SSS23-P01 Room:Convention Hall Time:May 24 16:15-17:30

A method of real-time prediction of main ground motions using vertical motions for the Earthquake Early Warning System

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The Earthquake Early Warning system (EEW system) by JMA was successfully operated during the 2011 off the Pacific Coast or Tohoku Earthquake (the Tohoku Earthquake, Mw9.0). The estimated seismic intensity by the EEW system was in good agreement with the observed ones near the hypocenter of the mainshock (for example Miyagi and Fukushima Prefecture). However, in the Kanto region far away from the hypocenter, the estimated seismic intensity was clearly underestimated in comparison with the observed one. It is caused to the fact that the attenuation-distance relationships of PGV and PGA for such great earthquake are well expressed as a function of not epicentral distance but the shortest distance from site to source fault.

So far, we have found that the attenuation-distance relationships of both horizontal and vertical PGAs tend to have a certain level of saturation near the source faults during large inland earthquakes. Based on the above results, we proposed a method of providing the information about the rupture extension before the arrival of the main motions from large earthquakes to calculate seismic intensity in wide areas using this information (Kurahashi et al, 2010). The seismic intensity in further regions is calculated using the rupture extension and the attenuation-distance relationships. We found that vertical PGAs at stations near the source fault of the Tohoku earthquake have a certain level of saturation, although the saturation levels are changeable due to site effects.

Hoshiba (2012) proposed that the method of the ground motions prediction method using real time monitoring. This method can predict the S wave motions at an optional station using the S wave motions at a near station by a method based on Kirchhoff Fresnel integral method. Irikura and Kurahashi (2013) proposed the method of calculating S wave motions from P wave motions based on Hoshiba (2012). In order to calculate the S wave motions accurately using the above-mentioned P wave motions, we need to estimate frequency-dependent site effects. In order to calculate the site effect correction by real time, it is necessary to estimate the site effects by IIR filter.

In this study, we propose a method of calculating instantaneously the seismic intensity and the S wave motions using the vertical motions.

The IIR filter as a method to the site effect is estimated using the Hoshiba (2012) method. The procedure is as follows,

1) The frequency-dependent site effect is obtained by removing the source spectra and propagation-path effect from the observed records. The source spectra are obtained by the omega-squared model with seismic moment and corner frequency. Therefore, the site effect means amplification of ground motions between bedrock and Earth surface.

2) The frequency parameter of the IIR filter is decided considering the site effect as a target.

Keywords: real-time information, vertical acceleration, predicted S wave motions

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Installation azimuth of Tonankai OBS estimated from air-gun data, and application to the single-station method of EEW

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1. Introduction

Ocean Bottom Seismograph (OBS) is promising tool for early detection of an earthquake in ocean areas, and thus it is also useful for quickening Earthquake Early Warning (EEW). However, the uncertainty of the installation azimuth of OBS may obstruct the back-azimuth estimation in the single-station method of EEW. Since the Principal Component Analysis (PCA) of the single-station method estimates the back-azimuths by using the principal axis of the first motion of P wave, we need to know accurate azimuth information of seismograph. But, OBS is not able to align installation direction with the true bearing correctly. The installation azimuth of horizontal components of Tonankai OBSs has been measured only by using Remotely Operated Vehicle (ROV). Nakano *et al*. (2012) estimated orientation of DONET seismometers by using seismic waveforms, and showed the difference between the presumed direction and the measurement of the ROV was about 50 degree at some stations. Hayashimoto and Hoshiba (2012) applied the single-station method to Tonankai OBS and DONET, and they mentioned that the uncertainty of the installation azimuth might be included in the results of Tonankai OBSs because the horizontal components were corrected by the measurement of ROV. In this study, we presume the installation azimuth of Tonankai OBSs by using particle motion of air-gun signals. Using the presumption of the orientation of Tonakai OBS, the azimuthal angle is corrected for the single-station method of EEW. We will show the results of improvement of the estimation of the azimuthal angle after the correction.

2. Data and Method

In this approach, we used air-gun signals which recorded at velocity and acceleration seismographs of Tonankai OBSs during the seismic survey KR11-09 and KR12-12. We applied a band-pass filter of 5-20Hz to the waveforms of five seconds from theoretical arrival time of direct water wave which was calculated from the shot-point and the shot-time of air-gun. And we calculated the arrival directions from these particle motions by using the principal component analysis. The results of arrival directions were selected at the amplitude of the seismic wave and the contribution ratio of the first principal component, and they were used for the installation azimuth presumption of Tonankai OBSs. We also applied same approach to DONET to show the validity of the technique.

3. Results

In Tonankai OBSs, the difference from the measurement of ROV is about 50 degrees at one seismograph, and at others the differences are about a dozen degrees. These results indicate that the estimation of installation azimuth using waveform is essential in OBSs. In addition, our results at DONET are in good agreement with the previous results of Nakano *et al*. (2012).

4. Application of azimuthal correction to the PCA of EEW

We applied the PCA of the single-station method of EEW to Tonankai OBSs by using the installation azimuth which we estimated above. Estimated epicenter directions are well improved, but errors of OBSs are still slightly larger than those of land stations. We consider one of the possible causes of these errors is the small incidence angle of P wave which is caused by the influence of the oceanic sedimentary layer.

Keywords: Tonankai OBS, Installation azimuth, Earthquake Early Warning

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A basic study for application of ocean-bottom seismographs to the EEW system

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In the railway field of Japan, to ensure the safety of trains running in a certain area which strong shakings will attack during earthquakes, the earthquake early warning (EEW) system using estimated earthquake information has been installed. To issue the EEW as soon as possible for subduction zone earthquakes, we considered it is important to apply ocean-bottom seismographs (OBSs) to the EEW system and performed a basic investigation for the difference between seismic motions observed on the seafloor and those on the ground.

In this study, we used 213 seismic motion data observed by three OBSs of Ocean Bottom Cable System off Sanriku and 23796 data K-NET/KiK-net for 71 earthquakes.

By investigating the relationships between peak accelerations observed on the seafloor and those on the ground using the differences from estimated values by the attenuation relationships for PGA (Korenaga et al., 2012), we confirmed the values of peak accelerations on the seafloor are about 3 times larger than those on the ground on average. For several earthquakes, we compared Fourier spectrums of S-waves on the seafloor and those on the ground and verified that amplitudes on the seafloor are about 10 times larger than those on the ground in low frequency below 5Hz and, on the other hand, those on the seafloor is significantly lower than those on the ground in high frequency over 5Hz. It seems that the high-frequency components are amplified by the soft sediment on the seafloor.

Those results indicate the characteristics of seismic motions observed on the seafloor are largely different from those on the ground. Therefore, the site amplification the frequency characteristics on the seafloor must be considered for applying OBSs to the EEW system.

Acknowledgement

The authors thank ERI and NIED to provide us strong motion data by Ocean Bottom Cable System off Sanriku and K-NET/KiK-net, respectively.

Keywords: ocean-bottom seismograph (OBS), earthquake early warning (EEW), peak acceleration, off Sanriku

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Developments in the Earthquake Early Warning System for Istanbul, NW Turkey

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The implementation of the earthquake early warning system (EEWS) in Istanbul commenced in 2001 following the devastating 1999 Izmit (Mw=7.5) and Duzce (Mw=7.2) earthquakes. At present the EEWS network consists of 10 inland and 5 OBS strong motion stations located as close as possible to the Great Marmara Fault zone. At the beginning data transmission was provided with Spread Spectrum Radio Modem; now, a satellite based and fiber optic data transmission system is used for communication between the remote stations and the base station at KOERI. The continuous on-line data from these stations is used to provide real time warning for emerging potentially disastrous earthquakes. A simulation of Early warning times for 280 earthquakes portrays a lead time between 0-30 seconds for Istanbul metropolitan area. The fiber optic lines provide high data transmission speed (2-4 miliseconds) from the remote stations to the KOERI data center, i.e. no latency exists taking into account the 100 sps sampling interval of the data. Redundancy of communication system is essential which we supply using a satellite data transmission system.

Considering the complexity of fault rupture and the short fault distances, a simple and robust Early Warning algorithm, based on the exceedance of specific threshold time domain amplitude levels (band-pass filtered accelerations and the cumulative absolute velocity) named as CAV is implemented. Onsite and regional early warning algorithms based on translation of the early P-wave waveform charactersitics to final source parameters of the earthquakes are to be implemented as well.

The early warning sygnal (consisting three alarm levels) is to be communicated to the appropriate servo shut-down systems of the receipent facilities, which will automatically decide proper action based on the alarm level. Among the prospective end users of the EEW sygnal are the facilities such as Fast Train and Tube Tunnel, Istanbul Gas Distribution Corporation (IGDAS), Recently constructed tall buildings, electric power plants and so on.

The continuous upgrade of the EEWS network, the software and the hardware is going on. In addition to the present strong motion stations additional ones are to be deployed along the southern coastline of the Marmara sea. The improved station coverage will enable regional warning technique be implemented along with the present on-site warning algorithm.

Keywords: early warning, rapid response, algorithms, fiber optic line, Marmara Sea, Turkey

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A social experiment of a new strong-motion monitoring system (Kyoshin Monitor) with earthquake early warning

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[1]NIED

In August 2008, NIED started " *Kyoshin Monitor*" that is a web service providing live maps of earthquake shaking in Japan. After the 2011 Tohoku Earthquake (M9), the number of people accessing the Kyoshin Monitor has soared, and the system has been drawing the attention of both experts and the general public. The JMA's earthquake early warning system for the 2011 Tohoku earthquake was not able to issue a warning that covered a sufficient spatial extent due to an underestimation of the earthquake magnitude. As a result, methods for detecting massive earthquakes based on the distribution of the observed strong-motion data have been examined as a system independent from the earthquake early warning system.

We consider that the combination of the earthquake early warning system as the latest forecast, and the Kyoshin Monitor as the observation is important in mitigating earthquake damage, thus we have developed a new Kyoshin Monitor that can provide the combined information (hereafter referred to as the "*Trial Version Kyoshin Monitor*").

In this research, a social experiment of the Trial Version Kyoshin Monitor has been carried out with the general public, and questionnaires were used to collect information on the background and motivation for using the Kyoshin Monitor, opinions on the version used, use status, usability, and other appropriate items, aiming to understand the public's needs for the delivery, use and utilization of strong-motion observation information in the future.

The social experiment was implemented through a limited online publication of the Trial Version Kyoshin Monitor to experiment participants following user registration. Public participation was invited thrice between September and October in 2012 through a social experiment website (http://www.kmoniexp.bosai.go.jp/), obtaining a total of approximately 4000 participants.

Acknowledgement: We would like to express our gratitude to the participants in this social experiment.

Keywords: kyoshin monitor, earthquake early warning, strong ground motion, social experiment

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Automatic Hypocenter Determination using Particle Filter Method

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Quick estimation of spatial and temporal hypocenter distributions in aftershocks is essential for taking a measure to mitigate earthquake disaster. The automatic hypocenter determination method is important to grasp seismic activities in real time, especially after the 2011 off the Pacific coast of Tohoku Earthquake. However, it is difficult to determine aftershocks due to a high trigger level and wrong phase pickings.

To solve above problems, Liu, Yamada (2011) proposed a particle filter method for detecting earthquakes that occurred at the same time. This method can estimate the most probable event parameter values (*t,lat,lon,dep,mag*). They formulated a likelihood function using the amplitude.

In this study, I proposed a new likelihood function using the amplitude and pickings. I defined the likelihood function as follows,

$lik(x|m,s)$=Product$_{i=1}{}^{N}[f(t_i{}^{obs}|m,s_i)*g(M_i{}^{obs}|m,s_M)]$,

where f is the likelihood function for variance of pickings, g is for variance of magnitudes, m is the particle (*t,lat,lon,dep*).

In addition, I considered the territory method and the hypocenter distribution of the past in the first probability density function.

I applied this method for some aftershock activities. This method can determine 90% or more hypocenters automatically compared with JMA catalog (Inland, M>=1.0).

Keywords: automatic hypocenter determination, particle filter

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Development of an automated source inversion system

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Source rupture process has now become one of the fundamental information to be released as soon as possible if a large and/or damaging earthquake occurs. The National Research Institute for Earth Science and Disaster Prevention (NIED) has conducted the source inversion for damaging earthquakes in Japan using strong-motion data recorded by K-NET and KiK-net. It takes at least about one day to derive and publish a preliminary but plausible result on Website. Due to speed up of the K-NET and KiK-net data retrieval, an improvement of strong-motion seismographs, an advancement of real-time estimation systems for the hypocenter location and source mechanism information, and a sophistication of computer systems, it has become feasible to perform the source inversion automatically just after the earthquake. We have developed a prototype system for the automated source inversion analysis using the NIED real-time data. The automated system will accelerate the first release of the information on the source rupture process.

Triggered by the seismic intensity data, the system collects the K-NET and KiK-net acceleration, and F-net velocity strong-motion data. The system also obtains the hypocenter location and the moment tensor solution automatically determined by the AQUA system using the Hi-net and F-net data. The fault models are constructed using this source information for the two nodal planes with several cases of the relative location of the hypocenter in the fault plane. An algorithm to select strong-motion data used for the inversion considers the epicentral distances, azimuthal coverage and the site response data of each station evaluated by Morikawa et al. (2007). The inversion method follows the procedure proposed by Sekiguchi et al. (2000, 2002). We test the automatic analysis procedure for the previous damaging earthquake data. For the 2008 Iwate-Miyagi Nairiku earthquake (Mw6.9), the slip distribution and the rupture progression pattern are in fairly good agreement with those derived in the previous study (Suzuki et al., 2010), though the slip amount and the total seismic moment are relatively larger. For the 2007 Noto Hanto earthquake (Mw6.7), the result is roughly consistent with that derived by Asano and Iwata (2011). We will run the system and test the performance with the real-time data.

Keywords: Source inversion analysis, Real-time earthquake information, Strong-motion data, Automatic analysis

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The questionnaire survey on the Earthquake Early Warning

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Japan Meteorological Agency (JMA) conducted the nationwide questionnaire survey using the Web to grasp how the nation were aware of the Earthquake Early Warning (EEW) and evaluated it, how they got the EEW information including by the mobile phones, how they acted when they recognized the information and how often they took part in the practice. After that, we analyzed the relationship of the action to the awareness and the experience.

The results were the followings: The 77 percents of the respondents knew the EEW and the percentage was larger in Tohoku and Kanto regions, where they experienced the strong motions of the 2011 off the Pacific coast of Tohoku Earthquake (Mw9.0) and the aftershocks. The large majority of respondents stated that the EEW was useful and they tend to criticize the EEW stronger in the case of underestimate than that of overestimate. The percentage of the people who were able to take useful actions was larger in the case where they had the repeated experience or had the more positive evaluation of the EEW.

Please refer the following JMA homepage in detail:

http://www.jma.go.jp/jma/press/1212/14b/manzokudo241214.html

Keywords: EEW, questionnaire survey, JMA