Extending seismic bandwidth using the harmonic energy of a marine vibrator source

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Objectives

In vibrator technology, the presence of harmonics is a common phenomenon. Several authors considered the problem of removing or utilizing harmonics from land vibrator data. However, marine vibrator (MV) harmonics are rarely discussed. Although much weaker than the fundamental signal, we show that the MV harmonics can in principle be successfully used for broadening the frequency band of interest for subsurface imaging. Utilization is enabled by a highly reliable MV source capable of producing high-fidelity repeatable sweeps and by a high-fidelity source signature estimator.

Procedures

In August of 2022, we conducted a BASS (Broadband Acoustic Seismic Source) MV test at Seneca Lake, US. The lake depth is around 143m at the test site. In this test, we placed the BASS MV at 4.6m below the surface of the water in a stationary state and equipped with NFHs (near field hydrophones) and accelerometers to estimate the notional source (NS) signature. We also placed two 4C nodes (one of which is used here) below the vibrator on the lake's bed.

To study the role of harmonics more thoroughly, we require a portion of sweep containing only harmonic energy. Therefore, from a wide variety of sweeps in our recent test, we choose one low-band sweep whose fundamental frequency energy is between 3 and 25Hz. Any energy above 25Hz in this low-band sweep is a harmonic. It is worth mentioning that the total harmonic energy is, on average, about 25dB lower than the fundamental signal. This low-band sweep has a duration of 10s and was repeated ten times in the sequence. The fundamental frequency of the high-band sweep chosen for comparison runs from 25 to 150Hz and is 5s long.

We processed the node data for band-passed low band and high band sweeps separately. To get an accurate subsurface image, we use the NFH recordings to estimate the NSs via a time-domain iterative algorithm. The node data corresponding to the low- and high-band sweeps are then processed through PZ calibration, sweep deconvolution and up-down separation.

Results

Figures 1a and 1b show the estimated up-going wavefield using low- and high-band data, respectively. Both images are band-passed to 25-150Hz to make them comparable. For better visualization, we arrange both up-going wavefields from low- and high-band sweeps into 10 channels according to the sweep number. The up-going wavefield from the low-band sweep is from harmonic signals only and the wavefield from the high-band sweep is from both fundamental and harmonic signals. Figure 1c shows the frequency spectrum of the two images.

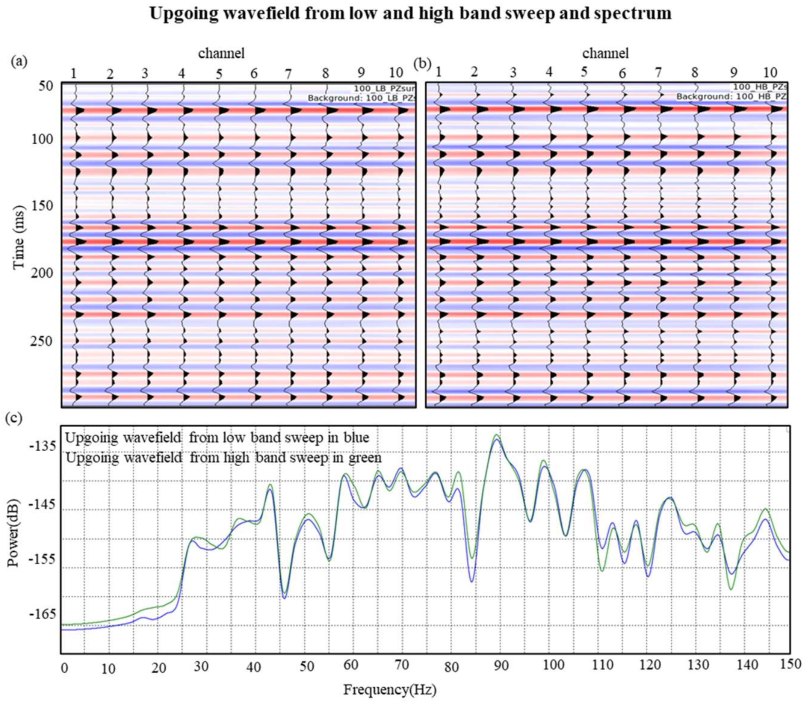

Figure 1 *Top row: The up-going wavefields (band passed 25-150Hz) obtained from low-band (3-25Hz) a) and high-band (25-150Hz) b) sweeps. Bottom row: The frequency spectrums from a) and b).*

Figure 1 shows that the low-band image (which can be called a harmonics-only image) is consistent with that of the high-band image (obtained from both fundamental and harmonics). This illustrates that, in a marine seismic survey with BASS operating, the harmonics can play a constructive role in widening the frequency band of the wavefield. This proof of concept was successful because of the high-fidelity sweep generation by the MV source and the high-quality estimation of the NSs. NS estimation for a MV is much more accurate than for a land vibrator for reasons of perfect coupling with the water layer. This improved accuracy paves the way for using harmonics in imaging. Furthermore, we can see that neighbouring traces within the up-going wavefield gathers show very high similarity, indicating a highly repeatable sweep emission.

Significance

MVs offer the potential for improved acquisition efficiency and reduced environmental footprint. Typically, harmonics in the emitted signals have been regarded as noise. Here we show that it is in principle possible to effectively estimate and use the harmonic energy associated with the MV. We show that harmonic energy can be used for extending the usable bandwidth of seismic data for subsurface imaging. This looks particularly attractive for shallow targets and overburden imaging in general. Further work is required to assess feasibility when the MVs are operated in an array and under tow.