Paper:

Earthquake Early Warning Technology Progress in Taiwan

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The dense real-time earthquake monitoring network established in Taiwan is a strong base for the development of the earthquake early warning (EEW) system. In remarkable progress over the last decades, real-time earthquake warning messages are sent within 20 sec after an event using the regional EEW system with a virtual subnetwork approach. An onsite EEW approach using the first 3 sec of P waves has been developed and under online experimentation. Integrating regional and onsite systems may enable EEW messages to be issued within 10 sec after an event occurred in the near future. This study mainly discusses the methodology for determining the magnitude and ground motion of an event.

Keywords: earthquake, early warning, P wave, ground motion

1. Introduction

Geologically, Taiwan is located on the western circum-Pacific seismic belt which is one of the most active seismic regions in the world. In the last century, nearly a dozen destructive earthquakes have occurred in Taiwan, including the Meishan earthquake in 1906 ($M_L = 7.1$, 1,258 death), the Hisnchu-Taichung earthquake in 1935 ($M_L = 7.1$, 3,276 death), and the Chi-Chi earthquake in 1999 ($M_L = 7.3$, 2,455 death). Since the occurrence of earthquakes can not reliably predicted by current technology, progress is being made globally in the research and development of the earthquake early warning (EEW) system [1–5]. With advances in seismic instrumentation and communication networks, EEW is becoming a practical tool for reducing casualties and damage from major earthquakes [6–9]. Two major approaches are being applied in the EEW development:

1. Regional warning, or front detection, uses real-time earthquake monitoring networks to determine the earthquake location, magnitude, and ground-motion distribution and to send EEW messages to regions far from the epicenter.
2. Onsite warning uses onsite seismometers to detect P waves and estimate the earthquake magnitude and the strong onsite motion [10].

Regional warning provides more reliable EEW messages but requires longer processing time. Onsite warning complements regional warning to speed up EEW processing and to reduce blind zones where no onsite warnings are received. Both approaches have progressed markedly in Taiwan [11], but the EEW system is still undergoing online testing and has not been applied for disaster reduction practically.

2. Real-Time Strong-Motion Network in Taiwan

In the dense earthquake monitoring network of 688 free-field strong-motion stations constructed in the Taiwan Strong-Motion Instrumentation Program (TSMIP), currently 109 are telemetered for real-time monitoring as shown in **Fig. 1**.

A three-component force-balanced accelerometer with a 16-bit resolution and a full dynamic range of $\pm 2g$ was installed for each station. The real-time data are transmitted to Taipei headquarter via dedicated telephone lines in 50 Hz. This network serves as a base for developing the earthquake Rapid-Reporting System (RRS) and the EEW system [12–15]. The RRS, developed and operated by the Central Weather Bureau (CWB) since 1995, provides such useful information as earthquake location, magnitude, and ground-motion distribution one minute after an earthquake occurs. EEW provides warnings to distant urban areas from the epicenter with a few seconds to several dozen seconds of lead time before destructive S waves arrive. With a short lead time, automatic emergency measures should be preprogrammed and implemented to reduce the potential loss due to strong shaking.

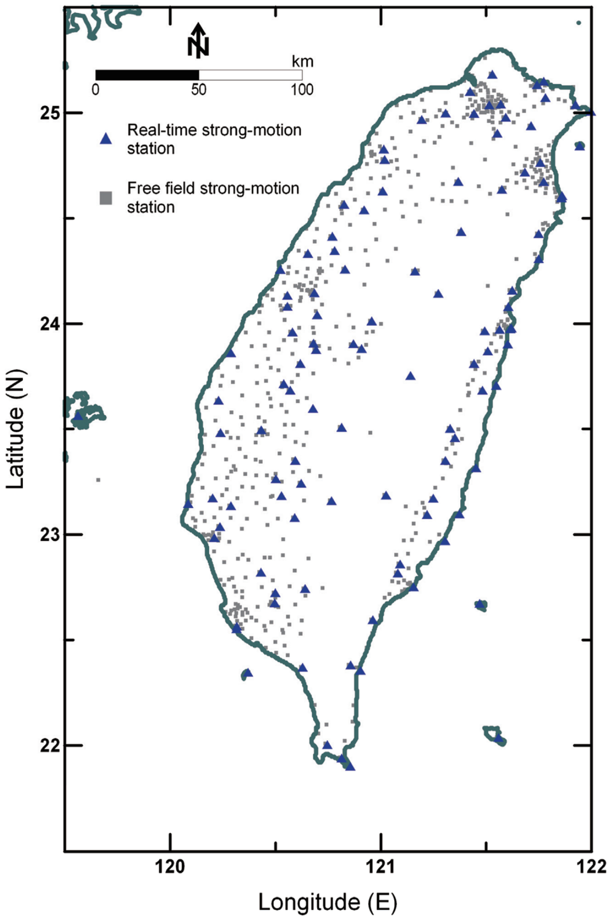

Fig. 1. Distribution of free-field strong-motion stations and real-time stations.

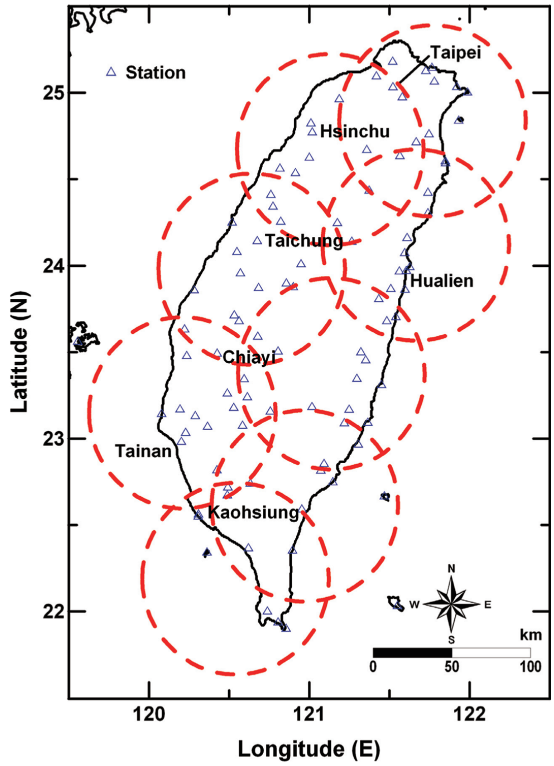

Fig. 2. Virtual subnetwork of 109 real-time stations.

3. Virtual Subnetwork Approach

3.1. Methodology

The Hualien offshore earthquake in November 15, 1986, magnitude (M_w) 7.8, with an epicenter 120 km from metropolitan Taipei, caused severe damage due to basin amplification and serves as a lesson in developing the regional EEW approach to reduce disaster effects. Obtaining the EEW information within 20 sec after an event occurred could ensure a lead time of 20 sec for Taipei before strong shaking starts. With this in mind, the Virtual Subnetwork (VSN) approach based on the regional approach has been developed and applied in the practical EEW operation since 2001 [2], as shown in **Fig. 2**.

Once the real-time monitoring network is triggered, the VSN data stream will be recorded for 10 sec after the first P-wave arrives. An average local magnitude (M_{L10}) is determined from the 10-second waveform among VSN stations. M_{L10} determination follows the conventional calculation of the local magnitude (M_L) using the peak simulated Wood-Anderson amplitude among vertical and horizontal components. However, earthquake magnitude (M_L) cannot be determined in this time frame because of the incomplete shear waveform recorded at some stations. A correlation relation was used to obtain M_L from M_{L10} [16]:

$$M_L = 1.28 \times M_{L10} - 0.85 \pm 0.13 \quad (1)$$

3.2. Online Experiments

The on-line experiments for EEW capabilities of the VSN have been proceeding since 2001. To verify its performance, we select earthquakes detected by the VSN until 2008 using the following criteria:

(1) $M_L > 4.5$

(2) Focal depth < 35 km

(3) Earthquakes occurring inland or within 50 km of the island

The 255 earthquakes detected achieved a 90% trigger rate, for which we compared automatic and manual processing results. The performances of automatic locations are shown in **Fig. 3**. Latitudinally, 60% of earthquakes were located within 2 km and 80% within 4 km; longitudinally, 50% located within 2 km and 70% within 4 km, and for depth difference, 60% were located within 4 km.

The magnitude determined automatically by the VSN and manually by CWB earthquake catalogs are compared in **Fig. 4**, showing considerable consistency for earthquakes up to $M_L = 6.5$ with a standard deviation of 0.28. For larger offshore earthquakes, however, magnitude was underestimated by the VSN due to the limited waveforms used. The March 31, 2002, Hualien offshore earthquake, shown in **Fig. 4**, is a typical case. As shown in **Fig. 5**, the average reporting time for the entire network by the RRS is within 50 sec in these two years. Using fewer stations with the VSN effectively shortens the average reporting time to within 20 sec. The VSN performance for determining hypocenter location is stable and acceptable for early warning targeting disaster reduction.