Performance of the Taiwan Rapid Earthquake Information Release System (RTD) during the 1999 Chi-Chi (Taiwan) Earthquake

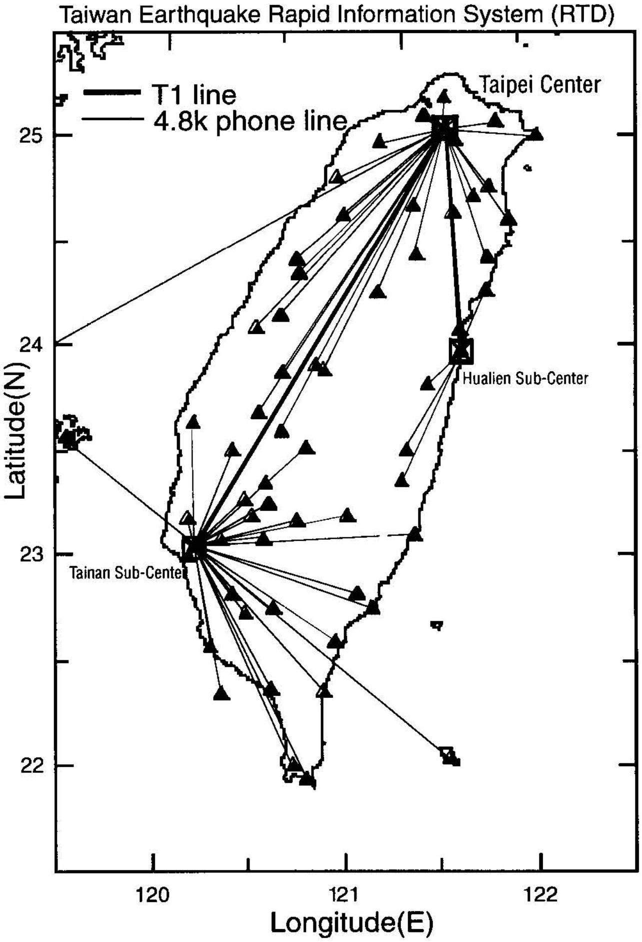
Yih-Min Wu[1], William H. K. Lee[2], Chen-Chun Chen[1], Tzay-Chyn Shin[1], Ta-Liang Teng[2], and Yi-Ben Tsai[3]

INTRODUCTION

A major earthquake occurred near the town of Chi-Chi in Nantou County, Taiwan, at 1:47 AM (local time), 21 September 1999, about 150 km south of Taipei. This is the largest earthquake to have occurred on land in Taiwan during the 20th century. Although Taiwan has an earthquake building code, thousands of buildings collapsed due to the earthquake, leaving more than 100,000 people homeless. The death toll exceeded 2,300 with more than 10,000 injured. Within 102 seconds after the earthquake's origin time, a good estimate of the hypocenter (23.87° N, 120.75° E, Depth = 10 km) and magnitude (M_L = 7.3), and a shaking map were determined automatically by the RTD system. The result was immediately disseminated to governmental emergency response agencies electronically in four ways, by e-mail, World Wide Web, fax, and pager. This rapid information system has been successfully operating in Taiwan for more than four years. During the Chi-Chi earthquake, the rapid availability of earthquake information facilitated the emergency response. The RTD system worked very well throughout the whole aftershock sequence (several aftershocks had local magnitude of 6 or larger). Again this timely information was useful to the emergency response teams. In this paper, we briefly describe the RTD system and summarize its performance during the Chi-Chi earthquake.

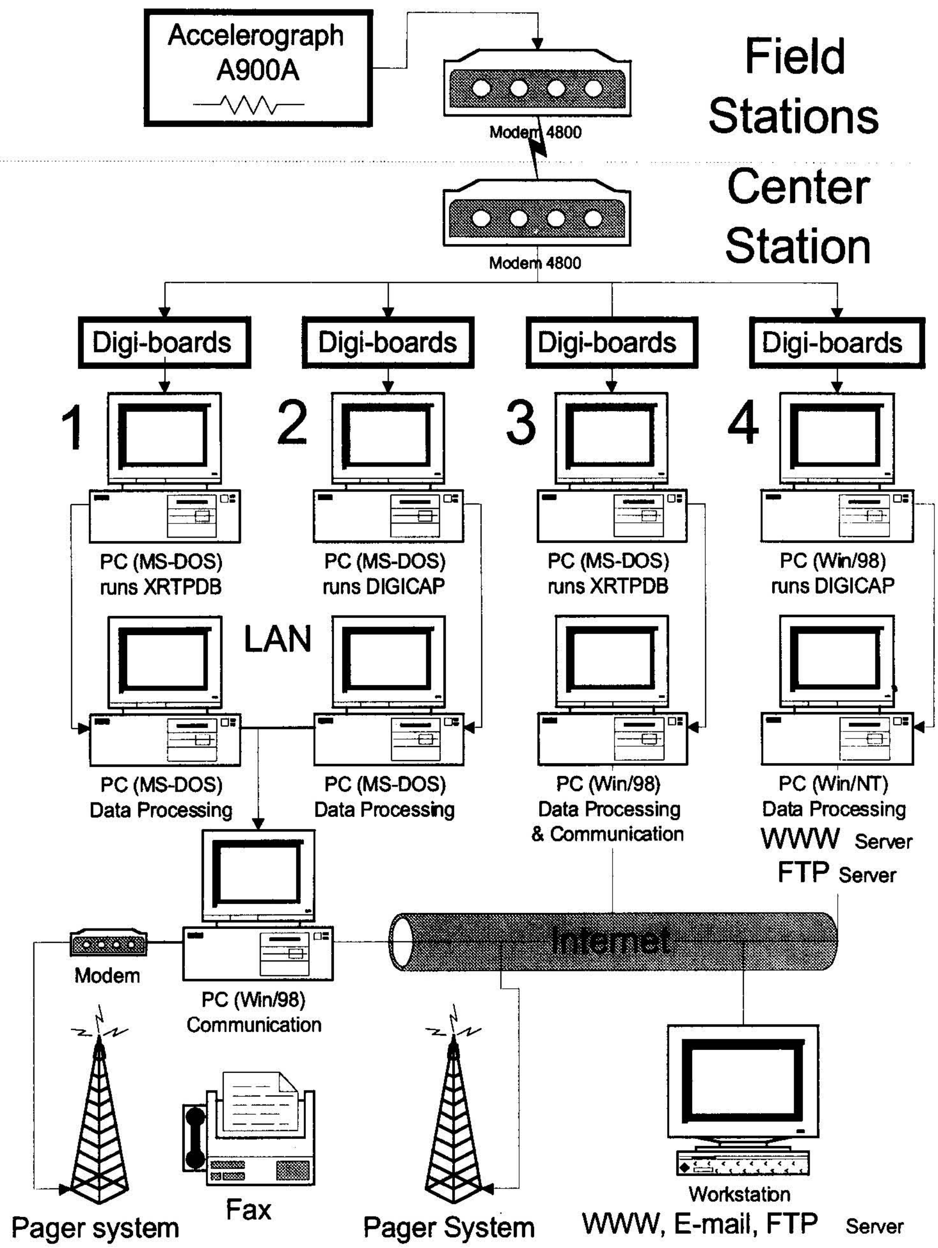
TAIWAN RAPID EARTHQUAKE INFORMATION RELEASE SYSTEM (RTD)

The Taiwan Rapid Earthquake Information Release System (RTD) is based on a simple hardware/software design first introduced by Lee *et al.* (1989). This system was subsequently improved and refined (Lee, 1994; Lee *et al.*, 1996; Shin *et al.*, 1996; Wu *et al.*, 1997, 1998, 1999). The RTD system consists of 61 telemetered strong-motion stations in Taiwan (Figure 1). Digital signals are continuously telemetered to the headquarters of the Central Weather Bureau (CWB) in Taipei via 4,800-baud leased telephone lines. Each telemetered signal contains three-component seismic data digitized at 50 samples per second and at 16-bit resolution. The full recording range is from –2 g to +2 g. The



▲ **Figure 1.** Map showing the telemetered stations of the Taiwan Earthquake Rapid Information Release System (RTD).

1. Central Weather Bureau, Taiwan
2. Department of Earth Sciences, University of Southern California
3. Institute of Geophysics, National Central University, Taiwan



▲ **Figure 2.** A block diagram showing the hardware of the RTD system.

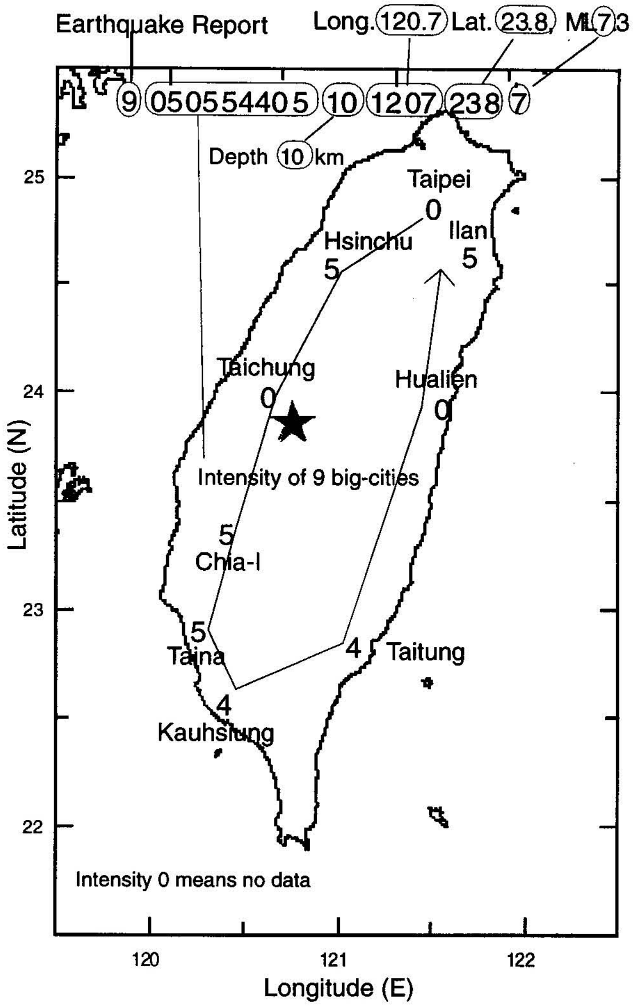
incoming digital data streams are processed by a computer program called XRTPDB (Tottingham and Mayle, 1994). Whenever the prespecified trigger criteria are met, the digital waveforms are stored in memory and are automatically analyzed by a series of programs (Wu *et al.*, 1998). The result was immediately disseminated to governmental emergency response agencies electronically in four ways: by e-mail, World Wide Web, fax, and pager (Figure 2).

MAIN SHOCK OBSERVATION AND MESSAGE DISSEMINATION

During the Chi-Chi earthquake, the RTD system performed as designed. Within 102 seconds after the earthquake's origin time, information about hypocenter, magnitude, and shake map were disseminated automatically by e-mail and pager and were also posted on the Web. Two CWB staff members were on duty in the office at the time of the earthquake. After the shaking was felt, Mr. C. Y. Wu went quickly to check the laser printer. At the same time almost all the phones were ringing. About two minutes after the earthquake's origin time, a report was printed on paper, and this report was sent out to a designated list of addresses via fax. Other methods of dissemination are discussed next.

Pager

For pagers, the delivered message was shortened to twenty digits (Figure 3) and was dialed out automatically to a com-



▲ **Figure 3.** Twenty digits representing the Chi-Chi earthquake information delivered by the pager system.

mercial pager system via a modem. Two PC's were used for sending the pager message in parallel. It took 20 seconds to send an earthquake message to a user. The pager users include some CWB staff members and fire department chiefs in central and local governments. The sending order is sorted with respect to the epicentral distance. Thus, fire department chiefs in the epicentral area received the pager message within five minutes after the earthquake occurrence. About thirty fire department chiefs and ten CWB staff received the pager message. The twenty digits sent via the pager system include observed seismic intensity for nine major cities in Taiwan, the earthquake location, and the magnitude. For the Chi-Chi earthquake, almost all nine cities had intensity of more than 4 on the Taiwan intensity scale. However, Taipei, Taichung, and Hualien did not have observed data in this pager report due to a large-scale electric power failure in the northern part of Taiwan caused by this earthquake. Nevertheless, the information sent by the pager system clearly indicated a large earthquake had occurred in central Taiwan. After this event we added the Chinese pager system to disseminate earthquake information. It can carry 40 Chinese codes (or 80 English codes) as information and goes to multiple users in one delivery.

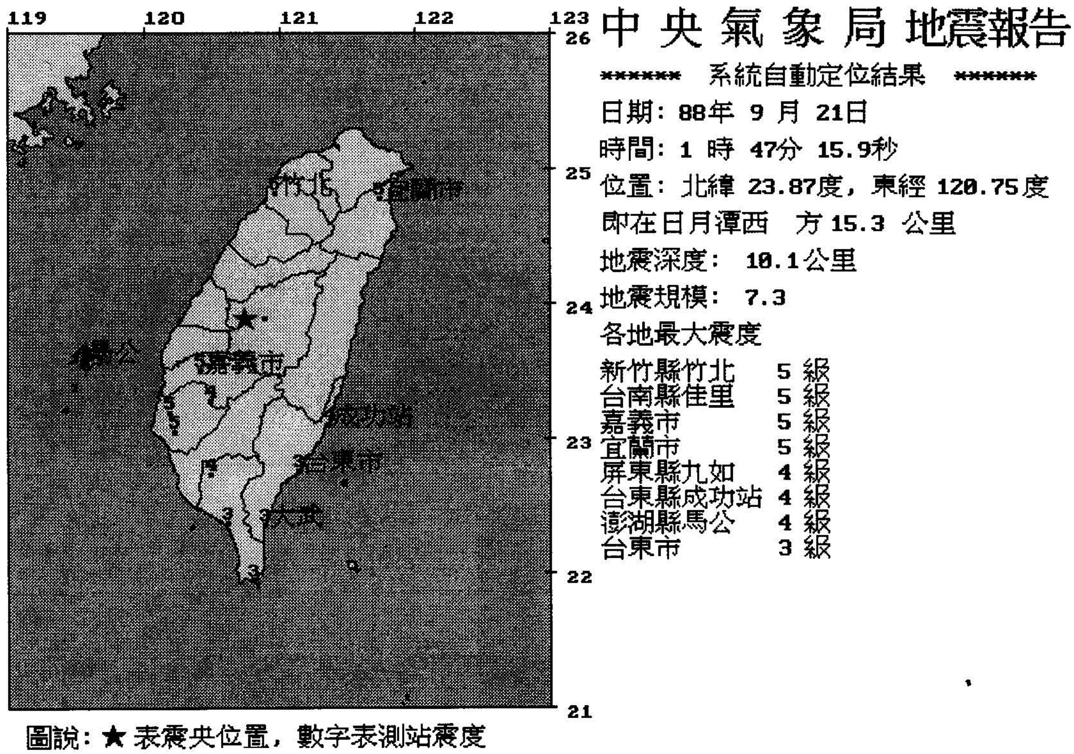
WWW and Fax

Within 102 seconds of the earthquake's origin time, information was transferred to an output report in Chinese (Figure 4) and was automatically posted on our Web server. Within about two minutes, the same report was printed on paper and was sent out to a designated list of addresses via fax. A total of 247 fax users were on the fax list, but 106 users did not receive this report because their fax machines were not operable due to a large-scale electric power failure in Taiwan. The fax users include government departments, rescue agencies, research agencies, public media, etc.

E-mail

The e-mail system also performed its rapid reporting function as designed. The e-mail users include some seismologists in Taiwan and overseas, and the staff members of the Taiwan Electric Power Company, four nuclear power plants, several dams, and the natural disaster prevention center of the National Science Council. The e-mail message also included a preliminary intensity or shake map (Figure 5). However, one problem encountered by the RTD system was the lack of intensity information in certain parts of Taiwan. It was caused by the electric power failure such that no instrumental data were received from many strong-motion stations. After the Chi-Chi earthquake we modified our data processing program. Using the attenuation formula of Shin (1998), we extrapolate the intensity values for areas without instrumental data and thus generate a more complete shake map (Figure 6). According to the preliminary intensity map of the Chi-Chi earthquake (Figure 5), the intensity observed in southern Taiwan had a normal attenuation with epicentral distance, while the intensity of northern Taiwan did not attenuate normally with epicentral distance. This implies that the earthquake fault rupture started from the epicenter and propagated to the north. It also indicates that it is better to use a line source model instead of a point source model to interpolate the intensity map for a large earthquake. However, for a rapid reporting system, it is difficult to use a line source model as fault rupture progresses. Therefore, we used a point source model combined with the real-time peak ground acceleration data for interpolation in the intensity map.

Some users in northern Taiwan did not receive the e-mail report of the main shock because of the electric power failure, although this information was sent within two minutes. However, overseas users did receive this information within several minutes because the Internet service was available during the first few hours after the main shock. The preliminary location of the Chi-Chi earthquake was determined by JMA to be offshore of eastern Taiwan, but JMA did not issue a tsunami warning. The preliminary location by USGS was in eastern Taiwan on land, but USGS issued a tsunami warning. Because a teleseismic location is uncertain for 25 km or more, the USGS system issued a tsunami warning as



▲ **Figure 4.** Report of the Chi-Chi earthquake automatic output (in Chinese) posted on the World Wide Web server.

the determined location could have been at sea and a tsunami could occur for such a large event. Therefore, accurate earthquake location by our RTD system is important with respect to issuing a tsunami warning. Based on this experience, we are willing to share our rapid earthquake location and magnitude results with other countries.

AFTERSHOCK REPORTING

The CWB's RTD system also worked very well throughout the aftershock sequence. It offered rapid information about the aftershocks, usually within one minute of their occurrence. Figure 7 shows the epicenter distribution of the main shock and aftershocks in September 1999 as determined by the RTD system. Most aftershocks occurred to the east of the surface rupture (mainly along the Chulongpu Fault).

IMPROVEMENTS FOR THE RTD SYSTEM

For the Chi-Chi earthquake sequence, the CWB's RTD system performed its rapid reporting function well. However, the 102-second reporting time is not quick enough for earthquake early warning purposes. The main reason for this reporting time for the Chi-Chi main shock is that its seismic wave amplitudes did not fall off very quickly. To compute a reliable magnitude, one must wait until after the passage of the largest seismic waves, which is increasingly longer for more distant stations. This waiting period can be minimized if there are more near-source stations. At present, about 10% of the free-field strong-motion stations are telemetered to the CWB Headquarters in Taipei as input to the RTD system. However, to increase the number of telemetered strong-motion stations significantly will be expensive in operational cost. A less expensive solution is to implement RTD systems at various regional centers, where additional stations can be telemetered at shorter distances.

The Chi-Chi earthquake experience indicates that leased telephone lines and electrical power supply can fail easily during a large earthquake. We are now planning to improve the electrical power supply by installing a larger back-up unit, and to explore other telemetry methods. In addition, we will implement more "virtual" network systems within our RTD system to shorten the reporting time. We implemented the Hualien subnetwork in 1997, and it can report reliable earthquake information more quickly for its monitoring area (Wu *et al.*, 1999). This idea is based on the concept of multiple subnetworks for earthquake early warning purposes as originally proposed by Lee (1993).

We will also study the problem of estimating intensity for areas without actual recordings in order to produce a better and more detailed shake map.

CONCLUSION

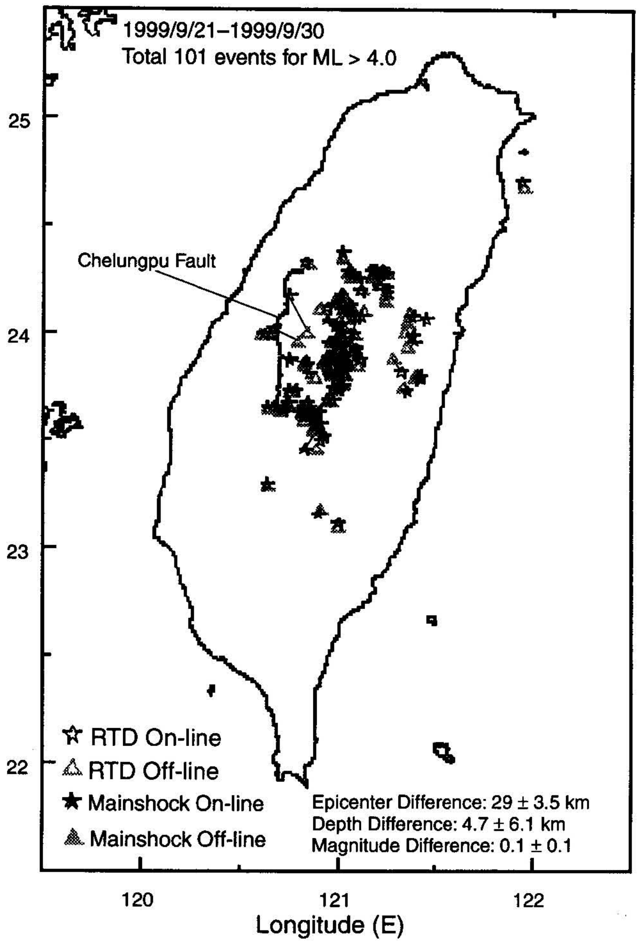
In this article, we reported our experience of rapidly reporting a large earthquake. For a good real-time seismic monitoring system, one must have reliable telemetry, dependable electric power and equipment, simple software, and plenty

```
Intensity Map:
              25N                 24N                 23N                 22N
122E+------/4444-------------------|-------------------|-------------------|---+
    |      444444444444444         |                   |                   |   |
    |     /4444444454444444///     |                   |                   |   |
    |   ///444444444444444/////////                    |                   |   |
    |   ////44444444444444///////////////////          |                   |   |
    |   /////44444444444/////////////////////444444    |                   |   |
    |     ///444444444///////////////////////44444444444                   |   |
    |      4444444444444/////////////////////4444444444443                 |   |
    |      44444444444444/////////////////////444444444443333              |   |
121E|_______4444454444444///////////////////////4444444443333333___________|___|
    |         44444444444////////////////////////////444443333333333       |   |
    |          |  4444445/////////////////////5444444//444333333333333333333333|
    |          |    444//////////////*//66665554444444444444333333333333333333 |
    |          |       ///////////////6666655554444444444444333333333333333333 |
    |          |          ///////////66666555555554444444444433333333       |   |
    |          |              ///////66655555555544444444444433333 3        |   |
    |          |                 ////55555555555554444444444443333         |   |
    |          |                   |//555555555555444454444444444           |   |
    |          |                   |   55555555554454444444                |   |
120E+----------|-------------------|-------------444444|-------------------|---+
Number is intensity, / -> No data
* -> Epicenter
Next map observed data post:
              25N                 24N                 23N                 22N
122E+------.....-------------------|-------------------|-------------------|---+
    |      ...............         |                   |                   |   |
    |     .........5..........     |                   |                   |   |
    |   ...........................                    |                   |   |
    |   .....................................          |                   |   |
    |   ...........................................    |                   |   |
    |     ..........................................4...                   |   |
    |      ...............................................                 |   |
    |      ................................................3.              |   |
121E|_______.....5..............................................___________|___|
    |         .....................................................3       |   |
    |          |  ...........................................................3.|
    |          |    .................*........................................ |
    |          |       ............................................3.......... |
    |          |          ..........................................       |   |
    |          |              ..............5....4..........4......        |   |
    |          |                 .................................         |   |
    |          |                   |..................5.........           |   |
    |          |                   |   ............5.......                |   |
120E+----------|-------------------|-------------......|-------------------|---+
```

▲ **Figure 5.** Preliminary intensity map of the Chi-Chi earthquake delivered by e-mail.

```
Intensity Map:
              25N                 24N                 23N                 22N
122E+------34444-------------------|-------------------|-------------------|---+
    |      444444444444444         |                   |                   |   |
    |     34444444454444444444     |                   |                   |   |
    |   333444444444444444444444444                    |                   |   |
    |   3333444444444444444444444444444444444          |                   |   |
    |   3333344444444444444444444444444444444444444    |                   |   |
    |     3334444444444444444444444555544444444444444444                   |   |
    |      44444444444444444445555555555555555444444444443                 |   |
    |      44444444444444444455555555555555555555444444443333              |   |
121E|_______44445444444444445555555666655555555544444444433333 33___________|___|
    |         444444444444555555666666666665555554444444443333333333       |   |
    |          |  4444445555555566666666666555544444444444333333333333333333333|
    |          |    44444555555566666*66666555444444444444433333333333333333333 |
    |          |      44455555566666666666555544444444444443333333333333333333 3 |
    |          |         45555556666666666555555554444444444433333 33       |   |
    |          |              5555666666555555555444444444444333333        |   |
    |          |                 55555555555555555444444444444 3333         |   |
    |          |                   |5555555555555544445444444444           |   |
    |          |                   |   55555555554454444444                |   |
120E+----------|-------------------|-------------444444|-------------------|---+
Number is intensity, / -> No data
* -> Epicenter
```

▲ **Figure 6.** Preliminary intensity map of the Chi-Chi earthquake produced by the new processing program after the event.



▲ **Figure 7.** About 100 felt aftershocks were also identified by the RTD system automatically in September 1999. Their on-line and off-line locations are shown here with the location of the main shock and the surface ruptures.

of redundancies. We are willing to share our experience with other institutions as our RTD system is "open"—the hardware is available from commercial vendors and most of the software has been published. ◼

ACKNOWLEDGMENTS

We wish to thank Dr. J. K. Chung, Mr. C. H. Jiang, and Mr. N. C. Hsiao for helpful comments and drawing figures. This research was supported by the National Science Council of the Republic of China under Grant No. NSC89-2625-Z-052-015.

REFERENCES

Lee, W. H. K., D. M. Tottingham, and J. O. Ellis (1989). Design and implementation of a PC-based seismic data acquisition, processing and analysis system, *IASPEI Software Library* Vol. 1., Seism. Soc. Am., El Cerrito, CA, 21–46.

Lee, W. H. K. (1993). *A Project Implementation Plan for an Advanced Earthquake Monitoring System*, Research Report of Central Weather Bureau, Taipei, Taiwan, R.O.C., No. 444. Also as U.S. Geological Survey Open-File Report 94-004, 89 pp.

Lee, W. H. K. (editor) (1994). Realtime seismic data acquisition and processing, *IASPEI Software Library* Vol. 1 (2nd Ed.), Seism. Soc. Am., El Cerrito, CA, 285 pp. and 3 diskettes.

Lee, W. H. K, T. C. Shin, and T. L. Teng (1996). Design and implementation of earthquake early warning systems in Taiwan, *Proc. 11th World Conf. Earthq. Eng.*, Paper No. 2133.

Shin, T. C., Y. B. Tsai, and Y. M. Wu (1996). Rapid response of large earthquake in Taiwan using a realtime telemetered network of digital accelerographs, *Proc. 11th World Conf. Earthq. Eng.*, Paper No. 2137.

Shin, T. C. (1998). A preliminary study of the earthquake early warning system in the Taiwan area, *Meteorol. Bull.* 42, 118–134.

Tottingham, D. M. and A. J. Mayle (1994). User manual for XRT-PDB, *IASPEI Software Library* Vol. 1 (2nd Ed,), 255–263.

Wu, Y. M., C. C. Chen, T. C. Shin, Y. B. Tsai, W. H. K. Lee, and T. L. Teng, (1997). Taiwan Rapid Earthquake Information Release System, *Seism. Res. Lett.* 68, 931–943.

Wu, Y. M., C. C. Chen, J. K. Chung, and T. C. Shin (1998). An automatic phase picker of the real-time acceleration seismic network (in Chinese), *Meteorol. Bull.* 42, 103–117.

Wu, Y. M., J. K. Chung, T. C. Shin, N. C. Hsiao, Y. B. Tsai, W. H. K. Lee, and T. L. Teng (1999). Development of an integrated earthquake early warning system in Taiwan: Case for the Hualien area earthquakes, *TAO* 10, 719–736.

Central Weather Bureau
Taipei, Taiwan
ludan@ss2.cwb.gov.tw
(Y.-M. W., C.-C.C., T.-C.S.)

Department of Earth Sciences
University of Southern California
Los Angeles, California
(W.H.K.L., T.-L.T.)

Institute of Geophysics
National Central University
Chung-li, Taiwan
(Y.-B.T.)