Adaptive Groundroll filtering

David Le Meur (CGGVeritas), Nigel Benjamin (CGGVeritas), Rupert Cole (Petroleum Development Oman) and Mohammed Al Harthy (Petroleum Development Oman)

SUMMARY

The attenuation of Surface Waves while maintaining a “friendly” preservation of the Body Waves is a difficult goal to achieve in land data processing. However, Groundroll (GR) characteristics can be extracted from the input data themselves to feed an adaptive filtering in order to remove the Surface and Guided Waves. This approach is based on a cascaded Elastic Modeling of the signal and noise in the FX domain that uses the GR characteristics of several frequency bands. The part of the model corresponding to the noise is then subtracted from the data using a least squares approach. This method has several advantages over techniques such as FK filtering because it better preserves the signal and works even when the noise is aliased, dispersive and has irregular spatial sampling.
Introduction

On land, the effect of the near surface variations is the major cause of poor seismic data quality. The attenuation of the Groundroll (GR) is one of the first issues that should be addressed during the data processing flow. GR are Surface Waves recorded as “pseudo-Rayleigh” waves on a vertical geophone. They are the result of interfering P and SV waves that travel along/near the ground surface. As GR arrives directly from the source, it is linear on the near offsets for the inline cables (of 3-dimensional data) but appears hyperbolic on the broadside cables for near offsets. They are characterized by their low velocity, low frequency and high amplitude. GR can be strongly dispersive and aliased and act as guided waves (sometimes called higher modes) - this means that for each frequency there are different phase velocities. Over the last 30 years, many approaches have been developed to try to attenuate the GR on 2D or 3D seismic data including FK approaches, HR Radon methods, Wavelet Transforms and Elastic Modeling. All of these methods are currently used sometimes individually and sometimes in cascaded applications. However, these methods mostly have fixed parameterization and regular grid spacing when used over large surface areas and hence have a very poor response to the changing characteristics of the near surface. This often results in leaving coherent artifacts and gives poor preservation of primary amplitudes caused by over-aggressive or inadequate filtering.

In this paper we present a data driven approach that performs an adaptive filtering of aliased and dispersive Surface Waves at their true spatial coordinates (AGORA). This approach uses the GR characteristics contained in each shot (group and phase velocities) to perform an Elastic Modeling of the “signal” and “noise (Surface Waves)” in the FX domain for several frequency bands. Finally, a least squares approach is used to adapt the “noise” to the input data before subtracting it.

Technical background

If we analyze several shots from the same survey we observe that the characteristics of the GR changes from one shot location to another with respect to their dispersion properties (see figure 1b-e). Maps of the main mode of the GR for non-aliased frequencies can easily be made to highlight significant spatial variation of the GR velocity reaching up to a factor of 4 at short distances (see figure 1a). Observations and measurements on records indicate a real change in the GR characteristics (frequency content, phase velocity, amplitude and degree of aliasing) (figure 1a-e). This is the reason why the GR characteristics should be taken into account and the group and phase velocities extracted from each record to feed the anti-noise filtering.

Our anti-noise filtering is based on an Elastic Modeling in the FX domain using the true distance between the source and the receiver (irregular spatial sampling). The principle is that the input data is a mixture of signal plus coherent and incoherent noise (see Perkins and Zwaan, 2000). The signal (S) is modeled as hyperbolic events whose trajectories are described by stacking velocity (Vrms) (see formula 1). The coherent noise (GR) is modeled as a series of dispersive linear events, each distinguished by group and phase velocities (see formula 2).

\[
S_{i,k} = e^{i\left(\frac{t_i^2 + \frac{x_k}{V_{rms}^2}}{2}\right)}
\]

\[
GR_{j,k} = e^{i\left(\frac{f_0 + \frac{f}{v_p j} - f_0}{v_g j} x_k\right)}
\]

For a \(j^{th}\) event: \(t_i\) is the zero offset travel time, \(x_k\) is the true shot to receiver distance, \(f_0\) is the central frequency of the wave and \(v_p j\) and \(v_g\) are the phase and group velocities extracted from the input data. These events form the components of the matrix A with column and row indices \(j\) and \(k\).
In the frequency domain, the input data is represented by a matrix \( \mathbf{D} \) which can be described by a matrix \( \mathbf{A} \) that contains the dispersive linear and hyperbolic events multiplied by a vector \( \mathbf{W} \) containing an unknown wavelet corresponding to the signal and GR plus a percentage of random noise \( N \) (see formula 3).

\[
 \mathbf{D} = \mathbf{A}\mathbf{W} + N
\]  (3)

Rewriting formula 3 in appropriate terms, a least squares iterative inversion approach is used to extract the GR from the input data. Notice that this scheme is efficient if the current frequency is reasonably close to the defined central frequency. However, in most cases the GR may have a bandwidth of more than 30 Hz! This dilemma, however, is resolved by splitting the data into several frequency bands that allows the use of several different central frequencies in order to optimize the modeling of the coherent noise.

**Data examples**

This adaptive anti-noise attenuation method is now applied to two data sets to demonstrate its effectiveness. The first example contains two receiver cables, a central and a broadside cable, extracted from a 3D shot record (figure 2). The top row of figure 2 shows the central cable and the bottom row the broadside cable. From left to right, we have successively the raw receiver cable, the receiver cable after the adaptive filtering and the difference of both. On both raw receivers high-amplitude dispersive GR energy is clearly visible with weaker primary reflection events crossing the GR cone (Figure 2a-2c). After the adaptive filtering the GR energy has been removed, but the weaker reflection events remain the same (Figure 2b-2e). Black arrows highlight the fact that no signal leakage appears on the difference panels (Figure 2c-2f) but that only linear or dispersive GR have been suppressed. The second example shows the efficiency of the filtering process on 2D data. From top to bottom are displayed the raw stack, the stack after the adaptive filtering (on the raw input shots) and the stack of the noise that has been removed (difference stack). On the raw stack high amplitude dipping events cross and partially cover the shallow section and the main primary events (Figure 3a). After the GR filtering on the raw shots the high amplitude low frequency GR has been completely removed allowing us to see the continuity of the shallower weak primaries at around 1 s TWT (Figure 3b). There is no signal leakage on the stack of the noise although some pseudo-coherent events appear due to a constructive stack of the GR.

**Conclusions**

We have described a data-driven filtering approach performing a shot by shot adaptive GR attenuation, even with irregular offset distribution, in order to preserve the signal amplitude. The GR characteristics are extracted from the data and used during the Elastic Modeling. Moreover, for improved efficiency a cascaded approach on narrow frequency bands gives the opportunity to use several central frequencies.

**Acknowledgements**

The authors would like to thank Petroleum Development Oman and CGGVeritas for their permission to publish this paper.

**References**

Figure 1: a) GR velocity map with record locations, b-e) the corresponding shot records.

Figure 2: a) raw input central cable, b) filtered central cable, c) difference between a) and b) d) raw input broadside cable, e) filtered broadside cable, f) difference between d) and e)
Figure 3a: stack of the input data

Figure 3b: stack after an adaptive filtering of the GR on raw shots

Figure 3c: stack of the noise removed during the adaptive filtering