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RAPID RESPONSE OF LARGE EARTHQUAKES IN TAIWAN USING A REALTIME TELEMETERED NETWORK OF DIGITAL ACCELEROGRAPHS

T. C. SHIN *, Y. B. TSAI **, and Y. M. WU *

* Central Weather Bureau, 64 Kung Yuan Road, Taipei, Taiwan, R.O.C.

** Dept. of Geophysics, National Central University, Chung-li, Taiwan, R.O.C.

ABSTRACT

A system for rapid response of large earthquakes in Taiwan has been recently implemented by the Central Weather Bureau (CWB). It uses a network of 42 three-component accelerographs with digital streams telemetered to the CWB Headquarters in Taipei via leased telephone lines in real time. Two realtime seismic data acquisition and processing systems are used to achieve rapid detection and location of strong earthquakes in and near Taiwan.

KEYWORDS

Accelerographs, earthquake early warning, earthquake rapid response, seismic alert, Taiwan.

INTRODUCTION

In 1989, a regional, telemetered, digital, short-period seismograph network of 75 three-component field stations was installed in Taiwan (see Fig. 1) using Teledyne Geotech equipment. The sensors are 1 Hz short-period seismometers (Teledyne's S13), and the signals are digitized at 12-bit resolution and telemetered digitally using 4800-baud modems on leased telephone lines to the CWB headquarters in Taipei. The incoming data are processed by Vax 6520/4400 computers with software written by the CWB staff for manual phase picking and earthquake location.

In 1991, a six-year program for strong-motion monitoring was initiated with the goal of installing an equivalent of 1,000 three-component, digital accelerographs in Taiwan. T. L. Teng pointed out in 1992 that CWB should utilize the full 9600-baud bandwidth of the leased telephone lines. Because the telemetered short-period network uses only a 4800-baud band, there is another 4800-baud band available. Teng suggested that by putting a digital accelerograph at each of the short-period station sites, strong-motion data can be telemetered to the CWB Headquarters in Taipei without additional telephone cost.

With this in mind, CWB specified that the digital accelerographs to be purchased must have digital stream output according to the digital seismic telemetry (DST) format developed by E. R. Jensen of the U. S. Geological Survey (USGS) in 1992 (see Lee, 1994a). Since the CWB procurement is via open-bidding, three commercial accelerograph vendors quickly produced such accelerographs at low cost. Acquisition and processing of data telemetered from the accelerographs were jointly developed by CWB and USGS under the co-direction of T. C. Shin and W. H. K. Lee in 1993-94. In the fall of 1994, CWB began the implementation of an automatic, realtime, telemetered network of digital accelerographs in Taiwan. As of January 1, 1996, there are 42 stations in operation, as shown in Fig. 1. Eventually, telemetered digital accelerographs will be placed at every short-period seismograph site. This realtime telemetered network of digital accelerographs is one of the two exploratory earthquake early warning systems being implemented in Taiwan (Lee *et al.*, 1996).

In this paper, we described briefly the scientific rationale, the instrumentation, data processing, and preliminary results.

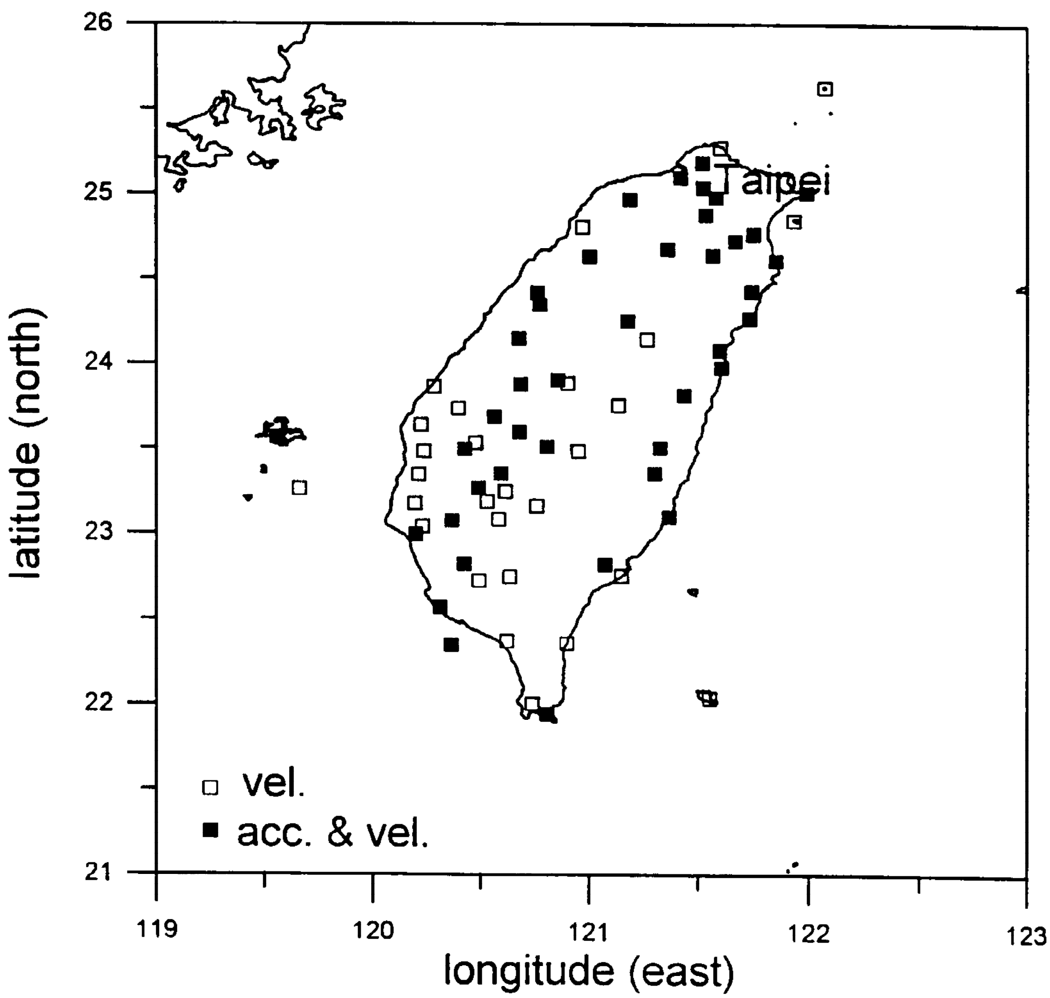

Fig. 1. Map showing station locations of telemetered digital accelerographs and short-period seismographs (solid squares), and of telemetered digital short-period seismographs (open squares) in Taiwan.

SCIENTIFIC RATIONALE

Telemetered regional and local seismic networks for monitoring earthquakes have been in existence for many decades (see, e.g., Lee and Stewart, 1981). Most of these telemetered networks, however, use short-period seismometers so that very small earthquakes can be recorded. Unfortunately, these networks "saturate" for larger earthquakes and the recorded waveforms are "clipped", so that their usage is limited to mostly their first P-arrivals and first P-motions. In order to record strong earthquakes on scale, strong-motion accelerographs were developed and deployed mostly for engineering purposes. Furthermore, the earlier accelerographs are self-recording instruments, requiring a visit to the site for data retrieval.

With the advance of modern digital accelerographs and personal computers, a realtime telemetered network of accelerographs can be implemented. As a result, rapid response of large earthquakes can be achieved with critical information, such as maximum ground acceleration, available quickly for engineering assessment of potential damage of man-made structures. By shortening the response time, an earthquake warning system based on a telemetered network of accelerographs can be implemented to minimize earthquake damage (Chung *et al.*, 1995; Lee *et al.*, 1995; 1996).

INSTRUMENTATION

A modern digital accelerograph with digital data stream output is used at the field site. In the present case, Model A900 made by Teledyne is used, although equivalent accelerographs by Kinemetrics and Terra Tech can also be used interchangeably. A digitization rate of 50 samples per channel per second is used in order to utilize the remaining 4800-baud band of the leased telephone line. Higher digitization rates of up to 200 samples per channel per second are available on the modern digital accelerographs and we will explore their use in the future when faster communication on telephone lines becomes available.

A block diagram of the hardware used for the instrumentation is shown in Fig. 2. Two IBM-compatible PC systems are used for data acquisition and processing. One system is for continuous recording, and the other for trigger recording. The reason for doing this is for redundancy, because it is much less likely that both recording systems fail at the same time.

The hardware cost is inexpensive. A modern digital accelerograph costs about \$ 6,000 (US) in large quantities. An IBM-compatible PC data acquisition and processing system costs about \$ 10,000 (US). The software required has been published (Lee, 1994b; 1994c) and costs \$ 500 (US). Telemetry can be implemented either by using leased telephone lines or FM radios (costing about \$ 2,000 (US) for a pair).

DATA PROCESSING

A flow-chart for the data processing is shown in Fig. 3. For rapid response, the incoming data is processed by the XRTPDB program (Tottingham and Mayle, 1994). Whenever certain trigger criterion is met, the digital waveforms are analyzed by two programs (one written by the CWB team, and the other written by the USGS team) for automatic phase picking and earthquake location. The reason to have two independently written programs is to minimize the chance for making software blunders. To avoid false alarms, results from these two programs must agree within certain limits and then an announcement is broadcasted using the communication port to send the message via the Internet.

The incoming data is also processed by a second system. The data is continuously recorded by the DIGICAP program (Mayle, 1995) at 1-minute intervals per file. Each one-minute file is then subjected to automatic triggering, phase picking, earthquake location, and PGA calculation. The results are made into an earthquake report for official announcement in the traditional manner.

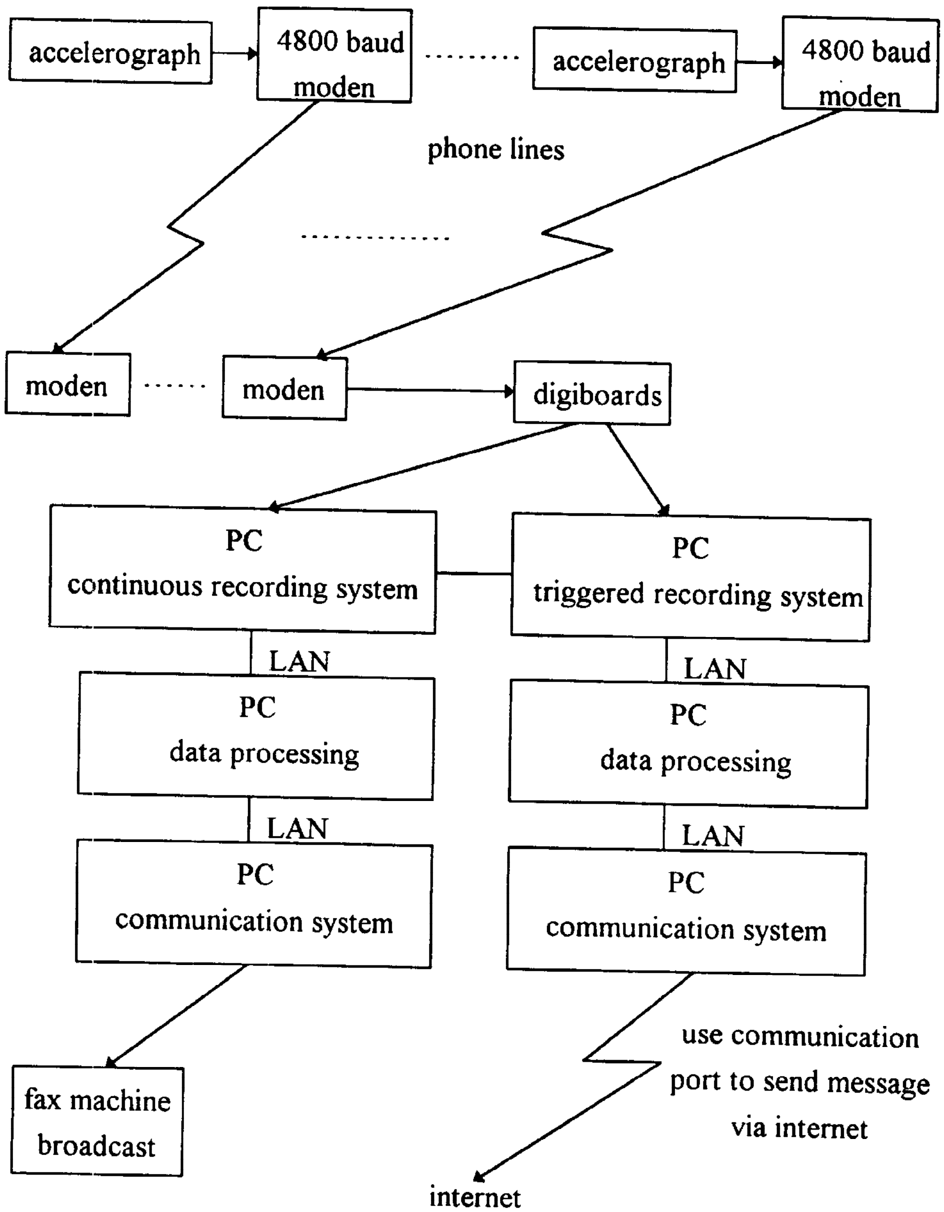

Fig. 2. A block diagram showing the hardware of the realtime telemetered network of digital accelerographs in Taiwan.

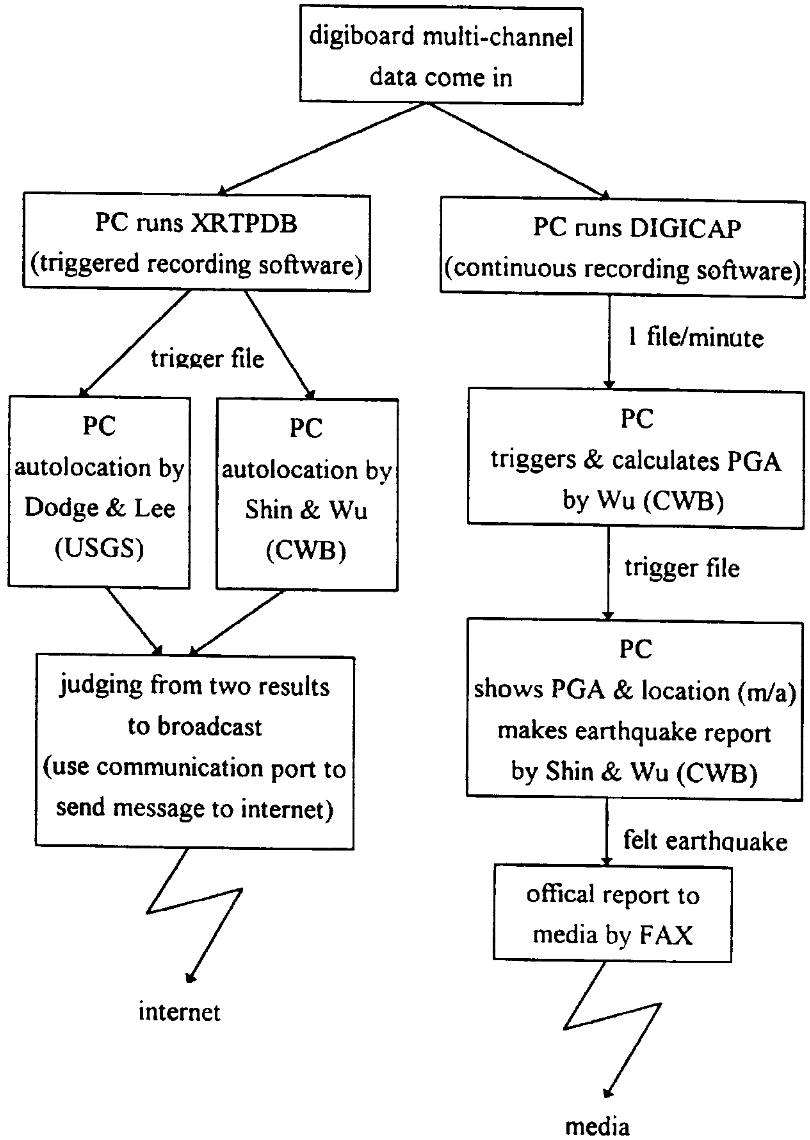

Fig. 3. A flow chart showing the data processing of the realtime telemetered network of digital accelerographs in Taiwan.

PRELIMINARY RESULTS

Fig. 4 shows the automatic rapid location of earthquake of June 25, 1995 (06:59:07.09 UTC) with the recorded waveforms (only vertical components are shown here). The final location using the telemetered short-period seismograph network with manual phase picking is very similar to the automatic location. In terms of the time spent, the automatic location earthquake report was generated by the telemetered accelerograph network in about 4 minutes, whereas the standard report based on the telemetered short-period seismograph network took about 30 minutes. Further improvement on the telemetered accelerograph network for a more rapid response is possible, and we hope to have a preliminary location within 1 minute and the final location within 2 minutes for the telemetered accelerograph network.

A map showing the epicenters of 104 earthquakes located by the automatic realtime network of digital accelerographs in Taiwan from January 1, 1995 to September 30, 1995 is shown in Fig. 5. Comparison of epicenter and focal depth of 17 larger earthquakes from this period as determined by the automatic accelerograph network versus the short-period seismograph network with manual phase picks is shown in Fig. 6. The average difference in epicenter location is about 4 kilometers, the average difference in focal depth is about 3 kilometers.

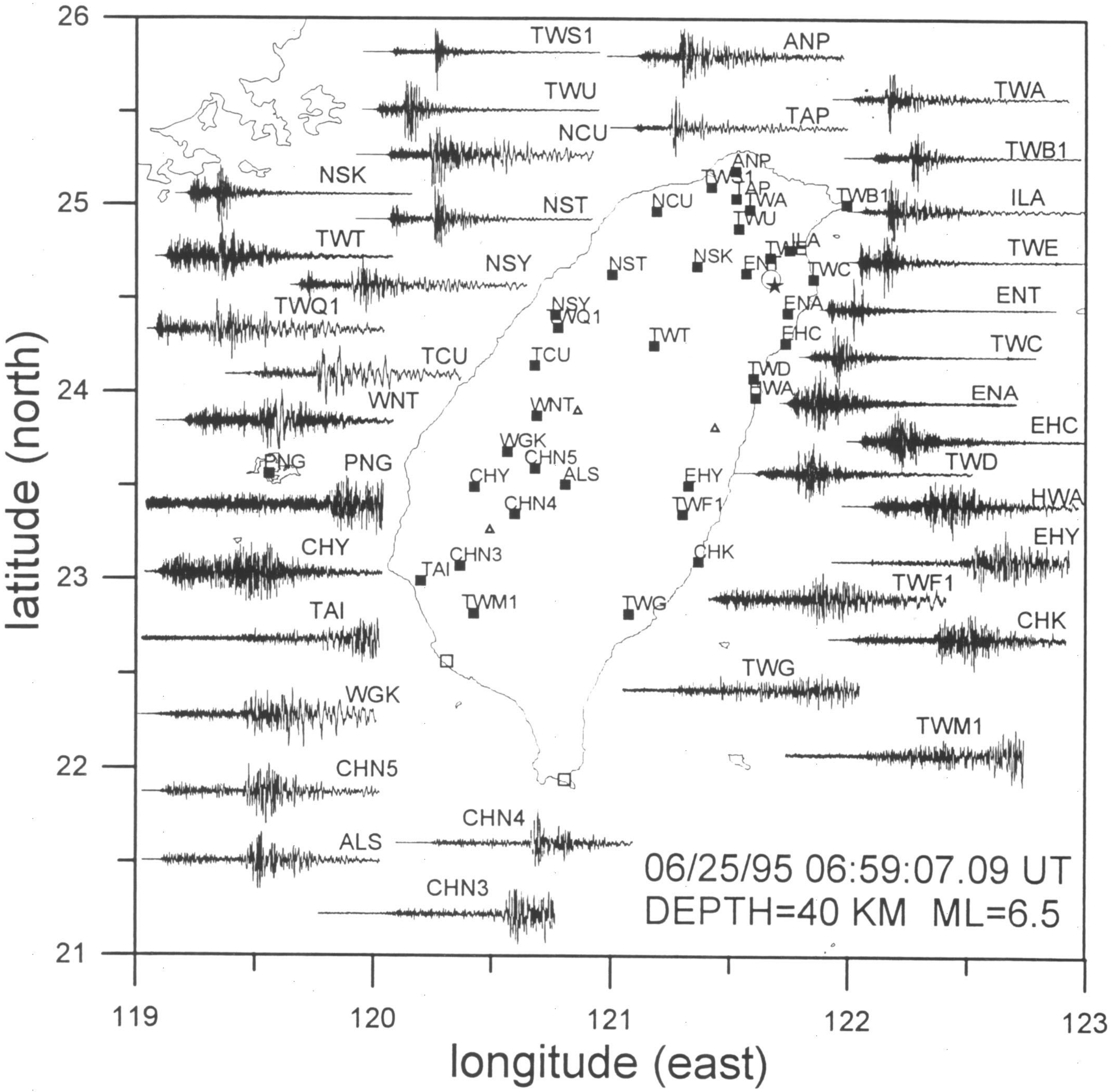

Fig. 4. Automatic rapid location of earthquake of June 25, 1995 (06:59:07.09 UTC) by the realtime telemetered network of digital accelerographs ("star" symbol). The "open circle" symbol is the final earthquake location based on the telemetered network of digital short-period seismometers with manual phase picks. The "open square" symbol indicates a station recording the event with too low amplitudes, and the "triangle" symbol indicates a station with failed telemetry.

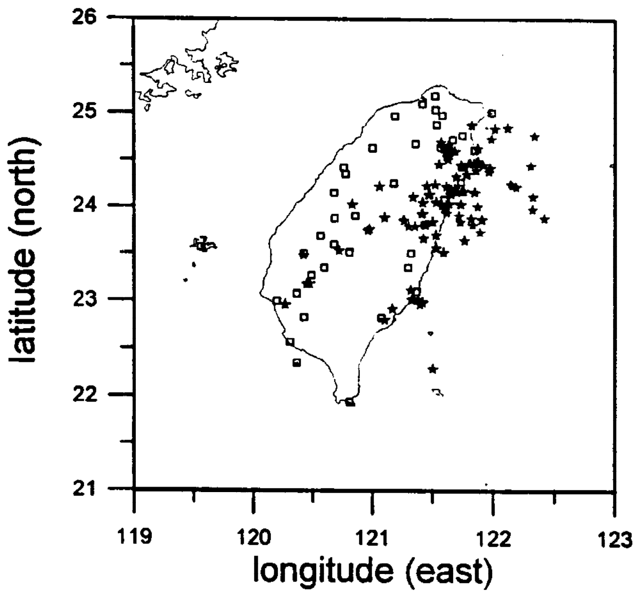

Fig. 5. A map showing the epicenters of 104 earthquakes located by the automatic realtime network of digital accelerographs in Taiwan from January 1, 1995 to September 30, 1995.

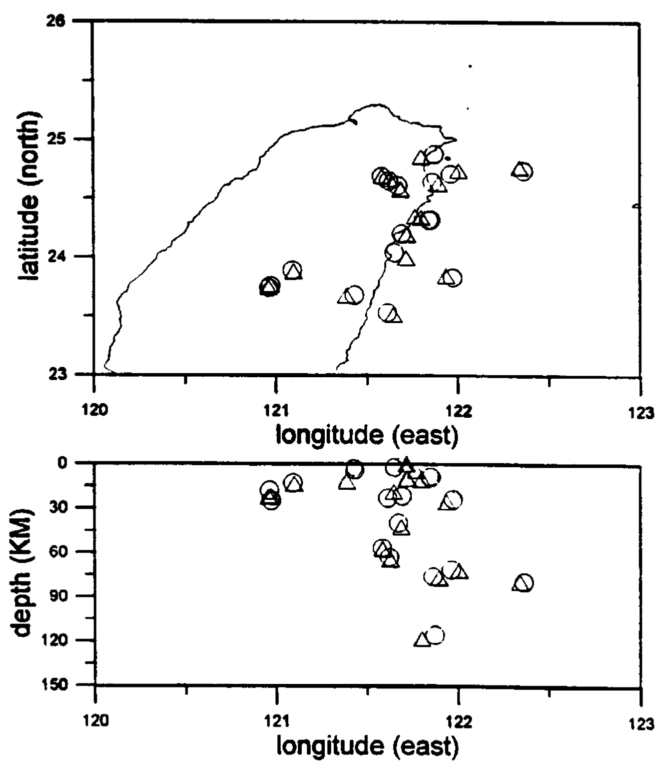

Fig. 6. Comparison of epicenter and focal depth of 17 larger earthquakes from January 1, 1995 to September 30, 1995 as determined by the automatic accelerograph network (△) versus the short-period seismograph network with manual phase picks (○).

DISCUSSION

We have implemented an inexpensive, realtime, telemetered accelerograph network in Taiwan, which is capable of rapid response to large earthquakes. This is possible because: (1) functionally equivalent modern digital accelerographs with digital stream output are available from three vendors, (2) existing leased telephone lines for the telemetered short-period seismograph network have leftover capacities for an additional 4800-baud transmission, and (3) a common software platform has been established by the IASPEI Software Library published jointly by the International Association of Seismology and Physics of the Earth's Interior (IASPEI) and the Seismological Society of America (SSA). We plan to submit our software for publication in the IASPEI Software Library in the near future, so that others may use or modify it.

To minimize earthquake hazards, the society should have capability to respond to damaging earthquakes quickly. Our realtime telemetered accelerograph network can be readily implemented by anyone because all hardware components are available from two or more commercial vendors (thus much lower prices than if they are available from only one vendor), and the IASPEI software required is available through SSA for a small token cost.

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