Proposal of earthquake early warning system estimating damage assessment of buildings and structures in metropolitan area

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An earthquake of magnitude 5.2 with focal depth of 57 km occurred beneath Tokyo bay on September 12, 2015. Shaking intensities by this earthquake are ranging from 2 to 5- in a small areas of nearly same hypocentral distances. This observation suggests that it is almost impossible to predict accurate shaking intensity by the present EEW system operated by JMA, which determines hypocenters and magnitude and transmits them for the estimation of shaking intensity at user’s location, because the spatial large change in observed shaking intensity is originated to the existence of very strong lateral heterogeneity in the site amplification factors and the complexed deep structure but not in the estimation errors of hypocenter location or magnitude. We proposed to install a new EEW system specialized for the metropolitan areas.

2. Why we need a new EEW system specialized for metropolitan areas

1) The present EEW system has about 30 km of blind zone in focal areas where most of earthquake damages occur, owing to the limitation of the number of seismic stations. 2) There are large estimation errors of seismic intensity owing to the large lateral heterogeneity of site amplifications. It is shown that estimated values of site amplifications with 250m mesh do not able to greatly decrease estimation errors. 3) Each building has different strength and the natural period. Estimation of earthquake damage should be done based on the response of building to the earthquake shaking. 4) Because the earthquake damages are huge in metropolitan areas, which is limited in a small area in general, specialized earthquake early warning system for urban area seems to be effective.

3. Proposed EEW system in metropolitan areas

1) Install seismometers with an interval of several hundred meters which send observed real-time waveform data to their data center. 2) Register data of user’s buildings or structures to the data center, such as the location, dumping factor, and strength of buildings. 3) At a time of strong shaking, the data center predicts shaking intensity using real-time P wave data transmitted from the closest station. It also calculates response of buildings associated with the ground shaking and estimates damage assessment of individual buildings. 4) The data center sends these computed results to each owner of building or users so as to do something for the mitigation of earthquake damage. Since there are seismic stations closed to each building in the proposed EEW system, we can consider that shaking at each building are approximated by the shaking recorded at the closest station. Therefore, we can consider that the proposed system can issue accurate EEW information to individual users. It is also pointed out that shaking intensity is predicted by the use of near-by stations, there are almost no blind zone.

4. Effectiveness of the proposed system

We checked the accuracy of shaking intensity estimation by the proposed system. We estimated values of shaking intensity using 1800 P wave data recorded by K-net station and found that the average estimation error of shaking intensity is 0.5. Since the shaking intensity is predicted by the use of waveform data at near-by station in the proposed system, we are able to consider that the average estimation error obtained by K-net data is approximated to that by the proposed system. We also calculated estimated errors of shaking intensity estimation from the attenuation equation with putting parameters of hypocenter location and magnitude used in the present EEW system. The average error in this case is 0.91, which is much larger than the value of 0.51. The proposed system compute the response of each building associated with ground shaking. it may be possible to issue warning about the fall down of unfixed furniture.

Keywords: Earthquake early warning, metropolitan area, proposal

Real Time Strong Motion Prediction by High Dense Seismic Observation Network

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Most of the damages by shallow inland earthquakes are concentrated on the fault and surrounding areas. For instance, the highest level of intensity by an event of M7 class is often located within an area of 50-60 km from the source area. It is also noted that the shaking duration in the source area is approximately of 20-30 s. However, the current Earthquake Early Warning (EEW) in Japan has the difficulty to reach the strong motion prediction information in this area. In this study, we argue the possibility of using the peak ground accelerations (PGAs) and peak ground velocities (PGVs) obtained from P-wave amplitude for EEW. We investigated PGAs and PGVs in time step of 0.1 s (10 samples) of P-waves using 100,000 records from 2,000 events. The data were obtained from K-NET of National Research Institute for Earth Science and Disaster Prevention (NIED) from 1996 to 2016. Events were located in inland and coast regions, and records with a maximum epicenter distances of 20 km were included. In our results, the amplitude ratio of PGAs and PGVs obtained from S-wave to those obtained from P-wave has approximately a value of 5.9, which is close to the theoretical value (i.e., value of 5). The amplitude ratio shows a strong correlation with the time step when reach 0.5 s and follows, measured from the onset of P-wave. The PGAs and PGVs amplitude obtained from short period of P-waves are likely proportional to the scale of destruction, which it makes possible to estimate the microscopic seismic source parameters such as the inhomogeneity, strong motion generation area (i.e., asperity size), and the stress drop in the source area. We discuss the changes of the apparent velocity with different azimuthal angles of the source and surrounding areas. We also discuss the optimum network distribution for EEW using the proposed method. This study shows the potential of strong motion prediction obtained from short-period amplitudes by densely distributed seismic networks.

Keywords: Earthquake Early Warning , microscopic seismic source parameters , optimum network

Rapid Magnitude Estimation in Earthquake Early Warning with Seismogeodesy

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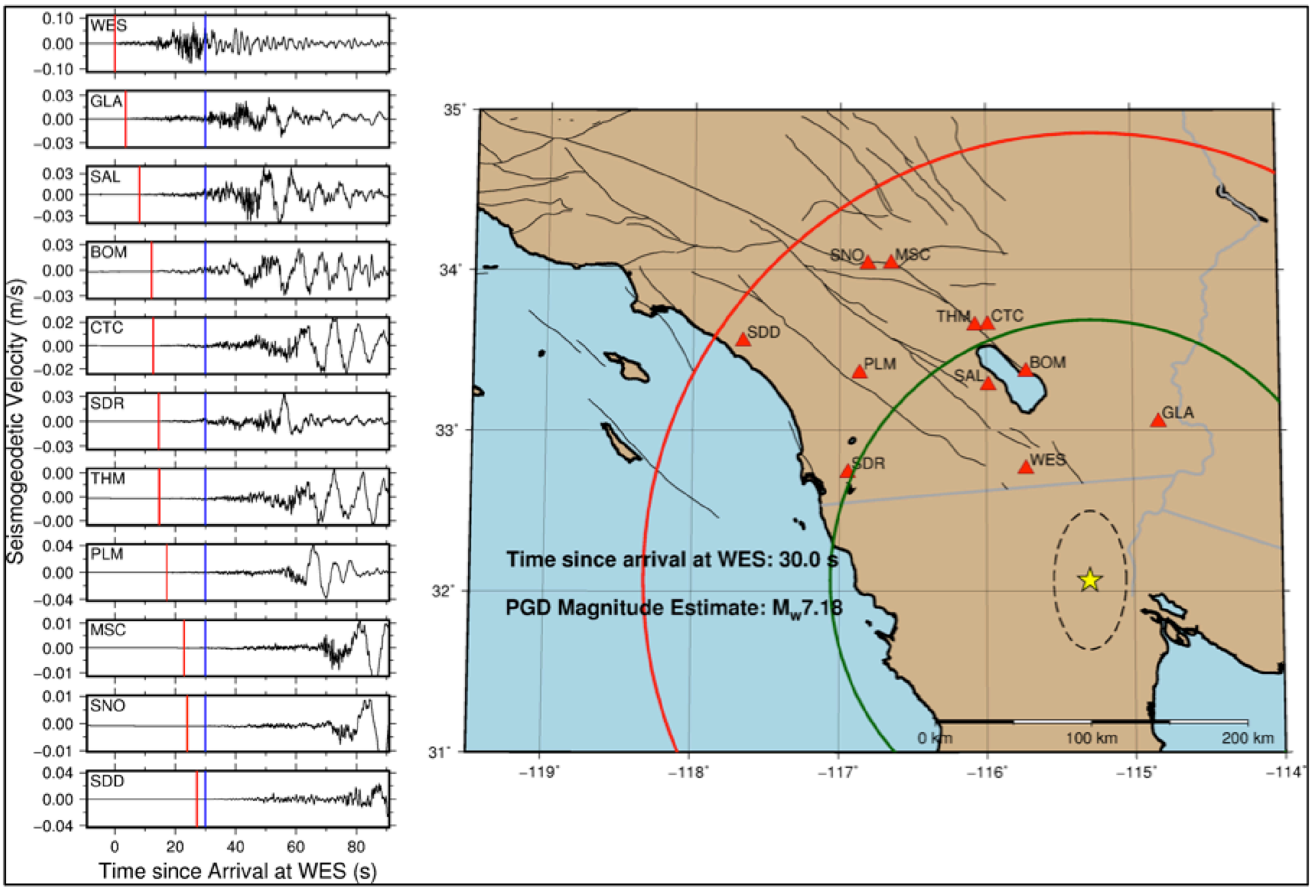
Earthquake early warning (EEW) is critical to reducing injuries and casualties in case of a large magnitude earthquake. Fault systems often coincide with populous cities, thus we require a P-wave detection method for effective early warning. Such a system must rely on near-source data to minimize the time between event onset and issuance of a warning. Current early warning systems typically rely on seismic instruments (seismometers and accelerometers). Global Navigation and Satellite System (GNSS) instruments are starting to be deployed, but are not yet fully exploited. Seismic instruments experience difficulty maintaining reliable data within close epicentral distance of large events. Large motions can exceed the dynamic range of broadband seismometers, and accelerometers conflate rotations and translations, causing spurious translational recordings that obscure the true nature of shaking. Moreover, the relation between ground motion amplitude and earthquake magnitude “saturates” for large earthquakes, causing magnitude underestimation that proved catastrophic for the 2011 M_w9.0 Great East Japan earthquake and resulting tsunami [*Hoshiba and Ozaki*, 2014; *Yun and Hamada*, 2014]. GNSS instruments capture the long period motions and have been shown to produce robust estimates of the true size of the earthquake source. However, GNSS alone is not precise enough to record first seismic wave arrivals, which is an important consideration for issuing an early warning. Our approach is to optimally combine direct measurements from collocated GNSS and accelerometer stations using a Kalman filter [*Bock et al.*, 2011] to estimate broadband coseismic displacement and velocity waveforms with complete spectral recovery from the static offset to the accelerometer Nyquist frequency, regardless of the intensity of shaking. This approach, referred to as seismogeodesy, includes the long period and static offset without interference from accelerometer errors or saturation for large magnitude events and, unlike GNSS alone, is precise enough to detect P-wave arrivals. We demonstrate the advantages of seismogeodesy for earthquake early warning via retrospective simulated real time examples for earthquakes in the western U.S., Japan and Chile. For event detection and location we use the seismogeodetic velocity. We also discuss the sensitivity of hypocenter location as a function of the distribution of monitoring stations near the source and demonstrate rapid magnitude scaling relationships [*Crowell et al.*, 2013; *Melgar et al.*, 2015]. The prototype early warning system developed at Scripps is being applied to local tsunami warning by the U.S. National Oceanic and Atmospheric Administration’s Tsunami Warning Centers. The critical input for tsunami warning is a rapid estimate of magnitude.

Keywords: earthquake early warning, seismogeodesy



Left: Seismogeodetic velocity waveforms at 11 GPS/seismic stations sorted by order of P-wave detection. Continuous blue vertical line denotes current epoch. Preceding red lines indicate when P-wave was detected from seismogeodetic velocity at each station.
Right: Once 4 stations have triggered, an estimate of the hypocenter can be made, denoted by the yellow star with one-sigma error ellipse on map. Hypocenter is updated with P-wave arrivals at additional stations. Propagation of P- and S-waves are shown by the partial circles (red and green, respectively), with the S-wave trailing the P-wave. In this scenario, it would take the S-wave front about 80-90s before arriving in the heavily populated areas of Riverside and Los Angeles Counties. Magnitude is estimated through Peak Ground Displacement (PGD) scaling relation using seismogeodetic displacement. Shown here is a frame 30s after P-wave detection at the first station.

Improvement of the P-wave detection method in real time by using kurtosis statistics

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The current the earthquake early warning system uses ST/lT algorithm (Allen, 1978), to detect seismic waves. Recently, Saragiotis et al,(2002) suggested a method to identify P-waves by using kurtosis statistics which was more robust than the STA/LTA. The method was used to create seismic catalogs, and designed for off-line process. To apply this method for an earthquake early warning, we need a modification to make the calculation acausal and enable the real-time processing by getting a little creativity with data length and noise rejection. Here, we propose a real-time P-wave detection method using kurtosis. an d We use strong motion records for earthquakes which record seismic intensity greater equal to 6 in the JMA scale between April,2005 and July, 2015. We selected the records with hypocentral distance within 100km. We tested various P-wave detection algorithm; STA/LTA, off-line kurtosis algorithm(Baillard et al,2014)), and real-time kurtosis algorithm (this study). We compared manual detected P-wave arrival times with P-wave arrival times detected by those methods, and evaluated the performance of our method. As a result, we can determine P-wave arrival time more precisely and earlier than STA/LTA and manual pick time by using kurtosis(this study) because our method is more robust and more sensitive to small changes in amplitude. Our approach will contribute to increase the accuracy of location determination of earthquakes, and improve the estimation of the shaking intensity of earthquake early warning.

Keywords: kurtosis, P-wave picking, earthquake early warning

Reduce False Alarm Due to Non-Earthquake Events for On-Site Earthquake Early Warning System in Schools

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An on-site earthquake early warning system (EEWS) can provide more lead-time at regions that are close to the epicentre of an earthquake since only seismic information of a target site is required. The on-site system extracts some P-wave features from the first few seconds of vertical ground acceleration of a single station and then predicts the intensity of the forthcoming earthquake at the same station according to these features. However, the system may be triggered by some vibration signals that are not caused by an earthquake or by interference from electronic signals, which may consequently result in a false alarm at the station. In order to reduce false alarms caused by non-earthquake events and at the same time keep earthquake alarms, an approach based on Support Vector Classification (SVC) and Singular Spectrum Analysis (SSA) is proposed. The established SVC model are employed to classify the vibration signals and then a SSA criterion is added for identifying earthquake events that are classified as non-earthquake events by the SVC model with increased accuracy. The proposed approach is verified by using data collected from earthquake early warning stations of the National Center for Research on Earthquake Engineering (NCREE). The results indicate that the proposed approaches effectively reduce the possibility of false alarms caused by unknown vibration events.

Keywords: On-Site Earthquake Early Warning, False Alarm, Non-Earthquake Events

Site Effective Earthquake Early Warning Outreach

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The earthquake early warning (EEW) concept is getting increasingly prevalent and somewhat replacing the expectation for earthquake prediction. An extensive real-time monitoring and EEW system installed in a wide region can detect an earthquake within seconds, and immediately issue alerts to affected areas through public media. On-site EEW systems developed for specific facilities may also detect an event and enable the facilities to take necessary actions before strong hits. Having timely warnings come accurate, EEWs can mitigate economy losses and save many lives. However, there are issues regarding EEWs provided by a big network and on-site monitoring systems that specialists in seismology know clearly, for which the general public has to be educated.
A big EEW system estimates seismic intensities using a conventional ground motion prediction equation (GMPE) as a function of distance that are not always in agreement with observed intensities. The actual intensity distributions in felt earthquakes show short-wavelength variation. The frequency band in which seismic intensities are determined is from about 0.5 to 10 Hz, and thus the response of subsurface structure is significant in the estimation. The ground motion at a specific site should be evaluated not only by a GMPE and a site amplification factor, but also accounting for the incident azimuth of incoming seismic waves. We have some exploratory studies to illustrate the local subsurface effects using data recorded by the dense network of strong motion instruments (with a station interval of less than 1.5 km) in Yokohama City. We used several small earthquakes of a similar magnitude (M~4.5) that are located at an epicentral distance of ~60 km from the network and provide different incident azimuths of incoming waves to the network. The observed ground motions at the stations show variations among the events reflecting 3D structural effects along the propagation paths. We also show the variation of amplification from a borehole to the surface using Kik-net data, and suggest that on-site calibrations are necessary for better intensity estimates. Should an earthquake occur directly beneath a crowded metropolitan area, e.g. Tokyo, the warning time is very short and cannot be extended by increasing the station density of a big network.

Keywords: Site Effective Earthquake Early Warning

