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# Source Model and Strong Ground Motion Simulation for the 2013 Northern Tochigi Prefecture, Japan, Earthquake

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On February 25, 2013, an inland crustal earthquake ($M_{JMA}$6.4, Strike-slip type) occurred in the northern Tochigi prefecture, Japan. Strong ground motions with a peak acceleration of 1225 cm/s$^2$ and a peak velocity of 39 cm/s were recorded at one of the nearest strong motion stations, TCGH07, about 5 km away from the hypocenter. Maeda and Sasatani (2009) showed that a similar large ground motion of 1100cm/s$^2$, 75cm/s at HKD020 during the 2004 South Rumoi district, Hokkaido, Japan, inland crustal earthquake ($M_{JMA}$6.1, Dip slip type) is mainly attributable to the source effect, short distance from the strong motion generation area (SMGA) and the forward directivity effect. To investigate how large ground motions at TCGH07 from a source's point of view, we estimate the source model based on the two different approaches.

First, we employ the multi-time window linear waveform inversion method (Sekiguchi et al., 2000) by using the 15 strong motion waveforms (0.1-1.0Hz) recorded by K-NET, KiK-net near the source. A finite extent of the fault plane is assumed referring to the aftershock distribution and moment tensor solution determined by F-net. The fault plane is divided into 84 subfaults of 1.0 km $\times$ 1.0 km. The temporal moment release history from each subfault is expressed by a series of 6 smoothed ramp functions with a rise time of 0.6 sec separated by 0.3 sec. The first time window triggering velocity (FTWTV) was 2.4 km/s. The rise time and FTWTV are given by the smallest misfit solution. The weight of the spatio-temporal smoothing constraint value for inversion was determined based on Akaike's bayesian Information Criterion (ABIC). The velocity structure model for each strong motion station is improved by the downhill simplex method (Nelder and Mead, 1965) using the receiver function. The theoretical Green's function is calculated by using the discrete wavenumber integration method (Bouchon, 1981) with the reflection and transmission matrix (Kennett and Kerry, 1979). To validate the improved velocity structure models, we simulate the aftershock records with a point-source approximation.

The derived rupture model has a large slip area whose maximum slip of 0.98 m in the vicinity of the hypocenter. The rupture mainly propagated from the hypocenter toward the shallower northern part. Seismic moment of the estimated model is $6.67\times10^{17}$Nm ($M_w$ 5.8). From the contribution of the large slip area to the synthetic waveforms for TCGH07, we find both the SH-wave radiation pattern from the strike-slip fault source and the forward directivity effect toward TCGH07 mainly yield the large pulse velocity waveform (0.1-1.0 Hz) at TCGH07.

Second, the source model is constructed based on the forward simulations using the empirical Green's function method (Irikura.1986) in the frequency range 0.3-10 Hz. One rectangle SMGA is estimated to include the rupture start point, i.e., the hypocenter of the mainshock. The rupture of this SMGA mainly propagates from the hypocenter to shallow side for dip direction, and also propagates to the northward for strike direction. The obtained source model explains the observed acceleration, velocity, and displacement waveforms of this event in the broadband frequency range fairly well. As same as the result from waveform inversion (0.1-1.0 Hz), we also see the large pulse velocity waveform is caused by the forward directivity effect toward TCGH07.

Consequently, we concluded that the main factors generating large pulse velocity waveform at TCGH07 are as follows: 1) the SH-wave radiation pattern from the strike-slip fault source and 2) the forward directivity effect along dip direction toward TCGH07.

Keywords: The 2013 Northern Tochigi Prefecture, Japan, Earthquake, Waveform inversion, Empirical Green's function method, Source model, Strong ground motion simulation