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Suppression of (sub)harmonic noise on Vibroseis data

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Vibroseismics is, besides the classical explosion seismics, the most important energy source to acquire seismic reflection data in the hydrocarbon industry as well as in crustal-scale seismic profiling. The basic principle is to send a periodic signal of varying frequency (a so-called sweep) over a longer time period into the ground (mostly several times in succession). For this, one or more hydraulic-controlled vibrators transmit the desired source signal via large metal plates coupled with high peak-force into the ground. The mathematical process of correlation between the vibroseis trace measured at the geophone and the utilized control-sweep is able to calculate directly an impulse seismogram that is equivalent to an explosive trace. If the source signal leaving the vibrator baseplate and propagating through the subsurface is for any reason not exactly identical to the controlling pilot-sweep, then the following correlation (which aims to concentrate the long-duration stimulation signal into a sharp wavelet) will be false. The reasons for such a mismatch could be: either (1) that the baseplate doesn't follow the pilot sweep in a proper way (e.g. due to insufficient peak-force control), or (2) that the baseplate does follow the pilot-sweep, but the ground does not follow the baseplate properly (e.g. due to non-linear behavior of the weathering layer when a too high peak-force is applied.). Each deviation of the periodic excitation signal from a strict, frequency-variant cosine shape will automatically produce harmonic waves with whole multiples of the instantaneous frequency. These harmonics, however, will generate 'ghost events' after correlation with the pilot-sweep (which does not contain the harmonic wave portions). These ghosts originate from additional correlations of the fundamental frequencies on the control-sweep with the harmonic multiples on the geophone trace. This can easily lead to mis-interpretations, especially in deep crustal seismics where the signal/noise-ratio is already very small at later traveltimes. In the framework of the project DESIRE 2006 (DEad Sea Integrated REsearch) a part of the reflection traverse in Israel (from the Negev Desert to the Dead Sea) was recorded

with high-fold vibroseismics. Here (to our knowledge for the first time), also strong subharmonic wave-portions were observed, i.e. in addition to the fundamental frequencies prescribed by the pilot-sweep (and some less surprising harmonic multiples of them) the source signal contains a significant amount with half of the fundamental frequencies after propagating from the baseplate to the geophone. These subharmonic partials are especially disastrous (with respect to the seismogram quality) for the simple reason that the corresponding ghosts are imaged towards later traveltimes where the signal amplitudes have already considerably decayed, whereas the ghosts of the less crucial harmonic partials are imaged towards earlier traveltimes where the signal amplitudes are still relatively high. A mathematical procedure has been developed to recognize, separate, and selectively suppress these extremely disturbing (sub)harmonic side-bands. For this, the recorded vibrograms are transformed into a domain, that could be best named as '(sub)harmonic domain', where all (sub)harmonic frequency portions focus separately from each other and can be properly eliminated before backward-transformation. The method introduced here does not operate blindly but is data-driven, and it is available as a manual, a semi-automatic or a fully-automatic version. Results of application to DESIRE vibroseis records will be shown.