Experimental Analysis of the Polarity of Vibrator and Impulsive Source Data

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Summary

Although our understanding of vibrator source characteristics continues to increase, the fundamental issues of signal polarity and phase remain controversial. Improvements in the accuracy of vibrator control have reduced the potential for phase inconsistencies in processed data, but field setup procedures and variations in data processing still create confusion.

This paper describes an experiment comparing a vibrator and two impulsive sources. Downgoing and reflected waveforms from these three sources are analyzed at selected stages in the processing sequence. Emphasis is placed on polarity procedures during data collection and phase considerations during digital processing. Polarity issues are examined in detail.

Downhole tests compare first-arrival energy from dynamite, an ARIS* impulse source, and a 45,000 pounds peak force vibrator. Stacked sections and VSP data recorded using the ARIS source and vibrator over a well are compared to a synthetic seismogram derived from the lithology of the well. The results show that controlling the vibrator ground force permits the polarity of the vibrator signal to be defined consistently with respect to impulsive signals for both downgoing and reflected energy.

Introduction

In recent years there has been increasing use of the ground-force signal to control the phase of vibrators. Ground force is the contact force at the earth/baseplate interface and is the vertical component of the compressive stress field integrated over the baseplate contact area. This signal is usually approximated with a weighted sum of the outputs from accelerometers on the reaction mass and baseplate assemblies. It has been demonstrated empirically (Sallas, 1985) and mathematically (Baeten *et al.*, 1986) that this approximation deviates from the true ground force at higher frequencies but is reasonable in typical seismic frequency bands.

Theoretical and test results indicate that the phase of the far-field signal can be better controlled using ground-force phase locking (Sallas, 1984). This advantage was considered important enough that a proposal was made (Wason *et al.*, 1984) to change the SEG baseplate velocity reference (Thigpen *et al.*, 1975) to a ground-force reference.

Vibrator polarity in this experiment was set so the correlation pilot and the negative ground force were in phase. In this case, the stress convention is such that compression of the earth by the baseplate is defined as negative (Sallas, 1985). It is shown that this approach is most consistent with the current baseplate velocity convention and produces vibrator data whose polarity is opposite to data from an impulsive source.

Procedure and Results

The tests were recorded at the Arco Oil and Gas Co. geophysical test site near Sulphur Springs, Texas. A 96-channel DFS V†/FT 1† recording system was used with a surface spread on channels 1 to 48 and downhole phone and vibrator similarity signals on channels 49 to 96. The surface spread had inline offsets of 500 to 1675 ft from a 2180-ft-deep cased borehole (Enix 1). The recording convention was that a downward motion of the case of a p-wave phone, on the surface and downhole, resulted in a positive voltage and a positive number on tape.

Downhole data were recorded into a 4 Hz wall-lock Geophone at 1700 ft using dynamite, the ARIS source, and a vibrator at several offsets from the well. From an offset of 500 ft, first-arrival waveforms are compared in Figure 1 for a 1 pound dynamite charge in a 7 ft shothole, a single ARIS impulsive source shot, and a vibrator sweep. The ARIS is Arco's propelled weight drop source and the vibrator was a TR4-X3 model designed by GSI. A static correction has been applied to the dynamite data to compensate for the shothole depth.

The vibrator sweep was linear, 5 to 115 Hz in 10 seconds. Output of the vibrator was controlled so that the fundamental amplitude of the ground force was a constant 30,000 pounds from 10 to 110 Hz with 455 ms cosine tapers at the start and end of sweep. The downhole signal was correlated with a minimum-phase inverse-filtering technique (Wason *et al.*, 1984). First-arrival energy from the impulsive sources produces an initial downward motion of the geophone case and a positive break. The vibrator signal breaks negative, which is consistent with the polarity convention described in this paper.

It was shown (Wason *et al.*, 1984) that the minimum-phase inverse-filtering technique, followed by wavelet deconvolution

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† Trademark of Texas Instruments Incorporated.

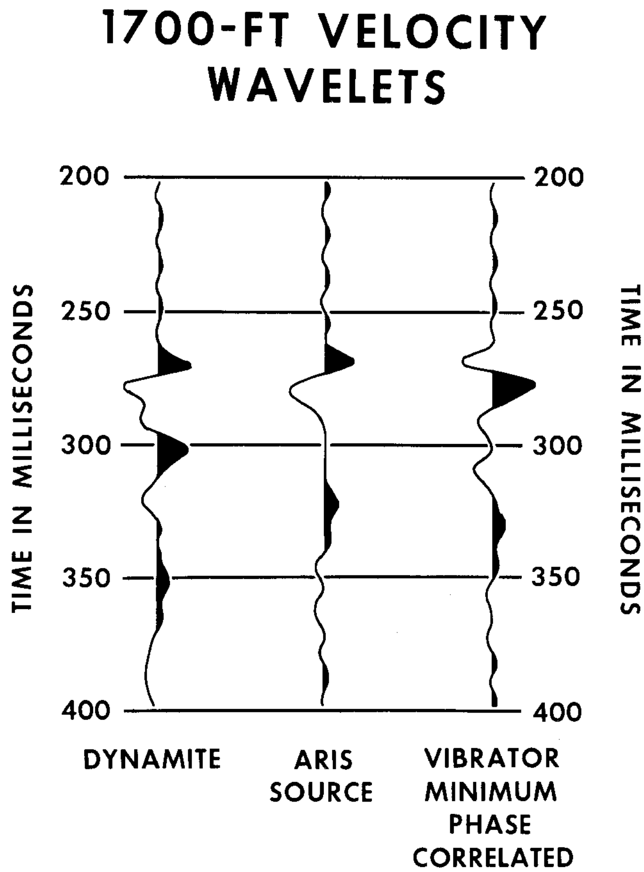

FIGURE 1
Downhole first arrival wavelets recorded at 1700 ft depth.

yields a zero-phase output wavelet. The first arrival wavelets for all three sources approach zero phase after deconvolution (Fig. 2), with the vibrator data still reversed compared to the impulsive sources. Note also that all three seismic sources provide wavelets of comparable signal-to-noise ratio. Figure 3 shows the deconvolved downhole vibroseis wavelet filtered with four overlapping band pass filters. The consistent symmetry of the filtered wavelets shows that the polarity and zero phaseness of the vibrator data is the same at all the frequencies of the sweep.

A synthetic seismogram was generated using a 20 to 90 Hz zero phase wavelet to compare reflected waveforms with the well data (Fig. 4). Note the good reflection sequence between 350–580 ms. The convention used was that an increase in impedance appeared as a trough on the synthetic seismogram.

CDP sections with six-fold data at the well were recorded with walkaway shots from the ARIS source and the vibrator. Minimum-phase correlation of the vibrator data was followed by identical processing sequences for each source. Compensation for Q was applied, based on previous research at the test site (Kan *et al.*, 1983). VSP shots recorded with both sources were used to tie the CDP data to the synthetic data in the zone of interest. Vibrator data was found to produce a peak at an increase in impedance. Reversed-polarity vibrator data and normal-polarity impulsive data, both filtered in the 20-to-90-Hz passband, tied the synthetic seismogram (Fig. 5). Note that the vibrator data was displayed in mirror image to the impulsive data. Excellent character correlations were also seen between the VSP sections for both sources and the synthetic seismograms.

Conclusions

This experiment illustrates the polarity relationship between vibrator and impulsive sources for a specific data collection and processing sequence. The ground-force signal was used to control the vibrator in both phase and fundamental amplitude. The convention used was that negative ground force was in phase with the pilot. The vibrator signal was correlated so that the same deconvolution process could be applied to vibrator and impulsive data. The results of the experiment support published theory.

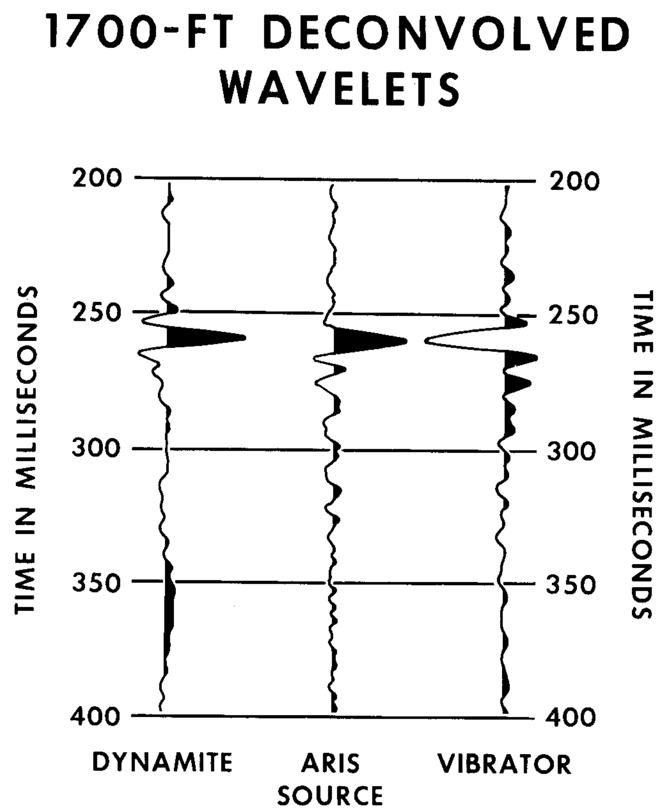

FIGURE 2
Downhole first arrival waveforms after wavelet deconvolution.

Improvements in vibrator control suggest the need for more clearly defined polarity standards. Variations in field procedures, data quality, and data processing give rise to contradictions. An industry standard for ground-force polarity would be a first step in resolving this problem.

Acknowledgements

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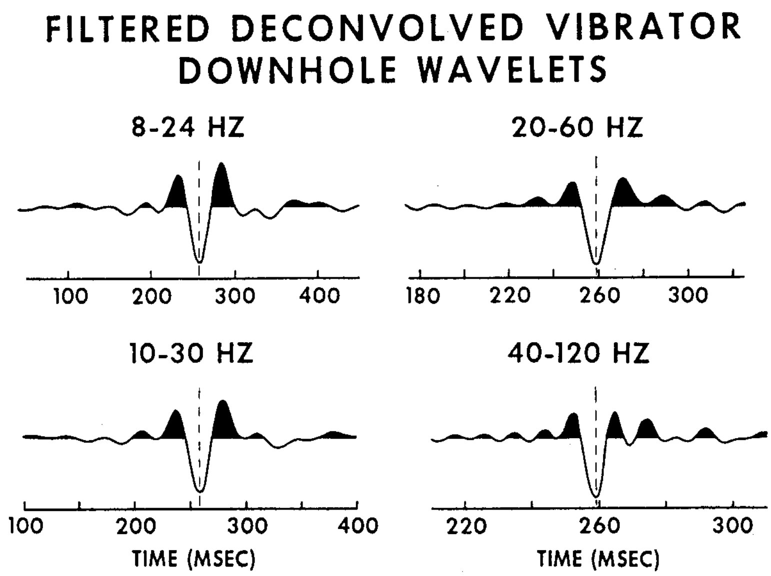

FIGURE 3
Deconvolved downhole vibrator wavelet after passband filtering.

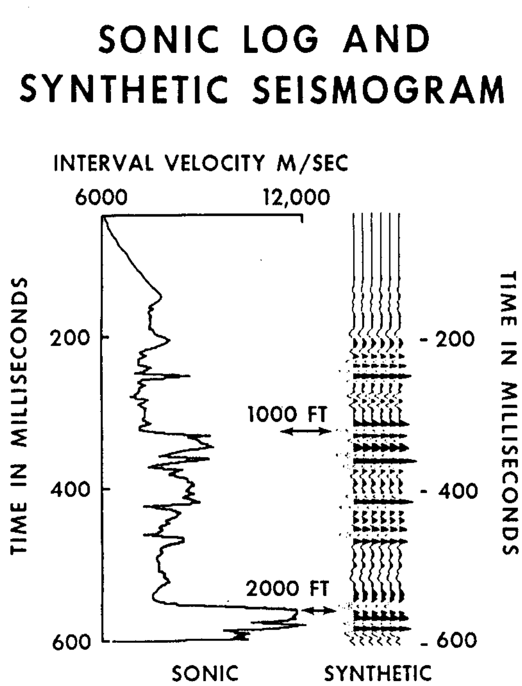

FIGURE 4
Sonic log and synthetic seismogram of borehole Enix 1.

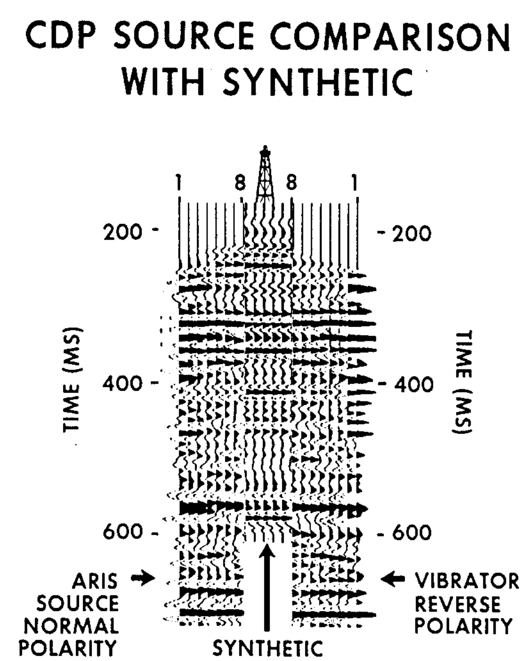

FIGURE 5
Comparison of the CDP Stacks from the Aris Source and vibrator to the synthetic seismogram.