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Soil structure inversion and strong motion estimation based on H/V spectral ratio for earthquakes

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During the 2011 Off the Pacific Coast of Tohoku earthquake which occurred on March 11, 2011, the maximum acceleration of 585.7 cm/s^2 and JMA seismic intensity 6 upper was observed at the K-NET Furukawa (MYG006) station, in Osaki City, Miyagi Prefecture. Near the K-NET Furukawa several buildings were collapsed or heavily damaged due to strong motion and subsequent ground liquefaction. We investigated underground structures at and near the K-NET site by using aftershock records to delineate site amplification effects on the strong motions during the main shock.

We deployed five temporary aftershock observation sites around MYG006 on June 2011, and measured ground motions continuously for six months. Among the 63 aftershocks triggered at MYG006 the observed earthquake data at the temporary aftershock observation sites were used. Average Fourier spectra were computed for the NS and EW components to determine the HVRs of NS/UD and EW/UD. As for the aftershock HVRs, a peak was observed at around 0.2 Hz at all six observation sites including MYG006, and all of the sites recorded similar HVRs in the frequencies below 1.5 Hz, which is believed to be the effect of the deep soil structure.

The strong motion HVRs for the main shock and the aftershock that occurred at 23:32 on April 7 (M7.1) and weak motion HVRs calculated as the average of other small aftershocks were compared. The HVRs were almost the same between the two major events but they were different from those of weak motions, which shows the effect of nonlinearity on the strong motion HVRs. During the strong motion, due to the effect of nonlinearity, the frequencies that are said to cause severe damages to buildings, namely 0.5-2 Hz, were greatly amplified and this is believed to be one of the causes for the severe building damages in Furukawa. If we focus our attention to the troughs around 8 to 10 Hz, we can see weak frequency shift from the average HVRs of small aftershocks to the two strong motion HVRs by half at most.

Identification of the soil structure immediately below each observation site was attempted based on the HVRs of weak motion data recorded at each site. For the initial model the results of the previous study (Kawase and Matsuo, 2004) with two more layers for better characterization were used. The theoretical HVRs were calculated based on the concept of Kawase et al. (2011), and were identified by changing both shear wave velocities Vs and thicknesses of assumed layers. We used Hybrid heuristic method (Yamanaka 2007) and minimized the misfit between observed and theoretical HVRs. First we identified common deep soil layers for all observation sites to much all the HVRs in the longer period than 1.0 s. Next we determined shallow soil layers to fit observed HVRs at each observation sites for period range from 10 s to 0.05 s. The identified velocity structures reproduced the observed HVRs quite nicely in a wide period range.

One-dimensional deconvolution analysis was applied to derive the incident seismic wave on the seismic bedrock using the equivalent linear analysis, taking the nonlinearity of the soil structure into consideration. We calculated the incident waves for the main shock record in the frequency range from 0.1Hz to 20Hz. The maximum acceleration of NS bedrock wave was found to be 159.5 m/s^2 and the maximum acceleration of EW bedrock wave was 454.2 m/s^2 . The latter is high because of large amplification in high frequency range over 10Hz.

We computed the seismic motion at the temporary observation site near MYG006 during the main shock by using the above inverted bedrock motions. The maximum acceleration of calculated wave was almost the same as the observed wave at MYG006. The transfer function between the bedrock and the surface shown strong peak shift to longer period due to the effect of soil nonlinearity with the same degree as the shift observed at MYG006.

Keywords: H/V spectral ratio, strong motion, defuse field theory