Improvement of Accuracy to Estimate Phase Velocity using Arbitrary Shape Arrays with Extra Observation Sites

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Based on the analytical solution of Lamb's problem for vertical components of Rayleigh wave, the relationship between two observation points, p and q for example, is given in a discrete representation with the Bessel function of the first kind and higher-order Bessel functions, which is called Complex Coherence Function (CCF) [4]. Zhang and Morikawa [5] extended the CCF to apply it to linear array situation. By adding an extra observation points, the relationship between p and s can be expressed [6]. At last, the CCF equations have only 5 unknowns left, including the phase velocity. Therefore, we proposed an algorithm [7] to estimate the phase velocity using Artificial Bee Colony (ABC) algorithm [8] under a constraint of $kr \in [0, 5]$. The numerical simulation results confirmed the availability of the proposed algorithm for array shapes that are not near linear-array situations [7]. And for near linear-array situations, relative accurate results might be get by increasing the observation time.

In theory, we can extend the CCFs to the array with 4 and more observation points [7]. Although the total number of CCFs increases with increasing observation points, the 5 unknowns remain the same. That is to say, with increased observation points, the number of CCFs will be greater than the unknowns’ number 5. Then we think better results can be obtained due to the increased constraint conditions. Numerical simulations of a 4-site array, as shown in Figure 1, were conducted. It consists of one 3-site obtuse triangle and one 3-site near linear-array triangle. With same wave field consisting of 8 randomly generated wave sources, the results of shape 1 (obtuse triangle), shape 2 (near linear-array triangle), and 4-site array are shown in Figure 2. It can be seen that for shape 2, the near linear-array triangle, the results are not satisfactory and the constraint line $kr = 5$ can be obviously seen. And compared with shape 1’s effective range [0.25Hz, 0.9Hz], the 4-site array’s effective range can be seen as [0.25Hz, 1.25Hz], although still with fluctuations around 1.0Hz and the shape of the constraint line clearly seen after 1.0Hz. In conclusion, the 4-site array results are better than the more regular shape, as predicted before. But the computation time is longer than 3-site arrays since the total number of the equations increased from 3 to 6.

To confirm the availability of the proposed algorithm, a field test will be conducted.

[1] Capon, J. (1969). *Proceedings of the IEEE*, 57(8), 1408-1418.
[2] Aki, K. (1957). *Bull. Earthq. Res. Inst.*, 35, 415-456.
[3] Cho, I., Tada, T., & Shinozaki, Y. (2006). *Journal of Geophysical Research: Solid Earth*, 111(B9).
[4] Shiraishi, H. & Matsuoka, T. (2005). *BUTSURI-TANSA,* 58(2), 137-146.
[5] Zhang, X. & Morikawa, H. (2014). *British Journal of Applied Science & Technology*, 6(4), 350–363.
[6] Morikawa, H. & Iiyama, K. (2015). *Program and Abstracts, The Seismological Society of Japan, Fall Meeting.*
[7] Zhang, H., Iiyama, K. & Morikawa, H. (2020). *17th World Conference on Earthquake Engineering.*
[8] Karaboga, D. & Basturk, B. (2007). *Journal of global optimization*, 39(3), 459-471.

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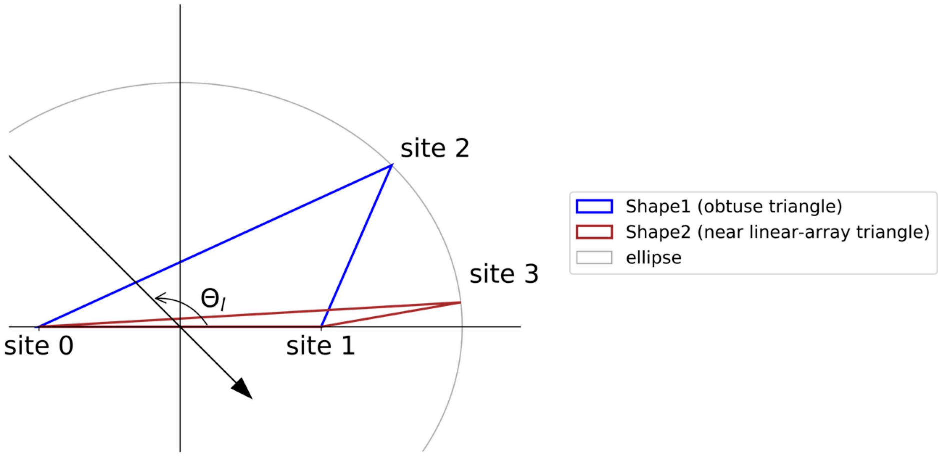

Figure 1: Array settings used for numerical simulations.

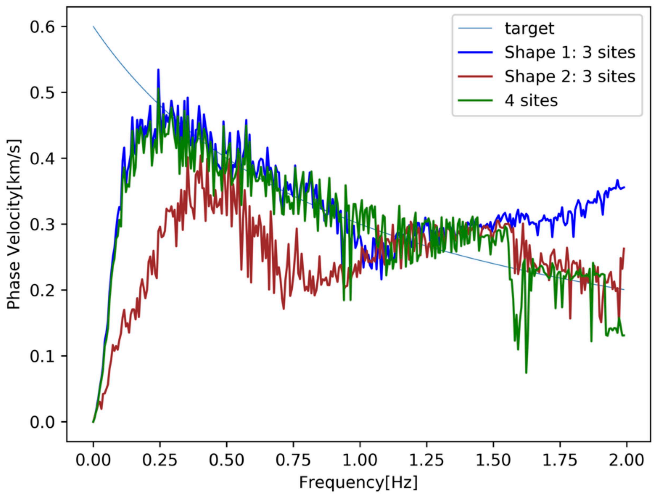

Figure 2: The average phase velocity results of 3 array shapes.