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Parabolic Radon Transform for Acoustic Reflection Wave Separation

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SUMMARY

Recent studies have revealed the great potential of acoustic reflection imaging logging in detecting near borehole geology structures. One of the main issues concerning acoustic reflection imaging logging is reflection wave separation. However, the overlapping of these reflection waves (PP wave, PS/SP wave, SS wave) increases the difficulties in making use of individual reflection wave properly. In this paper we have developed an effective wave separation algorithm and corresponding code for acoustic reflection image logging, by accommodating the PRT to the borehole environment for reflection wave separation and extraction. The parameter related to curvature between seismic and borehole acoustic for PRT have been analyzed and determined. The extracted reflections can then be used for better migration and imaging of near borehole geological structures. Applications to the numerical modeling data from different interface models (not shown here as the limitation of length) and the field data from a well in an oil field in the southwest of China have demonstrated the validity and capability of our PRT algorithm.

Introduction

Borehole full-wave acoustic-logging measurements can be used to obtain an image of formation structural changes away from the borehole provided that the acoustic wave phenomena in the near-borehole region are properly understood and detected. Theoretically, the different types of reflection waves have different applications. For instance, PP and SS wave are widely used for near-borehole structure imaging, and converted wave (PS wave or SP wave) has its unique advantages in imaging fracture and interface across the borehole (Wang et al, 2011). However, reflection waves of real data are mixed together in addition to the strong interferences from borehole mode waves. The overlapping of these reflection waves increases the difficulties in making use of individual reflection wave properly. Therefore, an effective wave separation method for these reflections is indispensable.

Based on the linear Radon transform, Hampson (1986) proposed parabolic Radon transform (PRT) for multiple removal in surface seismic exploration. As reflected wave events in time domain ($t-x$) are hyperbola, linear superposition will bring a larger error but hyperbola Radon transform on the other hand needs huge computer resources. The PRT we used in this paper, by contrast, might be able to superpose reflected wave events properly, while saving computation time and reducing the consumption of CPU cycle. The least-squares PRT is a popular transform for suppressing multiples and reconstructing missing traces in seismic exploration. This paper, for the first time, introduces PRT in the borehole acoustic for reflection wave filed separation. PP wave, PS /SP wave, and SS wave could be clearly recognized and separated in Radon domain. In addition, the empirical parameter of curvature is modified according to different rock models, which is quite different from that applied in seismic exploration. Finally, results from the application of this method to the numerical modelling data by finite difference method, and to the real oilfield data, are presented to demonstrate the validity and capability of the modified PRT method.

Theory

Borehole parabolic Radon transform can be divided into three parts: (1) forward transform: the acoustic wave is transformed from the time domain (t, x) to the radon domain described by curvature q and intercept τ ; (2) different reflect waves are extracted in the radon field according to different curvature; (3) inversion transform: PP, PS/SP SS waves are transformed back to the time domain, respectively.

To avoid instability and energy dissipation caused by alias, choosing proper sampling intervals in the transform domain (Δq) and curvature range (Q) are of vital importance (Huang et al, 2003; Zhang, 2007). The experience parameter for both Δq and Q should be smaller than that in seismic (same magnitude). The modified parameter has been tested by numerical models of mudstone, sandstone, limestone and dolomite with different P wave and S wave velocity by high order staggered grid finite difference method, which demonstrates its validity.

Examples

As the limitations of length, we do not show the synthetic data and related analysis here. The field data used in this paper was acquired by an array acoustic logging instrument Sonic Scanner developed by Schlumberger from Sichuan, China. Time sampling interval is 10 μ s, transmitter-receiver spacing is 11ft. There are 13 monopole receivers. The reflected waves are extracted by our own software ARI (Acoustic Reflection Imaging), which are mixed with each other, as shown in Figure 1(a). Then, Forward PRT is applied. We see clearly that three reflect waves converge on different areas in the Radon domain shown in Figure 1(b), which can be easily extracted. The red, black, blue rectangle represent the PP wave, PS/SP wave, SS wave, respectively. The separated results of the inversion PRT are shown in Figure 1(c), (d), (e). Compared to the messy phenomenon of Figure 1(a), the extracted PP wave, PS/SP wave, SS wave are clear and correspond well to the original waveform.

Figure 1 (a) The original waveform in time domain (b) waveform in the Radon domain (c) extracted PP wave (d) extracted PS and SP wave (e) extracted SS wave.

Conclusions

In this paper we have developed an effective wave separation algorithm and corresponding code for acoustic reflection image logging, by accommodating the PRT to the borehole environment for reflection wave separation and extraction. The parameter related to curvature between seismic and borehole acoustic for PRT have been analyzed and determined. The extracted reflections can then be used for better migration and imaging of near borehole geological structures.

Applications to the numerical modeling data from different interface models (not shown here as the limitation of length) and the field data from a well in an oil field in the southwest of China have demonstrated the validity and capability of our PRT algorithm.

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