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From seismic waveforms to seismic wavefield: A feasibility study of the seismic gradiometry applied to the Hi-net array

MAEDA, Takuto[1*] ; NISHIDA, Kiwamu[1] ; TAKAGI, Ryota[1] ; OBARA, Kazushige[1]

[1]Earthquake Research Institute, UTokyo

Introduction

The high-sensitive seismograph network (Hi-net) operated by NIED, Japan equipped with nearly 800 velocity-type seismographs of natural frequency 1 Hz with average separation of 20 km. Although its main target of observation is small, high-frequency seismic waves, it also can act as an ultra-dense long-period seismograph array in particular for large earthquakes because of the wide dynamic range and high S/N of the observation system [Maeda et al., 2011, 2014]. In such long period band, station separation is shorter than the wavelength. Thus, it is expected that they bring us the 2D complex wavefield rather than independent seismic wave traces at individual stations.

Recent advances of the seismic gradiometry method (hereafter referred to as SG) and its successful applications report that we can measure the spatial variation of geometrical spreading and radiation pattern, in addition to the slowness vector from the dense array data [Langston, 2007a,b,c; Liang and Langston, 2009]. In this study, we attempted to assess the feasibility of applying the SG to the Hi-net array to extract complicated wave propagation properties.

Seismic Gradiometry

The SG first estimates the wave amplitude and its spatial derivative coefficients from discrete station record by the Taylor series approximation and an inverse problem. Then, by assuming the incoming wave packet is constituted by plane wave having spatially varying amplitude term, the slowness vector and spatial derivative of the amplitude term are estimated. The latter term corresponds to the geometrical spreading and radiation pattern. It is a remarkable feature of the SG to separate the amplitude variation due to between wave propagation and other effects.

Application to the Hi-net

We applied the SG with synthetic data at the actual Hi-net station layout. The synthetic data has the Gaussian function in time with phase speed of 3 km/s, having geometrical spreading reciprocal to the square root of the horizontal distance, and the four-lobed radiation pattern. This synthetic wavefield has a wavelength of about 60 km, which is corresponds to the surface waves at the period of about 20 s. The time series at locations of the Hi-net stations were used to as the synthetic data of the numerical experiment. At equally spaced grid points, the wave amplitude and its derivatives are estimated by using the data at nearby stations with distance is shorter than 50 km by the least square. We here note that the least square is always well-posed, inverse matrices to solve the inverse problem can be calculated in advance. Comparing the analytic solution, it was found that the wavefield and the derivatives are quite well estimated with maximum relative errors of about 5% and 10%, respectively. The slowness vector, the radiation pattern and the geometrical spreading terms are estimated by the wavefield and its spatial derivatives at every grid point. The estimated direction of the wave propagation well fitted to the azimuth from the assumed epicenter, and the radiation pattern shows significant variation at around the null axis.

Our preliminarily results suggest that the SG method well suite to the band-broaden Hi-net seismograph to extract wavefield behavior at the periods longer than 20 s. This method is appealing that it can estimate the arrival directions at spatially homogeneous grid, and that it can extract amplitude variation not due to simple wave propagation such as radiation pattern. It is promising to obtain spatial phase velocity variation from direct waves, and to grasp wave packets originated from scattering from later coda, to applying the SG to Hi-net dense array data.

Keywords: seismic wavefield, broadband, surface waves, arrival direction