S11B-1951: Surface-Wave Isolation with the Interferometrically Obtained Green Tensor

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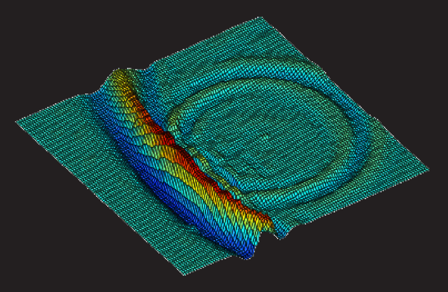
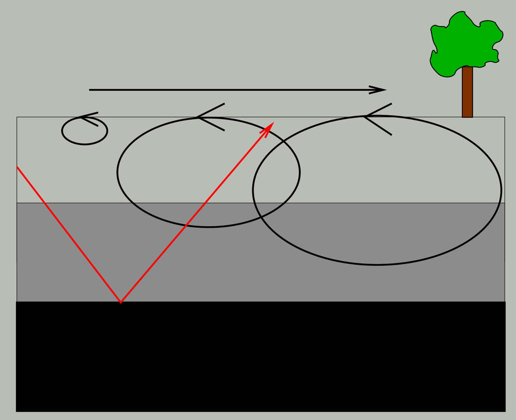


Abstract

Surface and body waves inherently coexist in seismic records. Usually we are interested in the one, while the other is unwanted.
To complicate things, body and surface waves often overlap in time and space. Hence, separation of these different wave modes is complicated, and remains an active topic of research. Here we use estimates of the Green tensor obtained via seismic interferometry to provide waveforms with isolated body and surface waves, allowing us to focus our further studies on one or the other. These ideas are illustrated by a laboratory, numerical and field example.



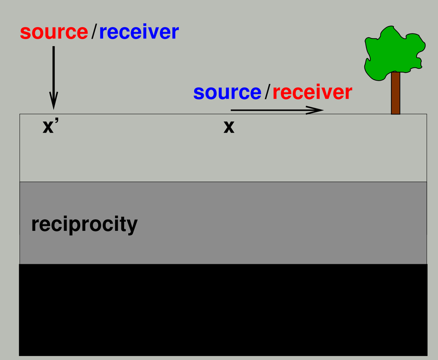
Introduction

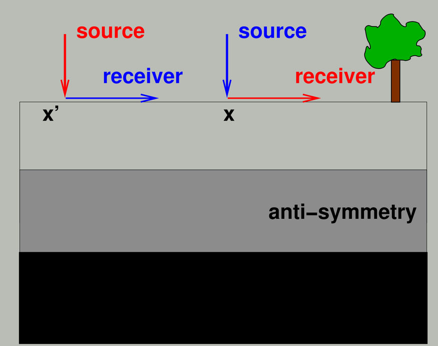
For all components of the wavefield, we can exchange the point source and receiver location and observe the same field (reciprocity):

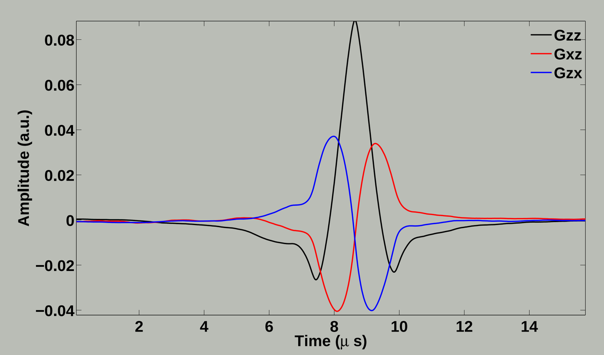
$$G_{xz}(\mathrm{x},\mathrm{x}',\omega) = G_{zx}(\mathrm{x}',\mathrm{x},\omega),$$

where G_{ij} is the Green tensor. However, the ellipticity of the Rayleigh wave for a horizontally layered earth causes an anti-symmetry between the horizontal component of the Rayleigh wave from a vertical force source, and the vertical component of the Rayleigh wave from a horizontal force source [1, equation 7.147]:

$$G_{xz}(\mathrm{x},\mathrm{x}',\omega) = -G_{xz}(\mathrm{x}',\mathrm{x},\omega) = -G_{zx}(\mathrm{x},\mathrm{x}',\omega).$$



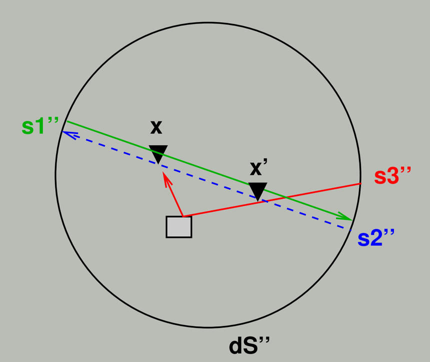




On the left, $G_{zx}(x,x')$ is the vertical component of the Rayleigh wave from a horizontal point force in a homogeneous model. Flipping to source to vertical ($G_{zz}(x,x')$) results in a 90 degree phase shift, and flipping the receiver as well ($G_{xz}(x,x')$) gives rise to one more 90 degree phase delay.

Seismic interferometry for the elastic Green tensor

As we have seen in the last years, we can obtain the impulse response between receivers from correlating the wavefields. Most common is the correlation of the vertical components of the wavefield for an estimate of G_{zz}, but the far-field elastic Green tensor can be represented by [6]:

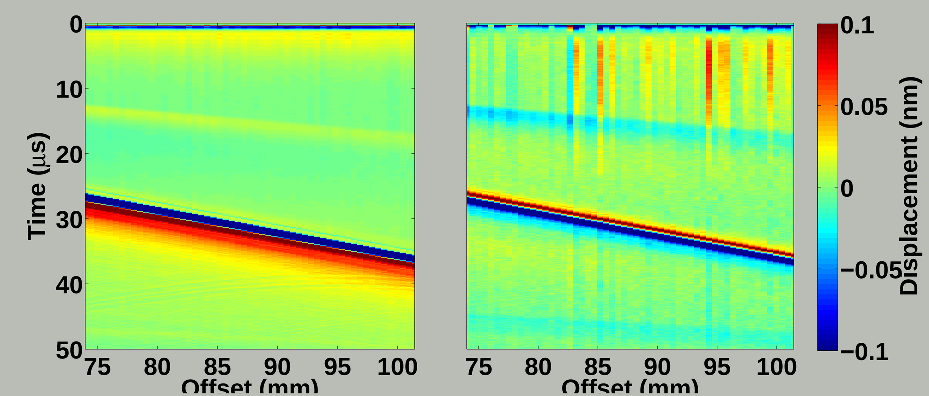


$$G_{ij}(\mathrm{x},\mathrm{x}',\omega) + G^*_{ij}(\mathrm{x},\mathrm{x}',\omega) \propto \oint_S \frac{U^*_{ik}(\mathrm{x},\mathrm{x}'',\omega)U_{jk}(\mathrm{x}',\mathrm{x}'',\omega)}{\rho(\mathrm{x}'')c(\mathrm{x}'')} dS''.$$

This means that from a source in the k-direction only, we can get estimates of the impulse response in direction i from a virtual source in direction j. This is particularly interesting for passive seismology with no control over the source parameters, and active-source seismology where horizontal (vibroseis) sources are not common.

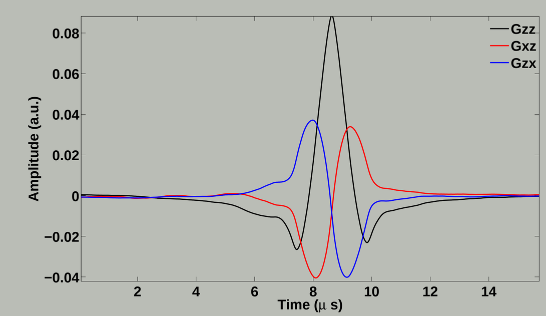
A Laboratory Example: a Rayleigh wave in an aluminum halfspace

By focusing the beam of a pulsed Nd:YAG laser onto a small area of a sample, thermoelastic expansion in the sample results in broad-band ultrasonic wave propagation. A newly developed laser ultrasonic interferometer measures the absolute ultrasonic displacement for both the vertical and the radial component by collecting light scattered from the sample at high angles [2].



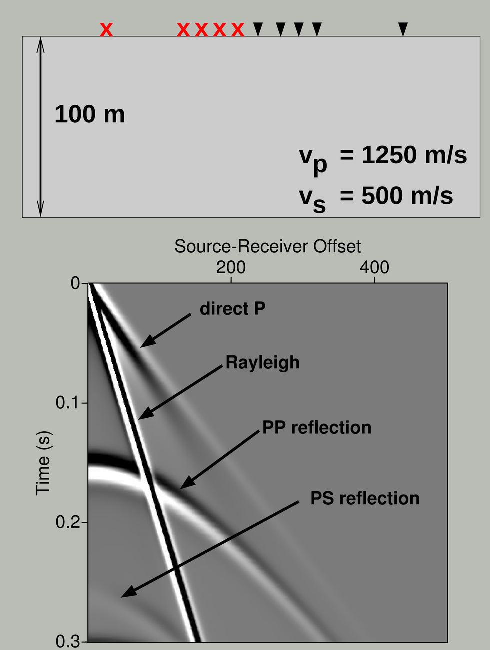
On the left, we show measurements of the vertical (left panel) and radial component (right panel) of the Rayleigh wave in an aluminum block every 0.5 mm.

The cross-correlation between the vertical and radial components of the receivers provides an estimate of the Rayleigh-wave Green tensor. Notice the 90-degree phase shift between components.

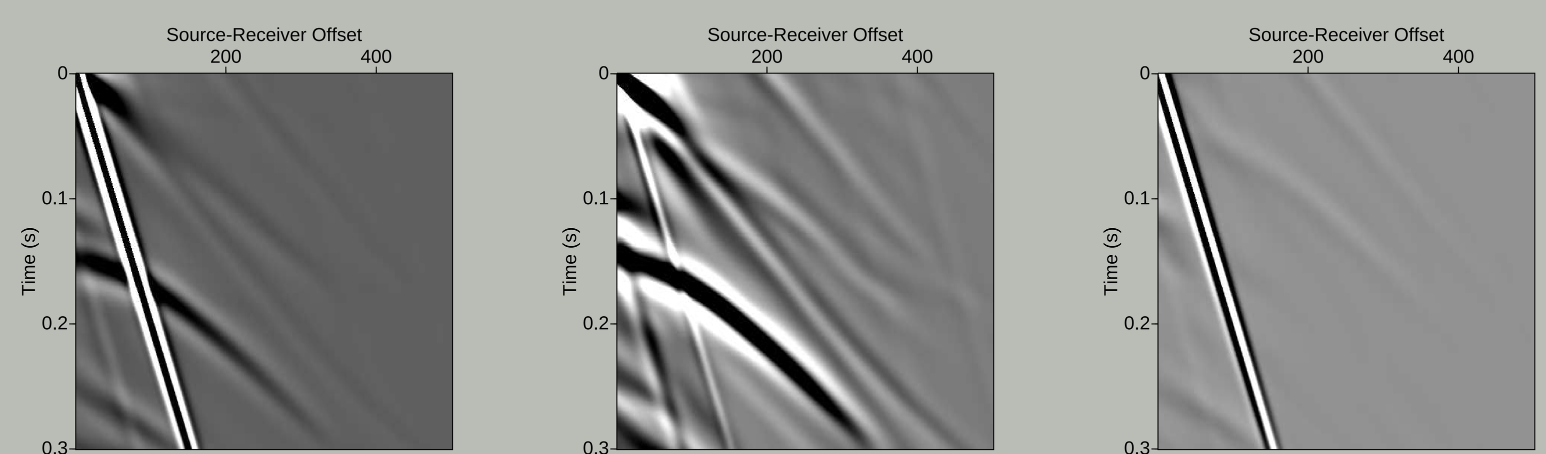


In this halfspace the Rayleigh wave is not dispersive, nor do we have body-wave reflections, but in the next examples we explore the value of the Green tensor estimates for both such cases.

A Numerical Example: Body and Rayleigh waves in a slab

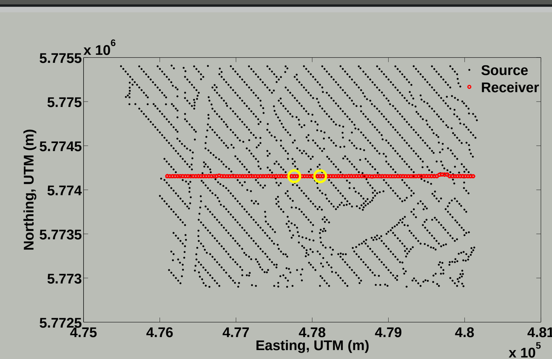


Spectral-element simulations [4] of vertical impact point-force sources at the surface ranging from 500 to 1050 m at 2 meter increments are recorded on 501 receivers, spaced every meter between x=1050-1550 m. Each receiver records the vertical and horizontal component of the wavefield. U_{zz}, the vertical component of the wavefield from a vertical force source, is depicted on the left, showing a direct p-wave, a Rayleigh wave, a reflected PP-wave and a PS converted wave.

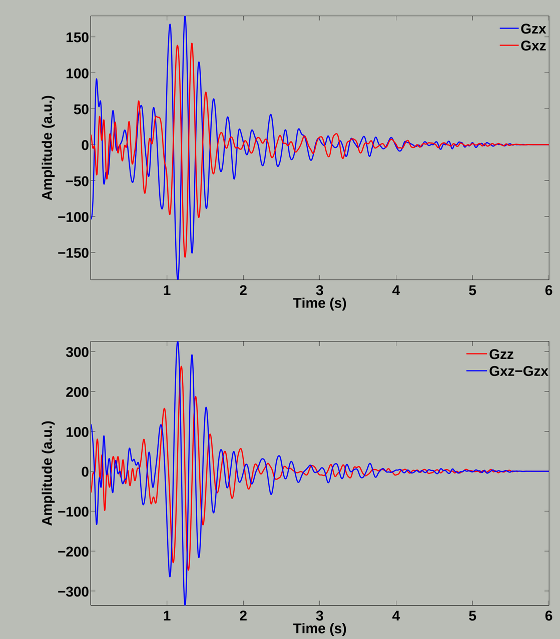


Compared to the correlations of the vertical components (G_{zz}, left), the cross-terms of the Green tensor help to either suppress ($G_{zx}+G_{xz}$, middle) or highlight ($G_{zx}-G_{xz}$, right) the surface wave arrival [5]. In the next example, we explore a dispersive surface wave for near-surface characterization.

A Field Example: Dispersive Rayleigh Waves at Coronation Field



On the left is a map of sources and receivers for a subset of the 80 km^2 Coronation field data set, where sources are 1 kg of dynamite buried at 18 m, and the receivers are three components [3]. Surface-wave dispersion between sources and receivers can be used for near-surface characterization. Seismic Interferometry can provide additional information with receiver-receiver dispersion curves.



Wavefields between receivers 50 and 60 (separated by 350 m, yellow markers on the map) are obtained interferometrically from 17 in-line sources, filtered between 1 and 10 Hz. The estimate of the components of the Green tensor are on the left. The cross-terms are clearly anti-symmetric for the Rayleigh wave around t=1 s. A comparison between G_{zz} and $G_{zx} - G_{xz}$ reveals that in this case the surface wave for the cross-terms has a signal-to-noise ratio which is as good or better than the vertical result.

Conclusions

In numerical, laboratory and exploration seismic data we exploit the ellipticity of Rayleigh waves in horizontally layered media to isolate them from other wave modes. With interferometrically obtained components of the Green tensor we can

- reduce surface waves where we aim for the strongest possible body waves
- enhance surface waves to invert their dispersive properties

Acknowledgments

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References

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