Real-time forecasting of long-period ground motions for the Nankai Trough earthquake: The effectivity of the Green function-based data assimilation method

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In this study, we considered the possibility of more efficient data assimilation method in order to realize real-time forecasting of Long-Period (LP) ground motions based on the assimilation of strong-motion records and simulation of seismic wave propagation.

Furumura et al. (2019) conducted the real-time forecasting experiment of LP ground motions in the metropolitan area for the 2007 Off Niigata and the 2011 Off Tohoku earthquakes based on the data assimilation of the K-NET and KiK-net records and seismic wave propagation simulation using 3-D FDM. They used optimum interpolation technique, which was also used for real-time forecasting of seismic intensity (Hoshiba and Aoki, 2015) and tsunami (Maeda et al., 2015; Gusman et al., 2016). Since the performance of the supercomputers has improved a lot for recent years, simulation for the Japanese islands scale can be done several times faster than the propagation speed of the seismic wave. However, more effort is necessary to reduce the computational time in order to attain longer lead time before the shaking.

In this study, we considered the applicability of Green's function-based data assimilation. This method is proposed by Wang et al. (2017) as Green'sFunction Tsunami Data Assimilation (GFTDA). GFTDA is the method developed for efficient data assimilation and forecast of tsunami using offshore tsunami network. The Green's functions between the target point and each station are calculated beforehand. The tsunami waveform at the target point is calculated instantaneously by convoluting these Green's functions and the residuals between observation and forecast calculated for each station. This method is proved to be mathematically equivalent to the previous data assimilation method in Wang et al. (2017).

To validate the use of this Green's function-based method for the forecast of LP ground motions, we first conducted the numerical experiment for the 2004 off the Kii Peninsula earthquake (M7.4) and forecasted the LP ground motions at Shinjuku (K-NET TKY007) using the strong-motion records observed in this event. Green's functions are calculated efficiently using reciprocity. The results showed that instant forecast can be available with its accuracy equivalent to that of the previous method. LP ground motions in the distant target point can be forecasted immediately after the assimilation of the observed data near the source, which leads to much longer lead time. Moreover, more accurate forecast and longer lead time were obtained by using offshore stations in DONET, a dense oceanfloor network system for earthquake and tsunamis.

Next, we conducted the forecast experiment for the Nankai Trough earthquake using this method. The target points were Konohana (KiK-net OSKH02), Tsushima (K-NET AIC003) and Shinjuku (K-NET TKY007) stations. For the source model, we used the 1944 Tonankai earthquake, the 1946 Nankai earthquake and the largest event expected (M9) suggested by the Cabinet Office, Japan (2016). For each event, LP ground motions were calculated by 3-D FDM and were used as the observation data. In addition to aforementioned networks, stations in the JMA submarine cable network and hypothetical stations of N-net, a newly-planned ocean bottom seismograph/tsunameter network off Hyuganada, were also used. The intensity of strong ground motions was evaluated by GMRotD50 (the median value of the geometric means of the response spectra for two horizontal components when rotating from 0 to 90 degree; Boore et al., 2006). For the evaluation of the duration of LP ground motions, cumulative displacement was calculated. The accuracy of the forecast improved with the assimilation time. In the experiment for the 1946 Nankai earthquake, for example, when the rupture started form the east side, the forecast at Shinjuku with velocity response spectrum and cumulative displacement 70% of the actual observation was obtained about 80 s before the large amplitude LP ground motions started. It required 70 s assimilation after the rupture started. In the case that the rupture started from the west side, the longer lead time (˜120 s) was secured when the accuracy reached the same level due to the farther distance between the target point and the rupture initiation point. However, because LP ground motions developed as the fault rupture approached the metropolitan area, longer assimilation time (˜100 s) was necessary. From these results, it will be suggested that assimilation should be done while the fault rupture extends and the forecasts should be updated constantly as well as the importance of the strong-motion records near the source region in order to the realize both accurate forecast and longer lead time.

Keywords: long-period ground motions, data assimilation, Green's function