Empirical relations between elastic wave speeds and density inferred from Hi-net and K-net borehole logs

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When we calculate strong ground motions or carry out waveform inversions, firstly we need to construct reasonable 3-D models of compressional-wave velocity (Vp), shear-wave velocity (Vs), and density. Seismic tomography and refraction studies often report Vp only in spite of the fact that the Vs values are even much more important that those Vp values since the ground motions are mainly determined by the S wave. This situation is more significant in the case of a real-time system, for example the Realtime Earthquake Information System (REIS) developed by NIED aims at quickly and automatically determining the slip distribution using realtime data with a conventional waveform inversion method. Reasonable regional 1-D models of Vp and Vs are of critical importance in this case. In this study I analyzed the relations between Vp, Vs and density by using the borehole logs reported by Hi-net and K-net. Typical depth of the Hi-net borehole is about 100m to 200m, with some special boreholes as deep as 2km, whereas the typical depth of the K-net borehole is merely 10m to 20m.

Using the least squares method, density values (denoted as d g/cc) reported in the K-net borehole logs can be approximated by a function of Vp (km/s) as follows

d(g/cc)=1.58+0.18Vp-0.0096Vp*Vp (1)

or formulated as a function of Vs (km/s) as follows

d(g/cc)= 1.54+0.98Vs-0.34Vs*Vs (2)

Regression of Vp and Vs values reported in K-net and Hi-net borehole logs leads to the following relationship for Vs as a function of Vp

Vs (km/s)=0.54-0.73 Vp+0.49 Vp**2-0.076 Vp**3+0.0043Vp**4 (3)

Poisson's ratio as a function of Vp is obtained as follows

Poisson = 0.65-0.20 Vp+0.044Vp**2-0.0036Vp**3 (4)

The abovementioned formulae are somehow different from those obtained by Brocher (2005). It is quite reasonable when we notive that what I used here is confined to observations of surface layers the rock basis, and epsecially note that those surface observations depend on regional geological situation. It remains to be verified in the future study whether these empirical relations can be extrapolated to the case of the whole crust. Especially the formulae 1 and 2 are limited to surface layers of merely 20 meters deep. I would point out that we should be very careful to extrapolate those relationships to deeper structures. Formulation of the relationship of Vs and Vp is our main purpose. Fortunately, we have enough observation data for Vp and Vs. In details, Vp in Formula 3 varies in the range from 1.0km/second to 6.0km/second. Formula 3 tells us that Vs decreases slowly and nonlinearly when Vp decrease from 2.0km/second to 1.0km/second (those with values smaller than 1km/second are not included in this study). Vs increases with Vp when Vp is greater than 2 km/second. Since Vp/Vs varies dramatically in the surface layers, here only the values reported for the basis rock are taken into account to determine the formula 4. The Poisson's ratio curve shows a similar pattern with Brocher's observation. The Poisson's ratio decreases rapidly from 0.5 to 0.35 when Vp increases from 1.5km/second to 3.5km/second. It decreases slowly when Vp exceeds 3.5km/second. The values of Poisson's ratio obtained in this study are generally larger than Brocher's results.