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Deconvolution of a Non-Stationary Seismic Data Based On Hyperbolic Stockwell Transform

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ABSTRACT: A non-stationary deconvolution method has been modified to increase the resolution of the seismic data. The product of modification is called as deconvolution hyperbolic Stockwell transform. The procedure to construct deconvolution were: (1) Replacing the Gabor transform with the hyperbolic Stockwell transform to convert the seismic data into time-frequency domain; (2) Smoothing seismic data in time-frequency domain to get an estimation waveform of variant time; and (3) Dividing seismic data in time-frequency domain by estimation waveform of variant time to get an estimation of reflection coeficient. This method was applied to synthetic non-stationary seismic data and real seismic data. The method can separate the interferenced reflection coefficient due to the effect bandwidth of wavelet and sharpen the reflection coefficient on a non-stationary seismic data. Deconvolution hyperbolic Stockwell transform applied to synthetic and real seismic data proved that this method can effectively increased a non-stationary seismic data resolution.

KEY WORDS: deconvolution, non-stationary, anelastik attenuation, hyperbolic Stockwell transform

I.INTRODUCTION

Deconvolution is a method to increase the resolution of seismic data. Deconvolution removes wavelet to increase the resolution of the seismic data [1]. Generally, the deconvolution method used in processing seismic data are Wiener deconvolution [2], prediction deconvolution [3], least square inverse filtering and spectral modeling [4]. The above-mentioned deconvolution method assumes that the shape of wavelet propagating into the earth is stationary, but in fact the shape of wavelet changes over time, so it will be nonstationary. Absorption or known as nonelastic attenuation is the effect that causes seismic data to be nonstationary [5].

The research idea is inspired by [6]. The idea is to modify the Stockwell transform that applied to deconvolution algorithm. Modification in this research adds parameters to the window function in Stockwell transform. The results will be referred to as Hyperbolic Stockwell Transform (HST). HST will have some parameters to set the window shape to be more flexible, so its application into the deconvolution algorithm will be more appropriate.

II. LITERATURE SURVEY

There are several studies that develop deconvolution to deal with nonstationary seismic data. These studies will be used as a reference in developing non-stationary deconvolution in this research. [7] reconstructed a nonstationary deconvolution with short time Fourier transform (STFT). In the following year, [8] reconstructed the Gabor deconvolution by substituting the smoothing technique of a 2-D boxcar with the least square to obtain wavelet estimation and attenuation. [9] reconstructed the Gabor deconvolution using hyperbolic smoothing to derive wavelet estimation and attenuation. [6] reconstructed the Gabor deconvolution by replacing the Gabor transform with a modified Stockwell transform. Modified Stockwell transform is the result of the development of Stockwell transform.

III. RESEARCH METHODS

The aims of this research are construction of Hyperbolic Stockwell Transform (HST) and then construct non-stationary deconvolution using MATLAB. HST is used to convert the 1-D signal (time zone) into 2-D (time-frequency region). HST is applied into deconvolution algoritm to get a non-stationary deconvolution. A non-stationary

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deconvolution is a series of processes to estimate the reflection coefficient function by estimating the changing wavelet shape over time due to the anelastic attenuation effect. The anelastic attenuation be identified in time-frequency domain produced by HST.

A. Construction of HST

The procedure to construct HST are:

1. constructing the hyperbolic window function (the hyperbolic window function is derived from the hyperbolic window substitution [10] into the window function [6]),
2. converting the window function into the frequency domain (spectrum window),
3. converting data (time series) into the frequency domain (spectrum data),
4. localizing the data (the window spectrum (step 2) is multiplied by data spectrum (step 3) to generate localization of the data spectrum),
5. geting time-frequency domain (localization of the data spectrum shows the spectral localization at each frequency value of the data. These spectral localization convert to the time domain by inverse Fourier transform to obtain data information in a time series on each localization frequency),

B. Construction of Deconvolution Hyperbolic Stockwell Transform

The procedure to construct deconvolution are:

1. applying HST to seismic data (HST convert the seismic data from time domain to time-frequency domain),
2. estimating the amplitudes of the wavelet spectrum at each traveltime (wavelet will vary over traveltime due to the effects of anelastic attenuation; variation of wavelets can be estimated in time-frequency domain; each column in the domain is smoothed to obtain variation of wavelet spectrum amplitude),
3. estimating minimum phase (the smoothing process can only estimate the wavelet amplitude value, while designing the deconvolution operator requires amplitude and phase values; the wavelet (dynamite source) is assumed to have a minimum phase, then Hilbert's transformation of the logarithm value of the amplitude can be used to generate the phase),
4. producing the deconvolution operator (the deconvolution operator is generated by combining the amplitude of the wavelet estimated and the minimum phase estimated),
5. estimating the reflection coefficient function (the estimation of the reflection coefficient function is obtained by dividing the seismic trace in the HST domain by the deconvolution operator; the result of the dividing is estimation of the reflection coefficient function in the time-frequency domain; estimation of the reflection coefficient function in the time domain can be generated using inverse HST; the estimation of reflection coefficient function is a product of deconvolution).

IV. RESULTS

A. Hyperbolic Stockwell Transform (HST)

Figure 5.1 shows three spectral decomposition methods applied to a time series data consisting of a cross-chirp signal and two high frequencies values. The three methods are Gabor transform, Stockwell transform, and hyperbolic Stockwell transform (HST). These methods are used to construct a time-frequency representation (TFR). Each method uses its parameters to produce optimal TFR. The HST TFR produces the thinnest cross chirp. Besides, the two high frequency values are the clearest and most precise to identify compared to the two methods. It proves that HST can produce high resolution TFR with high resolution in both the frequency and time domains.

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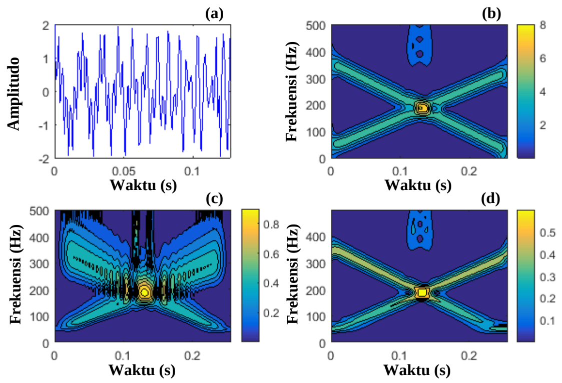

Figure 5.1. a crossed chirps signal and two high frequency (a); the time-frequency domain generated by: Gabor transform (b); Stockwell transform (c); HST (d).

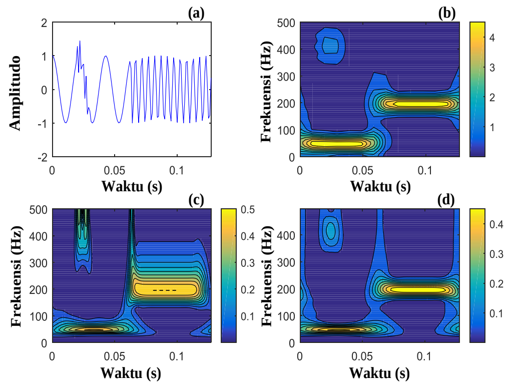

Figure 5.2. a high and low frequencies in a certain time range (a); the time-frequency domain generated by: Gabor transform (b); Stockwell transform (c); HST (d).

Figure 5.2 shows three spectral decomposition methods applied to a time series data consisting of high and low frequencies in a certain time range which are then combined with more high frequencies. The parameter values used in the Gabor and Stockwell transforms are same values as in the previous time series data (Figure 5.1), as well as the parameter values used in the HST. The results of the HST can show the three frequency values with highest resolution than the Gabor transform and the Stockwell transform.

HST can produce images in time-frequency domain or time frequency representatif (TFR) with higher resolution because of the additional parameters in the window function that can be used to generated the window to be more flexible. The window will optimize its function in localizing the signal, so that it will make higher resolution.

B. Deconvolution hyperbolic Stockwell transform is applied to synthetic non-stationary seismic data using dynamite sources

A non-stationary seismic data is made by a minimum phase wavelets with dominant frequency 30 Hz, an attenuation function is generated using Q = 45, and a reflection function over 0,5 s. the reflection function over 0,5 s. Figure 5.5 (a) shows the TFR of non-stationary seismic data generated by HST using parameters $\gamma_{HY}^{F} = 0{,}001$, $\gamma_{HY}^{B} = 0{,}1$, $\lambda_{HY} = 1000$, and $r = 0{,}1$. The result of the deconvolution or estimation of the reflection coefficient function is shown in Fig. 5.5 (d). The result is obtained of dividing the input signal in the HST domain (figure 5.5 (a)) by the deconvolution operator (5.5 (b)). After applied deconvolution to the data, it shows an increasing resolution in signal. An increasing resolution is determined by the appearance of frequency values over time and they correspond to the actual reflection coefficient function shown in Figure 5.5 (c).

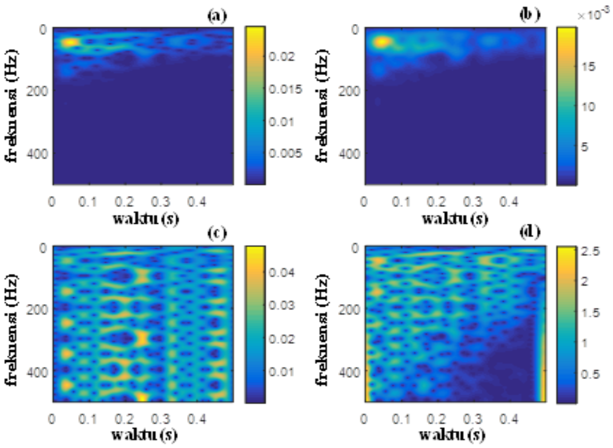

Figure 5.5. TFR using HST: (a) non-stationary seismic traces of dynamite sources; (b) deconvolution operator; (c) the reflection coefficient function; and (d) estimation of the reflection coefficient function.

ISSN: 2350-0328
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Figure 5.6 is the result of transformation figure 5.5 into the time domain. Figure 5.6 (a) -5.6 (c) shows the function of the reflection coefficient, the non-stationary seismic data, and the estimated function of the reflection coefficient obtained from the application of deconvolution has made. Seismic data in the time domain cannot show a function of the reflection coefficient, especially between adjacent reflection coefficients and small differences in distance.This is due to the interference effects of the wavelet width. After the deconvolution process, the the interference of reflection coefficient can be separated (it is shown by a dashed red box). This shows that this deconvolution has succeeded in increasing the resolution of the data or can estimate the function of the reflection coefficient with high resolution.

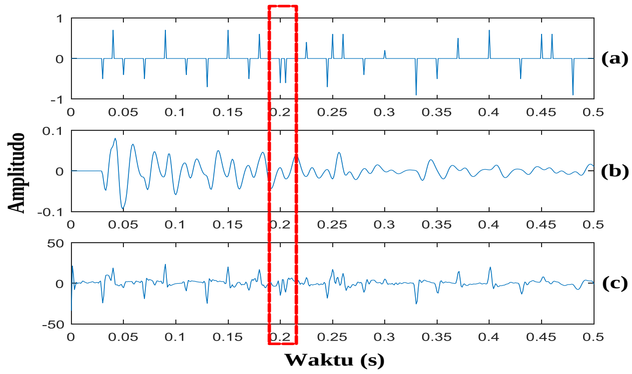

Figure 5.6. time domain of: (a) the reflection coefficient function; (b) non-stationary trace seismic of dynamite sources before deconvolution; and (c) after deconvolution.

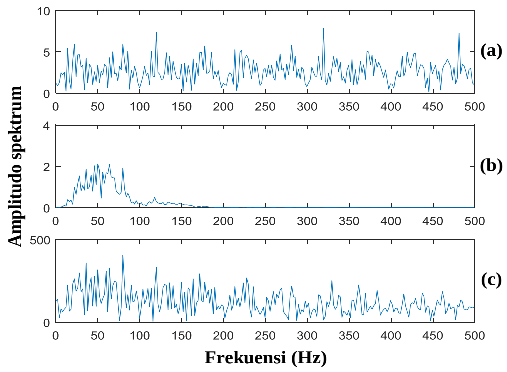

Figure 5.7. amplitude spectrum of: (a) the function of the reflection coefficient; (b) non-stationary trace seismic of dynamite sources before deconvolution; and (c) after deconvolution.

Figure 5.7 is the spectrum amplitude of Fig. 5.6. Figure 5.7 (a) - 5.7 (c) shows the spectrum of the reflection coefficient function, the amplitude spectrum of seismic data before the deconvolution is applied, and the amplitude spectrum of seismic data after deconvolution. Before deconvolution is applied, the amplitude spectrum of the seismic data is seen cut off from the 100 Hz frequency. It is influenced by the effect of the width of the wavelet spectrum. After deconvolution is applied, the spectral amplitude of the seismic data is seen to extend to the end of the spectrum and look more flat. This shows that the deconvolution process has succeeded in removing the effect of the wavelet width.

C. Deconvolution hyperbolic Stockwell transform is applied to synthetic non-stationary seismic data using vibroseis source.

A non-stationary seismic trace using a vibroseis source is made by a sweep formed with a sinusoidal character that starts with a frequency of 9 Hz and ends with a frequency of 96 Hz, an attenuation function formed using Q = 45, and a reflection function over 0,5 s. The result of the deconvolution or estimation of the reflection coefficient function is shown in Fig. 5.8 (d) in the form of TFR. The result can not generate the frequency value from 0,2 s to the signal end. This is because the deconvolution process has not completely removed the wavelet effect. However, the results obtained show an increase in data resolution. The increase in resolution is indicated by the appearance of a frequency value that corresponds to the actual reflection coefficient function between the initial ends of the signal up to 2 seconds, whereas this value does not appear in the data before deconvolution. This indicates that the deconvolution is able to increase the resolution of data seismic using vibroseis source. Increased resolution can also be shown in figures 5.9 and 5.10. Figure 5.9 is the data converted to the time domain. after deconvolution, the data show a corresponding to the actual reflection coefficient function. Figure 5.10 is the data converted to the frequency domain showing the amplitude of the flat spectrum which indicates the wavelet effect erased.

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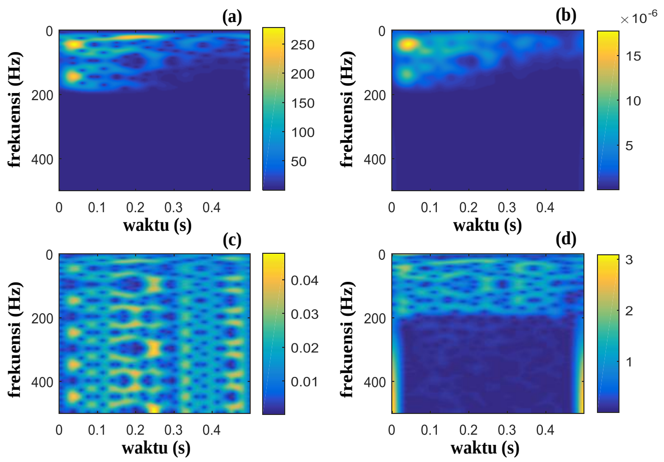

Figure 5.8. HST domain of: (a) trace seismic source of vibroseis; (b) deconvolution operator; (c) the function of the reflection coefficient; and (d) estimation of the reflection coefficient function.

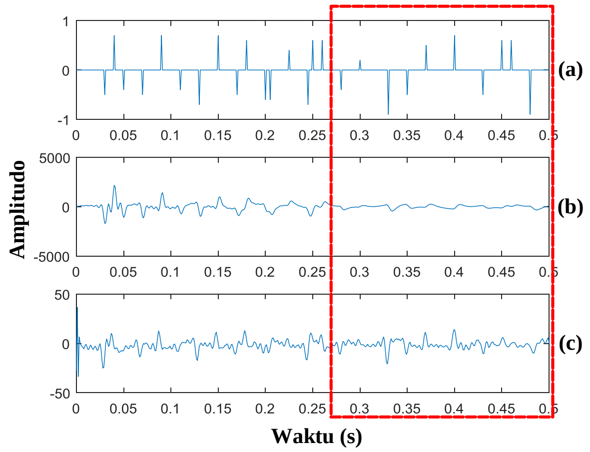

Figure 5.9. time domain of: (a) the reflection coefficient function; (b) non-stationary trace seismic of vibroseis sources before deconvolution; and (c) after deconvolution**.**

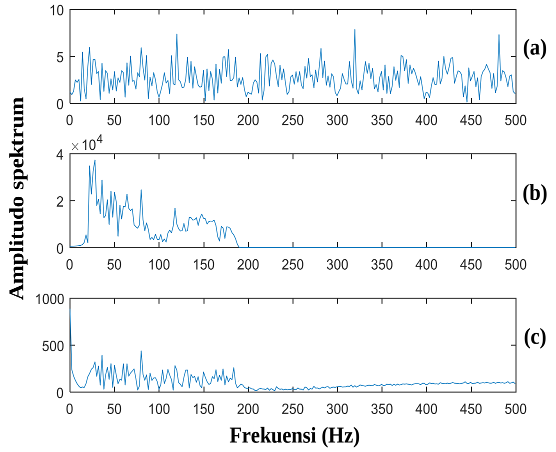

Figure 5.10. Spectrum amplitude of: (a) the function of the reflection coefficient; (b) non-stationary trace seismic of vibroseis sources before deconvolution; and (c) after deconvolution.

D. Deconvolution hyperbolic Stockwell transform is applied to real seismic data using dynamite source

Figure 5.11 is the result of applicated deconvolution using parameters $\gamma_{HY}^{B} = 0{,}1$, $\gamma_{HY}^{F} = 0{,}002$, $r = 0{,}1$, dan, $\lambda_{HY} = 1000$ on real seismic data using dynamite source. The approximate value of the earth reflection coefficient in Figure 5.11 can be indicated by the black and red color lines. The data after the applied deconvolution is shown by Figure 5.11 (b). It removes some black lines on the data (shown in dotted yellow box). The removed of the black line does not mean that the applied deconvolution is incorrectThis only shows that the applied deconvolution has succeeded in increasing the resolution of the seismic data. Black lines in the deconvolved data is actually replaced with a red lineThis can happen when the data that has a minimum phase in the seismic data is converted to zero phase. The phase change in the data indicates that deconvolution has successfully removed its wavelet effect. The success of this deconvolution can also be shown in Figure 5.11 (b), where two previously invisible lines become visible. they can be seen in the blue dashed box. The appearance of two lines shows that the deconvolution hyperbolic Stockwell transform can increase the resolution of seismic data using dynamite source.

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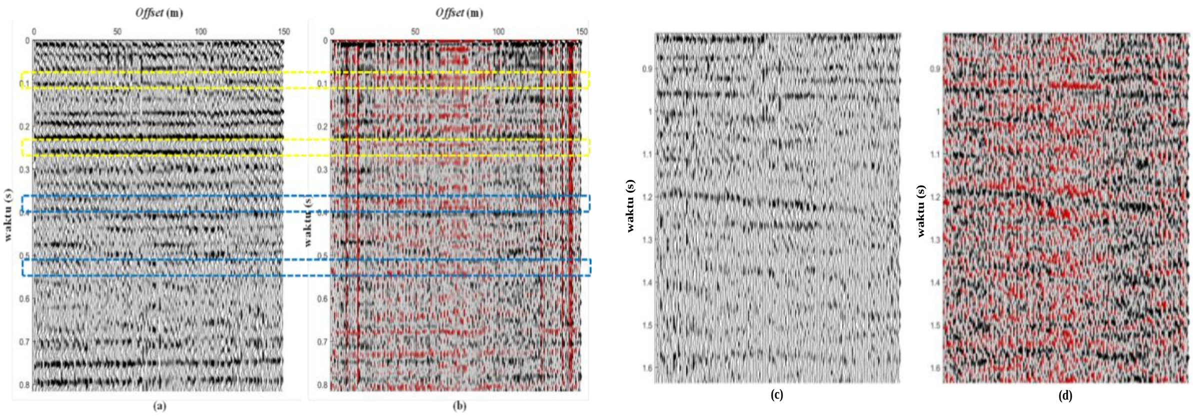

Figure 5.11. (a) seismic data using dynamite before and (b) after deconvolution using parameter $\gamma_{HY}^{B}=0{,}1$, $\gamma_{HY}^{F}=0{,}002$, $r=0{,}1$ and $\lambda_{HY}=1000$ at traveltime (0 - 0,8) s, (c) seismic data using dynamite before and (d) after deconvolution at traveltime (0,8 - 1,6) s.

E. Deconvolution hyperbolic Stockwell transform is applied to real seismic data using the vibroseis source

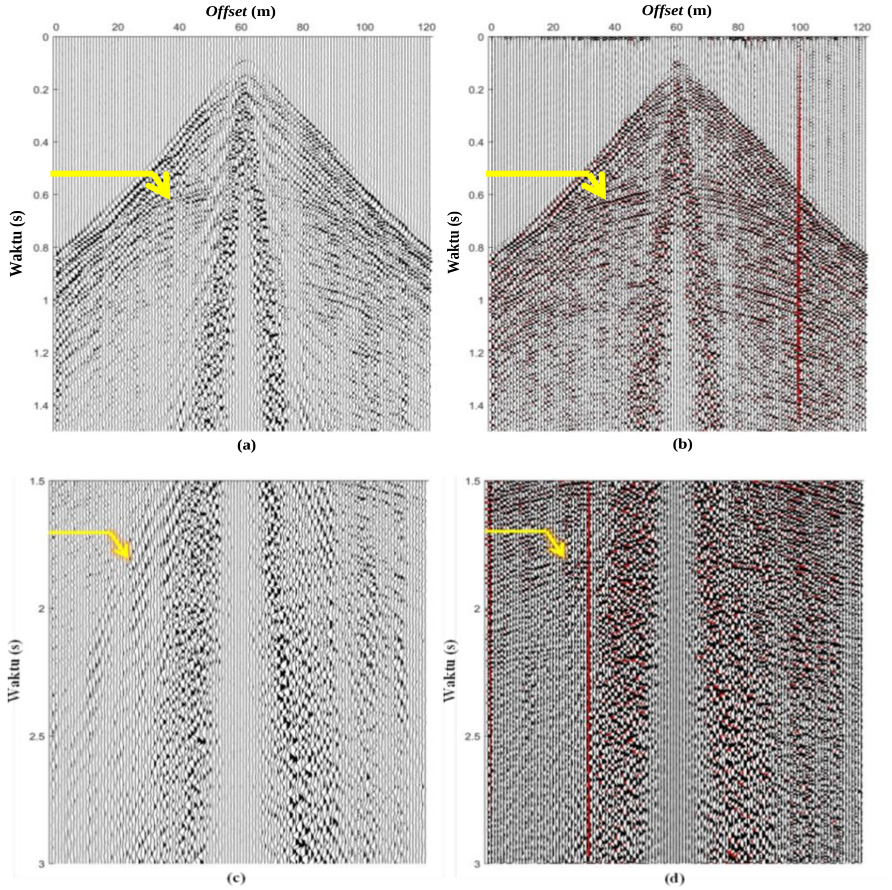

Figure 5.12. (a) seismic data using vibroseis before and (b) after deconvolution using parameter $\gamma_{HY}^{B}=0{,}1$, $\gamma_{HY}^{F}=0{,}002$, $r=0{,}1$ and $\lambda_{HY}=1000$ at traveltime (0 - 1,5) s, (c) seismic data using vibroseis before and (d) after deconvolution at traveltime (1,5 - 3) s.

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 8, Issue 4 , April 2021

Figure 5.12 is the result of applicated deconvolution using parameters to vibroseis source seismic data using parameters $\gamma_{HY}^{B} = 0{,}1$, $\gamma_{HY}^{F} = 0{,}002$, $r = 0{,}1$, dan, $\lambda_{HY} = 1000$. Seismic data before the deconvolution process is shown in Figure 5.12 (a). The seismic data is a common shot point gather of offset seismic trace to 1139 to 1420 m. Seismic data after the deconvolution process is shown in Figure 5.11 (b) that indicatimg a line sharpening and a new line appears (it is indicated by a yellow arrow). These points show that deconvolution has succeeded in increasing data resolution in field data using vibroseis sources.

V. CONCLUSION

The research has produced a spectral decomposition method, the method is called hyperbolic Stockwell transform (HST). HST is formed using MATLAB. The HST is a spectral decomposition method resulting from a modification of Stockwell's transformation using a hyperbolic window. The method is tested using time series data with known frequency values within a certain range time and the chirp signal, then the results are compared with the results of the Gabor and Stockwell transformations. The tests show that TFR produces the thinnest cross chirp. Besides, the two high frequency values are the clearest and most precise to identify compared to the two methods

This research also produced a nonstationary deconvolution using MATLAB. The deconvolution is a method to improve resolution or recovering the reflection coefficient function of non-stationary seismic data due to the effects of the anelastic medium in the earth. Deconvolution was formed using HST as a method to estimate the effect of anelastic attenuation. Deconvolution was tested to seismic data synthetic and real seismic data. The test shown that deconvolution can improve spikes of the reflection coefficient function. Moreover, it separates the reflection coefficients which have a thin spacing, where previously the reflection coefficient is fused due to the interference effect. This suggests that the deconvolution in this research has succeeded in increasing the resolution of the seismic data and can estimate the reflection coefficient function of the non-stationary seismic data due to the effects of anelastic attenuation.

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