Improving Thin Bed Identification in Sarawak Basin Field using Short Time Fourier Transform Half Cepstrum (STFTHC) method

O. Nizarul1, M. Hermana1, Y. Bashir1 and D.P. Ghosh1
Centre for Seismic Imaging (CSI), Department of Petroleum Geoscience, Universiti Teknologi PETRONAS, Tronoh, Perak, Malaysia.

E-mail: ni87ideas@gmail.com

Abstract: In delineating complex subsurface geological feature, broad band of frequencies are needed to unveil the often hidden features of hydrocarbon basin such as thin bedding. The ability to resolve thin geological horizon on seismic data is recognized to be a fundamental importance for hydrocarbon exploration, seismic interpretation and reserve prediction. For thin bedding, high frequency content is needed to enable tuning, which can be done by applying the band width extension technique. This paper shows an application of Short Time Fourier Transform Half Cepstrum (STFTHC) method, a frequency bandwidth expansion technique for non-stationary seismic signal in increasing the temporal resolution to uncover thin beds and improve characterization of the basin. A wedge model and synthetic seismic data is used to quantify the algorithm as well as real data from Sarawak basin were used to show the effectiveness of this method in enhancing the resolution.

1. Introduction

Stratigraphic interpretation of thin layers had not became attention until late 1970s when advances in field acquisition techniques rendered seismic amplitude interpretation more reliable. In case of our field study in Sarawak basin, specifically on clastic reservoir, deepwater exploration shows a good prospect. In Silantek Formation, the Basal Sandstone Member, Temudok Member and Upper Silantek Redbed Member showed an alternating thin beds of siltstone and sand [1]. The same trend can also be seen in Temodok Member [2]. Shell Sarawak by using Thomas-Stieber thin bed analysis increased the STOIIP estimate by 18% which was mostly contributed to by significant increment in net-to-gross (NTG) and improved estimations of porosity and saturation in one of the acquired block in Sarawak [3]. But imaging thin beds is an issue of resolution although the thin bed analysis has now become the routine in petrophysical analysis for Malaysian field [4]. A thin bed imaging gives interpreter brighter chance to produce a good petroleum model or in other cases predicts pitfalls that will hinder the petroleum system efficiency.

1.1 Thin Bed Definition

Seismic resolution is one of the key elements to estimate the quality of seismic data. Even with the advance technology of seismic acquisition through which we can obtain 50 Hz dominant frequency...
seismic data, definition of 10 m beds are still a difficult task. Widess [5] considered a thin bed as one where the complex waveform across it does not differ significantly from the derivative of the convolving wavelet itself.

This definition is useful for thin bed detectability studies, but causes problems when it comes to thin bed resolvability considerations. At the bed thickness Widess [5] first considers a bed to become a “thin” bed, i.e., when the bed thickness is about 1/8; the apparent thickness is actually 1/4.6 which is the peak-to-trough time of the derivative of a Ricker wavelet [6]. Koefoed and de Voogd [7] refined thin bed definition and suggest that a bed is considered to be thin if the amplitude response, as a function of thickness, deviates less than 10% from a linear relationship.

A thin layer, formed by the intrusion or sedimentary process, commonly exhibit opposite reflectivity. If the separation of the layer boundaries is large enough, say exceeding one-eighth of the dominant wavelength of the propagating wavelet, and if it can be resolvable, the volume of the layer can be estimated by analyzing the configuration of the composite wavelets. Nevertheless, a thin layer of unresolvable thickness will very possible be ignored and become invisible on the seismic section [8]. Farr (1976) also emphasize that a bed as thin as 1/40 may be detected. It should be fully understood, that the apparent thickness remains at 1/4.6.

An important aspect of thin beds delineation is the frequency content of a composite wavelet made up of superimposed reflections from closely spaced interfaces [9]. Therefore, we apply STFTHC method to increase bandwidth of frequencies and later improved vertical resolution of the section for better interpretation work and seismic to well correlations.

2.2 STFTHC technique formulation

STFTHC algorithm was first proposed in Sajid [10] and was implemented in the Malay basin which also experience thin bed problem. The algorithm was made after an extensive comparative study on other well established signal enhancement algorithm comprising of Fanbeam transform [11], Wavelet transform [12], Ridgelet Transform [9] Curvelet transform [13] and Radon Transform [14]. The basis of STFTHC is combining the feature of Short Time Fourier Transform (STFT) with Half Cepstrum (HC) to to smooth and expand the frequency spectrum at each translation of the spectral decomposing window. The key idea is to replace the amplitude spectrum with its logarithm in each window of the STFT, the logarithm of the amplitude spectrum provides the opportunity to study the low energy and high frequencies information in frequency domain. The algorithm is the implementation of the Half Cepstrum (HC) algorithm on each slice of seismic trace. This is achieved by the merging of HC algorithm, originally from Cepstrum [15] with STFT algorithm [16]. Half Cepstrum (HC) is user independent frequency broadening algorithm which expands the frequency bandwidth by implementing logarithm on the amplitude spectrum of the trace.

2. Methodology

2.1 Method and Available Data

This frequency broadening technique depends upon the frequency contents in the seismic waveform. By incorporation of STFT, this logarithmic frequency broadening is implemented on each amplitude spectrum of the trace spectrogram. Reconstruction from this modified spectrogram leads to non-stationary high resolution seismic trace without greatly boost in white noise. The workflow on how we test the algorithm as seen in Figure 1. In the Half Cepstrum algorithm, frequency bandwidth is expanded in four simple steps as described below.

1. Fourier transform of the input signal,
2. Implementation of logarithm to expand bandwidth and smoothing,
3. Energy balancing with respect to the original amplitude spectrum. But before that the amplitude spectrum is brought to positive side.

4. Reconstruction back of the signal from broadening amplitude spectrum while using original phase spectrum. Below is the final algorithm of STFTHC:

$$STFTHC(t) = \int_{-\infty}^{\infty} (HC_c(\tau, f) \gamma(t - \tau)) e^{2\pi j f \tau} df d\tau$$

Where \( t = \) time, \( f = \) frequency in hertz, \( x(t) = \) time domain signal, \( h(t) = \) Gaussian Spectral decomposing window, \( \tau = \) translation of Gaussian window along time axis, \( \gamma(t) = \) reconstruction window

The Gaussian windows of the windowing function:

$$W_{gw} = \exp\left\{ -\left( \frac{n - b}{w} \right)^2 \right\}$$

where \( n = \) number of samples in a trace, \( b = \) position of the window, \( w = \) half width of the window

**Figure 1:** Flowchart of the working procedure we used to test the algorithm effectiveness.

In the STFTHC, the selection of the spectral decomposing window plays an important role and its size must be greater than the expected wavelet duration.

A time reflectivity method was used to create a synthetic seismic of known time thickness. It convolved with Ricker wavelet (zero phase) with the desired parameters (Figure 2a) and the resultant reflectivity (Figure 2b). The synthetic seismic created in Figure 3 is of 35 Hz dominant frequency with signal to noise ratio of 3 (Figure 2c). It contains 4 layers, layer 1 and 2 are the thin layer with same polarity while layer 3 and 4 produce the wedge model.

The produced synthetic model later was tested with STFTHC method to increase the resolution of the section by improving bandwidth.

For the real data testing, a section from Sarawak basin was used. Sarawak basin, as the adjacent Malay basin suffer thin beds problem, where thin coal beds are intercalated between reservoir sand shale layers and well data provides good control for our algorithm testing as most of the synthetic generated from well logs correlates well with the seismic. With the assumption that the proposed algorithm after bandwidth expansion will increase resolution of the layer. The data used is seen in Figure 6.

### 3. Result and Discussion

After the application of method we have test our data, the resolution was enhanced on both synthetic and real data. The synthetic section shows a boost in frequency content without generating gain for the noise shown below (Figure 3 and 4). In case of the synthetic section, which have S/N ratio = 3, the
output of the test enhanced the visibility ranges from 60 Hz – 150 Hz, where thin beds usually fall in between the value.

**Figure 3:** The amplitude spectrum comparison of original signal (black) and enhanced signal (red). Note the frequency ranges from 60 Hz to 150 Hz was boosted.

**Figure 4:** After STFTHC processing, the model now can have an enhanced resolution by gaining of the frequency content ranges from 60 Hz – 150 Hz, causing better resolution of thinner bed in the wedge (from black line to blue line).
Figure 5: The enhanced resolution after application of STFTHC method (right) with clear reflectors for better subsurface interpretation of the wedge model.

In the real data for a seismic section in Sarawak, we expect to recover frequencies ranges from 10 Hz to 80 Hz (Figure 6). The range of frequency is very useful in thin bed tuning in seismic data processing and interpretation.

Figure 6: Real seismic section before STFTHC application (top) and after STFTHC application (below). The bed become more separable to unveil the thin bedding in between. Seen on the below right the bed become connected. With permission from PETRONAS.
4. Conclusions

We have demonstrated that the STFTHC method used help us in increasing the bandwidth of the seismic data for thin bed delineation. The resolution achieved through this algorithm depends upon the information preserved in the seismic waveform; therefore we can call them as data driven seismic resolution algorithms. This spectral enhancement method provide subsurface interpreter with more detailed data to uncover the once unresolved images of thin beds. STFTHC works in frequency domain, providing more flexibility for user to use it in spectral study with other domain for better and reliable interpretation.

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