal	M_S=7.6	results in ~50 min.
Refined:	23.86^{o} N	120.81^{o} E	11 km		

Values for the epicenter and the focal depth are essentially the same from the RTD and the S13 system. The latitude of the USGS solution agrees well with the local solutions, but the longitude differs by about 25 km. Amplitudes from the short-period instruments are saturated, but the RTD's M_L value agrees well with the M_W value of 7.6 from the USGS's moment tensor solution. A refined solution was obtained by combining the S-13 arrival time data with a few S-P interval times from near-source strong-motion records using the HYPO71PC program (Lee and Valdes, 1994) and the CWB layered velocity model. The epicenter does not change, and the focal depth of 11 km provides the best fit of the observed data. A simple experiment (of fixing the epicenter but placing the focal depth at various depths from 0 to 20 km) indicates that a focal depth shallower than 9 km or deeper than 13 km has significantly higher RMS residuals and more misfits of the first P motions.

Since 1900, the ten most disastrous earthquakes in Taiwan according to Cheng et al. (1999) are shown in Table 1 (some are earthquake sequences). Figure 5 shows the epicenter of the Chi-Chi earthquake with respect to the past disastrous earthquakes of Taiwan. Locations of these historical earthquakes are based on the values given in Table 1. The Chi-Chi earthquake occurred very near the location of the Nantou earthquake sequence in 1916-1917.

A fault-plane solution using first P motions data and the refined hypocenter was obtained. The nodal plane consistent with the regional tectonics and the surface ruptures is shown below and agrees well with that determined from the moment tensor inversion by Harvard and by the USGS:

First P-motion: Strike = 5^o, Dip = 36^o

Harvard: Strike = 18^o, Dip = 25^o

USGS: Strike = 357^o, Dip = 29^o.

Since the above nodal plane agrees with the general strike of the faults in the area, we suggest that faulting occurred along this nodal plane. Surface ruptures were observed along the Chelungpu fault (Central Geological Survey, 1999), a north-south trending thrust fault dipping about 30^o to the east (Chang et al., 1988; Bonilla, 1999).

NEAR-SOURCE STRONG-MOTION RECORDS

As of October 23, 1999, 312 records for the Chi-Chi main shock were retrieved from the free-field accelerographs. Figures 6, 7, and 8 show 15 samples of near-source strong-motion records for the vertical, north-south, and east-west component, respectively. Along the northern end of the surface ruptures, very simple waveforms were observed (stations TCU068 and TCU052). Please note the large amplitudes recorded at some stations to the east of the surface ruptures (hanging wall). Stations to the west of the surface ruptures recorded lower amplitudes in general, but there are exceptions (TCU129 and CHY028). We are now in the process of verifying the location of these two stations with respect to the mapped surface ruptures.

DISCUSSION

A large set of over 300 strong-motions acceleration records (especially for near source distances of < 50 km) have been retrieved by the Central Weather Bureau as of October 23, 1999 for the Chi-Chi earthquake. Since this paper was prepared within one month after the earthquake, it is of necessarily brief. It will take months and years to process and analyze this large data set, probably the best so far recorded for a major earthquake. During the first week of the Chi-Chi earthquake, eleven aftershocks with local magnitude greater than 6 were recorded; two of these aftershocks have moment magnitude similar to the 1994 Northridge, California mainshock (M_w=6.7). Aftershocks (down to magnitude of about 4) have also been recorded by many digital accelerographs in the free-field sites. As a result, we estimated that over 10,000 digital 3-component, strong-motion accelerograms had been recorded in the first 4 weeks of the Chi-Chi earthquake sequence. We plan to publish these strong-motion data as soon as practical, so that other scientists and engineers can make use of this data set for scientific and engineering studies. Please visit the following Web site for publication information:

http://www.iris.washington.edu/DOCS/taiwan.htm

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Table 1. Ten most disastrous earthquakes in Taiwan according to Cheng et al. (1999) along with the Chi-Chi earthquake

Date	Origin	Latitude (Degrees N)	Longitude (Degrees E)	Depth (km)	Magnitude	Name
1904 /11/06	04:25	23.575	120.250	7	6.1	Touliu
1906/03/17	06:43	23.550	120.450	6	7.1	Meishan
1916/08/28	15:27	24.000	121.025	45	6.8	Nantou
1916/11/15	06:31	24.100	120.875	3	6.2	Nantou
1917/01/05	00:55	24.000	120.975	very shallow	6.2	Nantou
1917/01/07	02:08	23.950	120.975	very shallow	5.5	Nantou
1935/04/21	06:02	24.350	120.817	5	7.1	Hsinchu-Taichung
1941/12/17	03:19	23.400	120.475	12	7.1	Chungpu
1946/12/05	06:47	23.070	120.330	5	6.1	Hsinhua
1951/10/22	05:34	23.875	121.725	4	7.3	Longitudinal Valley
1951/10/22	11:29	24.075	121.725	1	7.1	Longitudinal Valley
1951/10/22	13:43	23.825	121.950	18	7.1	Longitudinal Valley
1951/11/25	02:47	23.100	121.225	16	6.1	Longitudinal Valley
1951/11/25	02:50	23.275	121.350	36	7.3	Longitudinal Valley
1959/08/15	16:57	21.700	121.300	20	7.1	Hengchun
1964/01/18	20:04	23.200	120.600	18	6.3	Paiho
1986/11/15	05:20	23.992	121.833	15	6.8	Hualien
1999/09/20	17:47	23.862	120.814	11	7.6	Chi-Chi

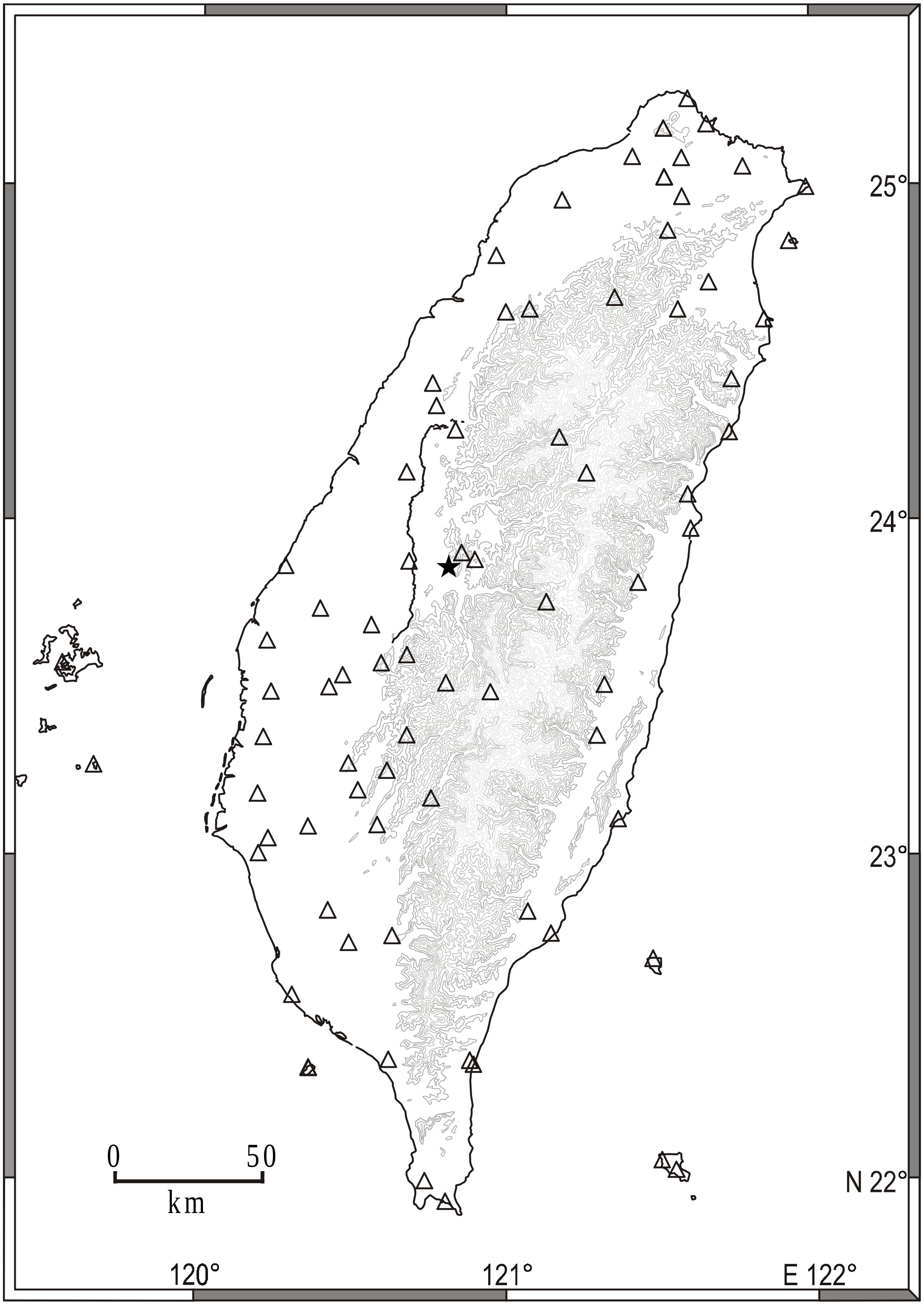

Figure 1. Locations of the CWB realtime, short-period, 3-component stations. The "star" indicates the location of the main shock. Surface ruptures extending about 80 km north-south are shown to the left of the main shock.

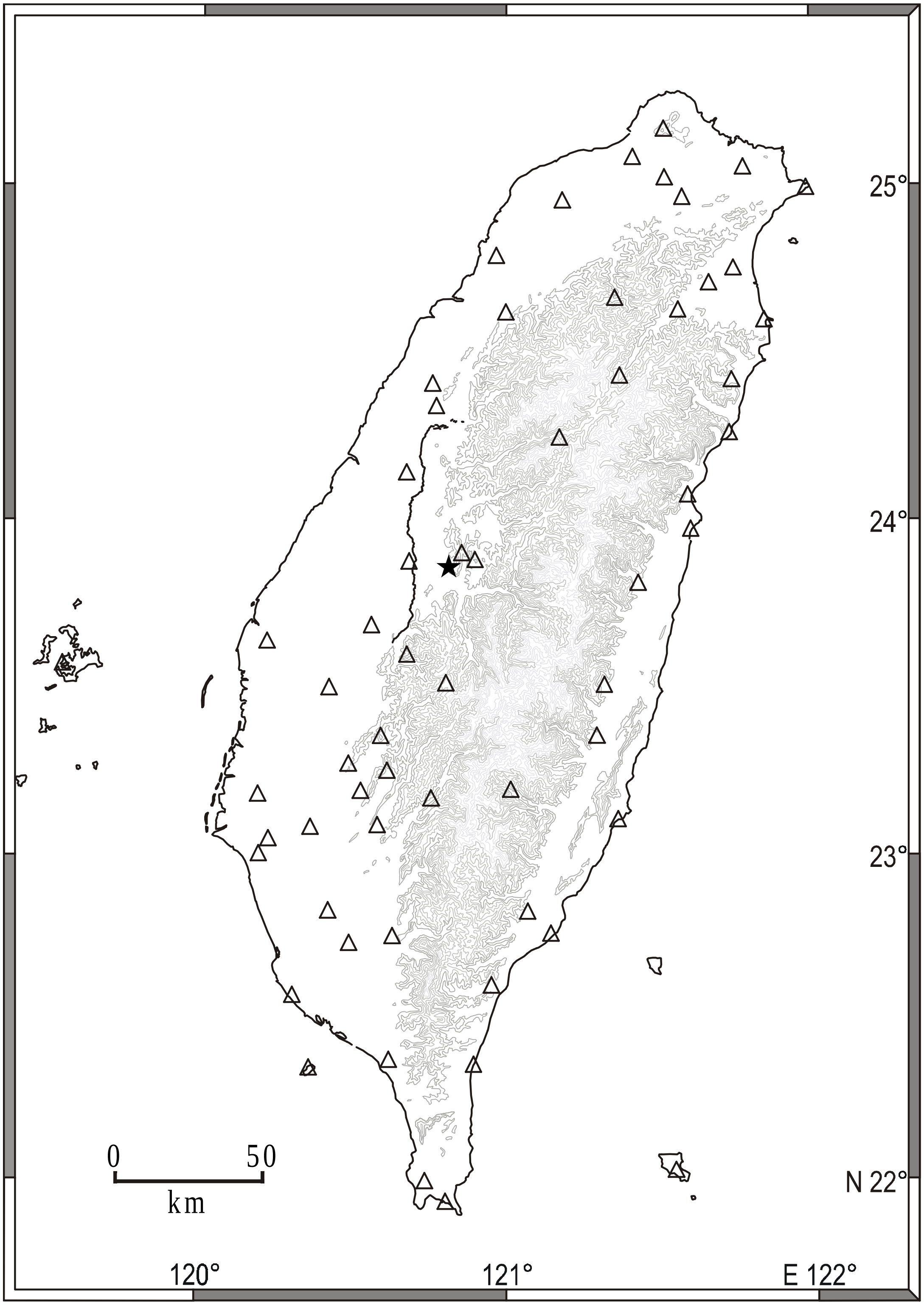

Figure 2. Locations of the CWB realtime, strong-motion, 3-component stations. The "star" indicates the location of the main shock. Surface ruptures extending about 80 km north-south are shown to the left of the main shock.

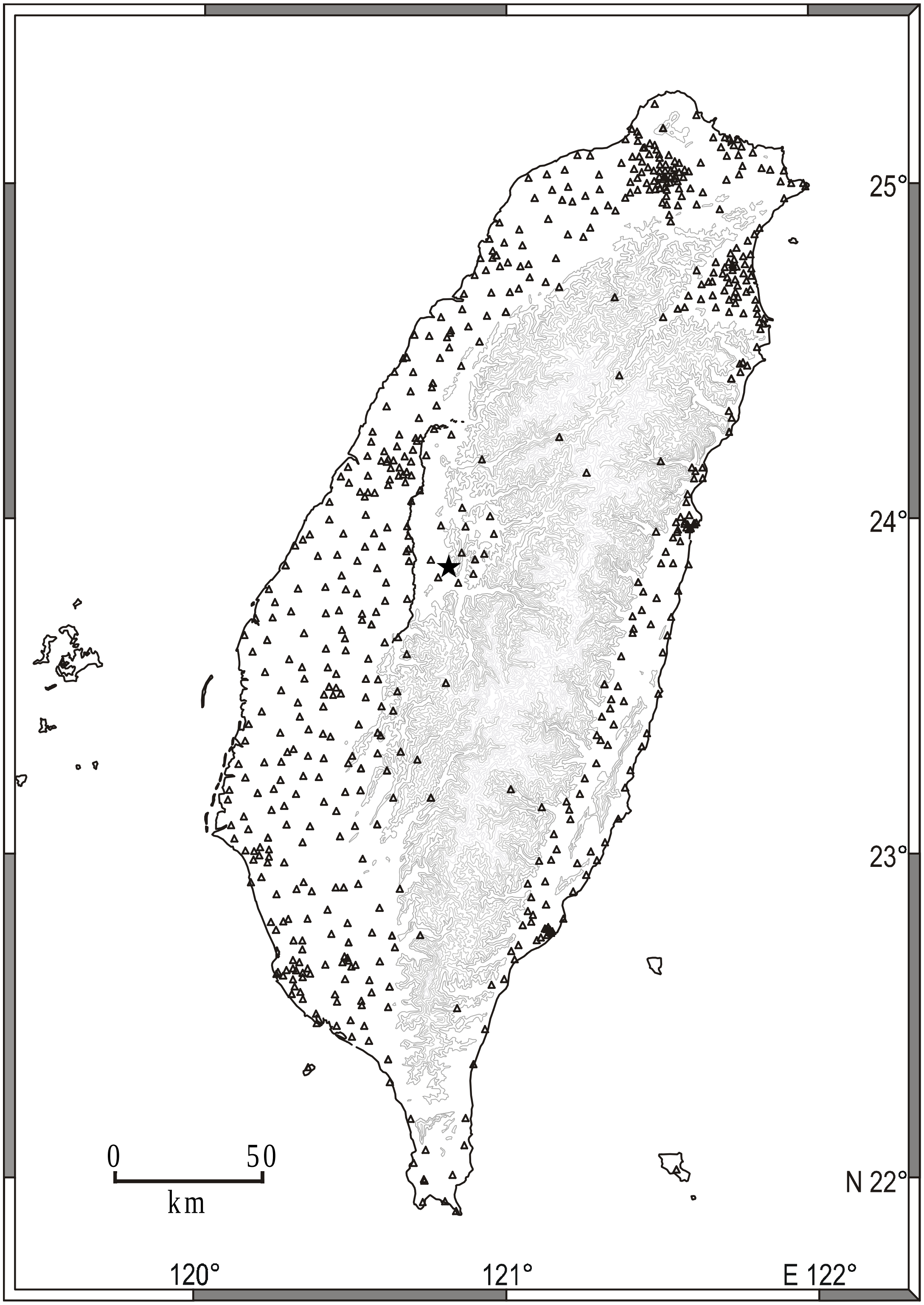

Figure 3. Locations of the CWB free-field, 3-component, digital accelerograph stations. The "star" indicates the location of the main shock. Surface ruptures extending about 80 km north-south are shown to the left of the main shock.

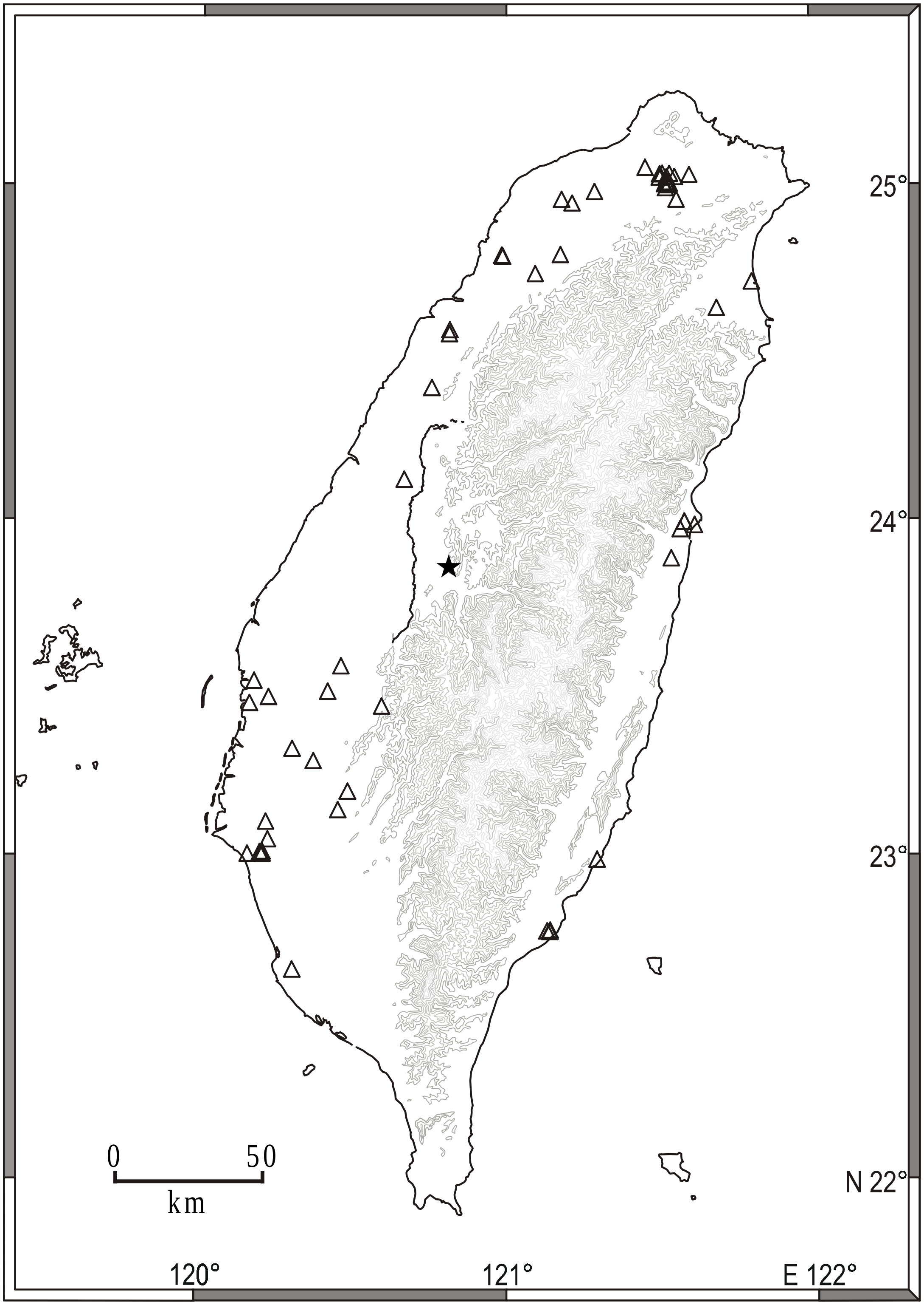

Figure 4. Locations of the CWB realtime strong-motion arrays in buildings and bridges. The "star" indicates the location of the main shock. Surface ruptures extending about 80 km north-south are shown to the left of the main shock.

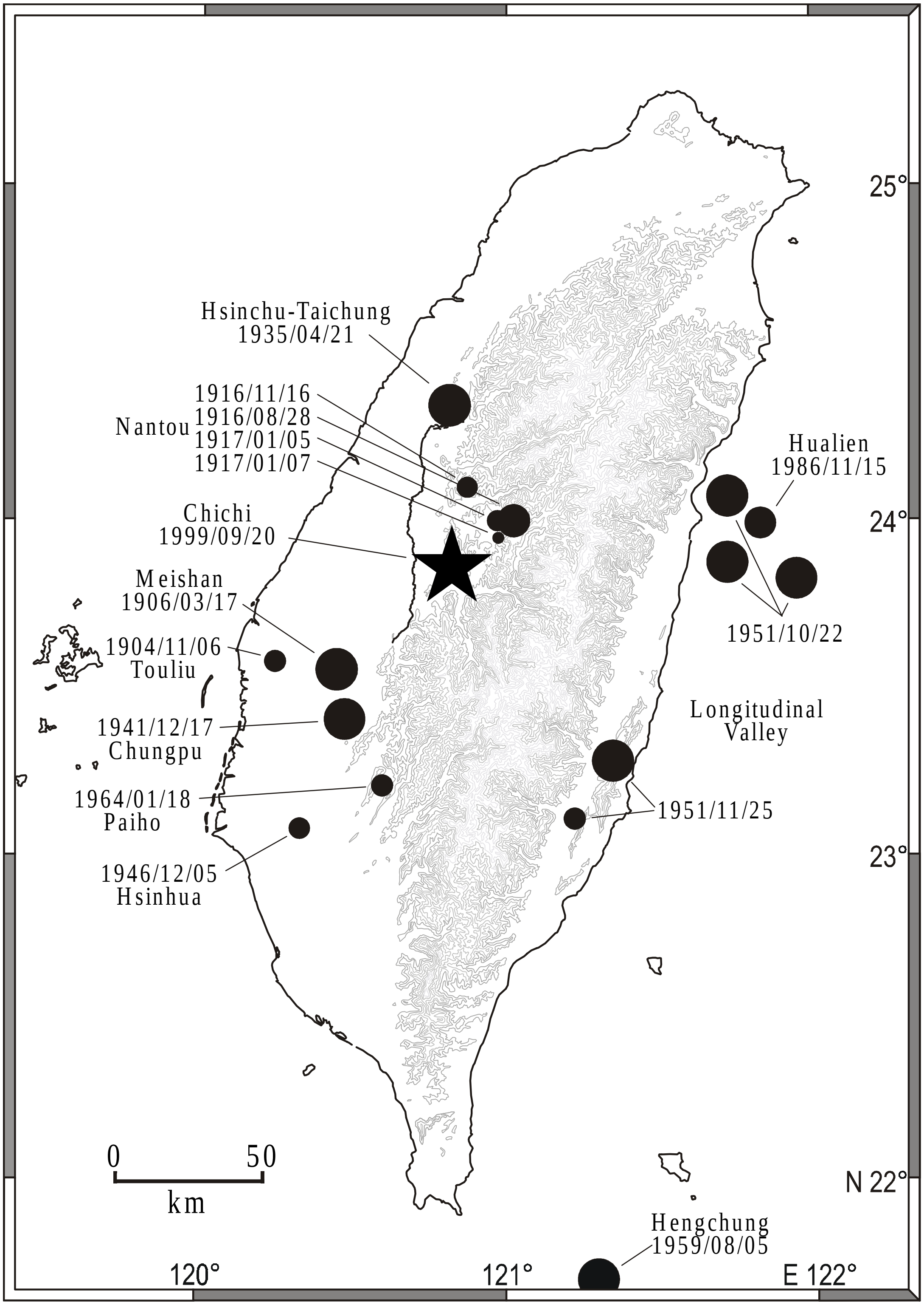

Figure 5. Location of the Chi-Chi earthquake and of historical earthquakes from Cheng et al. (1999). See Table 1 for details. Surface ruptures extending about 80 km north-south are shown to the left of the Chi-Chi earthquake.

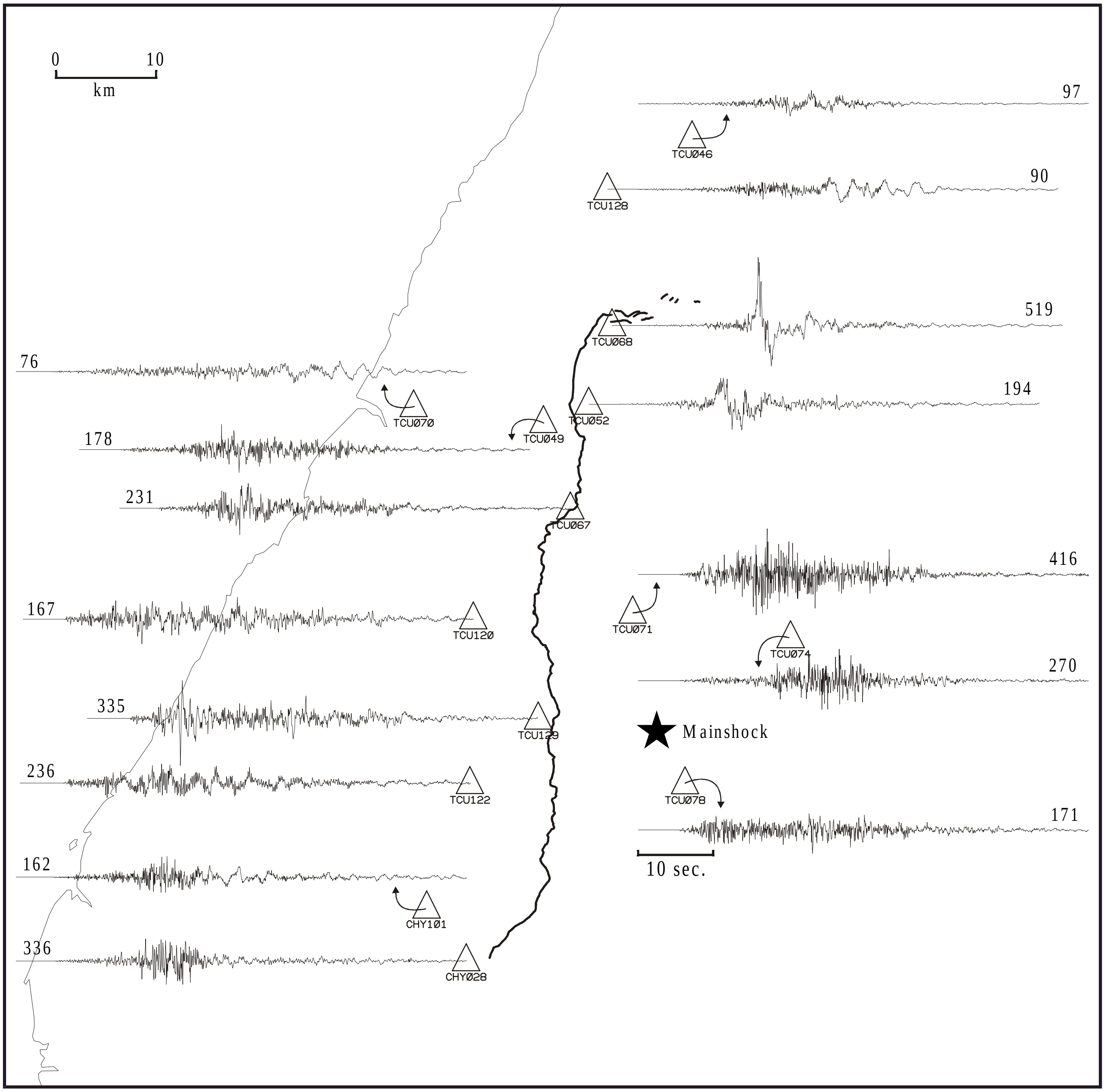

Figure 6. Vertical component of some samples of near-source strong-motion acceleration records. The number above the waveform trace is the peak acceleration value (PGA) in cm/sec/sec. Surface ruptures extending about 80 km north-south are shown to the left of the main shock.

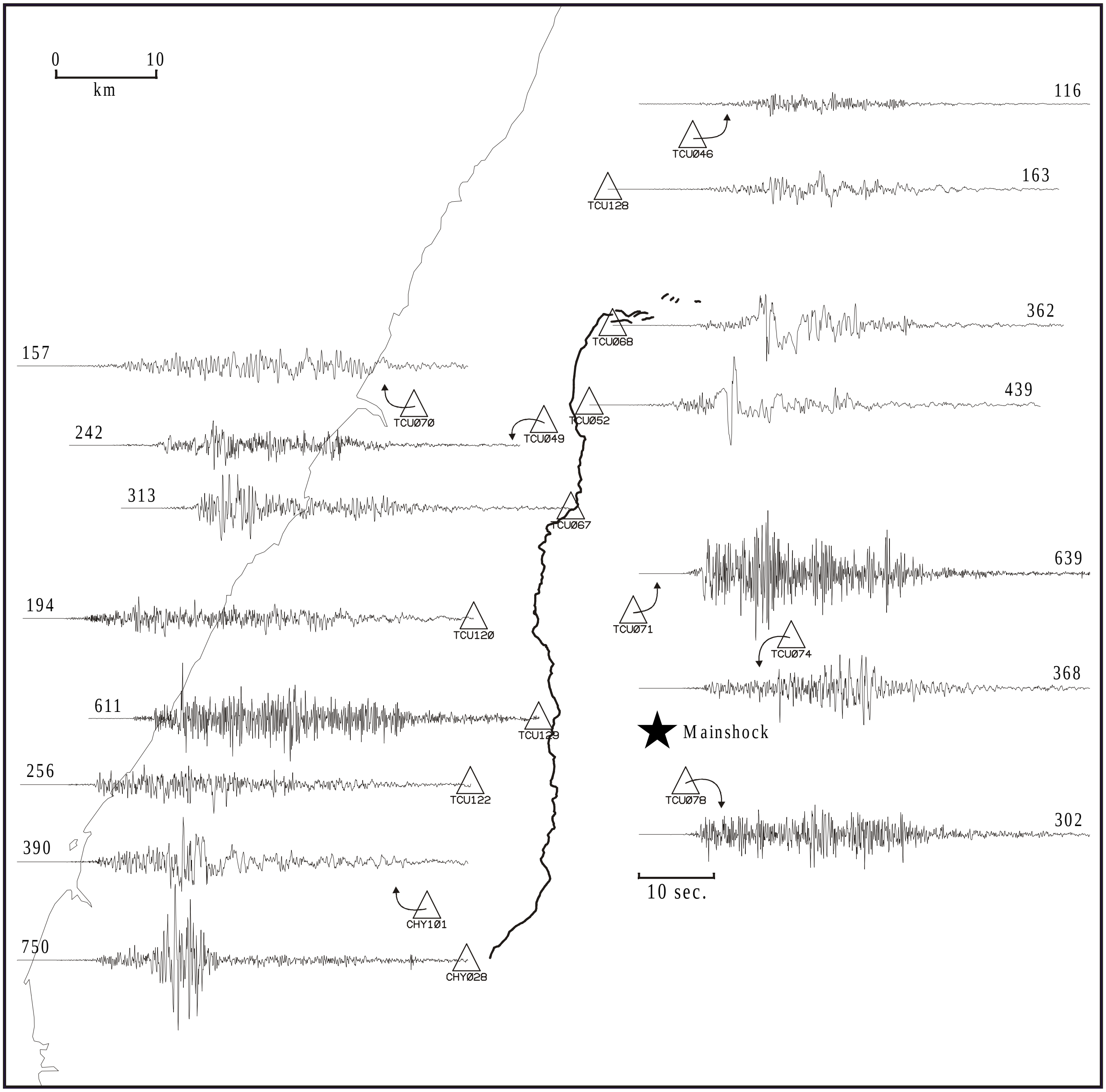

Figure 7. North-south component of some samples of near-source strong-motion acceleration records. The number above the waveform trace is the peak acceleration value (PGA) in cm/sec/sec. Surface ruptures extending about 80 km north-south are shown to the left of the main shock.

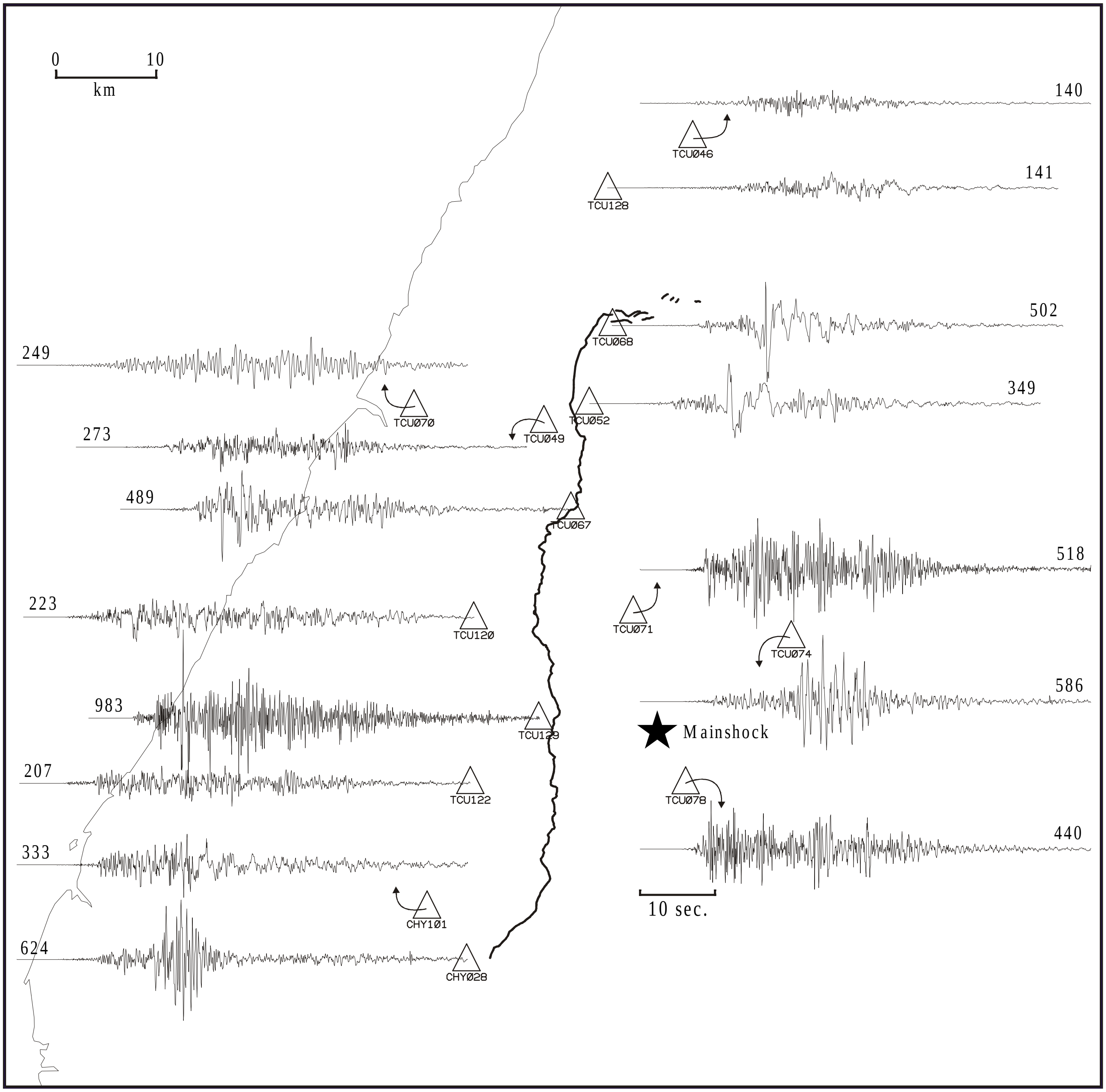

Figure 8. East-west component of some samples of near-source strong-motion acceleration records. The number above the waveform trace is the peak acceleration value (PGA) in cm/sec/sec. Surface ruptures extending about 80 km north-south are shown to the left of the main shock.