# A Field Experiment Recording Low Seismic Frequencies

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**G e o C o n v e n t i o n   2 0 1 2 : V i s i o n**

## Summary

We describe a seismic field experiment and subsequent data analysis designed to test the performance of common sources and receivers at low frequencies. Both dynamite and vibroseis sources were tested.  Receivers tested included Vectorseis (MEMs) and both 4.5 Hz and 10 Hz geophones. Dynamite produced the strongest low-frequency signal but vibroseis was able to operate effectively down to around 2 Hz using low-dwell sweeps.  Both geophones recovered low frequency signal down to 1-2 Hz after correction for their intrinsic response.  Vectorseis produced a strong response to very low frequencies but increasing noise becomes a progressive problem.

## Introduction

In early September of 2011, CREWES collaborated with Husky Energy, Geokinetics, and INOVA to conduct a unique seismic experiment near Hussar Alberta.  The goal of this experiment was to use modern source and receiver instrumentation to extend the seismic bandwidth as far into the low-frequency range as possible without sacrificing the higher frequencies.

Seismic inversion methods, both post-stack impedance inversion and full-waveform inversion, require low-frequency information about the desired earth model.  It has been common practice for many years to supply this low-frequency information from well logs in the course of impedance inversion.  While this has been a reasonable solution, well logs are usually only available at a few locations while seismic data is densely sampled spatially.  If it were possible to get this information from seismic data, that would ultimately be preferable.

Most modern land seismic data is recorded with either 10 Hz geophones or MEMs accelerometers, with the former being the most common.  The 10 Hz geophone performs very well in the band 10-250 Hz but below the 10Hz resonance, amplitude attenuates and phase rotations occur.  This circumstance has been acceptable for many years and seismic signal bandwidths in final images, obtained on land, typically begin at 10 Hz.  Now, with growing emphasis being placed on accurate inversion for rock properties, the 10 Hz low-end is becoming increasingly unsatisfactory.  In truth, a 10 Hz geophone records data well below 10 Hz but its recovery requires applying an inverse filter for the geophone response (Bertram et al, 2010).

We report here on the description and conduct of the Hussar experiment and present a few initial results from data analysis of the raw records.  The answers to the above questions will require much more time and space than that available here.

## Description of the Fieldwork

The location of the line and its relation to available well control is in Figure 1.  The line ties 3 wells precisely and passes near several others.  In well 12-27 a both a dipole sonic and a density log are available from roughly 200m to 1500m.  The exploration target is the Glauconitic sand at about 1400m.The line was about 4.5 km long and was shot with both dynamite and vibroseis.  The dynamite effort was fairly conventional, being single 2kg shots in 15m holes, at a source interval of 20m.  Three different vibroseis sources were tested, all at 20 m source intervals, and all using sweeps that ranged from 1 to 100 Hz.
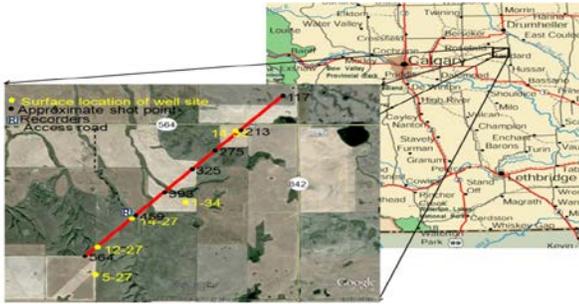
Figure 1: The Hussar line is show in relation to Calgary. The village of Hussar is about 100km east of Calgary, and our 4.5 km seismic line lies a short distance NW of Hussar.

The line was shot twice with different sweeps (Figure 2) using INOVA's AHV-IV model 364 (62,000 lb) and once using a conventional Failing vibrator (47,000 lb). INOVA's 364 vibrator is specially designed to operate at low frequencies and was provided by INOVA (from Houston) as a generous contribution to the experiment. For the 364 vibrator, a special low-dwell sweep and a normal linear sweep were used, both extending from 1 to 100 Hz. For the Failing vibrator, only a low-dwell sweep was used. The low-dwell sweeps move slowly through the low frequencies at reduced power and then move linearly through the normal (10-100Hz) frequency range.
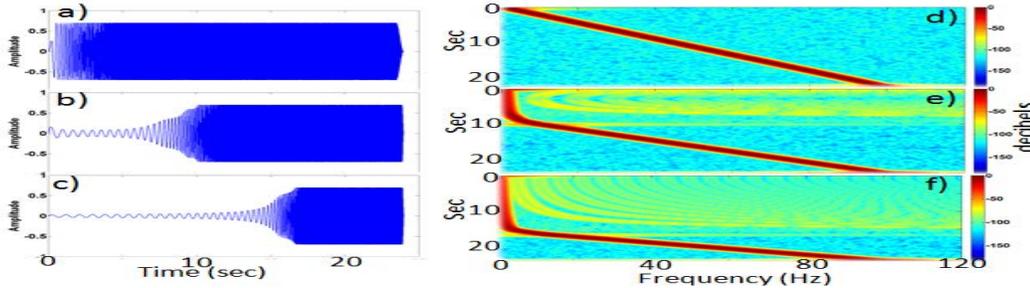


Figure 2. The time-domain sweeps used in the survey for linear (a), 364 low-dwell (b), and Failing low-dwell (c). Also shown in d), e), and f) are the Gabor (time-frequency) spectra for the three sweeps.

We deployed a variety of receivers in order to evaluate what can be done with standard equipment and what might be possible. We deployed four physical receiver lines consisting of (1) Vectorseis 3C accelerometers at 10m intervals, (2) 10Hz Sensor SM7 3C geophones at 10m intervals, (3) 4.5 Hz Sunfull (China) 1C geophones at 20m intervals, and (4) a variety of special devices including 15 Nanometrics seismometers at 200m intervals and 50 ION-Sensor 10Hz SM24 high-sensitivity 1C geophones at 20m intervals near well 12-27.

## Spectral Analyses

The resulting dataset is quite large. We recorded both correlated and uncorrelated records and, considering only receiver lines 1-3, we have 4 sources recorded into each line. Since receiver lines 1 and 2 are multicomponent while line 3 is only single component, we have 12 possible PP lines and 8 possible PS lines. At this time, work is underway to process the data; but for now, we show some interesting spectral analyses on a selected shot record near the center of the line (sp321).

For a given receiver type, it is possible to show the spectra in true relative amplitude to one another because all of the recording gear is common for the sources. In Figure 3, the performance of Vectorseis receivers is shown for the four source types, with a) being the raw accelerometer data and b) being after integration to velocity. The integration in time is essentially a division by $f$ (frequency) and this produces a dramatic upswing at low frequencies. If is apparent that the dynamite source was most effective in producing low frequencies.

Figure 4 shows a similar analysis for the 4.5 Hz geophones with panel a) being the analysis of the raw data and panel b) being after application of a correction filter for the geophone response. Such a correction filter can be designed as the inverse of the geophone's impulse response. Bertram and Margrave (2011) showed that the instrument response of a properly damped geophone can be

modeled as a Butterworth high-pass, minimum-phase filter where the Butterworth frequency cutoff is the geophone resonance frequency. As shown in Figure 6, this model predicts strong attenuation of low frequencies for both 4.5 Hz and 10 Hz geophones with the former showing 47db of attenuation at 2 Hz and the latter showing 60 db of attenuation. Correcting for these responses was done by complex-valued division in the frequency domain, hence correcting for both amplitude and phase.

Figure 5 shows similar information as Figure 4 but this time the 10 Hz geophones are examined. It is apparent from a comparison of Figures 4 and 5 that the correction for geophone response is essential for the lowest frequencies and that the two geophones are almost equalized by this correction. Of the four different sources tested, it is clear that the best performance at low frequencies was from dynamite but the low-dwell sweeps also did well. Of special note is that the 364 vibrator was able to execute a 1-100 Hz linear sweep without any reduction in power at the low end.
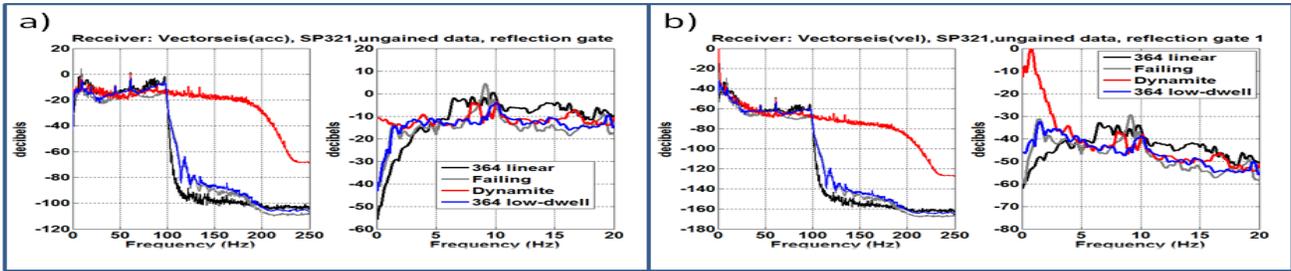


Figure 3: a) The Fourier amplitude for four sources as recorded by Vectorseis accelerometers at a representative shotpoint. The left panel of a) shows the entire spectrum while the right panel of a) shows only the first 20 Hz. b) Similar to a) except that the data has been converted from acceleration to velocity for comparison with geophones.
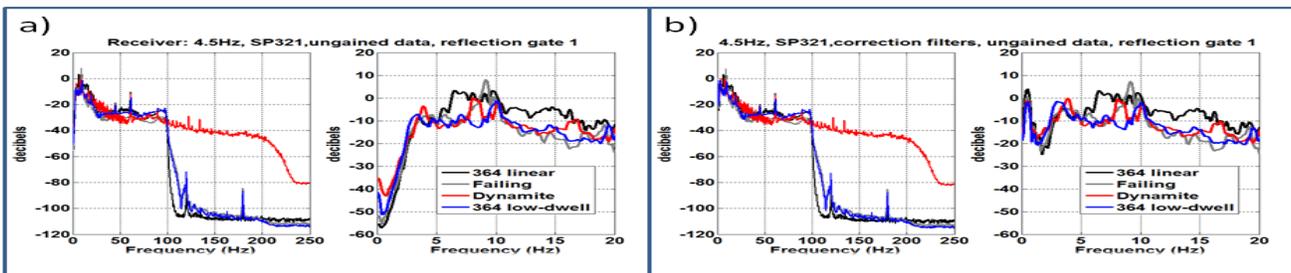


Figure 4: Similar to Figure 3 except that the performance of 4.5 Hz (Sunfull) geophones is illustrated. a) The Fourier amplitude spectra of the raw data for the four sources, b) Similar to a) except that the data have been corrected for the geophone response.

Figure 7 shows a comparison of three different receivers for a fixed source, dynamite and 364 low-dwell sweep. In this case, the data went through different recorders so the curves are normalized to one another at 70 Hz. In both cases the geophones have been corrected for their response. It is apparent that Vectorseis shows increased power at lower frequencies relative to the corrected geophones. It is conjectured that this is due to 1/f noise in the MEMs device.
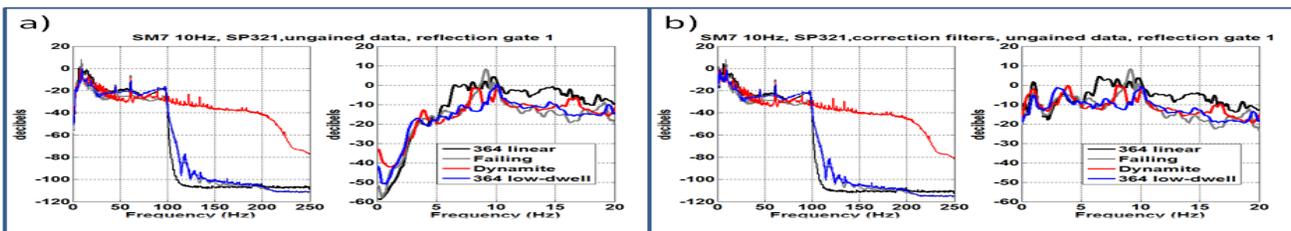


Figure 5: Similar to Figure 3 except that the performance of 10 Hz (Sensor SM-7) geophones is illustrated. a) The Fourier amplitude spectra of the raw data for the four sources, b) Similar to a) except that the data have been corrected for the geophone response.

## Discussion and Conclusions

We have conducted a seismic survey that tests the performance of common seismic receivers and sources at low frequencies. We found that dynamite is a better low-frequency source than vibroseis but suitably designed vibroseis sources with custom sweeps can perform very well down to frequencies approaching 2 Hz.  Common geophones also perform well at low frequencies but it is necessary to correct them for the intrinsic geophone response for best results. Vectorseis (MEMs) receivers operate to well below 2 Hz but it seems that internal noise (likely 1/f noise) becomes very significant. We understand that common practice in modern data processing is to assume that deconvolution corrects for the geophone response even at low frequencies. An investigation of this claim is in progress.
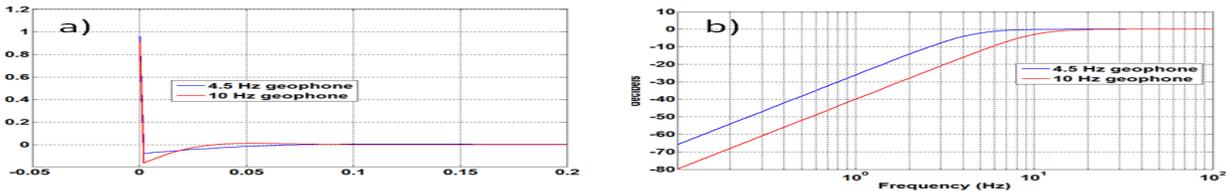


Figure 6: The impulse response of 4.5 Hz and 10 Hz geophones modelled as Butterworth, minimum-phase, high-pass filters. a) Time domain, b) Frequency domain.
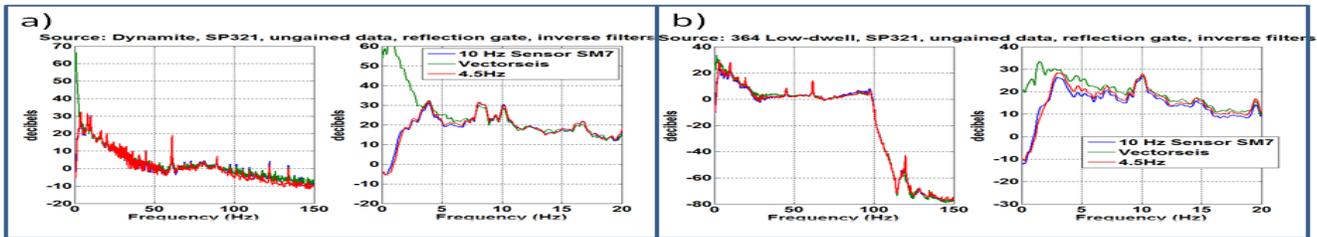


Figure 7: a) Spectral performance of the dynamite source for three different receivers is shown with the geophones having been corrected for their instrument response. The right panel of a) is an enlargement of the low-frequency portion of the left. b) Similar to a) except that the source is the 364 vibrator with a low-dwell sweep.

## Acknowledgements

### References

Bertram, M. B., and Margrave, G. F., 2011, Recovery of Low Frequency Data from 10Hz Geophones: CSEG Annual Convention, Calgary, AB., Expanded Abstracts.