Seismic source comparison for compressional and converted-wave generation at Spring Coulee, Alberta.

Gabriela M. Suarez and Robert R. Stewart, The CREWES Project, University of Calgary*

Summary

Multicomponent 2D seismic lines were acquired with three different seismic sources in January, 2008 at Spring Coulee, Alberta. Fifty-two source positions (using dynamite, 58,000 lb vibrators, and one IVI 18,000 lb Envirovibe) were recorded into a line of 3C receivers. The objective of these tests was to determine the ability of each source to generate PP and PS reflections. Examination of the raw P-wave data indicates that the frequency content and signal strength of the dynamite data appear superior. However, the final stacked sections of the dynamite and heavy vibroseis datasets showed very similar character. F-x spectra of the raw data and stacked sections reveal that both heavy vibe and dynamite datasets also show similar characteristics for signal and noise from 10 to 40 Hz in the P-wave stacked section, and from 10 to 25 Hz in the converted-wave stacked section. The same analyses were performed on the Envirovibe (which had signal to about data 1.5 s). The sections from the Envirovibe have higher random noise and lower resolution in comparison with the other two sources. For the radial channel, the Envirovibe data is of lower quality, with no energy below 1 s and discontinuous reflectors. However, the Envirovibe gave surprisingly good results for its weight.

Introduction

In seismic reflection surveys, the acquisition of good quality data is made more likely by choosing optimum parameters with respect to the target zone (Scheffers et al., 1997). One of the key acquisition considerations is the seismic source along with its characteristics. Some of the important criteria in the source selection are its energy content, bandwidth, and ultimate wavelet shape. Other selection criteria are related to its convenience, safety, and repeatability. Finally, all of the previous criteria are judged with respect to the cost of the source (Karastathis et al., 1995).

A number of comprehensive source tests have been undertaken in the past (Davis and Lawton, 1985; Pullan and MacAulay, 1987; Miller et al., 1986; ibid, 1992; Parker et al., 1993, Tilander and Lattimore, 1994; Karastathis et al., 1995; Steer et al., 1996; Scheffers et al., 1997; Bühnemann and Holliger, 1998; Staples et al., 1999, Bremner et al., 2002; Quigley, 2004; Calvert et al., 2005). These efforts have been mostly geared toward shallow seismic reflection, refraction seismic applications, and deep seismic reflection profiling. Technological advances have improved the performance of the different source types; however, the results of previous studies showed clear differences between various seismic sources at various different sites. The performance of a source can be quite different at varying locations (Miller et al., 1986; Millet et al., 1992; Pullan and MacAllay, 1987; Bühnemann and Holliger, 1998).

In this work, we are interested in the performance of impulsive (dynamite) and vibratory (mini- and heavy-vibe) sources for exploration-scale reflection seismic surveys. We are especially curious about comparing the sources for their ability to generate converted (P-to-S) waves. In pursuit of these goals, the CREWES Project (with ARAM Systems Ltd., CGGVeritas, and Outsource Seismic) acquired three 2D 3-C lines with different seismic sources. The sources used were the IVI Envirovibe, two 58,000 lb vibrators, and dynamite). The tests were conducted during a blustery January, 2008 in the Spring Coulee area of southern Alberta. This paper describes the analyses undertaken to assess the different sources. We then compare the sources for their PP and PS seismic imaging capability.

The Spring Coulee Survey

The Spring Coulee data discussed here were part of a large seismic test of geophones, accelerometers, recording systems as well as sources. The lines were also acquired with petroleum exploration goals as the University of Calgary owns the mineral rights to the two sections of land traversed by the seismic lines. The data used here were recorded with an ARAM system and SM-7 10 Hz 3-C geophones.

For the total survey, there were 52 dynamite shot points (2 kg at 15 m depth), 657 vibrated points with two 58,000 lbs and 134 vibrated points with one IVI Envirovibe (18,000 lb). The 58,000 lb vibroseis had a 4 times vertical stack, sweeping from 4 to 130 Hz with an 12 s listening time; for the 18,000 lb mini-vibe, a 4 times vertical sweep was also used but sweeping from 10 to 200 Hz with an 11 s listening time. The receivers were located every 10 m and the sources every 30 m, and the shot lines were separated by one meter.

Processing

After acquisition, the data from the three different source types were passed through the same processing sequence using identical processing parameters (except for statics).

The survey geometry resulted in a maximum fold of 50 for the coincident sources lines.

In general, the quality of the data was very good: clear reflections can be observed in the raw data up to 2.2 s. Stronger surface-waves are observed in the dynamite dataset.

Part I: Heavy vibe versus dynamite

1. Raw data characteristics

For a better understanding of the difference between the two sources, the most significant signal and noise will be first described as observed in the raw data. Consistency from shot to shot along the line is another characteristic that should be considered as it reflects how variable the source is and how dependent it is on the near surface conditions.

Vertical channel: Qualitative analysis of the raw shots indicates an improved bandwidth and S/N with the dynamite source, but also shows an increase in the level of ground roll and low-frequency noise (Figure 1a and 1b). The vibroseis data shows less prominent ground roll and low-frequency noise, but stronger airwaves and high-frequency noise especially at short offsets and deeper times.

Although deep reflections are dramatically clearer on certain explosive source records, the quality of such records varies considerably. These differences occur because shots could be placed in different media (clay, sand, shale, or sandstone), into different hole sizes and water saturation. The shot-to-shot variability could be evaluated comparing shots from different locations along the line; another way is analyzing amplitude spectra from first breaks to see how their character varies. For the vibroseis, the records appear slightly more consistent in terms of the data character and in the level and nature of the ground roll.

An average Fourier amplitude spectrum was calculated on a raw shot gather for a window corresponding to what is interpreted to be subsurface reflections (Figure 2). From 0-10-Hz the dynamite shows slightly higher power, then to about to 40 Hz the curves are similar with a dominant frequency of 25 Hz. After 40 Hz, the dynamite shows higher power up to 65 Hz, and then the amplitudes of the vibrator stay higher until the maximum sweep frequency (130 Hz).

Radial channel: Compared with the vertical-component, the converted-wave data looks noisier, with less bandwidth and the reflection energy is not as strong and evident (Figure 1). The overall noise content appears less in the dynamite than in the vibroseis data, with a strong incoherent noise masking most of the reflections. In the dynamite data, the near offsets are more contaminated with noise and its amplitude level is lower. Overall, the frequency content looks higher in the dynamite data than in the vibroseis data.

The consistency from shot to shots looks similar for both datasets; there is not as much difference in amplitude levels on the radial channel between the dynamite shots as in the vertical-component.

The same Fourier analysis was undertaken for the radial channel (Figure 2). In this signal window, the dynamite shows slightly higher amplitudes to about to 10 Hz, but from 10-25 Hz the curves are similar with a dominant frequency of 20 Hz; in the 30-40 Hz the dynamite shows higher amplitudes.

2. Unmigrated stacked sections

Vertical channel: The dynamite data generally appear to have improved coherency and resolution at the shot-gather stage in comparison with the vibroseis data. Of course, both sources will take advantage of depth point (CDP) redundancy to achieve useful S/N levels at depth (Schrodt, 1987). The comparison of the stacked seismic sections indicates (Figure 3) that the vibrator data might be slightly superior in the shallow section (0–0.6 s) and the dynamite in the deeper section (0.6-2 s).

The target zone for this area is located between 0.5 and 1.5 s two way time. Analysis of this interval suggests that improved bandwidth and signal-to-noise ratio is achieved with a dynamite source, but of course its cost relative to vibrators needs to be considered. In addition, one landowner would not allow the use of dynamite.

Radial channel: Some of the observations made for the vertical channel stacks can be applied to the radial channel stacks (Figure 4). However, the difference on the shallow reflectors is not as noticeable as for the vertical; in the deeper part the dynamite shows better resolution that might be a reflect of a higher frequency content.

Between CMP’s 287 and 447, there is an area of lower amplitude in comparison with the rest of the section. This difference might be caused due to a higher attenuation of the converted-wave by scattering and absorption that did not allow obtaining usable high frequencies.

3. F-x analysis of the unmigrated stacked sections

Vertical channel: The phase coherence of the two datasets is contrasted in Figure 5(a) and (b). For the vibroseis, there is a reduction in phase coherence at 40-45 Hz that is coincident with the drop in spectral power. However, subtle phase coherence persists up to at least 85 Hz. The dynamite reduces its phase coherence at about 55 Hz. These observations may be interpreted as indicating similar signal levels below 45 Hz.

Radial channel: The same f-x analyses for both unmigrated, unfiltered CCP stacked sections show a drop in spectral power at 20 Hz and a reduction in coherency at about 25 Hz, showing low signal after this frequencies (Figures 5c and 5d).

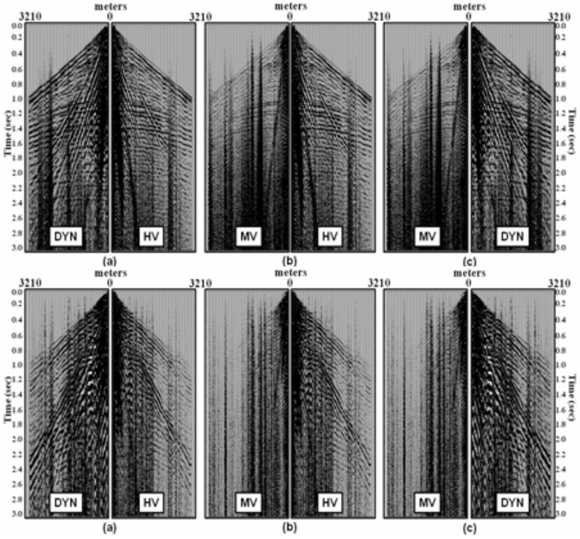

Figure 1: Comparison of a vertical-(top) and radial-component raw shot gather (bottom). In (a), half of a split spread record from the dynamite (DYN) and heavy vibroseis (HV) line with the lateral coordinate reversed to ease the comparison. The same idea is shown in (b) but for the mini vibroseis (MV) and heavy vibroseis data. The final comparison between the mini vibroseis and the dynamite is shown on (c).

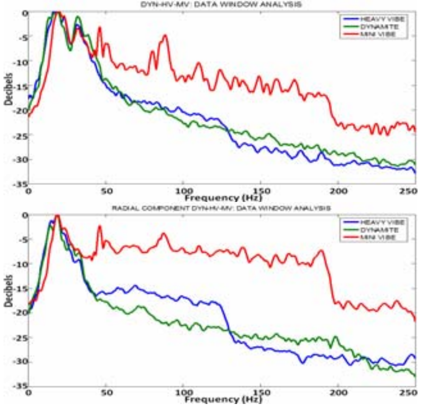

Figure 2: Average Fourier amplitude spectrum of a raw shot gather for a window corresponding to a signal only area for the heavy vibroseis line (blue), dynamite (green) and mini vibroseis (red). Vertical channel (top) and radial channel (bottom).

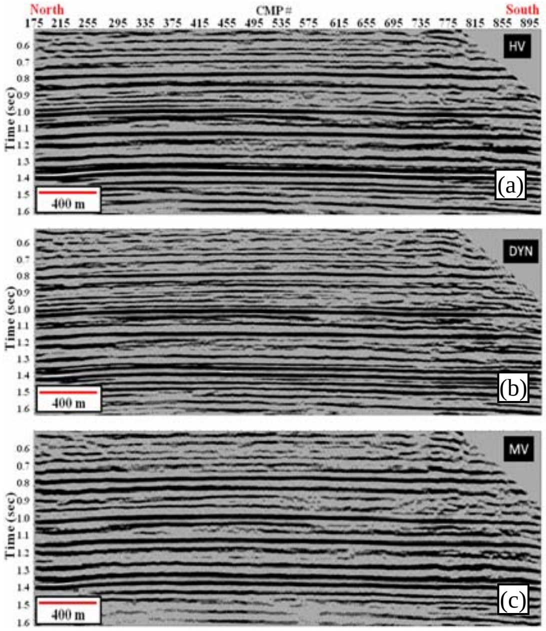

Figure 3: Portion of the vertical-component, (a) heavy vibroseis, (b) dynamite and (c) mini-vibroseis stacked section, zoomed in the zone of interest (500-1500 ms).

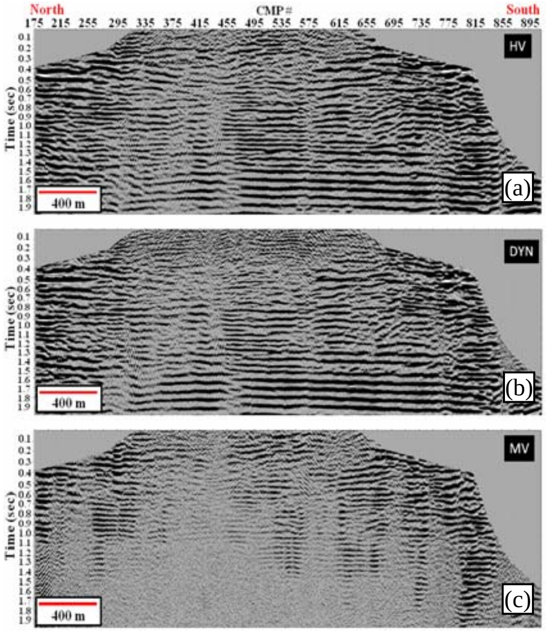

Figure 4: Portions of the radial-component sections (a) heavy vibroseis, (b) dynamite, and (c) mini-vibroseis stacked sections, zoomed on the early times (0-1900 ms).

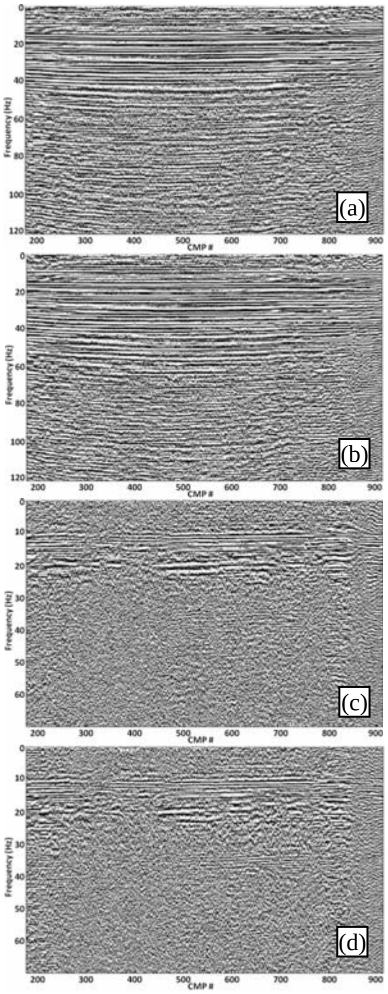

Figure 5: F-x phase spectra for the final unmigrated, unfiltered P- and PS-wave stack for the comparison heavy vibroseis and dynamite. The spectrum of the P-wave heavy vibroseis and dynamite are shown in (a) and (b). In (c) and (d) are shown the same spectra but for the PS-wave heavy vibroseis and dynamite, respectively.

Part II: Heavy vibroseis-dynamite-mini vibroseis comparison

The objective of the second part of the source comparison is to explore the benefits and limitations of the use of 18,000 lb vibroseis trucks (IVI-envirovibe) for exploration projects that involve the use of converted-wave data. Once again, we used the dynamite and heavy vibroseis datasets but more towards their difference with the Envirovibe (mini-vibroseis) data.

Our analysis concentrated on the shallow section of the data and included some of the tools presented in part one. Comparison of raw shot gathers, spectral analysis and stacked sections showed that in the vertical channel, the mini-vibroseis data was confined to the first 1.5 s of data, showing the same stronger reflectors as in the dynamite and heavy vibroseis data (Figures 1b, 1c, 2, 3 and 4). However, the mini vibroseis data showed a higher content of random noise, weaker appearance of the reflections, and lower resolution in comparison with the other two sources (Figures 1, 3 and 4).

The f-x analysis of the P-wave stacked sections showed that while in the dynamite and heavy vibroseis there is a drop in spectral power at 45-50 Hz, for the mini vibroseis happens at about 30-35 Hz. These analyses could suggest that there is a similar signal level below 40 Hz for the three sources, but different amounts of incoherent, source-generated noise at higher frequencies.

For the radial channel, the f-x amplitude spectrum for the mini-vibroseis shows little signal for the range 12-25 Hz. For the other two sources, clear and strong signal is shown in this range. One possible explanation is because of the lack of reflection’s continuity for the mini-vibroseis data.

Conclusions

A comparison of three seismic sources (heavy vibroseis, dynamite and mini vibroseis) was undertaken in the Spring Coulee area in Alberta. The objective was to study the characteristics of each source, and their capability to generate converted-waves. The qualitative analyses included visual inspections of raw shot gathers and fully processed unmigrated stacked sections. The quantitative analyses included f-x analysis of raw shot gathers and unmigrated stacked sections to define which source performs better in terms of seismic resolution.

Our results indicate that the quality of the dynamite, and heavy vibroseis sources for P- and converted-wave generation are very similar, with some small resolution advantage going to the dynamite. The mini vibroseis proved to be a good source for generating near-surface P-wave data but not very effective for generating coherent converted-waves (at this stage of processing).

Acknowledgements

We would like to thank ARAM Systems Ltd. (now ION), in particular, Glenn Hauer, for their support of this experiment. We express our gratitude to all of the CREWES sponsors for their continuing interest and support. Thanks to CGGVeritas and Outsource Seismic for their excellent field expertise. We also appreciate the assistance of Malcolm Bertram, Joe Wong, Eric Gallant, Kevin Hall of the CREWES Project. Drs. Gary Margrave and Rob Ferguson performed admirably as field hands.

EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2009 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Bremner, D. L., G. Tite, P. Thompson, and J. Brooks, 2002, Enhanced signal-to-noise ratio and bandwidth through explosive design: 72nd Annual International Meeting, SEG, Expanded Abstracts, 64–66.

Bühnermann, J., and K. Holliger, 1998, Comparison of high-frequency seismic sources at the Grimsel test site, central Alps, Switzerland: Geophysics, **63**, 1363–1370.

Calvert, A. S., J. M. Novak, J. Maher, and D. N. Burch, 2005, A tale of two surveys: experiences processing two similar but different land 3D-3C MEMS surveys: 75th Annual International Meeting, SEG, Expanded Abstracts, 975–978

Davis, T. L., and D. C. Lawton, 1985, Field testing of explosive surface sources in the Canadian thrust belt: Geophysics, **50**, 56–62.

Karastathis, V. C., I. F. Louis, G. A., Karantonis, and G. V. Apostolopoulos, 1995, Comparison tests of shallow seismic reflection sources: 57th Annual Meeting, EAGE, Extended Abstracts, P035.

Miller, R. D., S. E. Pullan, J. S. Waldner, and F. P. Haeni, 1986, Field comparison of shallow seismic sources: Geophysics, **51**, 2067–2092.

Miller, R. D., S. E. Pullan, D. W. Steeples, and J. A. Hunter, 1992, Field comparison of shallow seismic sources near Chino, California: Geophysics, **57**, 693–709.

Parker, J. C., J. R. Pelton, and M. E. Dougherty, 1993, A versatile shotgun source for engineering and groundwater seismic surveys: Geophysics, **58**, 1511–1516.

Pulland, S. E., and H. A. MacAuley, 1987, An in-hole shotgun source for engineering seismic surveys: Geophysics, **52**, 985–996.

Quigley, J., and P. Thompson, 2004, A comparison of seismic explosives-a case history: 74th Annual Meeting, SEG, Expanded Abstracts, 25–28.

Scheffers, B. C., W. M. A. Otte, S. A. C. Meekes, and R. J. Arts, 1997, Special aspects of acquisition of 2D HRS data using dynamite and Vibroseis sources: 59th Annual Meeting, EAGE, Extended Abstracts, P045.

Staples, R. K., R. W. Hobbs, and R. S. White, 1999, A comparison between airguns and explosives as wide-angle seismic sources: Geophysical Prospecting, **47**, 313–339.

Steer, D. N., L. D. Brown, J. H., Knapp, and D. J. Baird, 1996, Comparison of explosive and vibroseis source energy penetration during COCORP deep seismic reflection profiling in the Williston Basin: Geophysics, **61**, 211–221.

Tilander, N. G., and R. K. Lattimore, 1994, Comparison of vibroseis and dynamite acquisition techniques from an area of rough surface topography and outcropping high velocity carbonates: 64th Annual International Meeting, SEG, Expanded Abstracts, 1637–1638.