

THIN BED IDENTIFICATION IMPROVEMENT USING SHORT – TIME FOURIER TRANSFORM HALF – CEPSTRUM ON “TG” FIELD

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ABSTRACT

Thin Bed Identification is still a difficult task even with the advanced technology of seismic acquisition. Certain high frequency component is necessary and could be obtained through resolution enhancement. Short – Time Fourier Transform Half Cepstrum (STFTHC) is performed to enhance seismic resolution thus a better separation of thin bed could be improved. Basic principal of STFTHC is to replace the frequency spectrum by its logarithm while phase spectrum remains the same. Synthetic seismic was built based on Ricker and Rayleigh criterion. They were used to test the program yielding a better separation of two interfaces under tuning thickness without creating new artifacts. The algorithm was applied to seismic data from TG field. Using post-STFTHC seismic data as input of acoustic impedance inversion, well tie correlation increases by 10% and decreases inversion analysis error by 17,5%. Several thin bed -which once could not- could be identified on acoustic impedance result.

Keywords: Seismic resolution, thin bed, STFTHC

INTRODUCTION

Digit term of seismic trace is a time series which can be described as a set of sinusoids with its own amplitude, frequency and phase. Seismic trace analysis based on its component can be done through Fourier Transform (Yilmaz, O. 2001). It is a tool to represent any function as superposition of simpler function called basis function. Usually the basis is trigonometric function with several frequencies (Gary, 2003). Frequency domain representation is more flexible and efficient than time domain.

On non – stationer signal, the frequency changes with respect of time. Conventional Fourier Transform gives frequency characteristics for entire signal. It successfully figures out what frequencies exist yet fails to recognize at what time those frequencies occur (Chakraborty dan Okaya, 1995). If the signal is assumed stationery at a small window range, the Fourier transform will give frequency information in the respective time range. Sliding the window on time domain allows us to extract frequency content from each time window (Cohen, 1995). Those time and frequency domain representation is called Short Time Fourier Transform (STFT).

Spectrum is a Fourier transform (ω) of time domain signal $x(t)$ while Cepstrum is Fourier transform of $\ln|X(\omega)|$. Cepstrum was first introduced by Bogert et. al. in 1963. If spectrum is plotted with frequency, the Cepstrum will be plotted with so called Quefrequency (/Hz). It is well known in the echo elimination of speech. Sajid (2014) introduced STFT – half Cepstrum (STFTHC)

method that combines the advantages of STFT and Cepstrum to aim at broader frequency band on every translation window of spectral decomposition. Gaussian window was used in his research and successfully enhanced seismic resolution with 8 m increase in resolution and with almost the same S/N ratio. This method also brought a good result for seismic data from Serawak basin by separating two interference reflectors (Nizalul, 2016).

Methods

Main idea of Short – Time Fourier Transform Half – Cepstrum is to change the amplitude spectrum with its logarithm to obtain broader bandwidth. The Fourier transform of seismic trace with translation τ along time axis is:

$$X_s(\omega, \tau; w) = \int_{-\infty}^{\infty} x(t)w(t - \tau)e^{-i\omega t} dt$$
$$Amp(\omega, \tau)$$

$$= \sqrt{(\text{real}(X_s(\omega, \tau)))^2 + (\text{im}(X_s(\omega, \tau)))^2}$$

$$Q(\omega, \tau) = \tan^{-1} \left(\frac{\text{im}(X_s(\omega, \tau))}{\text{real}(X_s(\omega, \tau))} \right)$$

Where t is time; ω is frequency; (t) is seismic trace; (t) is the spectral decomposition window; τ is translation along time axis; $Amp(\omega, \tau)$ is amplitude spectrum; $Q(\omega, \tau)$ is phase spectrum; and $X(\omega, \tau)$ is Fourier transform of $x(t)$.

Amplitude spectrum is manipulated as:

$$\begin{aligned} (\omega, \tau) &= \log_{10}(Amp(\omega, \tau)) \\ L(\omega, \tau) &= LF(\omega, \tau) - \min(LF(\omega, \tau)) \\ LF(\omega, \tau) &= LFP \times t \left(\frac{\int (Amp(\omega, \tau)) d\omega}{\int LFP(\omega, \tau) d\omega} \right) \end{aligned}$$

Where (ω, τ) is the logarithm of amplitude spectrum on translation τ ; $LFP(\omega, \tau)$ is the positif of LF; and $LFPE(\omega, \tau)$ is the energy balance of amplitude spectrum.

Complex STFT reconstruction is:

$$\begin{aligned} RHC &= LF(\omega, \tau) \cos Q(\omega, \tau) \\ IHC &= LF(\omega, \tau) \sin Q(\omega, \tau) \\ HCC(\omega, \tau) &= \text{complex}(RHC, IHC) \end{aligned}$$

Where $H(\omega, \tau)$ is complex STFT coefficient; RHC is real and IHC is imaginary part; $\gamma(t-\tau)$ is reconstruction window (Sajid, 2014).

STFTHC is applied to 1D and 2D (wedge model) synthetic data for validation.

1D synthetic trace was built by convolving previous Ricker wavelet with following reflection coefficient series:

- Single reflector
- Double reflector with 6 ms thickness (under Ricker and Rayleigh criterion) (Ricker, 1953)
- Double reflector with 8 ms thickness (under Ricker and Rayleigh criterion)
- Double reflector with 10 ms thickness (Ricker criterion)
- Double reflector with 12 ms thickness (Rayleigh criterion)
- Double reflector with 14 ms thickness (above Ricker and Rayleigh criterion)

The algorithm was applied to 3D real seismic. The output seismic was then used as input for Model Based Acoustic Impedance (AI) inversion process.

Result and Discussion

Application of STFTHC

Figure 1 illustrates STFTHC algorithm through application on Ricker wavelet. The wavelet has dominant frequency 35 Hz, sampling rate 2 ms and record length 0,1 s. Application of STFTHC reduced wavelet duration and its sidelobe energy. Total energy of input signal was preserved through energy balance. Amplitude spectrum is broader after STFTHC and sidelobe energy reduction suppresses the interference of two reflectors.

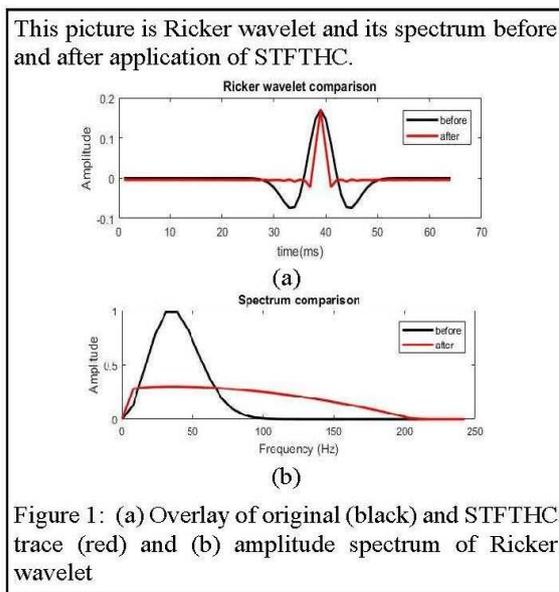


Figure 1: (a) Overlay of original (black) and STFTHC trace (red) and (b) amplitude spectrum of Ricker wavelet

Figure (2) shows -on the original trace- the flat spot indicating resolution limit based on Ricker criterion happened at 8 ms thickness. Peak and trough separation happened on 12 ms thickness, agreeing with Rayleigh criterion. The figure demonstrates that on the single reflector, there were no significant changes. It gives us insight that STFTHC algorithm preserves the amplitude if there is no reflector interference. On output trace, the second reflector shows amplitude decrease indicating the reflector was started to separate. When the thickness is 8 ms, a clear separation is observed and -based on Rayleigh criterion- is considered as resolved. Figure 2 (b) is the amplitude spectrum of original (black) and STFTHC (red) trace given on fig. 2 (a). The spectrum is broader after application of STFTHC particularly on a higher frequency. The amplitude spectrum also becomes smoother after STFTHC.

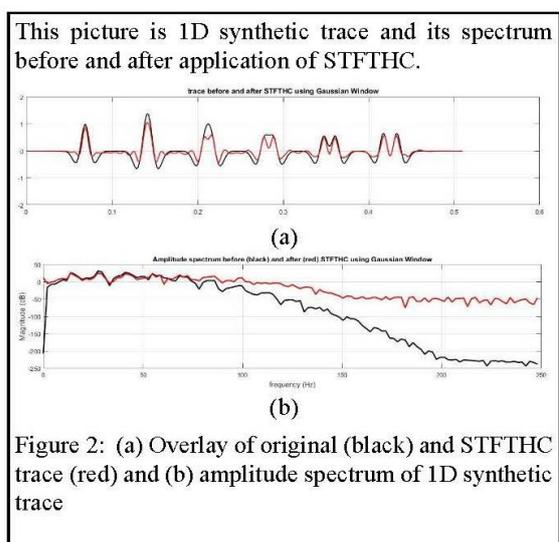


Figure 2: (a) Overlay of original (black) and STFTHC trace (red) and (b) amplitude spectrum of 1D synthetic trace

As seen in figure (3), on the original trace, the reflector separation occurs at the 17th trace while trace after STFTHC shows reflector separation since the 13th trace. Besides the improvement of reflector separation, application to Wedge model shows that when there is just one reflector (1st – 5th trace), the peak amplitude remains the same.

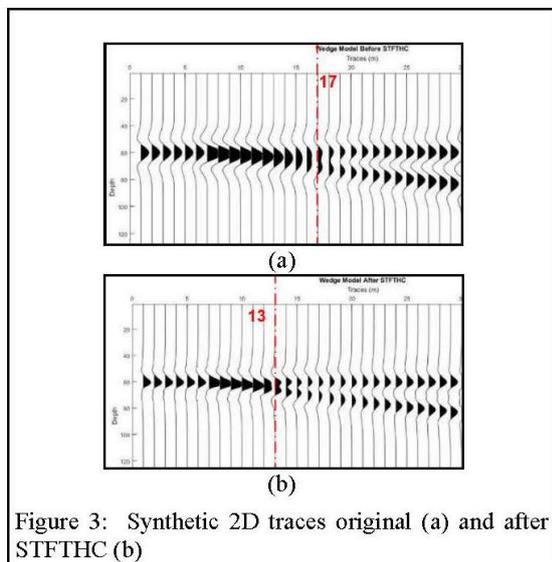


Figure 3: Synthetic 2D traces original (a) and after STFTHC (b)

This algorithm was applied to seismic data from “TG” field with sampling rate 2 ms. Reservoir’s thickness in this zone vary from 6 – 32 m based on sequence stratigraphic study. Resolution enhancement can be observed from the amplitude spectrum (fig. 4). The bandwidth is broader therefore, in return the interface of two unseparated reflectors can be noticed clearer. Figure (5) shows real seismic section which contains two poorly separated reflectors. The existence of two reflectors was verified by Gamma ray log. Those reflectors were better separated after the application of STFTHC as shown on fig. 5 (a) and (b). Another 2D section of real data shows a better separation after STFTHC from another inline is given on fig. 6. The existence of two reflectors is verified by log data as well.

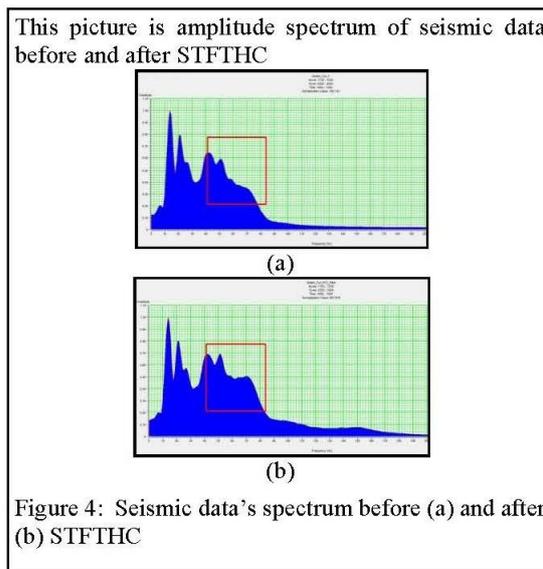


Figure 4: Seismic data’s spectrum before (a) and after (b) STFTHC

AI Inversion Result

Acoustic impedance inversion is performed using five wells and seismic data before and after application of STFTHC algorithm with same parameters. Synthetic trace generated from well data is more similar to seismic trace after STFTHC than the original one. Correlation and coefficient for each well increased by 10% on average. Inversion analysis error decreased by 17,5 %. These improvements happened because seismic data tends to gain its higher frequency amplitude after STFTHC and since seismic trace generated from well log has a high frequency, the correlation becomes stronger. Thus, inversion result could give a better separation of subsurface layer.

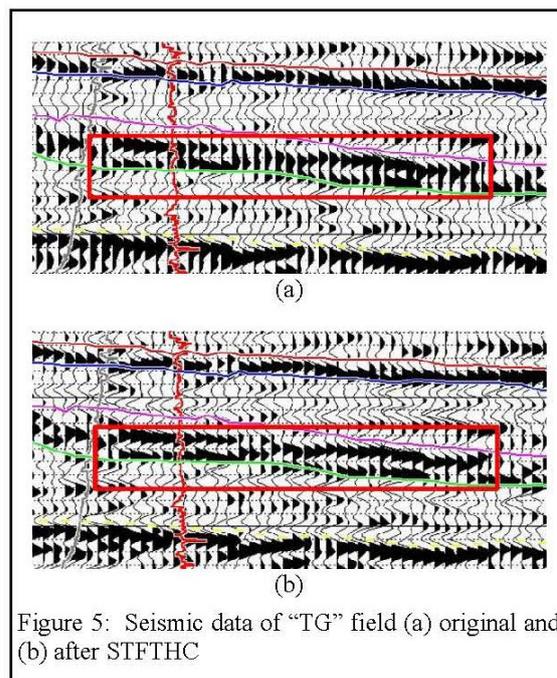


Figure 5: Seismic data of “TG” field (a) original and (b) after STFTHC

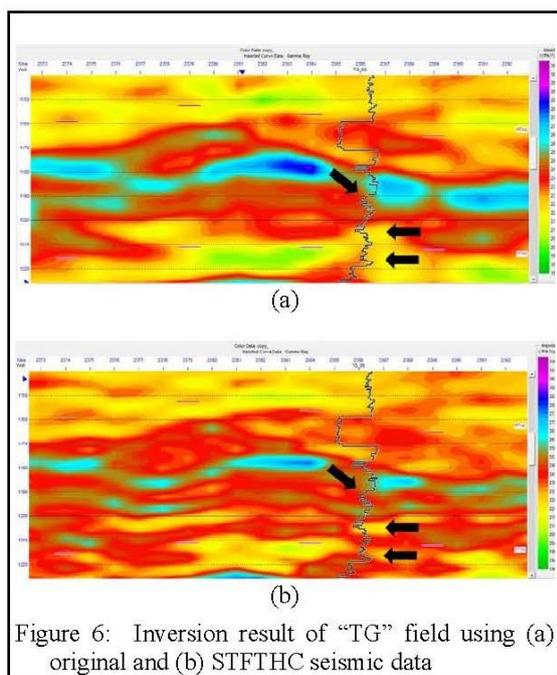


Figure 6: Inversion result of "TG" field using (a) original and (b) STFTHC seismic data

Conclusions

Validation test of STFTHC on 1D and 2D synthetics trace successfully enhances seismic resolution and thin bed whose thickness is less than what resolution limit can separate. Application of STFTHC on real seismic data provides a better separation between interfere reflector. Seismic – well tie correlation increases by 10% and inversion analysis error decreases by 17,5% yielding to an improvement of thin bed identification on inversion result.

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