Advantages and disadvantages of pre-correlation, pre-vertical stack processing on near-surface, high-resolution Vibroseis data

Jamie L. Lambrecht, Richard D. Miller, and Theresa R. Rademacker, Kansas Geological Survey*

Summary

Pre-correlation processing has advantages and disadvantages. A form of Vibroseis whitening (VSW) applied to data from two different locations in Kansas was effective in reducing vehicle noise and surface wave energy while increasing the high-frequency portion of the reflection spectra. Data from Site 1 was part of a 4-D CO_2 injection survey using an IVI minivibII seismic source and data from site 2 was part of a 2-D salt study using the IVI minivibI as the seismic source. Site 2 was on the right-of-way of a major east-west highway in central Kansas that supports heavy vehicle traffic.

Introduction

Near surface high-resolution reflection data can be overwhelmed with high ambient noise and suffer seriously from very low signal levels especially within the upper portion of the useable bandwidth, thereby reducing the potential of recorded data to delineate small targets (Doll et al., 1995). In both cases spectral characteristics were improved and signal-to-noise (S/N) was increased. These improvements came with a cost, which included about double the processing time and a little less than two orders of magnitude more storage space. Signal-to-noise problems resulting from stationary, continuous sources of noise like those found in industrial facilities, power lines, or pumping equipment are particularly difficult. Noise bursts from vehicle traffic, wind, or other non-stationary noise sources are troublesome, but when multiple shots are recorded at each source station, suppression through vertical stacking is possible.

Spectral enhancements are also of particular concern for most near-surface high-resolution surveys (Doll et al., 1998). Any method possible to enhance the high-end portion of the reflection bandwidth without significant detraction of the S/N ratio is welcome. Use of different correlation techniques have proven successful in enhancing the high frequency components of vibroseis data used for conventional targets (HRVS) (Allen et al., 1998). A variety of cross correlation approaches have been developed and depending on specific data characteristics any one might be superior at a given site (Klemperer, 1987).

For this particular study into the utility of pre-correlation processing on high-resolution near-surface seismic reflection data two sites were studied each with unique vibrator characteristics and noise environment. The first study area was a rural setting in Kansas where an ongoing 4-D monitoring project provided an excellent opportunity to piggy-back data enhancement experiments. A second site was selected to evaluate the consistent problems associated with working along busy highways.

Previous researchers have made significant advancements in the area of pre-correlation processing and ones that we are capitalizing on with this work (Doll et al., 1995; Coruh and Costain, 1983; Klemperer, 1987). These works confirm that noise reduction techniques can be effective on data from noisy areas. Coruh and Costain (1983) address how Vibroseis whitening (VSW) can enhance reflections otherwise not visible within the shot. Doll et al. (1995) found that spectral whitening improves the narrow bandwidth and the interference from ground roll. Diversity stacking is a technique that has been used to minimize the effects of noise bursts on seismic data through time window zeroing based on near trace comparisons.

At our sites we encountered not only noise from gusty winds and vehicles passing through the area but also stationary noise associated with pump jacks and pipelines. Vibrator frequencies over 200 Hz were generated, but with the high attenuation of these frequencies with offset, enhancement techniques will be necessary to make this part of the spectrum useable on stacked sections.

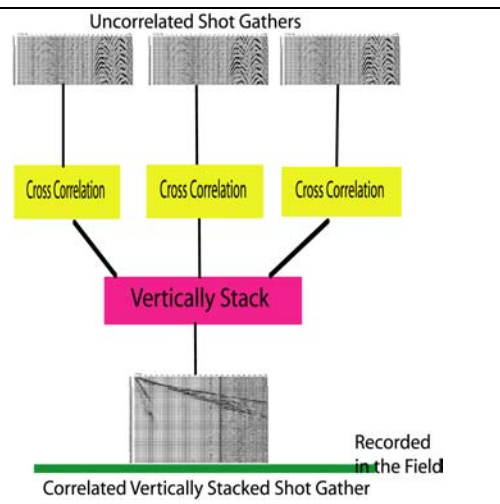

Figure 1: First processing flow used, equivalent to vertical stacking in the field.

Processing

Pre-correlation processing on these data involved routinely used algorithms already available in commercial software packages. Automatic gain control (AGC) was tested on uncorrelated data to both enhance the low-amplitude high-frequency components of the data and to reduce the relative amplitude of noise burst associated with vehicles. Since this process does not discriminate between noise and signal, high frequency noise such as that associated with wind is enhanced along with reflections. This process, referred to as Vibroseis whitening (VSW) when used to balance the spectrum, has already been shown to enhance spectral characteristics; interesting is its effectiveness reducing the contributions of high-amplitude noise bursts (figure 2). For our case, balancing amplitudes with a long time window AGC (1 second or more), contributions from high-amplitude noise are reduced, spectral characteristics of the source wavelet are improved, and amplitude analysis is still possible on CMP stacked sections.

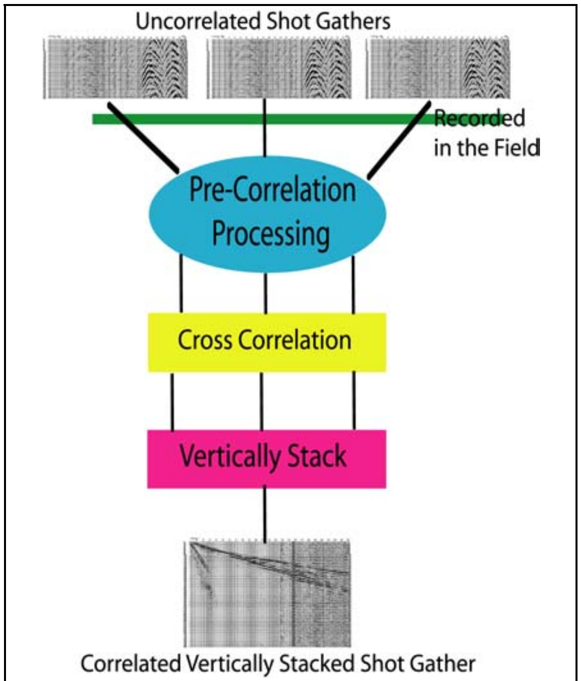

Figure 2: Second processing flow used, equivalent to collecting shot records in the field and processing in the office.

Field Examples

Site 1, 4-D seismic monitoring project in central Kansas: Four-dimensional reflection data designed to monitor a CO_2 injection project in the Hall-Gurney Field, Russell County, Kansas, was recorded using a 240-channel spread and a single IVI minivibII sweeping 5 times at each location for 10 seconds. Each linear P-wave up-sweep included a frequency band from 25 to 250 Hz. Receivers used were three digital grade 10 Hz Mark Products Ultra2w geophones wired in series, with 14 cm oversized spikes, grouped to form a 1 m equilateral triangle.

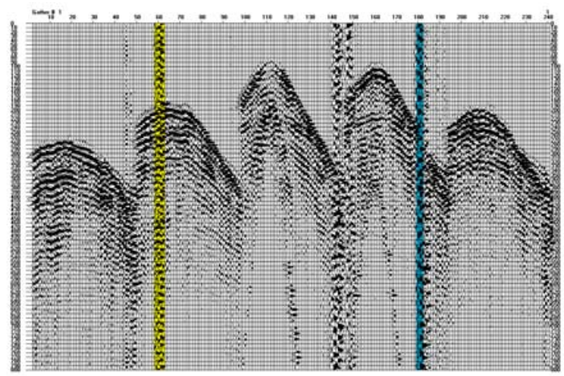

Figure 3: Shot Gather from site 1 processed by following the processing flow seen in figure 1. The trace containing the ground force record has been removed.

Correlated shot gathers without and with pre-correlation processing are displayed with normalized amplitude in figures 3 and 4, respectively. In figure 3 the blue highlighted area is noise from a car moving along the line. Comparing these noise traces with adjacent traces, car noise appears to have an amplitude 14 dB larger than coincident first arrivals from the seismic source. Noise from a pump jack (highlighted in yellow on figures 3 and 4) possesses energy levels 27 dB greater than first arrivals generated by the seismic source.

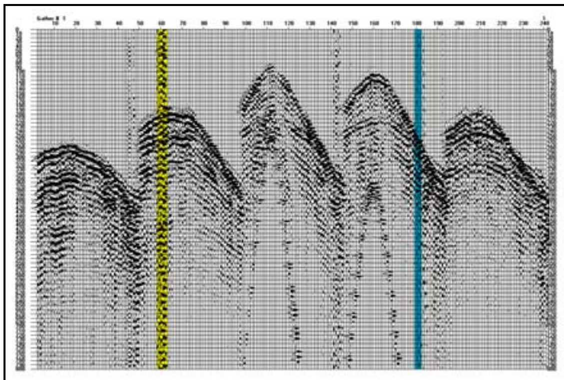

Figure 4: Shot Gather from site 1 processed by following the processing flow 2 seen in figure 2. The trace containing the ground force record has been removed.

Reduction in the vehicle (moving) noise after amplitude balancing but before correlation is dramatic, with even greater improvement in signal-to-noise coming as a result of zeroing traces with evidence of noise after pre-correlation processing and cross-correlation. Vehicle noise remaining after cross-correlation can be almost completely eliminated by removing one or two noticeably noisy traces that move as the vehicle moves from trace-to-trace between sweeps before vertical stacking.

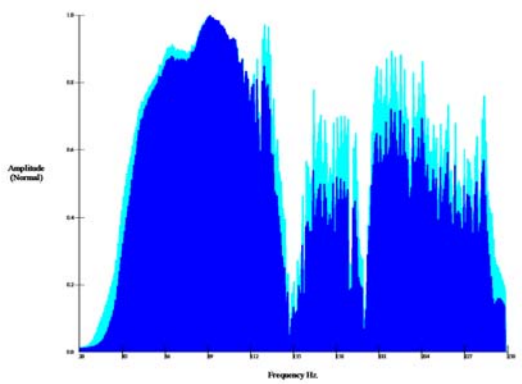

Figure 5: Ground force correlated with the synthetic sweep. Dark blue in the foreground has undergone processing flow 1. Light blue in the backgound has undergone processing flow 2.

We also compared the normalized cross-correlation of the ground force and the synthetic sweep with and without VSW to evaluate the effects on the near-field source signature (figure 5). This comparison demonstrates the efficiency of high-frequency energy transfer between base-plate and ground. Evident is the approximately 20 percent increase in amplitude of the higher frequency portion of the signal bandwidth after a large time window AGC before cross-correlation.

Site 2, 2-D seismic project in central Kansas:

High-resolution seismic reflection data acquired along highways always have unique and substantial noise problems. A data set acquired in the road ditch and shoulder of US Highway 50 east of Hutchison in Reno County, Kansas, provides an excellent example of the power of pre-correlation and pre-vertical stack processing when heavy vehicle traffic is a problem. Data for this survey were recorded on a 240-channel spread. The source was a single IVI minivibI sweeping 3 times at each location for 10 seconds. The P-wave linear up-sweep included a frequency band from 25 to 300 Hz. The receivers used were two 40 Hz Mark Products L28E geophones wired in series and grouped at each receiver station.

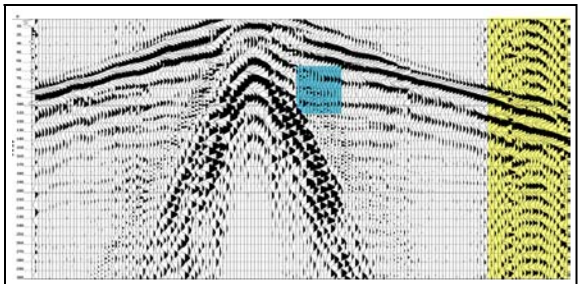

Figure 6: Shot gather of site 2 processed by following the processing flow 1 shown in figure 1.

As would be expected, data from this survey were filled with ambient moving noise from all sizes of vehicles from motorcycles to semi-tractor-trailers. Sixty-hertz power-line noise is also a dominant noise source on longer offset traces.

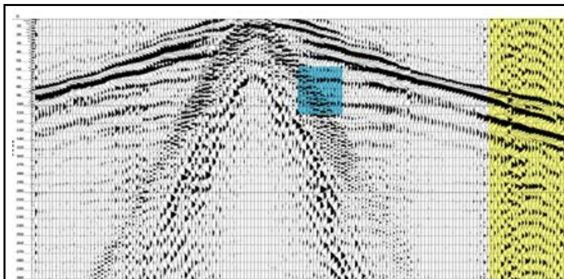

Figure 7: Shot gather of site 2 processed by following the processing flow 2 shown in figure 2.

The green area in figures 6 and 7 demonstrate the relative reduction in ground roll and apparent increase in reflection energy resulting from pre-correlation amplitude balancing. These findings are consistent with those of Coruh and Costain (1983). The reduction in power-line noise, although not surprising, was not noted during previous studies.

Significant reduction, 26 dB, in heavy traffic noise on these data resulted from pre-correlation scaling and pre-vertical stack muting. This high level of noise reduction is surprising, considering only three sweeps using a single vibrator were acquired at each station. With higher velocity traffic come higher noise levels, but also greater spacing between noisy traces on coincident sweeps at a single shot station. This higher velocity traffic can be attenuated by more than 12 dB using only two sweeps per station.

Conclusion

Cross correlating and vertically stacking high-resolution near-surface seismic data in the field eliminates any opportunity to optimize shot gathers through pre-correlation processing, different cross-correlation approaches, or pre-vertical stack muting. By applying only a long time window automatic gain control before cross-correlation, noise bursts dropped in amplitude by as much as 18dB on CMP stacked sections and did not jeopardize amplitude analysis. Increases upwards of 20 percent are possible in the high-frequency portion of the source wavelet bandwidth with a modified version of VSW. Recording data uncorrelated allows different correlation schemes to be tested using either ground force or synthetic pilots.

The main disadvantage of collecting uncorrelated data is the time and space necessary to reach an equivalent point as data returning from the field correlated and vertically stacked. Depending on how many shots are acquired per station, increases in storage space could be as much as 50 times and processing time could double.

Acknowledgments

I want to thank Chevron Texaco for graduate research fellowship through the Kansas Geological Survey.

References

Allen, K.P., Johnson, M.L., May, J.S., 1998, High fidelity vibratory seismic (HFVS) method for acquiring seismic data, Soc. Explor, Geohys., Expanded Abstracts, 140-143.

Doll, W.E., Miller, R.D., and Xia, J., 1998, A noninvasive shallow seismic source comparison on the Oak Ridge Reservation, Tennessee: Geophysics, Vol. 63, 1318-1331.

Doll, W.E., and Coruh, C., 1995, Spectral whitening of impulsive and swept-source shallow seismic data, Soc. Explor. Geophys., Expanded Abstracts, 398-401.

Coruh, C., and Costain, J.K., 1983, Noise attenuation by Vibroseis Whitening (VSW) processing, Geophysics, Vol. 48, 543-554.

Klemperer, S.L., 1987, Seismic noise-reduction techniques for use with vertical stacking: An empirical comparison, Geophysics, Vol. 52, 322-334.