

P 162 REMOVING LOVE WAVES AND THEIR SCATTERING IN THE SHALLOW SUBSURFACE

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Introduction

SH-waves (Shear Horizontal) are often assumed to be decoupled from the other wave types (P- (Pressure) and SV- (Shear Vertical) waves) in elastic media. In air or gas filled media, P-waves are often severely scattered. Therefore seismic SH-wave experiments are more suitable for imaging the shallow subsurface. Unfortunately, the data of a seismic experiment are polluted with coherent noise. In SH-wave experiments, Love waves provide the largest contribution.

Under certain circumstances, Love waves are difficult to separate from reflection data. First, they are surface waves, and therefore attenuate slowly, thus providing the most energy in a seismogram. Second, their wave velocity is almost equal to the shear wave velocity in soft soils, making it difficult to filter them with for example f-k filtering. Third, they are dispersive, meaning that their phase velocity is frequency dependent. Love waves are discussed in more detail by Aki and Richards [1].

With the help of reciprocity, a mathematical tool which can relate two states to each other, an expression can be derived, which removes Love waves from SH-wave data [2][3]. No structural subsurface model is needed for this procedure. The approach is similar to that of Van Borselen et al. [4], who used acoustic reciprocity to remove surface multiples from marine seismic data.

Theory

In previously published results [2][3], an expression was derived for removing Love waves from seismic SH-wave data:

$$\frac{1}{2\pi} \int_{k_1 \in \mathbb{R}} \frac{\mu \gamma_s}{s \hat{f}_2(s)} \tilde{v}_2^{\text{nosurf}}(k_1, 0 | x_1^S, 0, s) \tilde{v}_2^{\text{surf}}(x_1^R, 0 | k_1, 0, s) dk_1 = \hat{v}_2^{\text{surf}}(x_1^R, 0 | x_1^S, 0, s) - \hat{v}_2^{\text{nosurf}}(x_1^R, 0 | x_1^S, 0, s). \quad (1)$$

Due to Parseval's theorem, the terms under the integral are in the wavenumber-Laplace domain (denoted by a *tilde* (\sim)), whilst the terms outside the integral are in the place-Laplace domain (denoted by a *hat* (\wedge)). In this equation, v_2^{surf} is the crossline component of the particle velocity measured in the field on the stress-free surface $x_3 = 0$, v_2^{nosurf} is the desired particle velocity field, also measured on the "depth level" $x_3 = 0$, as if no surface were present, μ is the shear modulus of the top layer, γ_s is the vertical wavenumber, defined as: $\gamma_s = \sqrt{\frac{s^2}{c_s^2} + k_1^2}$, in which c_s is the shear wave velocity of the top layer, \hat{f}_2 is the signature wavelet of the volume source density of force, x_1^R is the receiver position, x_1^S is the source position, k_1 is the horizontal wave number, and finally s is the Laplace parameter.

Eq. (1) is an integral equation of the second kind, meaning that the unknown term (v_2^{nosurf}) is both

inside and outside the integral. When the terms under the integral are transformed back to the space-Laplace domain and discretized, it can be written as an explicit matrix equation:

$$\hat{\mathbf{V}}_2^{\text{nosurf}} = \left[\mathcal{F}^{-1} \left\{ \frac{\mu\gamma_s}{s\hat{f}_2(s)} \mathcal{F} \left\{ \hat{\mathbf{V}}_2^{\text{surf}} \right\} \right\} \Delta x_1 + \mathbf{I} \right]^{-1} \cdot \hat{\mathbf{V}}_2^{\text{surf}}, \quad (2)$$

where the Fourier transformations (denoted by \mathcal{F}) have to be applied to the shot coordinates.

As stated, these equations show that no model of the structure of the subsurface is needed for the removal of Love waves. The method does need the material parameters of the top layer (via $\mu\gamma_s$) and the source wavelet. When a vibrator source [5] is used, the source wavelet can be recorded, in which case a wavelet estimation procedure is not necessary. The recorded wavelet is used for deconvolving the data, after which the dataset has a constant wavelet for each shot.

Examples

Synthetic data examples

To show the potential of the method, several datasets were modeled, using finite difference modeling as developed by Falk [6]. Two examples are shown here. Both datasets have a subsurface model with a thin Love-wave-generating layer with a shear wave velocity of 200 m/s, then a thicker layer with a shear wave velocity of 300 m/s, generating a normal reflection, and finally a lower half-space with a shear wave velocity of 350 m/s. In both cases, the sources and receivers are placed on the surface. The source spacing is equal to the receiver spacing, which is 0.8m. For the implementation of eq. (2), a complex Laplace parameter was used: $s = \varepsilon + j\omega$, where ω is the radial frequency, and an independent value of $\varepsilon = 4.0$ was chosen. The input data were spatially tapered with a cosine taper, and only the non-tapered parts are shown in the pictures.

In the first example, the model of the subsurface has an interface with a jump. The depth of the small layer jumps from 0.8m to 2.8m. Figure 1a) shows a graphical representation of this model. Figure 1b) shows a shot record from the dataset. The source is located exactly above the jump. Love waves are the most dominant feature in this record. They obscure the reflection of the deeper layer for larger offsets. Due to the jump, the Love waves on the left differ from the ones on the right. Figure 1c) shows the same shot record after the removal of the Love waves. With the Love waves gone, what remains is the direct wave, which is interfering with the reflection from the small layer and the refraction from the small layer. The reflection from the deeper layer is no longer obscured.

In the second example, the model of the subsurface has a more complex interface. The thin layer makes several jumps, such that the depth varies from 0.4m to 2.0m. Figure 1d) shows a graphical representation of this model. Figure 1e) shows a shot record from the second dataset. Again, Love waves are the dominant feature. There are also scattering effects which are the result of the wave field hitting such a jump. Figure 1f) shows the same shot record after the removal of the Love waves. Again, the reflection from the deeper layer is no longer obscured. But the scattered Love waves have also been removed.

The Sofia dataset

A real field dataset has been shot at the site of the future Sofia tunnel near Hendrik Ido Ambacht in the Netherlands. Figure 2 shows one shot record from this dataset. There are indeed Love waves visible in the record, especially at the right of the source. The removal procedure will be applied to this dataset. The most important differences which have to be overcome are: different source and/or receiver coupling effects, absence of the zero-offset trace and filtering from three-dimensional to two-dimensional data.

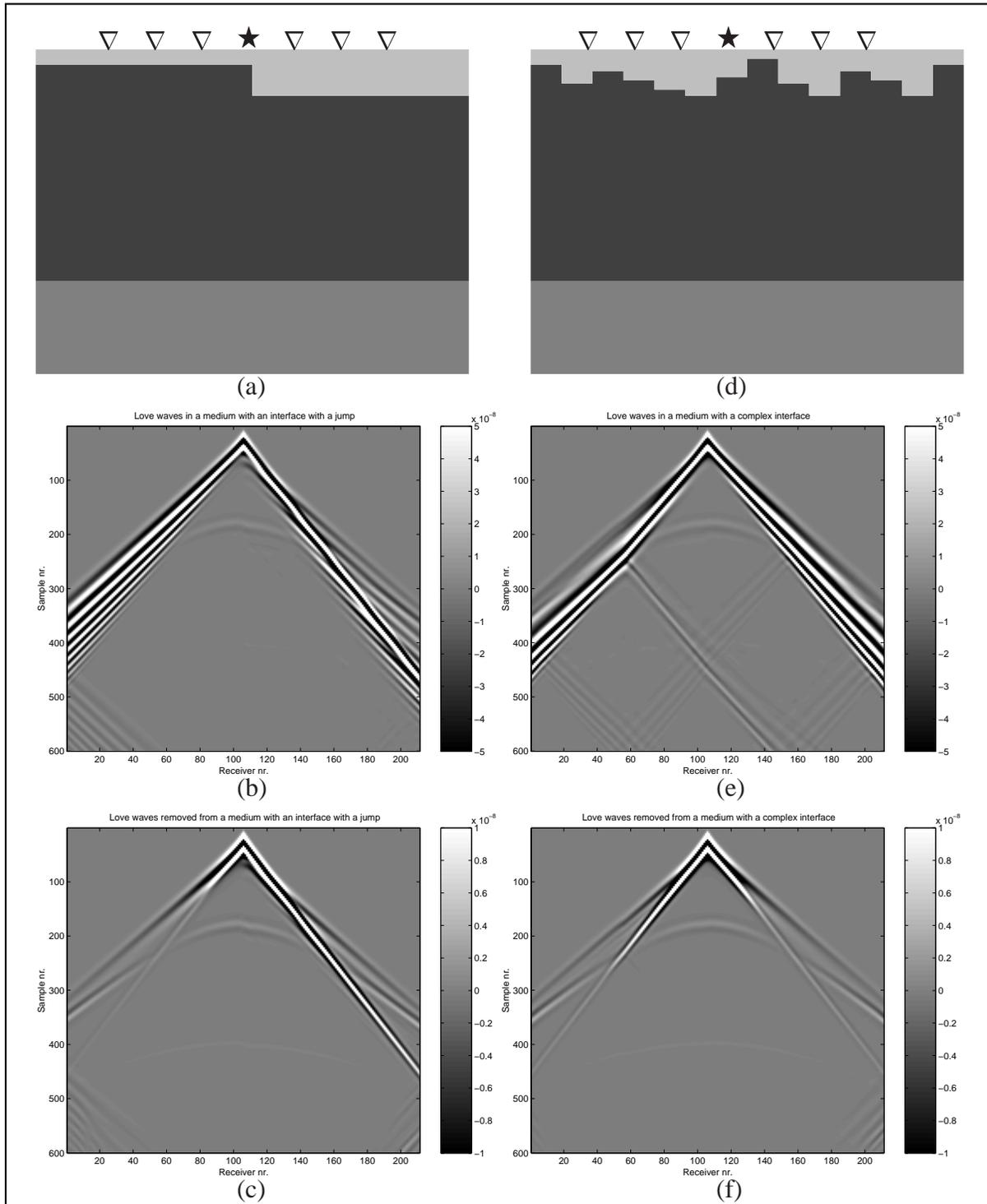


Figure 1: *Removing Love waves, a) model of a medium with an interface with a jump, b) input data where the model is a), c) Love waves removed from b), d) model of a a medium with a complex interface, e) input data where the model is c), f) Love waves removed from e).*

Conclusions

This paper presented a technique which is capable of removing Love waves and their scattering effects from SH-wave data. No structural subsurface model is needed. The method only needs

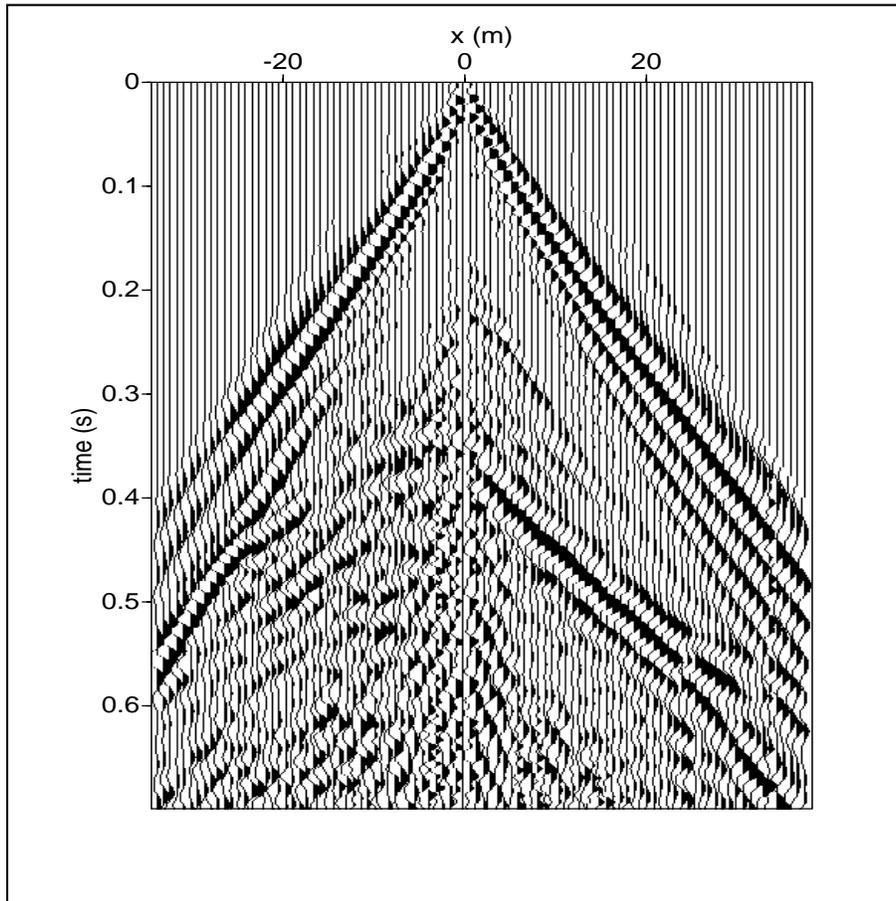


Figure 2: *One shot record with agc from the Sofia dataset*

the source wavelet and the material parameters of the top layer. It has been tested successfully on synthetic datasets. Presently, every effort is put into making this method operational on field data.

References

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