Novel depiction of love wave dispersion and inversion for inversely dispersive medium by full SH-wavefield reflectivity method – part II: field example

J Safani¹, La Hamimu¹, Firdaus¹, Deniyatno¹, S R Harati¹, La Aba²

¹Department of Geophysical Engineering, Halu Oleo University, Kendari, Indonesia
²Department of Physics, Halu Oleo University, Kendari, Indonesia

E-mail: jamhir-safani72@gmail.com

Abstract. In this part we discussed field example of SH wave data recorded using horizontal component of the three-component geophone that might represent characteristic of the inversely dispersive medium. Extraction of the SH wavefield data, both for north- and south-source impact, using tau-pi transform showed increasing phase-velocity dispersion with the frequencies. Such patterns of “effective” dispersion curves illustrated the nature of the inversely dispersive medium. Inversions of the dispersion curves were carried out by utilizing a series of Love wave inversion approaches. These approaches included forward modelling of Love wave dispersion curve by full SH-wavefield method and partial derivatives of the Love wave phase velocity. The inversion procedures utilized a linearized inversion of Occam’s algorithm. Inversions of the Love wave real data, both for north- and south-source impact, confirm the presence of an inversely dispersive medium.

1. Introduction

Discussions on Love wave for shallow surface applications were frequently published. A real example discussed in [1] seemingly showed generation of SH body-wave only, and there was no Love wave generated. A numerical modelling of high-frequency phase velocities trapped in low velocity layer (LVL) has been investigated and presented in [2]. The use of numerical and real dispersion data of Love wave for shear-wave velocity estimation was also discussed in [3]. The use of multimode dispersion of Love wave phase velocity for LVL estimation was reported firstly by [4] and continued by [5]. Rayleigh wave dispersion data combined with those of Love wave data may improve accuracy of estimation of the shear-wave velocity profile, as addressed in [6]. Multimode dispersion of Love wave data for estimating near-surface layer was also presented in [7]. Sensitivity analysis on the dispersion mode of Rayleigh and Love wave showed that fundamental mode of both those waves worked poorly to the layers beneath an HVL or LVL [8].

The discussion of Love wave phase velocity for inversely dispersive medium is actually contradictive with the theoretical requirement for the presence of Love waves deduced in [9], which mentioned that the Love wave can only travel in the medium if the base is harder than the upper layers. This research, however, is conducted to ensure the condition in real case and to enrich curiosity on nature of Love wave propagation in uncommon medium, namely the inversely dispersive medium. Such a medium may represent wet mud below a compacted layer or a cave under a hard top layer.
2. Experimental Methods

2.1. Seismograms and dispersion images
These data were acquired at Matsudai, Japan [10]. SH wave data were acquired with the 24 channels of three-component geophones. The geophones were planted at 0.5 m spacing with 1 m near-offset. Since a 48-channel OYO DAS-1 was used, channels 1-24 were connected to the vertical component, and channels 25-48 to the crossline component, to save acquisition time and identify any cross-wavefield interference. A horizontal impact of 5 kg hammer was used for Love wave generation.

The SH shot gathers and the resulted Love dispersion images for different impact direction are shown in Figure 1. The shot gathers and dispersion image shown in the top part (Figure 1a and b, respectively) were generated from north side of the steel I-bar, and the bottom ones (Figure 1c and d) were those impacted from south side. There was no air waves recorded in the seismograms, a typical often found of using planted geophones. Comparing these seismograms to those of the inversely dispersive profile as shown in the numerical test, we can see that they most likely represent the presence of Love wave propagation. It is because the body wave propagation for such a profile is usually non-dispersive as discussed in the above numerical test.

The resulted Love dispersion curves for the both different impact sides, picked by the tau-p transform, have similar dispersion trend (Figure 1b and d). The curves show exponentially decreasing phase velocity trend from high to small frequencies, and a sharp slope acquired at frequencies below 20 Hz. A striking difference between the both curves occurs at frequencies of higher than 60 Hz (Figure 2a). However, the curves in general have a very good agreement. Figure 2b shows rough approximation of subsurface characteristics, by illustrating phase-velocity (inherently corresponding to shear-wave velocity) versus wavelength (representing subsurface depths).

The field examples discussed above have provided valuable information on how Love wave propagating in an inversely dispersive medium of the Earth. These will give a new perspective on the use of Love wave data for any subsurface condition hereafter. These field results confirm at least two aspects, namely: (1) the possibility of Love wave generation in the case where the stiffness of layers is inversely dispersive; and (2) the possibility of the use of the effective dispersion curve of Love wave, even for field data. It is different with the common assumption that Love waves cannot propagate in inversely dispersive medium.

3. Results and Discussion

3.1. Inversion results from field data
Inversions of the Love wave dispersion curves of Figure 2a, resulted from the north and south impact of the steel I-bar, were carried out using Occam’s algorithm. This inversion procedure has been addressed in [4]. Theoretical Love wave dispersion curve in the inversion process was provided by the full SH wavefield reflectivity. Both the ‘field’ effective dispersion curves were set at the frequency range of 7 - 60 Hz, to give the same condition of the inversion. Density, a parameter which is less sensitive to the phase velocity change, was set 1.8 g/cc for all layers. In the inversion process, we used 10 layer stacks, commencing at a thickness of 0.5 m to a thickness of 2.0 m. The half space was set at a depth of 7.8 m. The initial model of shear wave velocities used in the inversion was calculated from the available dispersion curve.

Figure 3 shows inversion results of the effective Love wave dispersion curve for the north impact. Small data misfit of 1.02% signifies accuracy of the inversion. A slight overestimate of the calculated effective dispersion curve was seen at the lower frequency end. Other phase velocities, however, are fitted very well. Inverted shear-wave velocity values show a decreasing trend with depth, depicting an inversely dispersive medium.

When the same layering parameterization as above was utilized for inverting the effective Love wave dispersion curve of the south impact, the inversion displays similar results (Figure 4). The measured and calculated data misfit is 0.91%. Decreasing shear wave velocity values with depth again confirms the
existence of the inversely dispersive medium of the Earth as cited above. These results demonstrate that
the real of the inversely dispersive medium can be imaged through the inversion of the field data of the
effective Love wave dispersion curve.

Figure 1 Left: SH wave seismograms and Right: dispersion images of Love wave for source impact
from north side (Top) and from south side (Bottom), measured in Matsudai site, Japan [9].

Figure 2 Love wave dispersion curves from the Figures 1a and b: (a) Phase velocity versus frequency,
and (b) Wavelength versus phase velocity [9].
Figure 3 Inversion results of Love wave phase velocity dispersion (north impact) in Figure 2a (a) comparison of measured and calculated dispersion curve, (b) Inverted shear-wave velocity versus depth, and (c) relative error for each inverted thickness.

Figure 4 Inversion results of Love wave phase velocity dispersion (south impact) in Figure 2a (a) comparison of measured and calculated dispersion curve, (b) Inverted shear-wave velocity versus depth, and (c) relative error for each inverted thickness.
4. Conclusion
The field dispersion curves showed exponentially decreasing phase velocity trend from high to small frequencies. These field examples provided valuable information on the Love wave propagation in an inversely dispersive medium of the Earth. These might give a new perspective on the use of Love wave data for any subsurface condition hereafter. These field results confirm at least two aspects, namely: (1) the possibility of Love wave generation in the case where the stiffness of layers is inversely dispersive; and (2) the possibility of the use of the effective Love wave dispersion curve, even for field data. This is different with common assumption that Love waves cannot propagate in the inversely dispersive medium. Inversions of the real Love wave data, both for north- and south-source impact, confirm the presence of an inversely dispersive medium.

5. References

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