Near-surface utility of vibroseis

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Introduction

Careful matching of practice with theory ultimately maximizes the resolution potential and signal-to-noise ratio of any seismic acquisition program, a fact clearly evident for coded source surveys (Lerwill, 1981; Sallas, 1984). With the general availability over the last decade of small (< 9,000 kg), portable (trailer or motor vehicle mounted), hydraulic vibrators has come a significant increase in the use of vibroseis on near-surface problems. Inherent with the less demanding and therefore less rigorous expectations related to attribute analysis and recovery of source signature on many near-surface applications there is usually less concern for fully optimizing source operations. This is most prevalent as it relates to accurately recording the true source energy and processing raw vibroseis data file by file with realistically distorted ground force calculated from the true source wavetrain (Lebedev and Beresnev, 2004).

Problems of nonlinearity of the vibroseis seismic energy have been observed, discussed, and theorized for petroleum applications with conventional vibrators for more than 20 years (Sallas and Weber, 1982). Even though much has been done to numerically describe (Walker, 1995) and in some cases find unique methods that resolve the problem (Allen et al., 1998), nonlinearities are still present even with modern closed-loop vibrator-control systems designed with feedback circuits that synchronize the amplitude envelope and phase of the fundamental frequency of the ground force. Estimation of the realistic ground force from mass and baseplate accelerometers is critical to compensate for the near-source distortion at the contact between the baseplate and soil where relatively large, nonlinear deformation occurs.

It is well known that deconvolution with the true source wavelet (generally assumed to be the realistically distorted ground force) produces a far more representative seismic image than cross correlation with an open circuit pilot or synthetic (Tada, 1988; Ghose, 2002). To that end, data used to calculate the weighted sum of the mass and baseplate accelerometers must accurately represent all the distortion, harmonics, and nonlinearities that radiate from the source. As with almost all near-surface applications, a reasonable reduction in the seismic data potential is accepted as a cost-cutting measure right to the point where the resulting seismic image is not able to meet the minimum goals of the project. Generally, those goals revolve around mapping the continuity of interfaces and the structural characteristics of the reflectors within depth range of interest.

Routine use of small vibrators for near-surface applications (target horizons < 1 km) generally involve an open-loop controller with data correlated in the field using the synthetic, ground force, or filtered ground force depending on the qualitatively determined ‘best’ looking shot gather. Rarely is uncorrelated data saved, thereby making field based, qualitative decisions concerning pre-correlation processing and the cross-correlation operation itself, irreversible. Most stock configurations and specification of mass and baseplate accelerometers provide output acceptable for QC applications, but too noisy for ground force calculations used for infield cross-correlation or deconvolution.

Resolution and signal-to-noise ratio of near-surface seismic reflection data are appreciably improved through optimized source coupling (Walters et al., 2006), use of low-noise baseplate and mass sensors and non-telemetry pilot (Rademacker et al., 2005), site-specific pre-correlation processing approaches (Miller et al., 2005), and site- and equipment-specific approaches to the correlation step (correlation with synthetic or deconvolution with ground force). Unlike an explosive or projectile source where saturated, fine grain sediments provide the best transmission of high frequency signal (Miller et al., 1986), the highest frequency response was observed when the baseplate was coupled to a compacted, minimally deforming surface. Ideal compression of the raw, swept-source wavelet to a minimum-phase broadband source wavelet from a single vibrator is accomplished by deconvolving the true ground force with the sweep data.

Terrain Dependent Source Coupling

As theory suggests and numerical models have shown the more closely the rigidity of the baseplate matches the ground the less nonlinear distortion and therefore the more accurately the ground force will represent the true source wavelet. Data from a 3-D survey near Russell Kansas recorded using a single 13,000-lb IVI vibrator using an open loop controller empirically demonstrates this relationship (Figure 1). A correlated shot gather from a gravel packed road surface recorded by a line of offset receivers possess several easily recognizable reflections in the upper 500 msec. The data from the road clearly possess higher frequency that that recorded from a location in a field less a 100 m away (Figure 2). All else was equal except the characteristics of the ground surface and therefore the nonlinear distortion between the baseplate and competent ground.

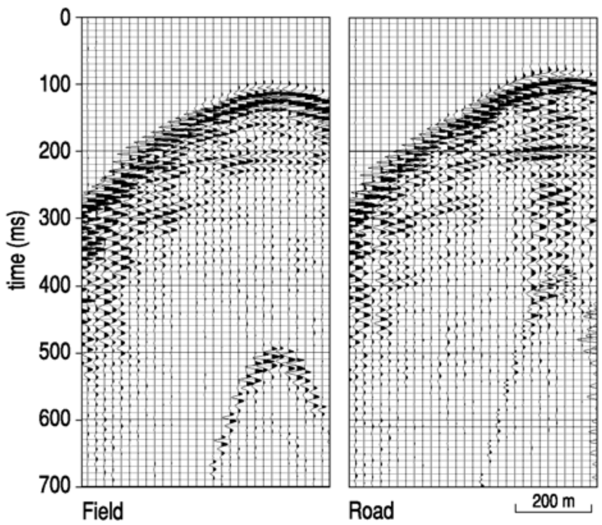

Figure 1. Correlated shot records from 3-D survey near Russell, Kansas.

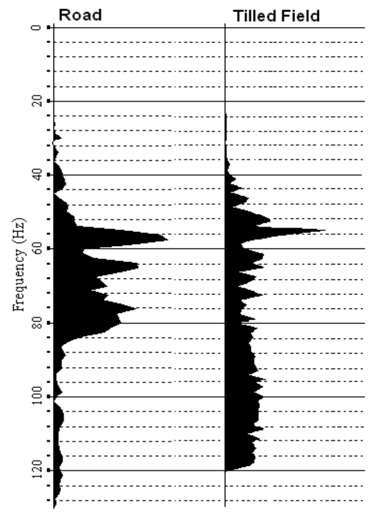

Figure 2. Amplitude spectra for shot records in Figure 1.

Low Noise Accelerometers

Ideally if the true source wavelet could be measured for each sweep, deconvolution of the ground force and recorded far source trace would represent the reflectivity series of the earth. Instrumenting the vibrator with high signal to noise accelerometers and locating those accelerometers accurately for the individual model of vibrator and pad is a critical step in recording mass and baseplate movement that can be part of a weighted sum that can be called the ground force. Testing showed with standard factory accelerometers the noise thresholds were problematic in producing the highest quality 'correlated' shot gather. Adding to the problem telemetry of the ground force from the vibrator to the recording vehicle for correlation or deconvolution also unacceptably elevated the noise levels (Figure 3).

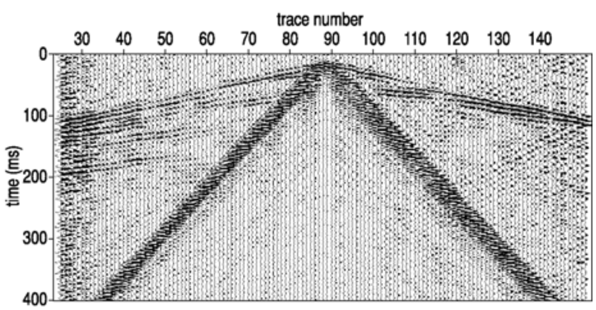

Figure 3. Deconvolution from telemetried real-time groundforce.

Upgrading the accelerometers with low noise charge amplifiers and recording the data on a Geometrics 24-bit A/D seismograph matched to the seismographs used for recording the geophone data provided as shot gather with very good reflection quality (Figure 4). Contrasting the two shot gathers provides some striking differences, considering these are the same data in both shot gather, just one (Figure 3) was deconvolved using the standard accelerometer package with the ground force telemetried via VHF radio to the seismograph, while the other (Figure 4) was deconvolved using the special low noise accelerometer recorded on a seismograph in the vibrator.

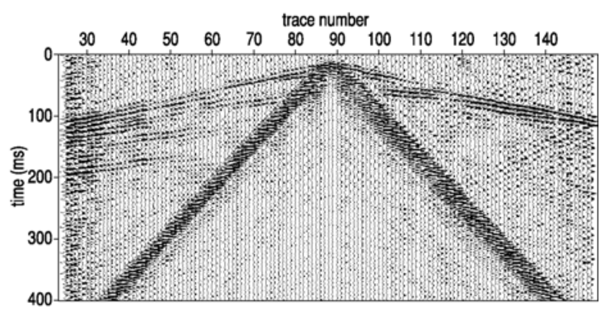

Figure 4. Deconvolution with groundforce using low noise accelerometers and recorded directly on 24-bit seismograph.

Clearly the utility of optimal place sensors on the baseplate, low noise sensors, and avoidance of radio telemetry of the ground force are obvious. The improvement in data quality in many cases would more than justify the increased cost of the sensors and recording of uncorrelated data.

Pre-correlation Spectral Whitening

For high frequency vibrators the ground force and recorded data are severely under represented on the high frequency end of the spectra. Of course natural attenuation of high frequencies by the earth plays a dominant role in the recorded seismic energy. The use of pre-correlation amplitude balancing greatly improves the high frequency portion of the spectra on correlated data. This balancing of the spectra is most effectively accomplished using an automatic gain control on the pre-correlated data. This technique was first introduced and show reasonably effective on conventional vibroseis data (Çoruh and Costain, 1983). On high-resolution data using these small vibrators this balancing prior to correlation provides a significant enough improvement in resolution potential over other methods to more than justify the cost and effort required to save uncorrelated data.

Vertical Stacking

Along the same lines as saving unstacked uncorrelated data for boosting the amplitude of high frequency signal, saving data unstacked also can greatly improve the resolution and signal-to-noise ratio of shot records. Sweep records recorded when plastic deformation of the ground surface occurred after preloading and during the sweep will not possess signal with the same phase, amplitude, and frequency characteristics as follow-on shots recorded once compaction was reduced and the surface acted in an elastic fashion. For high resolution single vibrator surveys recording data uncorrelated and unstacked can improve the signal to noise ratio and resolution by as much as 10 to 20% in some settings.

Correlation vs. Deconvolution

Ideally when the true source wavelet is measured for a single vibratory source deconvolution will produce the highest frequency and most geologically accurate reflection series possible (Ghose, 2002). Recording data from sensors properly located on the mass and baseplate to allow their weighted sum to represent to the true ground force is still a complex and unsolved problem. Comparison in this paper demonstrate that improvement is possible with low noise sensors and empirically placed sensors. Comparing deconvolution of the ground force with correlation of the open loop drive signal or synthetic provides some measure of accurately the calculated ground force matches the real nonlinear ground force (Figures 5 and 4).

Cross correlation of the synthetic with the data and cross correlation of the empirically determined optimal calculated ground force suggests the ground force calculated in the

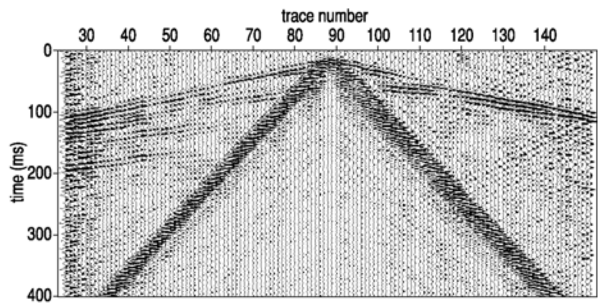

Figure 5. Cross-correlation with ideal.

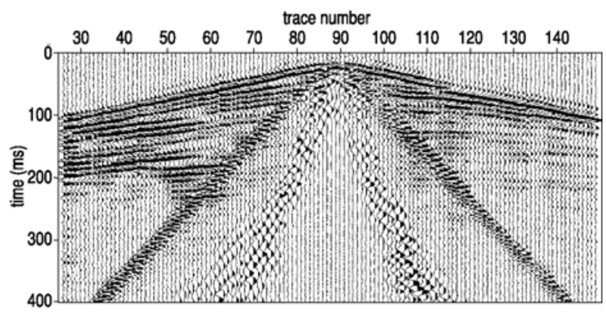

Figure 6. Cross-correlation with groundforce calculated from accelerometers.

fashion described here produces a higher frequency and higher amplitude reflection record (Figures 5 and 6). Data used in this example are from a 2-D survey acquired along US Highway 50 in south central Kansas with 2.5 m receiver spacing. The reflections are from the Permian and are predominantly shale, dolomite, salt, and anhydrite reflectors.

Conclusions

Improvements to resolution and signal-to-noise ratio are possible with all vibroseis data when uncorrelated data is saved. The improvement observed for small, high resolution vibratory data is significant and can clearly elevate the potential of the data set making the difference between meeting the project goals and recording useless data. Standard sensors and instrumentation on most of these small vibrators that use open loop controllers, collect data and transmit the calculated ground force from the vibrator to the seismograph with most operators opting for infield correlation. This approach results in correlate shot gathers that are notably inferior to those processed with very quiet accelerometers, using a seismograph equivalent to the field units to record and store the vibrator's sensor data for later processing.

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EDITED REFERENCES

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