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Rayleigh wave ellipticity as a tool to probe deep Earth structure

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Information for Earth structure from Rayleigh waves has often been collected in the form of phase or group velocity. Dispersion in velocities and its regional variations have given us important constraints on Earth's interior structure. In those studies, typically, only signals from vertical components were used.

With the development of three-component seismograph networks, there is the opportunity to use both vertical and horizontal components of Rayleigh waves for Earth structure inversion. A useful parameter is the ratio of these two amplitudes (hereafter Z/H), measuring the ellipticity of the associated particle motion.

Depth resolution kernels for Z/H can be computed numerically and the dispersion in Z/H provides us information for seismic structure, in a similar manner to phase and group velocities. The analysis gives us constraints on structure under each seismic station only but with high density networks now available in many parts of the world, it should help us to construct laterally varying seismic structure too. The initial attempt of ellipticity analysis was described in Boore and Toksoz (1969), for the period range 10-50 seconds, but it has not been pursued extensively, perhaps because quality of horizontal component data has not been good until recently.

One of the challenges in using the Z/H for structural inversion is its measurement from seismograms. For a given frequency and a dispersion branch (we focus on fundamental modes in this study), this ratio should be constant at each station but often its measurements show large scatters. We first confirmed that this is mainly because of interference effects from body waves and higher modes. In order to cleanly measure fundamental-mode Z/H, we have thus focussed on shallow earthquakes ($<$ 50 km) and particular distance ranges.

We developed two approaches to solve this problem; the first approach uses simple envelope-amplitude ratios between the vertical and horizontal amplitudes, combined with the 90-degree phase-shift criterion between the vertical and horizontal components that is indicative of Rayleigh waves and also of lack of interference.

The second approach uses the correlation between (90-degree phase-advanced) vertical and horizontal waveforms to select clean data before measurement of Z/H. We tested these approaches using more than 10-year long data for stations in Southern California, analyzing signals from all shallow earthquakes larger than Mo=10**19 (Nm). Both approaches give consistent results; the first approach seems to provide much less number of data because phase can be disturbed easily by minor perturbations from other phases and noise. Both techniques allow us to measure Z/H from 5 mHz to about 40 mHz, above which complex propagation effects, including multipathing effects, become problematic. But at even higher frequency range (100-200 mHz), microseims can provide the Z/H data (e.g. Tanimoto et al., 2005), thus potentially we can obtain wide frequency-band Z/H data from 5 mHz to 200 mHz, although intermediate frequency range between 40 and 100 mHz remain a hole because complex propation effects is still difficult to untangle.