Robust and Reliable Earthquake Early Warning System for Engineering

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The Japan Metrological Agency (JMA) has conducted formal operation of providing earthquake early warning (EEW) information to organizations for high-degree application since 2006. It issues basic information such as magnitude and source location, and it is necessary for users to establish post-process systems and to estimate shaking intensity and arrival time at their own risk. We have developed a warning system using the EEW information for construction sites, buildings and important facilities, utilizing our engineering knowledge and experience as a civil engineering and construction company (Kanda et al., 2006). However, some problems remain with the EEW information from JMA, such as estimation error, false alarms and alarm timing. Our research is focused on two issues: 1) enhancing the accuracy of seismic intensity estimation and 2) extending the interval from issuance of warning to arrival of strong tremors on a user basis. The most important point in solving these issues is to use site-specific data and information, and to customize the EEW system at each site.

The EEW system uses seismic intensity in JMA scale as an alarm and control trigger, which is the most commonly used index of ground motion in Japan. A lot of seismic intensity data covering more than 300 years are available in Japan. They include not only formal seismic intensity data released by JMA but also historical earthquake data evaluated from earthquake damage written in historical documents (e.g. Usami, 2003). First we analyze intensity data near the site to evaluate a mean attenuation relationship and intensity residuals depending on the hypocenter. Secondly, we investigate the soil profile of the site and modify the attenuation relationship taking account of differences between surface soil amplifications at the site of interest and its nearest observation station. We can thus more accurately estimate the intensity by combining the mean intensity obtained from the attenuation relationship and intensity residuals. We find that the RMS of estimation error is reduced to half by this method compared to the commonly used procedure.

In general, the observation stations for EEW information from JMA near an epicenter can pick up P-wave arrival and send the analyzed information to users in far-field before the arrival of strong shaking. For near-field earthquakes, however, the EEW information may not reach the user before the S-wave with strong shaking. This is because the EEW system takes several seconds to process and transmit the information and S-waves propagate faster than EEW information from JMA near the epicenter. In Japan, it is well known that there are many active faults in large urban areas such as Tokyo, Nagoya and Osaka. Thus, EEW information from JMA may be useless in such events. The concept of "on-site warning" (OSW) (Wu and Kanamori, 2005) can detect P-wave arrival using seismometers installed at the site using the automatic earthquake recognition procedure and estimate the intensity of impending strong shaking in a few seconds. The intensity estimation method is based on the empirical amplitude relationship between P and S waves. The warning can be issued before S-wave arrival taking advantage of the difference between the velocities of P and S waves.

The OSW is faster than EEW information from JMA for earthquakes within about 60km epicentral distance. In particular, within about 30km, the EEW information form JMA may not be transmitted before S-wave arrival. However, EEW information from JMA is more effective for distant huge interplate earthquakes such as the Tokai earthquake. Thus, the combination of OSW and EEW from JMA covers each other's shortcomings and can be applied to earthquakes covering a wide range of distance. The proposed integrated system consists of three parts: 1) a receiver of the EEW information from JMA, 2) an on-site warning device and 3) a server for information integration which contains combination logic to issue warning signals. Each part is assembled into a small box-type computer. It is designed especially to control important facilities and equipments.

The Iwate-Miyagi inland earthquake (MJ7.2, depth 8km) occurred in the northern part of Japan on June 14, 2008, and 26 people were dead or missing. The Isawa Dam construction site is located near the epicenter as shown in Figure 1(a). The EEW information from JMA has been received at the site since the end of 2007. Unfortunately, it was sent to the site after the arrival of the S-wave in the main shock. It was indicated that it was not very effective for such a near earthquake. Since the aftershocks were quite active, especially in the vicinity of the site, we installed the OSW system and a normal 3-component seismometer for practical use as well as validation of the system. The system can issue an alert signal from EEW or OSW, whichever comes first. The safety and announcing systems installed at hazardous places at the site can receive the signal and start to operate instantaneously. One second after P-wave pick-up is used for the estimation of intensity, considering the characteristics of targeted near-field events whose S-P time is quite short. Figure 1 (b) compares the measured and estimated intensities of all the events. It is indicated that intensity can be predicted quite accurately using the OSW system. Site workers may not notice an earthquake until its shaking level becomes quite strong due to the vibration at the construction site. It is therefore important to transmit the occurrence of an earthquake as soon as possible, even if it is after P-wave arrival. This is effective not only in keeping workers safe but also in raising workers' awareness of disaster prevention.

Furthermore, we have developed the integrated system to apply to critical facilities such as precision machine and semiconductor factories. Once their manufacturing lines are shut down, it takes much time and cost to recover. They need high robust and reliable system for control. There are several types of equipments and devices in such facilities from the view point of triggering shaking level. For example, manufacturing devices for microfabrication should be shut down even though little shaking level. In those cases, low seismic intensity is used for its threshold level. The OSW is most effective for the case, which consists more than three P-wave pick-up sensors for system redundancy. It is not necessary to use EEW information from JMA considering reliability. Others should be shut down in case of possibility of their own damage. Large seismic intensity is used for their trigger level, and the combination logic of the integrated system is effective. Since most of equipments and devices may be shut off in a few second in case of emergency, the issuance of control signal may wait until the signal from OSW for far events such as interplate earthquakes. The most important thing is to select appropriate EEW information and logic for each equipments and devices.

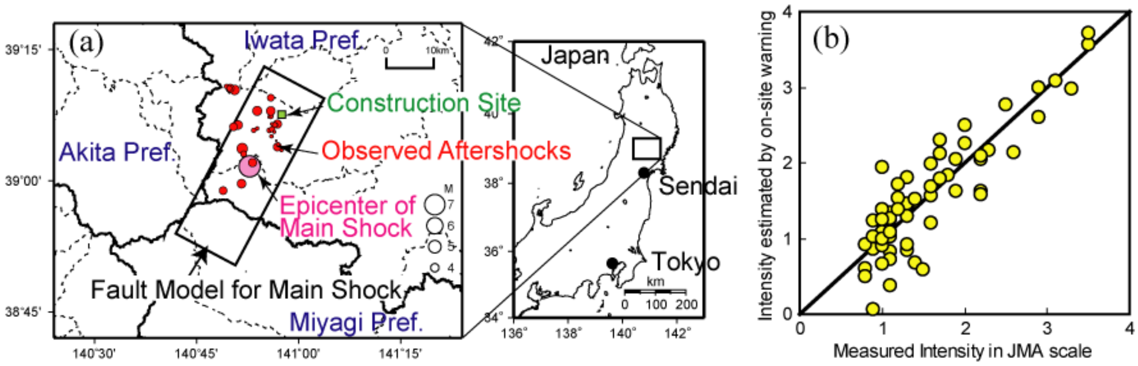

Figure 1 Application of the integrated system to a construction site in the fault zone of the 2008 Iwate-Miyagi inland earthquake. (a) Map of epicenters and construction site, (b) Estimated intensity versus observed intensity.