Vibroseis Multi-Sourcing using m-Sequence Pilots

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Summary

We conducted field tests to evaluate the effectiveness of filtered m-sequences used as Vibroseis pilots. In a test of single-source acquisition, we found that properly designed filtered m-sequences potentially are better than linear sweeps for controlling land vibrators. In a test of simultaneous multi-sourcing, quasi-orthogonal filtered m-sequence pilots proved to be suitable for driving two or four vibrators in synchronous operation. Seismograms extracted from the blended raw data by cross-correlation with the quasi-orthogonal pilots or the associated ground force signals show reflections that are somewhat degraded by crosstalk interference from large-amplitude arrivals from nearby vibrators. The crosstalk exists because the filtered m-sequence pilots are not perfectly orthogonal. For vibrators separated by 100m or less, source-to-source crosstalk is within acceptable limits as it does not totally obscure the reflections, and can be reduced to the point of negligible consequence using appropriate noise-reduction processing.

Introduction

Completing a high-resolution 3D seismic survey is much faster if field acquisition can be conducted with several simultaneous sources. In both marine and land seismic surveys, this is done with distance-separated seismic sourcing (DSSS), where several sources located at widely-spaced positions are activated synchronously or semi-randomly in time (Beasley, 2008; Bouska, 2010; Bagaini and Yi, 2010). Recorded seismic traces are the sum of the signals from all the sources, and before standard processing and imaging techniques can be applied, the summed data must be separated or deblended to yield ordinary common-source gathers. The different time moveouts of events on the gathers of blended seismograms are exploited to separate the summed field data into unique common-source gathers (CSGs) associated with the individual sources.

In Vibroseis-based land surveys, deblending of data acquired with multiple simultaneous vibrators can be done successfully at the cross-correlation step if the vibrators are driven by a set of quasi-orthogonal pilot signals. Pure m-sequences are periodic, and sets of shifted pure m-sequences are almost perfectly orthogonal (Wong, 2012; 2013). Shifted m-sequences become suitable Vibroseis pilots if they are filtered so that their final spectral content is compatible with the mechanical responses of land vibrators (Wong and Langton, 2014).
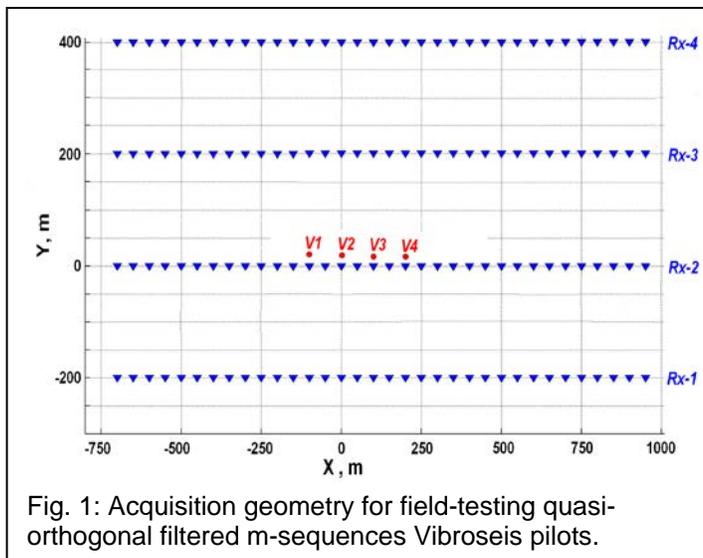

Fig. 1: Acquisition geometry for field-testing quasi-orthogonal filtered m-sequences Vibroseis pilots.

We conducted several field experiments to test the above ideas using the survey geometry depicted on Figure 1. Receivers (blue triangles) were placed at 50m intervals along four parallel 6800m-long lines. Vibrators V1 to V4 separated by 100m were placed about 5m from receiver line Rx-2.

Single vibrator field results

We recorded data for all four receiver lines with vibrator V1 driven first by a conventional linear sweep pilot, and then by a filtered m-sequence pilot (mSeq-1F). The linear sweep pilot covered 4Hz to 140Hz with a sweep time of 16 seconds and end tapers of 300ms. For the filtered m-sequence pilot, we swept with two full cycles for a total duration of 16.376 seconds. We digitized receiver signals with a 2ms sampling interval and recorded for 22 seconds for both types of pilots. Figure 2 shows the raw uncorrelated data produced by the two types of pilots for the near-offset receiver line. Seismograms were extracted from the raw field data post-survey by cross-correlating them with the ground force signal generated by the linear sweep pilot or by the filtered m-sequence pilot.

Fig. 2: Uncorrelated field data from receiver line Rx-2 for single vibrator driven by: (a) linear sweep pilot; (b) filtered m-sequence pilot. Seven seconds plotted; full recorded lengths = 22 seconds in both cases.

Fig. 3: Seismograms extracted from the uncorrelated field data recorded with a single vibrator. Left to right: common-source gathers (CSGs) for receiver lines Rx-1, Rx-2, Rx-3, and Rx-4.
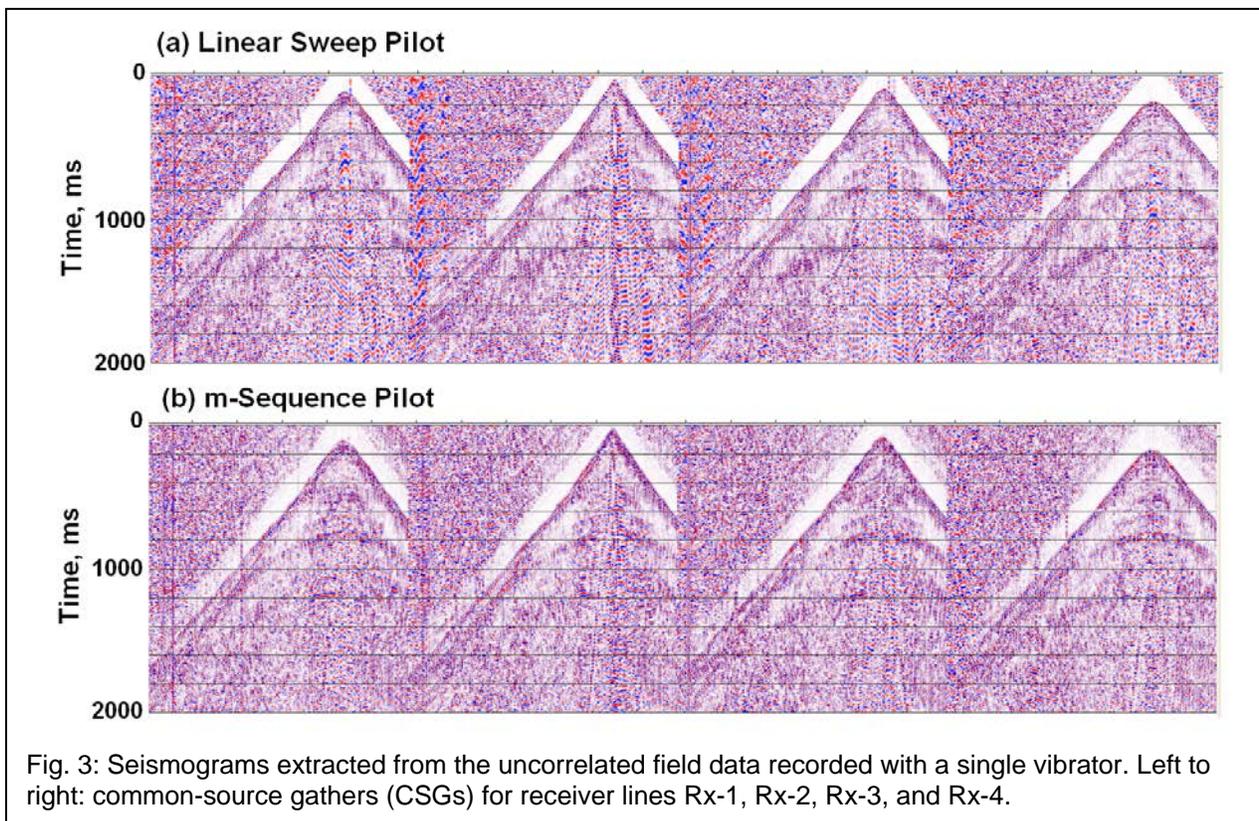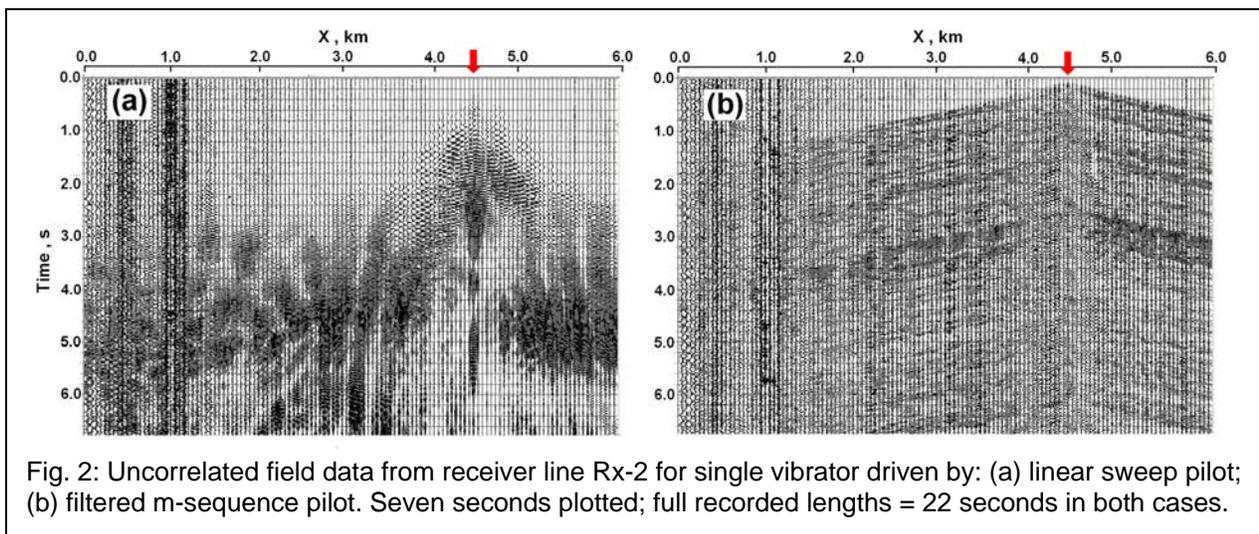
Figure 3 shows the common-source gathers of seismograms produced by cross-correlating the raw data on Figure 2 with the ground force signal associated with the correct (linear-sweep or m-sequence) pilot. The two types of CSGs are very similar in appearance with clearly discernible reflections. On the m-sequence CSGs, the deep reflections near 1200ms are somewhat degraded by artifacts that seem to be multiples of the first arrivals. Their SNRs are lower than the corresponding SNRs on the linear-sweep CSGs. For the shallow reflections at 800ms and above, the reflection SNRs appear to be better on the m-sequence CSGs, mostly because ground-roll noise is weaker on the m-sequence seismograms.

Four vibrators driven simultaneously by four m-sequence pilots.

Four quasi-orthogonal filtered m-sequences, mSeq-1F, mSeq-2F, mSeq-3F, and mSeq-4F, were used as pilots to drive the four vibrators V1 to V4 in simultaneous and synchronous operation. Two full cycles of each pilot were used for a total sweep time of 16.376 seconds. We recorded 22 seconds of uncorrelated data sampled at 2ms for all four receiver lines (we show results only for receiver lines Rx-2 and Rx-3, respectively 5m and 200m away from the line of sources). Figure 4 displays the raw uncorrelated data recorded for the near-receiver line Rx-2. Note the strong low-frequency ground-roll noise at receiver positions closest to the vibrators.

We extracted separated common-source gathers (CSGs) for each of the four vibrators by cross-correlating the raw data with the appropriate m-sequence ground force signals. The deblended CSGs for sources V1 to V4 and receiver lines Rx-2 and Rx-3 are plotted with an AGC window of 200ms on Figure 5. We have reduced low-frequency surface-wave arrivals with a (15-30-100-200) Hz bandpass filter.
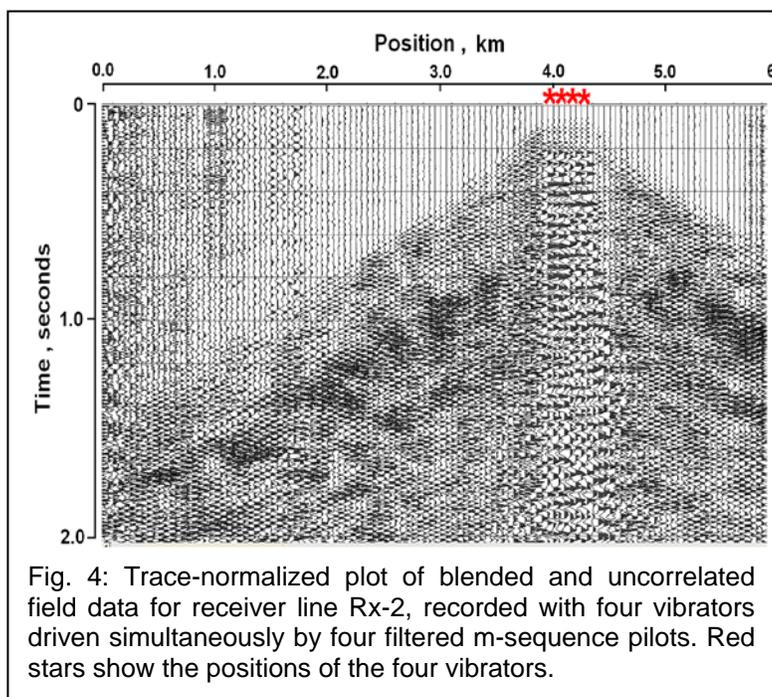

Fig. 4: Trace-normalized plot of blended and uncorrelated field data for receiver line Rx-2, recorded with four vibrators driven simultaneously by four filtered m-sequence pilots. Red stars show the positions of the four vibrators.

Figure 5 shows that reflection events on the deblended CSGs are somewhat degraded by weak artifacts and weak crosstalk interference, both of which are more apparent for the near-offset receiver line. The crosstalk originates from high-amplitude first arrivals and surface waves coming from nearby and adjacent vibrators. The crosstalk is strongest for receivers located close to the vibrator sources, and decreases rapidly as distance to the vibrators increases. The crosstalk interference is within acceptable limits as it does not totally obscure the reflections on any of the CSGs on Figure 5, and can be made negligible using various noise-reduction techniques before proceeding to migration and imaging.

Discussion and Conclusions

Our field experiments have confirmed that (1) hydraulically-powered land vibrators can be controlled successfully by filtered m-sequences, and (2) quasi-orthogonal filtered m-sequences can be used effectively as pilots for simultaneous-source acquisition with two or four vibrators.

Because the filtered m-sequences used in simultaneous multi-source acquisition are not perfectly orthogonal, signals from vibrators not driven by the m-sequence pilot of interest cannot be removed completely by cross-correlation. Crosstalk after cross-correlation is the residual signal from unrelated vibrators, and the stronger the unrelated signals, the stronger will be the residual. For receivers far away

from the vibrator locations, first-arrival and surface-wave amplitudes from unrelated vibrators are not overwhelmingly stronger than reflection events produced by the vibrator of particular interest. Consequently, the crosstalk interference after cross-correlation at these receivers is much reduced.

For a given receiver, the lower the disparity in amplitudes from different vibrators, the lower will be the residuals after cross-correlation. Amplitude disparity depends on differences in the ratio of the receiver distances to the different vibrators. The more nearly equal the distances, the smaller will be the disparity, and the lower will be source-to-source crosstalk. If the source interval shown on Figure 1 is reduced from 100m to 50m, source-receiver distance ratios would be closer to unity for more receivers, thereby improving the deblending effectiveness of the m-sequence pilots.

Numerical simulations indicate that deblending effectiveness also improves if the m-sequences are carefully filtered so as to concentrate their energy in the 4 to100 Hz frequency range.

Acknowledgements

References

Bagaini, and Ji, Y., 2010, Dithered slip-sweep acquisition: 80th International Annual Meeting, SEG, Expanded Abstracts, pp. 91-95.

Beasley, C., 2008, A new look at marine simultaneous sources: The Leading Edge, **27**, 914-917.

Bouska, J., 2010, Distance separated simultaneous sweeping for fast clean vibroseis acquisition: Geophysical Prospecting, **58**, 123-153.

Wong, J., 2012, Simultaneous multi-source acquisition using m-sequences: CREWES Research Report, **25**, 81.1-81.16.

Wong, J., 2013, Multiple simultaneous vibrators controlled by m-sequences: 83rd International Meeting, SEG, Expanded Abstracts, 109-113.

Wong, J., and Langton, D., 2014, Field testing of multiple simultaneous vibrator sources controlled by m-sequences: 84th International Meeting, SEG, Expanded Abstracts, 173-117.
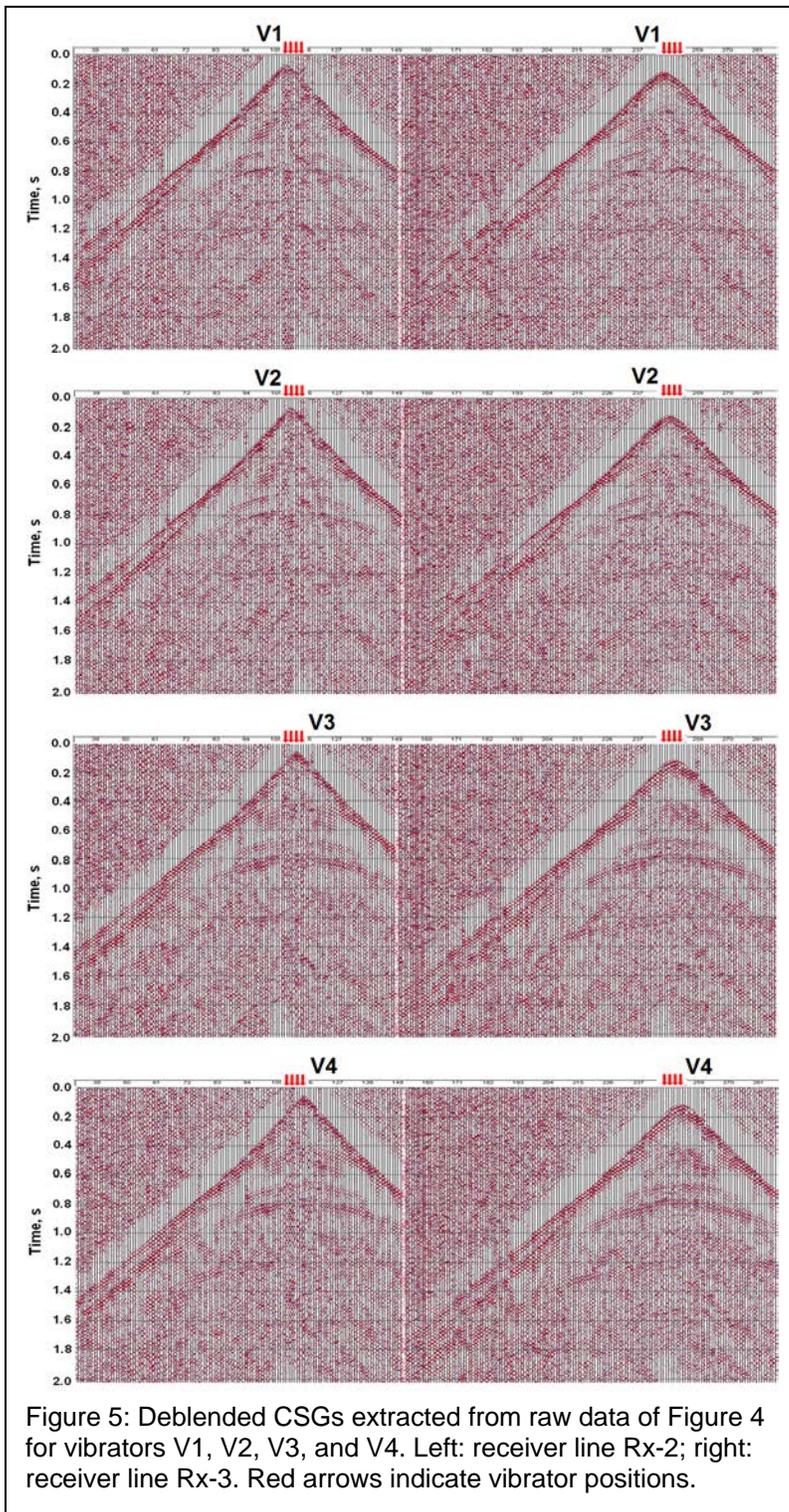
Figure 5: Deblended CSGs extracted from raw data of Figure 4 for vibrators V1, V2, V3, and V4. Left: receiver line Rx-2; right: receiver line Rx-3. Red arrows indicate vibrator positions.