

### 3-D elastic time-reverse imaging of a void anomaly: a case history

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#### ABSTRACT

Imaging undetected subsurface voids is an important task in near-surface investigations for the variety of issues that might arise if left unchecked, ranging from structural stability issues like subsidence and sink holes to drilling and security risks. The geophysical analyses associated with void detection may be challenging though, due to issues such as the scale of the survey and the risk of missing the anomaly. Various seismic approaches to this problem have been developed, with some of the more successful methods using backscattered surface-wave energy. However, these seismic analyses require a combination of high spatial wavefield sampling, significant processing power, or long computation run times. This motivates the development of migration methods that can quickly and robustly detect and image sources of backscattered surface-wave energy.

Elastic time-reverse imaging (E-TRI) is an emerging seismic analysis method for detecting near-surface anomalies including strong lateral heterogeneities such as void spaces. Originally developed for microseismic event location, this elastic full-wavefield migration method uses two time-reversed (or “adjoint”) elastic wavefields, generally reconstructed from the P- and S-wave data, and then applies an imaging condition (e.g., energy norm) to stack correlated energy throughout the migration domain over propagation time and generate an interpretable image of the location of subsurface energy sources (i.e., microseismicity).

When using E-TRI for the purpose of near-surface void detection, the aforementioned analysis can be modified to work on surface-wave data. First, one can partition the observed surface-wave data into two separate data subsets representing the: (1) outward-propagating transmission energy; and (2) inward-propagating backscattered wavefield energy. These two partitioned data subsets can be generated by judicious muting in the  $f-k$  domain, where the opposing wavefield dips are clearly separated. Figures 1a-c illustrates this separation on a representative shot gather extracted from a near-surface field seismic data volume. Figure 1a shows the full shot gather, while Figures 1b and 1c respectively show the  $f-k$  filtered, backscattered, and transmission data estimates.

Having separated the transmitted and backscattered data, the iterative E-TRI process begins at the last time step by completing the following three-step procedure: (1) injecting the two data subsets into their respective adjoint wavefields; (2) applying a single backpropagation step in time for each adjoint wavefield; and (3) evaluating the energy-norm (or other) imaging condition to form an image by correlating the energy found within the two adjoint wavefields. These three steps are repeated in reverse time until reaching the first time step.

To demonstrate the use of E-TRI on a field seismic dataset, we use a 3-D near-surface seismic data volume acquired at a field

site in Arizona, USA, over a long linear void anomaly centered beneath the receiver array (Figure 1d) located at 10 m depth. Figure 1d shows a depth slice of the resulting 3-D E-TRI image volume that clearly shows the presence and orientation of the long, linear void, highlighting the feasibility of using an E-TRI framework for void detection. The result was generated in under 4 hours on a single GPU, which is reasonable compared to other advanced elastic seismic void detection methods. These results suggests that E-TRI with additional constraints could become a reliable near-surface detection method for voids and other shallow small-scale lateral heterogeneities.

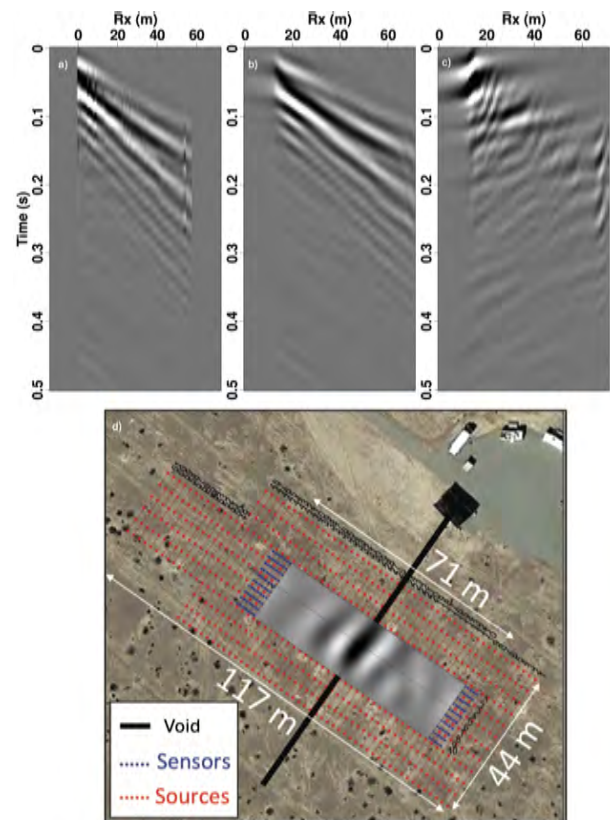


Figure 1:  $f-k$ -based separation of a (a) field data shot gather into (b) transmission and (c) backscattered data subsets. (d) E-TRI image showing a successful detection of a linear subsurface void at 10 m depth (orientation shown by black line) projected on site with surface acquisition geometry.

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