論 文 の 内 容 の 要 旨

論文題目　Long-Period Ground Motion Prediction Equations and Their Application to the Magnitude Estimation of Large Earthquakes Considering Site Effects

(長周期地震動予測式とサイト特性を考慮した大マグニチュード推定への応用)

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In the last ten years, there occurred many large earthquakes such as the 2004 Sumatra earthquake (M_w 9.0) and the 2011 Tohoku earthquake (M_w 9.1), which caused huge damage. The exact determination of the magnitude of such earthquake is an important issue in seismology, earthquake engineering, and seismic hazard assessment. The traditional magnitude scales such as the local magnitude M_L, body wave magnitude m_B, surface wave magnitude M_S, and Japan Meteorological Agency (JMA) magnitude M_{JMA} suffer from saturation for very large earthquakes. This makes the scaling for very large earthquakes unreliable.

The moment magnitude M_w does not saturate because it is directly defined by the seismic moment. Some methods have been proposed to estimate for the moment magnitudes such as the Centroid Moment Tensor (CMT) inversion (Dziewonski *et al*., 1981), and the W-phase source inversion (Kanamori and Rivera, 2008). However, these methods are time consuming to obtain a correct magnitude. Accordingly, they are not convenient for real time hazard assessment and precautions related to earthquake disasters. For instance, the correct magnitude of the 2011 Tohoku earthquake was estimated many hours after it occurred.

For rapid assessment, ground motion prediction equations are very useful, but the exact magnitude estimation using them requires the consideration of the source, path, and site effects. The use of a network of dense and good calibrated seismometers in Japan is quite helpful to evaluate these effects.

The strong ground motion networks are densely distributed in Japan such as K-NET and KiK-net operated by the National Institute of Earth Science and Disaster Prevention (NIED). Other networks are operated by JMA, local administration, and so on. The total number of strong motion data is about 5000 stations. The stations are deployed on the free surface such as K-NET and JMA station, where only KiK-net has two accelerometers, one on the free surface and other one on the layers of borehole.

In this thesis, we developed ground motion prediction equations (GMPEs) for peak ground velocities (PGVs) and peak ground displacements (PGDs) in a period range of 5 – 30 s. We only used strong motion data of KiK-net downhole stations located in layers of shear-wave velocities equal to or greater than 2000 m/s. The dataset consists of 20 earthquakes of $6 \leq M_w \leq 9.1$ occurred in and around Japan. Two-stage regression analyses were carried out to derive the GMPEs. We fit the data with two equations for smaller than M_w 7.5 and equal to or larger than M_w 7.5. Additional factors of focal depth and earthquake type were found to enhance the fitting with the observed data. Our developed long-period GMPEs predict the PGVs and PGDs of crustal earthquakes are larger than those of inter-plate and intra-plate earthquakes. The attenuation coefficients presented in the current study indicate that the long-period PGVs and PGDs increase by increasing depth.

We next evaluated the site effect at strong-motion stations located on the free surface in order to include them to our study. Using the strong-ground motion dataset of M_w 4 – 6 earthquakes in Japan from K-NET and KiK-net, we studied empirically the site amplification of 5%-damped spectral acceleration at periods of 0.05 to 5 s and PGV at period range of 0.1 – 10 s. The method of the study is based on estimating the empirical site effect from the observed and predicted ground motions using GMPEs. Our results are consistent with other studies and the theoretical transfer functions. Amplification factors were used to correct the observed strong ground-motion data of two crustal earthquakes, that are the 2008 Iwate-Miyagi Nairiku earthquake (M_w 6.9) and the 2004 Chuetsu earthquake (M_w 6.6). The corrected data fit better with GMPEs. The method is efficient for calculating site effects at observation stations where only insufficient velocity structure information is available.

We applied the same method as mentioned above to estimate the PGV and PGD amplifications of longer periods of 5 – 30 s. Strong-ground motion dataset of M_w 5.5 – 6.9 earthquakes from K-NET and JMA were used for site effect study. Our results are consistent with previous study. The site effects were applied to correct the PGVs and PGDs of 10 large earthquakes in Japan including the 2011 Tohoku earthquake (M_w 9.1). The fitting with GMPEs was improved after the site effect was removed from the observed data.

We finally proposed a method to estimate the moment magnitude by fitting observed PGVs and PGDs at period range of 5 – 30 s with GMPEs. We estimated the magnitudes of 20 earthquakes recorded by down-hole accelerometers of KiK-net. We also used data of KiK-net and the site effect corrected data of K-NET and JMA at 10 earthquakes to estimate their moment magnitudes. The results are consistent with the moment magnitudes from the Global CMT project. The results are improved when we used a combined dataset of KiK-net, K-NET, and JMA comparing of those by individual network. The method is useful to estimate the magnitude of giant earthquake such as the 2011 Tohoku earthquake. The proposed method can estimate the moment magnitude quickly if information of its source area is available.