KIT
Karlsruhe Institute of Technology

Geophysical Institute
Project TOAST
(Toolbox for Applied Seismic Tomography)

Appropriate line source simulation procedure for shallow seismic field data

Test case for structure with 2D heterogeneity

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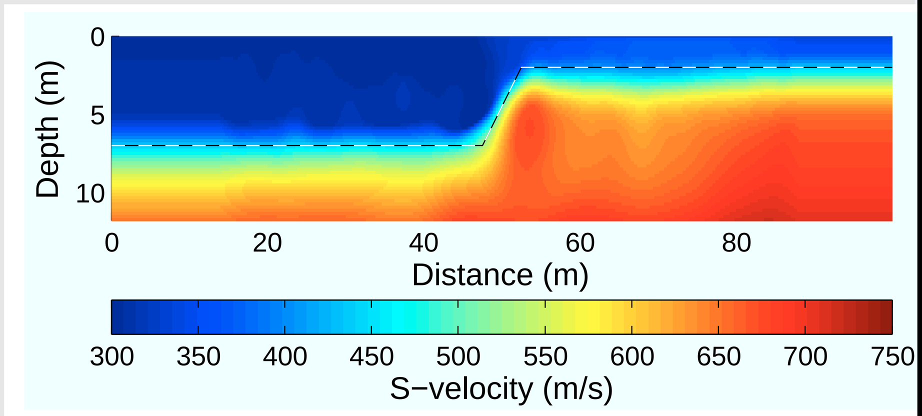
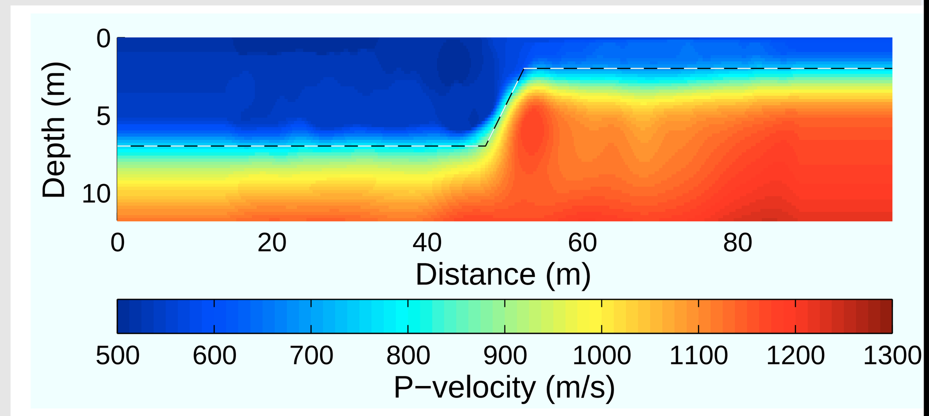
1. Subsurface model with significant lateral heterogeneity

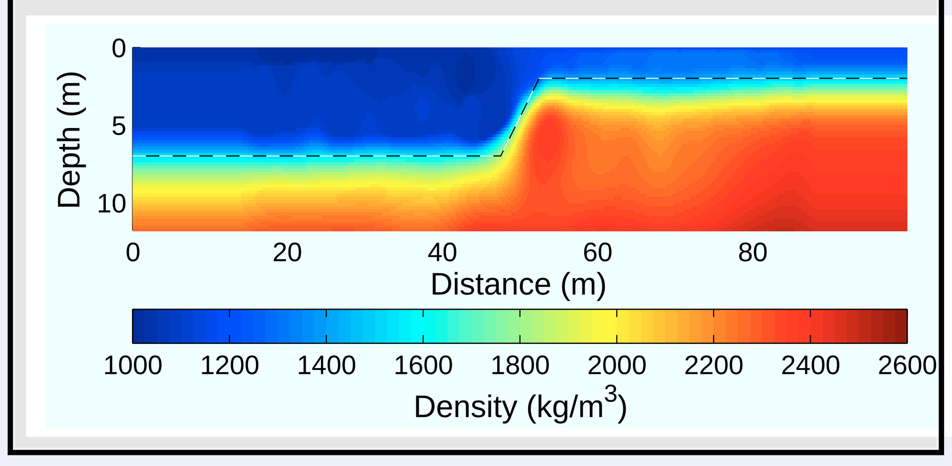
1.1 Shear-wave velocity



1.2 Compressional-wave velocity



1.3 Mass density



2. Test case: Application to 2D structure

2.1 Waveform simulation

As a test for the performance of the line source simulation procedure, we apply the transformation to waveforms calculated by a time domain finite difference algorithm for a subsurface structure of significant 2D heterogeneity. For the test we designed a smooth 2D structure which presents a significant lateral impendance contrast to surface waves. The horizontal size of the model is 100 m and the depth to half-space varies from about 8 m to 2 m at position 50 m. We emphasize the contrast between layer and half-space in all three parameters in order to establish a noticeable impedance contrast. The shot is applied at position 5 m and the reverse shot is applied at 94 m.

2.2 Line source simulation

Reference seismograms for a line source are simulated by a 2D finite-difference algorithm. Waves for a point source are calculated by a 3D finite-difference algorithm, where the subsurface structure is homogeneously extended in y-direction (perpendicular to the image plane). The point source seismograms are transformed by a hybrid approach. The large amplitudes of the taper function

$$F_{\text{amp}} = r\sqrt{\frac{2}{t}} = r\,\sqrt{2}\,F_{\sqrt{t^{-1}}}(t) \quad (1)$$

for small sample time t produces strong artefacts at small source offsets. For this reason we apply a single velocity transformation with velocity $v_{\text{ph}} = 280\,\text{m}\,\text{s}^{-1}$ at offset smaller than 5 m. From offset 5 m to 15 m we gradually shift to a direct wave transformation. At offset larger than 15 m we apply the direct wave transformation only. The taper of the direct wave transformation is delayed by 20 ms according to the broad-band group delay produced by the source.

2.3 Performance

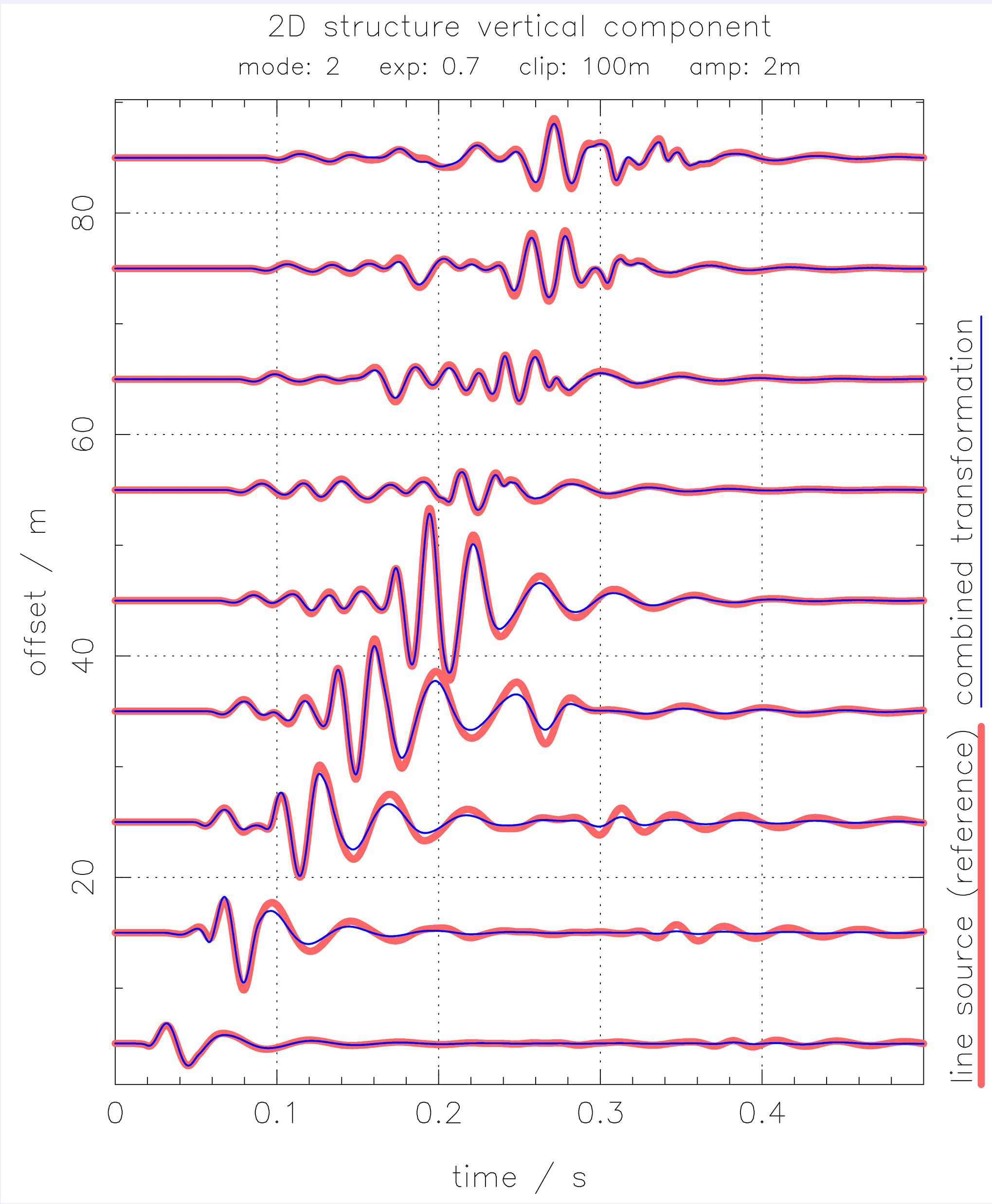
We compare true amplitudes (seismograms are scaled by an offset dependent factor). Almost all wave types at all offsets are appropriatly transformed to a signal of the equivalent line source. The procedure performs equally well for both domains of surface wave dispersion independent of shot location. Residuals are apparent for the radial component of the reverse shot at large offset and for reflected surface waves. In the wavefield excited by the shot, significant reflected surface waves are apparent which return from the step in the top of the half-space in the center of the model. For these waves the phase velocity estimated by $v_{\text{ph}} = r/t$ from offset r and sample time t obviously is inappropriate. The actual travel distance is $r_{\text{eff}} = 90\,\text{m} - r$ and the appropriate amplitude factor would be

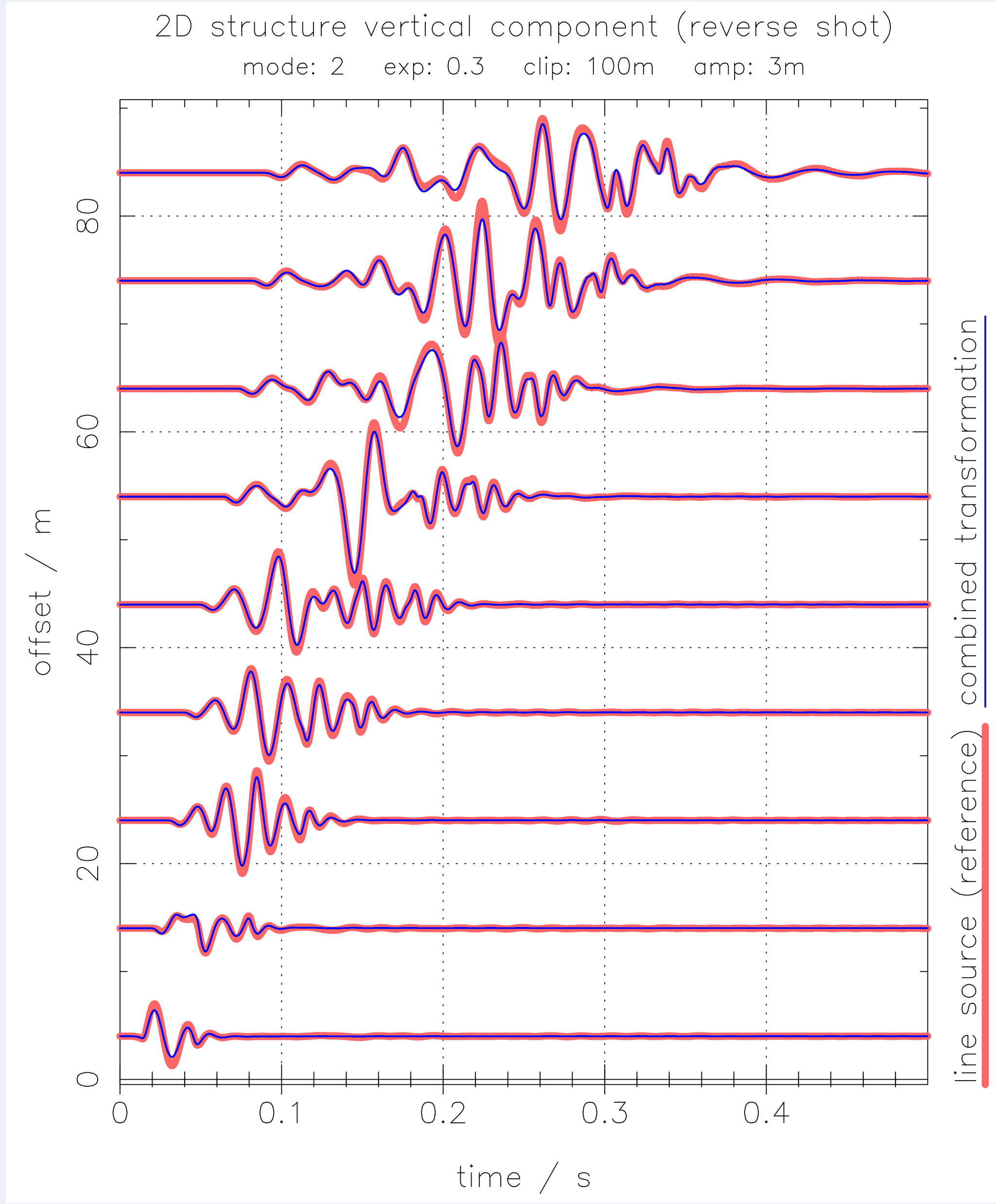
$$F_{\text{eff}} = (90\,\text{m} - r)\sqrt{\frac{2}{t}} = (90\,\text{m} - r)\,\sqrt{2}\,F_{\sqrt{t^{-1}}}(t). \quad (2)$$

The amplitude of the transformed waves consequently is systematically too small by a factor of

$$\frac{F_{\text{amp}}}{F_{\text{eff}}} = \frac{1}{\frac{90\,\text{m}}{r} - 1}. \quad (3)$$

3. Vertical component





4. Horizontal component