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SP-converted waves observed at KiK-net stations (Part 2)

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Strong motion is observed both at the surface and in the borehole at all stations of the KiK-net, seismographic network operated by NIED. Most of the boreholes reach the bedrock depth. PS logging has been carried out at most of the sites, and the results have been disclosed on the Internet. Aoi and Kasahara [2000] identified as waves converted from S to P on the bedrock surface (SP waves) the conspicuous phases preceding the direct S arrival at two observation sites in the Osaka Plains, OSKH01 and OSKH02, where the boreholes are more than 1500 m deep. They also showed that the observed travel time differences (TTDs) of the P, S, and SP waves were in agreement with theoretical expectations from the publicly disclosed velocity structure. However, the layering is too coarse in the currently available underground structure data for these two sites, and improved resolution and accuracy of the velocity structure is expected to enable more detailed evaluation of the data. In the present study, we reevaluated the velocity structure at these two sites in Osaka by inverting the ratios of strong motion spectra observed on the surface and in the borehole (S/B ratios). Moreover, we tried to simulate the SP waves observed on the surface by applying to the newly estimated velocity structure the 1-D propagation theory for P-SV waves.

In this study, we first calculated and averaged the S/B ratios of Fourier spectra for earthquakes with magnitude 5.0 or greater. The Fourier spectra were computed initial-5-sec-long part of the transverse component of the S waves in the frequency range of 0.5 to 10 Hz, considering the S/N ratios of the observed records. Next, under the assumption that the S/B ratios are due to multiple reflections of the SH waves, we carried out inversion analysis using the genetic algorithm (GA). In this analysis, the number and thickness of layers were fixed by referring to the soil property data and the S-wave velocities were allowed to vary, except that in the bedrock was fixed at 3200 m/sec. We also assumed that the Q value was 10f**0.7 in layers above the engineering bedrock, 50f**0.7 between the engineering bedrock and the seismic bedrock, and 100f**0.7 below the seismic bedrock. We made a velocity structure be inherited with priority by the next generation, on condition that the TTDs of the S-waves between the surface and borehole, as inferred from the former, well explained the observations.

We simulated the SP wave observed at the surface by applying to the estimated velocity structure the 1-D propagation theory for P-SV waves. The P wave velocities and densities were assumed to depend on the S wave velocity according to the empirical relationship of Kitsunezaki et al. [1990] and Ludwig et al. [1970], respectively, and the same Q value was used for the P-wave as for the S-wave. We computed the angle of incidence to the bedrock on the basis of the Snell's law, using the estimated velocity structure and underground structure model employed by DPRI, Kyoto University, for hypocenter determination. We separated the SV and P components using this incidence angle, and evaluated the seismic motion on the surface using the 1D propagation theory for P-SV waves. The theoretical waveforms underestimated the direct P and SP phases in the horizontal components because the presence of P coda waves, but they well reproduced the SP phases observed in the vertical components and the direct S phases in the horizontal components. These show the validity of the estimated velocity structure and of the method of estimation.

The available data on the velocity structure at observation sites with comparatively deep boreholes do not have enough resolution in thickness of layers for the evaluation of site effects in high frequency ranges. We hope to systematically reevaluation, in the near future, the underground structure data publicly disclosed by KiK-net using similar method as in this study.