Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SSS35-P04 Room:Poster Time:May 2 16:15-17:30

Estimation of phase velocity of Rayleigh wave using linear array

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Since the spatial autocorrelation (SPAC) method has been proposed by Aki (1957), the observation using a circular array of evenly spaced sensors and a central sensor becomes a commonly used measurement technique in the microtremor survey method (Okada, 2003). However, in practice, the strict arrangement of sensors required by the method is difficult to conduct because of the limit of real environment. In order to slacken the requirement of the arrangement, Chavez-Garcia et al. (2005) discussed the validity of performing the SPAC method with a linear array. However, the conclusion of this research is result-based and is not backed by theoretical demonstration. Aki's autocorrelation coefficient could be alternatively seen as the azimuthal average of CCFs (Okada, 2003; Shiraishi 2006). A CCF consists of the Bessel function and an error term which varies with the azimuth of sources. By taking the azimuthal average, the error term vanishes and direct J_0(kr) can be obtained. The discrete formula of the CCF offers the possibility of extending the original SPAC method. In this research, we develop the solution by controling the error term in CCF which can obtain directly the phase velocity instead of using records of sensors in a line instead of azimuthally arranged ones.

Under the assumption: 1) Only the fundamental mode is dominated. 2) Different sources are not correlated, the real part of discrete formula of CCF could be expressed as (Shiraishi, 2006). If we neglect the terms of order larger than 6, we can obtain:

Re(γ_{pq}=J_0(kr)-2J_2(kr)$\sum\lambda_l$cos2θ_l+2J_4(kr)$\sum\lambda_l$cos4θ_l. It can be seen that there are only three unknown variables kr, $\sum\lambda_l$cos2θ_l and $\sum\lambda_l$cos4θ_l. It is required of at least three sensors (3 different intervals) to solve the 3 unknown variables theoretically. The three sites need to be in a line to make the three CCFs share the same unknowns. Because of the coupling variables and non linear functions, we use the genetic algorithm and particle filter to solve out the optimum solution.

In order to comfirm the validity of this new theory preliminarily, the simple wavefield composed of unidirectional plane wave is used to examine the accuracy of estimating phase velocity obtained from a linear array with 3 sensors. The distances between adjacent sensors (r and 0.5r, r=30m) are set to be different so that we can have totally 3 different CCFs to solve out the optimum solution. Except for the analytical simulation, we also applied a field test to examine the availability of the new method. We have applied field test to comfirm the availability of the method. Observation was conducted on 23 October 2013 at the parking lot of Zoorasia Yokohama Zoological Gardens (ZRS) in Yokohama city of Japan. We deployed 7 seismometers (KVS-300, moving speedometer) constituting two linear arrays. The two linear arrays forms an angle of 60 degree so that the SPAC method could be applied for confirmation.

In the analytical simulation, we confirmed the availability of the new method. The sensitivity of CCF with respect to phase velocity depends on the direction of linear array. When the sensitivity is low, the estimation will be bad. Hence, it is better to use at least two linear arrays forming an angle (90 degree is the best). In the field test in Yokohama, we applied both the SPAC method and the new method using 7 speedometers. Both SPAC method and the new method show good match with the theoretical dispersion curve. The new method shows narrower effective scope and shows some unstablity in both low and high frequency range. Through both simulation and field test, the availability of the new method has been confirmed. This new method makes the arrangement of sensors easier which needs only two linear arrays with a non-strict angle. In the future, we will study more about improving the inversion technique and the application of linear array.

Keywords: SPAC method, linear array, coherence complex function, particle filter