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Membrane surface wave synthetics: modeling short period surface wave in heterogeneous media

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Surface wave tomography is one of the major seismic methods to study the heterogeneity in the earth's interior. However, the use of short period surface waves (period around 20s or shorter) has been usually avoided despite of its potential advantage in improving the resolution. This is because the structural heterogeneity near the earth's surface has considerable effects on the short period surface waves: they show complicated propagation effects such as curved paths, multiple rays and scattering that are difficult to be reproduced by conventional simple (i.e. computationally less intensive) methods.

We formulate a membrane method for surface wave synthetics in a flat earth model in order to reproduce these structural effects on surface waves and to calculate partial derivatives of the waveforms with respect to perturbations in material parameters with moderate computational efforts (i.e., with 2D calculations).

Based on the formulation by Tanimoto (1990), we assume smooth lateral variations in the material parameters by neglecting the terms of horizontal gradients of the eigenfunctions, so that the surface wave may be expressed in terms of local eigenfunctions multiplied by 2D (horizontal) potential functions. This potential function satisfies 2D Helmholtz equations (in frequency domain) with horizontally varying phase velocity distributions (i.e., the initial model can be laterally heterogeneous). This formulation is similar to that of the surface wave JWKB method, but we directly evaluate the potential function by numerically solving the Helmholtz equation instead of applying the asymptotic far-field formula and the ray theory. Thus, unlike the ray-theoretical approach, the effects of finite wavelength, curved paths, multiple rays and scattering (along a single dispersion branch) are all included in the potential functions.

The partial derivatives or the kernels for the tomographic study may be calculated based on the reciprocal theorem and Born approximation. The perturbations in the waveforms may be evaluated as a volume integral of the material perturbations multiplied by kernels that are calculated by using both waves from the source and from the receiver.

The primary potential function calculated as above does not include the effects of scattering between different branches or different wave types (note these are not caused by the perturbations but may be caused by the initial heterogenous structure). To evaluate these effects, we restore the effects of the horizontal gradients of the eigenfunctions: the terms of horizontal gradients of the eigenfunctions with the primary potentials act as forces that generate secondary scattered waves under the Born approximation.

Our preliminary study for a regional (flat) model with ocean-land transition (i.e., in and around Japan islands) shows that the dispersive behavior is quite strong in the synthetic waveforms from shallow suboceanic sources even at periods of around 20s. The tomographic kernel also shows considerable anti-symmetric pattern with respect to the straight-line path.