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Surface-wave phase velocity inversion using Markov Chain Monte Carlo method

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Microtremor exploration is often used to know an S-wave velocity profile. This method is especially popular in constructing S-wave velocity model for strong motion estimation. Accordingly many microtremor explorations have been conducted in the Tokyo Metropolitan area in Japan (e.g., Yamanaka and Yamada, 2006). These models must be improved using additional explorations for reliable estimations of strong motion. We must understand resolution of the model parameters for a further improvement of a basin model.

The estimation of surface wave phase velocity and its inversion to S-wave velocity profile is the main technological elements in the microtremor array exploration. The least square methods are the one of the often used techniques in the phase velocity inversion. Heuristic algorithms, such as GA and SA are also frequently used in the inversion (e.g., Yamanaka, 2007). One of the advantages of the heuristic inversion methods is the no requirement of calculation of derivatives of an objective functions and matrix inversions. Therefore the algorithms based on these approaches are so robust and used in various kinds of geophysical and seismological inversions. Although the heuristic methods can globally search model parameters in parameter space, it is sometimes difficult to estimate model sensitivity in these approaches.

Recently Markov Chain Monte Carlo Method (MCMC) is examined to sample model parameters for estimation of probability density function (pdf) of the parameters from random sampling with a statistic way (For example, Iba, 2005). According to Bayesian inference theory, posterior pdf is calculated from a prior pdf of parameters and likelihood function. If we assume a uniform pdf for the prior pdf, we can estimate pdf of model parameters from likelihood function which is proportional to error function. This allows us to estimate model parameters and their resolutions from observed data numerically. In this study I investigate applicability of MCMC method to Rayleigh wave phase velocity inversion using numerical tests, and apply the technique to actual phase velocity data from microtremor explorations in the Kanto basin, Japan.

A 4-layers model for deep sedimentary layers in the Kanto basin is used in the numerical tests. We generate synthetic phase velocity for fundamental Rayleigh waves at periods from 0.5 to 10 seconds, and add noises. The observation errors are included as standard deviation of the synthetic data which are set to be 5 to 40 % of the synthetic data. S-wave velocity and thickness of each layer is used as unknown parameters. The Metropolis-Hastings approach is used in the MCMC calculation. 210000 models were examined in the sampling of the parameters. After deleting initial parts of the sampled data, we calculated average and standard deviations of the sampled parameters for the inverted results. The averages of parameters are close to true ones with exception of slight differences for parameters of the third layers. This implies that the assumed data at periods less than 10 seconds is not enough. We also found that observed phase velocity must be obtained with an observational standard deviation of 10 % for estimation of the parameters with 10 % accuracy.

MCMC method can not find a model with the minimum misfit, but can provide a pdf of model parameters. This is one of the advantages of the MCMC methods over the other heuristic approaches. We will try to use the technique to understand a resolution of 3D S-wave velocity profiles from microtremor explorations in the Kanto basin for future improvements of the basin model. This technique is also attractive in the other geophysical and seismological inversions as a promising tool to estimate resolution of model parameters.

Keywords: microtremor exploration, basin model, surface wave, phase velocity, S-wave velocity, Markov Chain Monte Carlo