COMPARISON OF 1DWT AND 2DWT TRANSFORMS IN GROUND ROLL ATTENUATION

ROSITA HAMIDI[1], ABDOLRAHIM JAVAHERIAN[1,2] and ALI M. REZA[3]

[1] *Department of Petroleum Engineering, Amirkabir University of Technology, Tehran, Iran.*
[2] *Institute of Geophysics, University of Tehran, Tehran, Iran. javaheri@ut.ac.ir*
[3] *Department of Electrical Engineering and Computer Science, P.O. Box 784, Milwaukee, WI 53201-0784, U.S.A.*

(Received March 28, 2012; revised version accepted November 28, 2012)

ABSTRACT

Hamidi, R., Javaherian, A. and Reza, A.M., 2013. Comparison of 1DWT and 2DWT transforms in ground roll attenuation. *Journal of Seismic Exploration*, 22: 49-76.

Ground roll is the most important type of coherent noise in land seismic data. It usually has stronger amplitude than reflections and masks the valuable information carried by the signals. Wavelet transform is one of the methods which can be used for ground roll suppression. It can be used in one or two dimensions based on the nature of data which is supposed to be filtered. In one-dimensional wavelet transform (1DWT) any 1D trace is transformed into a time-scale domain. This enables the separation of features with different frequencies in different coefficients while preserving their time separation. Two-dimensional wavelet transform (2DWT) in fact takes two 1DWTs in columns and rows of a data matrix. In this case, seismic events with different velocities are represented in different horizontal, vertical and diagonal detail coefficients. It is enough to determine the coefficients corresponding to the noise and omit them to have the filtered data.

In this study, 1DWT and 2DWT were both reviewed, the MATLAB code for two filters was written to suppress the ground roll, and the results of filtering the synthetic and real data are presented. The synthetic data was based on an earth model of eight layers over a half space containing refraction, reflectors and a ground roll. The real data is a shot record from SW Iran with a strong ground roll. According to the results, 2DWT can extract the ground roll with less suppression of the desired signals compared to 1DWT. It is due to the fact that the noise separation from signals has a better resolution in the 2D case. The filters were based on the frequency content (in 1DWT), arrival time and velocity (in 2DWT) of the ground roll and signal. For that reason, these were the filter parameters (which depended on the input data). To have an appropriate result, at least one of these properties had to be different. In addition, the choice of the mother wavelet could affect the filter performance because different wavelets produced different results in the separation of signal and noise in a WT domain.

KEY WORDS: noise, ground roll attenuation, 1DWT, 2DWT.

0963-0651/13/$5.00

INTRODUCTION

Noise is the inevitable part of seismic data. It is crucial that coherent and incoherent noise is removed in an early stage of processing as much as possible to have a successful imaging. Ground roll is the main type of coherent noise in seismic data. It can easily cover other signals due to its higher energy and stronger amplitude making the desired reflected signals indistinct. Common filtering approaches are based on transforming data into a new domain where signal and noise are separated based on their different properties. Ground roll appears as low-velocity, low-frequency waves whereas the desired signals usually have a band of medium frequencies and higher velocities. As a result, frequency and frequency-wave number filters seem to be applicable in suppressing this type of noise. In spite of the fact that they are the most commonly used filters in the ground roll attenuation, they have some limitations such as signal distortion, data aliasing and artifacts which reveal the need for alternative filters.

Wavelet transform provides a simultaneous display of the time-frequency content of a trace that is desired to analyze the time evolution of its frequency content. The first mention of wavelets appeared in an appendix to the thesis of Haar (1909). One property of the Haar wavelet is that it has a compact support, which means that it vanishes outside of a finite interval. Unfortunately, Haar wavelets are not continuously differentiable which somewhat limits their applications. Wavelet transform analysis as we now know began in the mid 1980's when it was developed to interrogate seismic signals (Goupillaud et al., 1984). The study of orthogonal WTs by Daubechies (1988) and the development of the pyramid algorithm (Mallat, 1989a, b) have increased the efficiency of applications of the WT in image processing, data compression and noise attenuation in the late 80's and early 90's. Daubechies (1992) used Mallat's work to construct a set of wavelet orthonormal basis functions that are perhaps the most elegant, and have become the cornerstones of wavelet applications today. Meyer (1993) constructed the first non-trivial wavelets. Unlike the Haar wavelets, the Meyer wavelets are continuously differentiable; however they do not have compact support. Wavelet transform have been applied to the ground roll attenuation by Deighan and Watts (1996 and 1997), Osorio and Silva (2000), Abdul-Jauwad and Khene (2000), Matos and Osorio (2002), Stein and Langston (2007) and Chen et al. (2009).

The analysis of seismic traces using a wavelet transform decomposes each trace into a set of time-scale wavelet coefficients. Therefore, that scale can be considered as a frequency range, which then can be analyzed and filtered. The ground roll energy that contaminates the traces in a time limited fashion is represented in higher scales. As a result, a wavelet transform provides a basis for the ground roll and reflections separation, suitable for filtering purposes.

Moreover, these filters only affect those coefficients that are in the region contaminated by the ground roll, leaving other parts of data unaltered. In this study, 1DWT and 2DWT were reviewed and two filters in MATLAB were used to suppress the ground roll. The results of the ground roll suppression on synthetic and real data are presented and show that the 2DWT is superior to 1DWT in ground roll suppression on seismic data. Synthetic ground roll was created by Computer Programming in Seismology software (Herrmann, 2006) and synthetic reflections by MATLAB. Real data is a common shot record with off-end spread of the SW Iran.

WAVELET TRANSFORM

The Fourier transform (FT) converts a signal from the time domain, in which the basis functions are Dirac delta functions, to the frequency domain, in which the basis functions are complex sinusoids. However, the continuous wavelet transform (CWT) of a function in time, e.g., f(t), as defined by (Daubechies, 1992)

$$W_{a,b} = \int_{-\infty}^{\infty} \psi^*_{a,b}(t)\, f(t)dt \quad , \tag{1}$$

transforms the signal from the time domain to the time-frequency or the time-scale domain. This transform is based on the basis function $\psi_{a,b}(t)$ defined as

$$\psi_{a,b}(t) = (1/\sqrt{|a|})\psi[(t - b)/a] \quad , \tag{2}$$

where a and b are real numbers ($a \neq 0$) representing the scales and time shift of the fixed kernel wavelet $\psi(t)$, respectively.

The inverse transform is defined by

$$f(t) = (1/C_\psi) \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} [(da\, db)/a^2] W_{a,b}\psi_{a,b} \quad , \tag{3}$$

where

$$C_\psi = \int_{-\infty}^{\infty} (1/|\omega|)|\psi|^2 d\omega \quad . \tag{4}$$

and $\psi(\omega)$ is the FT of $\psi(t)$. Fig. 1a shows a schematic representation of the time-scale domain.

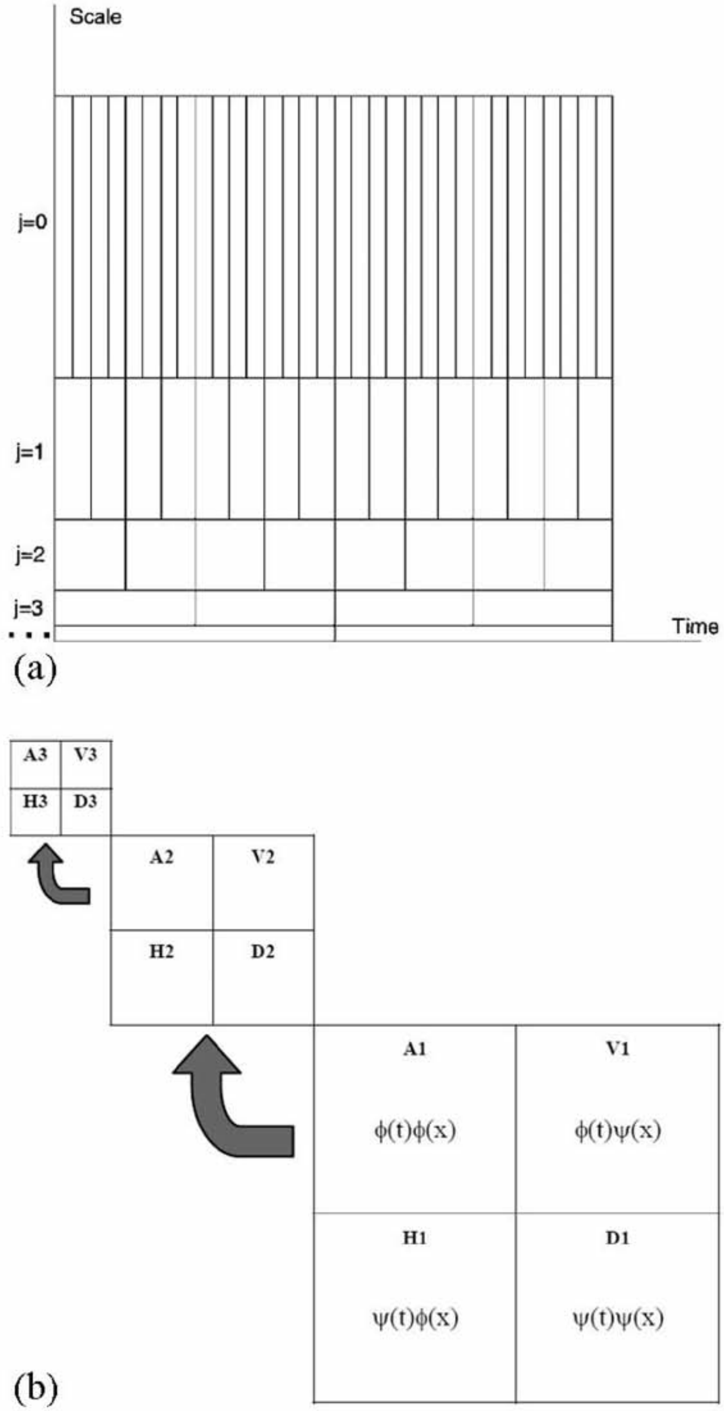


Fig. 1. (a) A schematic representation of partitioning the time-scale space by 1DWT (Daubechies, 1992) and (b) 2D Wavelet decomposition (Matos and Osório, 2002).

The aforementioned wavelet function $\psi(t)$ is obtained from what is referred to as the mother wavelet. The wavelet transform is not unique in the sense that there are many possible mother wavelets to choose from (see Appendix A). However, each mother wavelet must meet certain conditions, as outlined by Daubechies (1992). In summary, these conditions are:

1. The kernel wavelet $\psi(t)$ should have finite energy, i.e., it is absolutely integrable, and square integrable, as shown by

$$\int |\psi(t)| dt < \infty \quad , \tag{5}$$

and

$$\int |\psi(t)|^2 dt < \infty \quad . \tag{6}$$

2. The kernel wavelet $\psi(t)$ should be band limited, and the low-frequency behaviour of the FT is sufficiently small around $\omega = 0$, so that

$$\int |\hat{\psi}(\omega)/\omega| d\omega < \infty \quad . \tag{7}$$

Since the wavelet transform was used for the purpose of signal processing in this study, Daubechies wavelets (Appendix A) were chosen on which DB4 had shown better results.

The implementation of WT for a discretely sampled signal is possible using the discrete wavelet transform (Mallat, 1999). The drawbacks of the continuous wavelet transform are having much redundancy in the signal analysis and being impractical in implementation by digital computers. Since parameters (a, b) take continuous values in CWT, the resulting transform is a highly redundant representation of the signal. At the same time, continuous variations of these parameters make CWT impractical. Discrete wavelet transform (DWT), on the other hand, varies the scale and shift parameters on a discrete grid of time-scale plane leading to a discrete set of continuous basis functions (Daubechies, 1992). The discretization is performed by setting

$$a = a_0^j \quad \text{and} \quad b = k a_0^j b_0 \quad \text{for } j,k \in Z \quad , \tag{8}$$

where $a_0 > 1$ is a dilation step and $b_0 \neq 0$ is a translation step. The family of the wavelets then becomes

$$\psi_{j,k}(t) = a_0^{-j/2} \psi(a_0^{-j} t - k b_0) \quad , \tag{9}$$

and the wavelet decomposition of a function f(t) is given by

$$f(t) = \sum_j \sum_k D_f(j,k) \psi_{j,k}(t) \quad , \tag{10}$$

where the two-dimensional set of coefficients $D_f(j,k)$ is called the DWT of a given function f(t).

The set of basis functions $\psi_{a,b}(t)$, for discrete values of parameters a and b, can also be seen as a set of filter bank impulse responses. With an increase in scale (a > 1), the function $\psi_{a,b}(t)$ is dilated in time to focus on the long-time behaviour of the associated signal f(t). In general, a very large scale means global view of the signal while a very small scale means a detailed view of the signal. The scale change of the continuous time signals in CWT does not alter their resolution since the scale change can be reversed (Rioul and Vetterli, 1991).

There are two different forms of 2DWT. The first one consists of taking the 1DWT of the rows followed by the 1DWT of the columns (Stollnitz et al., 1995). This is equivalent of obtaining a base for the bi-dimensional space t and x by multiplying the one-dimensional bases in t and x:

$$\psi_{jj',kk'}(t,x) = \psi_{jk}(t)\psi_{j'k'}(x) , \tag{11}$$

where, ψ is the wavelet function. The main disadvantage of this base is the mixing of the scales j and j'. The other approach is to construct a base using a single scale j, by employing three wavelet functions as bases for each decomposition level j. These functions are represented in eq. (12) (Cohen and Chen, 1993) as follows:

$$\begin{aligned} \psi^{H}_{jkk'}(t,x) &= \psi_{jk}(t)\phi_{jk'}(x) , \\ \psi^{V}_{jkk'}(t,x) &= \phi_{jk}(t)\psi_{jk'}(x) , \\ \psi^{D}_{jkk'}(t,x) &= \psi_{jk}(t)\psi_{jk'}(x) , \end{aligned} \tag{12}$$

The scale function at level j is simply the product of the one-dimensional scale functions, and it is represented in eq. (13). This form of decomposition is called nonstandard or nonconventional, and it is the most widely used (Matos and Osório, 2002). It consists basically of taking alternately the decomposition between rows and columns.

$$\phi_{jkk'}(t,x) = \phi_{jk}(t)\phi_{jk'}(x) . \tag{13}$$

A convenient way to analyze the results of a 2DWT is to view the decomposition from the bases described in eqs. (12) and (13), and illustrated in the four panels of Fig. 2 (Matos and Osório, 2002). The panels marked A_i (i = 1, 2, 3, ...) represent approximations in each direction, in a fashion similar to the approximations in a 1D decomposition, whereas the other three panels correspond to the three wavelets in eq. (2). As in the 1D decomposition, each successive level has half of the samples from the previous one.

From eq. (12) and Fig. 1b it is seen that parts of the panels marked as Vi have emphasis in the vertical details, since they are generated from the "approximation" of the signal in t and its differentiation in x. V_i panels are called the vertical-detail coefficients. In the same way, H_i ones are called the horizontal-detail and D_i the diagonal-detail coefficients.

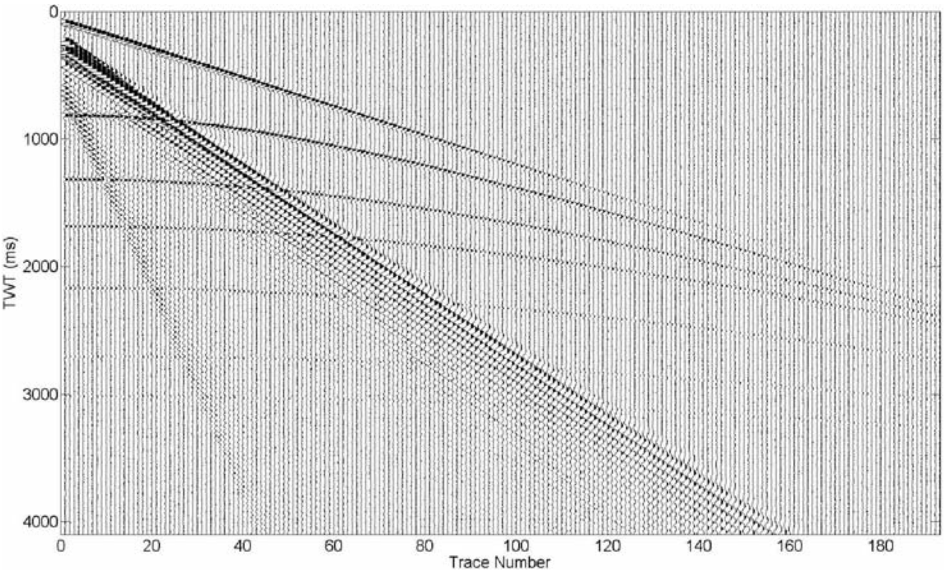


Fig. 2. Synthetic data related to the Table 1. Time sampling interval is 4 ms, near offset 200 m, and trace interval 25 m for 193 traces. The source is located at a depth of 14 m.

MATLAB IMPLEMENTATION

Two pieces of code were written for ground-roll attenuation based on the 1DWT and 2DWT and the wavelet toolbox (Misiti et al., 1996) was used to implement the wavelet transform. Filtering in the 1D wavelet domain consisted of zeroing the wavelet coefficients in the timescale areas corresponding to the ground-roll energy in the traces whereas, in the 2D filter, coefficients corresponding to the ground roll in vertical details are zeroed. The algorithm used for the 1D filter is as follows:

- Determine ground-roll contaminated region in data;
- Calculate the maximum possible decomposition level;

- Calculate the decomposition level from which the ground roll is present in coefficients;
- Select a trace in data;
- Apply a 1DWT;
- Select the coefficients representing the ground roll;
- Apply an inverse 1DWT;
- Select the next trace;
- Subtract the extracted noise from the data.

Matos and Osório (2002) presented an algorithm for the ground-roll attenuation by 2DWT. Their method consists of selecting the region affected by the noise in the vertical detail coefficients and applying a muting process to the coefficients located in this region. But there is a degree of frequency overlap between the basis functions of different scales in a WT technique which corresponds to a form of aliasing that is introduced by the transform when the down sampling is performed. In the reconstruction algorithm, this aliasing is taken into account and the reconstruction is perfect. If any operation, such as filtering, is performed in the wavelet domain, the reconstruction might not totally account for the aliasing and might lead to the introduction of aliased noise. With a proper choice of the wavelet, and minimizing the frequency overlap between the scales, this aliasing distortion can be minimized (Deighan and Watts, 1997). To minimize the effect of WT on reflections, the ground roll is extracted and subtracted from data; therefore, any changes in the data are limited to that part of data containing noise. Also, the region contaminated by the noise is determined in the input data and the equivalent region at each level of decomposition is calculated based on the down sampling along the time and offset axis. The algorithm used for the 2DWT filter is as follows:

- Determine the ground-roll contaminated region of the data;
- Calculate the maximum possible decomposition level;
- Decompose the seismic signal using a 2DWT;
- Analyze the vertical detail coefficients and identify the regions where the ground roll appears in each of them;
- Apply a muting process to the coefficients not located in these regions and also in other detail coefficients;

- Apply an inverse 2DWT to the selected set of coefficients to gain the ground roll in the t-x domain;
- Subtract the extracted ground roll.

The signal and noise coefficients for a synthetic data - with controlled parameters - are presented in Appendix B to test the filter capabilities in signal/noise separation.

DATA EXAMPLES

An earth model with eight layers over a half space (Table 1), two of which were considered to be weathered, was used to generate synthetic data. The ground roll was generated by Computer Programming in Seismology software (Herrmann, 2006) and the refractions and reflections were generated in MATLAB (Fig. 2). There were 193 traces with trace interval of 25 m and a near offset of 200 m; the time sampling interval was 4 ms and the seismic source was located at a depth of 14 m. The filters were applied to the synthetic data containing noise and signals. Fig. 3 is the extracted ground roll by 1D - and 2DWT filters, respectively.

Table 1. The earth model used for synthetic data generation.

Layers	Thickness (km)	P-wave velocity (km/s)	S-wave velocity (km/s)	Density (g/cm^3)
1st weathered	0.003	0.7	0.25	1.4
2nd weathered	0.01	1.9	1.1	1.8
1st layer	0.9	2.2	1.2	2
2nd layer	0.6	2.4	1.4	2.2
3rd layer	0.5	2.7	1.5	2.4
4th layer	0.7	2.9	1.6	2.5
5th layer	0.9	3.4	2	2.7
6th layer	0.6	3.8	2.2	2.75
Half space	Infinite	4.1	2.4	2.8

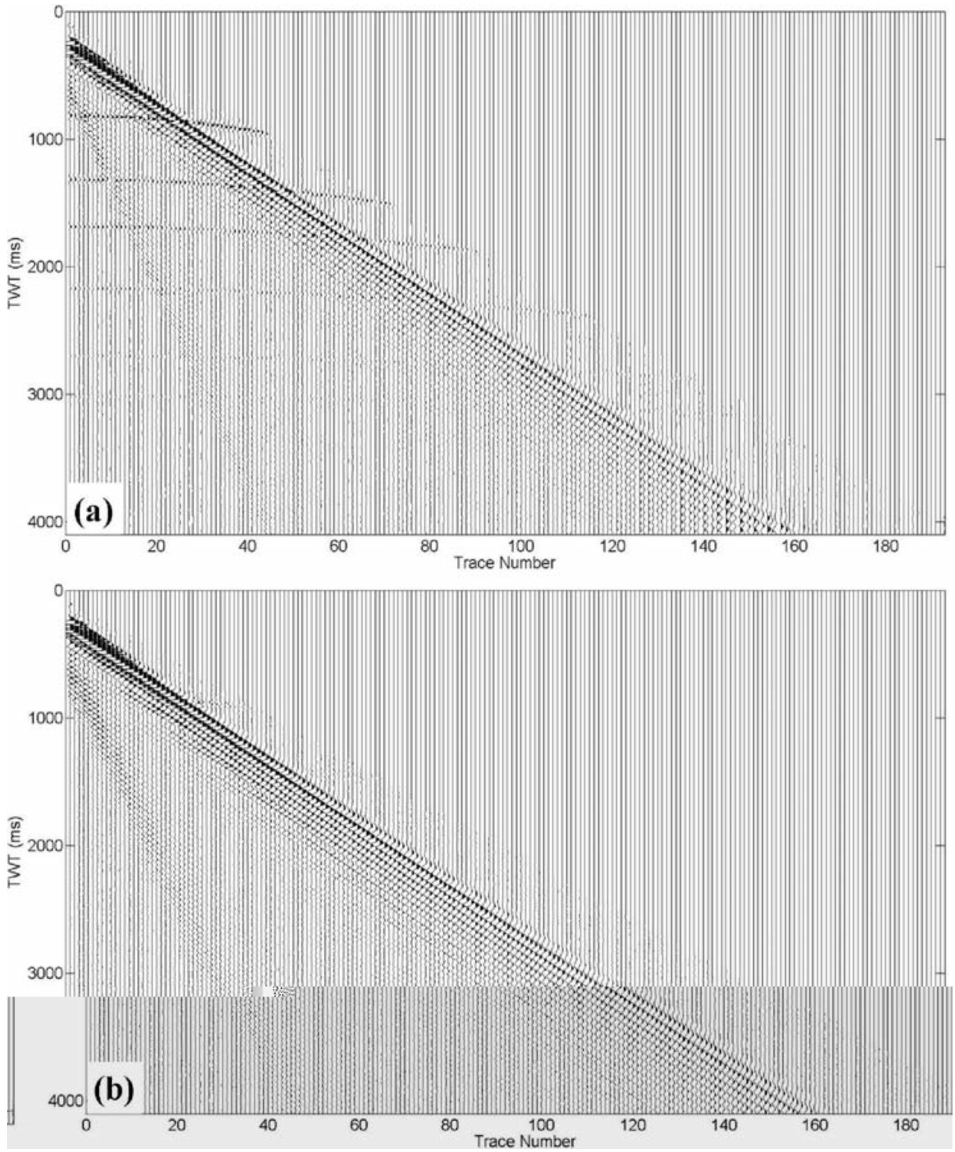


Fig. 3. Extracted ground roll using: (a) 1DWT filter and (b) 2DWT filter. It is seen that 2D filter can model the noise with higher resolution and it contains more details which give it a more coherent look.

The differences between the extracted noise and the noise present in data are shown in Fig. 4. The results of the filtering using 1D- and 2DWT filters are shown in Fig. 5. Both filters were applied only to the ground roll contaminated region of data. To have a closer look at data, Fig. 6 shows Trace No. 20 of the synthetic data before and after applying the filters. The ground roll wave train reached to this trace at about 0.6 s. The wavelet coefficients of 1DWT at later times were selected for scales higher than the noise-representing scale. In the 2DWT, coefficients of this trace were selected at later times for vertical details.

Fig. 7 shows the real data being a common shot record with an off-end spread from an Iranian oilfield. There were 183 receiver stations with a station interval of 30 m, a time sampling interval of 4 ms and total a recorded time of 2 s. True amplitude recovery (TAR) was applied to the data prior to the filter application. According to the data specifications, the maximum level of decomposition would be 8 for the 1D filter and 7 for the 2D one (because there were 183 samples in the horizontal direction). The data in 1D- and 2DWT domains are shown in Figs. 8 and 9, respectively. It is seen that how the ground roll and reflections are separated into different wavelet coefficients. As it is seen, there is no data present in scales greater than 5 (corresponding to a frequency bandwidth of 4-8). Therefore, the decomposition can be stopped at this level. Similarly, for the 2D case, a WT with 3 levels of decomposition provided a good result and further decomposition did not improve the filter performance. Considering the extracted noise in Fig. 10, both filters extract the noise well. Results of the ground roll suppression by 1DWT and 2DWT filters are shown in Fig. 11. As a comparison, 2DWT has attenuated the noise with less a change in reflections especially lowfrequency ones at a later time. To evaluate filter performance, amplitude spectra of data before and after filter application are shown in Fig. 12. It can be seen that the amplitude of the reflectors is mainly untouched in both filtering processes.

DISCUSSION

Two filters based on one- and two-dimensional wavelet transforms were used to suppress the ground roll. These filters were only applied to the ground-roll contaminated region of data. The required parameters to determine this region were minimum and maximum ground roll velocity, time-sampling interval, trace spacing, and the source location; therefore the time boundary at each trace was calculated. In a case where a minimum velocity was not determined, it was considered to be zero; therefore, the time boundary would continue to the end of each trace. The next step was to calculate the maximum possible decomposition level. At each level of a wavelet transform, the number of samples in data was halved; consequently, the decomposition could be continued as far as only. one sample remained. Accordingly, the initial number

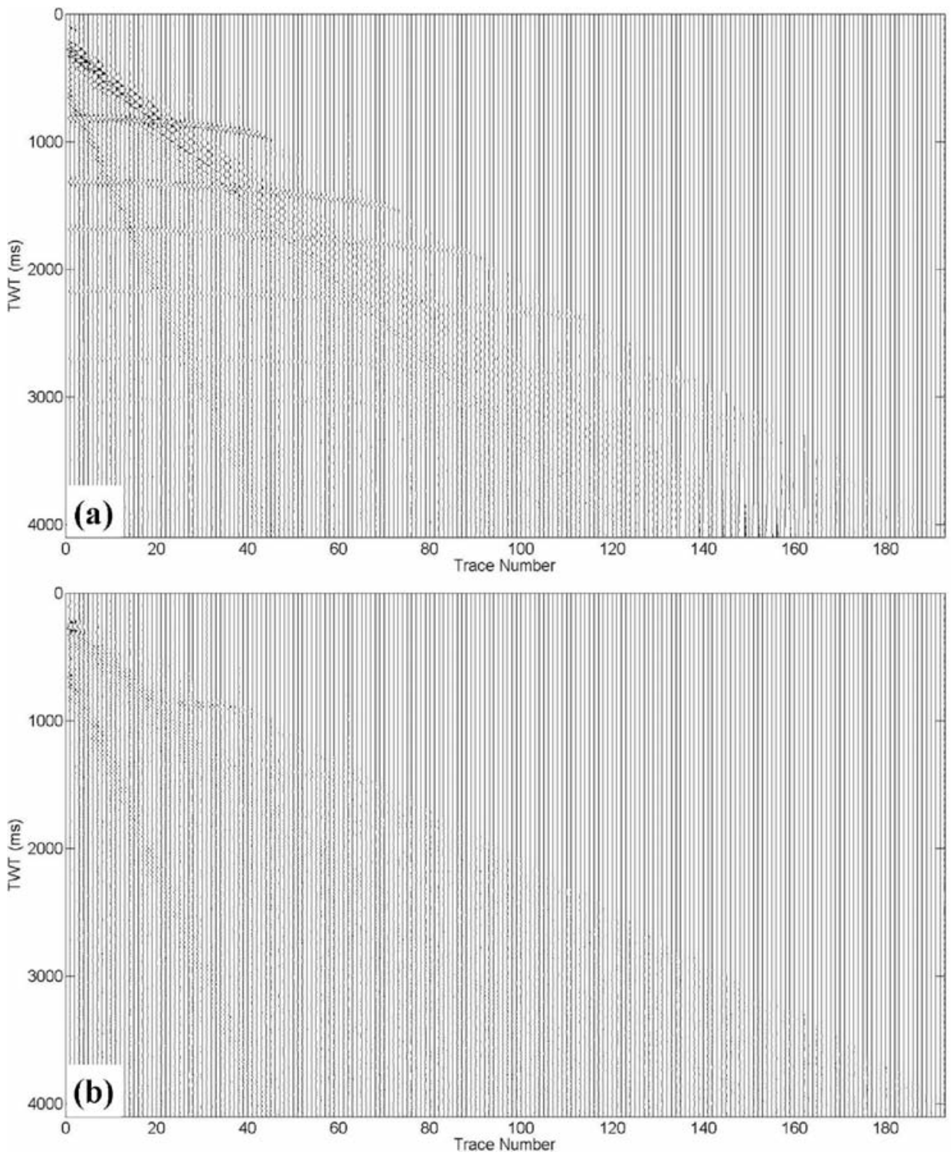


Fig. 4. The difference between the extracted noises by: (a) 1DWT and (b) 2DWT with an input ground roll using Computer Programming in Seismology software (Herrmann, 2006). These figures show the remaining parts of the noise and also the reflection suppression in the filtered data.

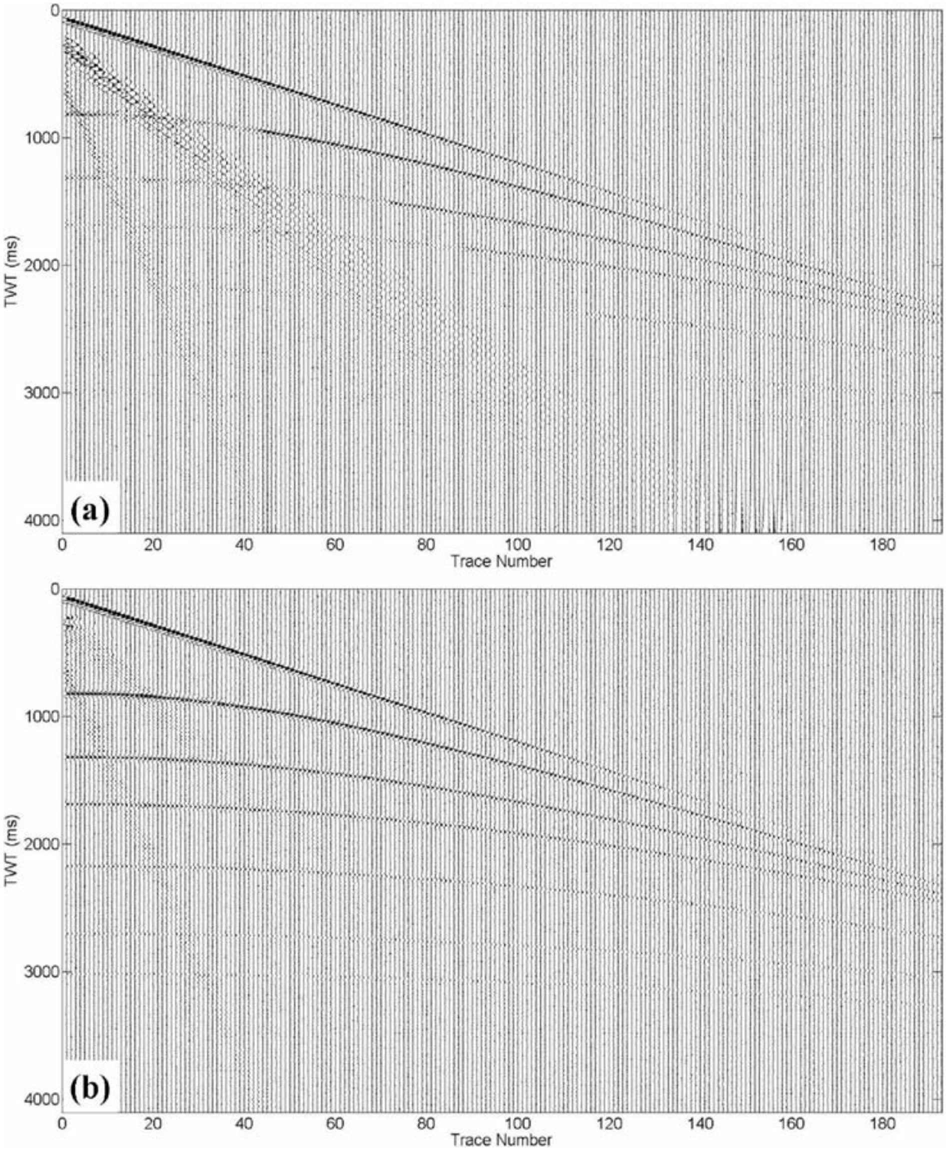


Fig. 5. Results of filtering processes using: (a) 1DWT and (b) 2DWT. Both wavelet transform filters are only applied to the ground roll contaminated region.

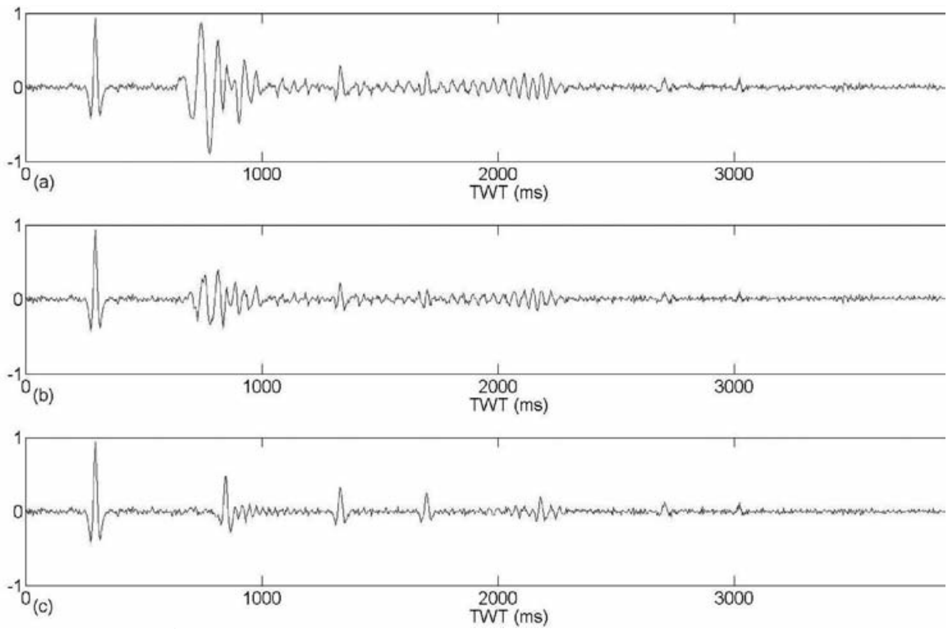


Fig. 6. Trace No. 20 of synthetic data: (a) before filtering, (b) after filtering by 1DWT, and (c) after filtering by 2DWT. The ground roll is started at about 600 ms at this trace; therefore, the wavelet coefficients at greater times are selected in scales representing the noise. 2DWT has obviously a better performance.

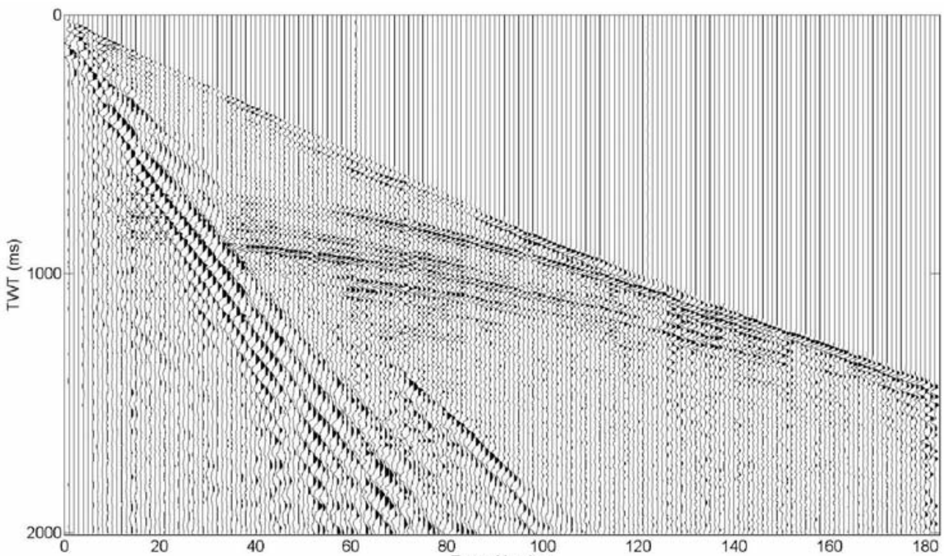


Fig. 7. A common shot record of a SW Iranian oilfiled with an off-end spread after application of a true amplitude recovery. The sampling interval is 4 ms and the receiver offset is 30 m.

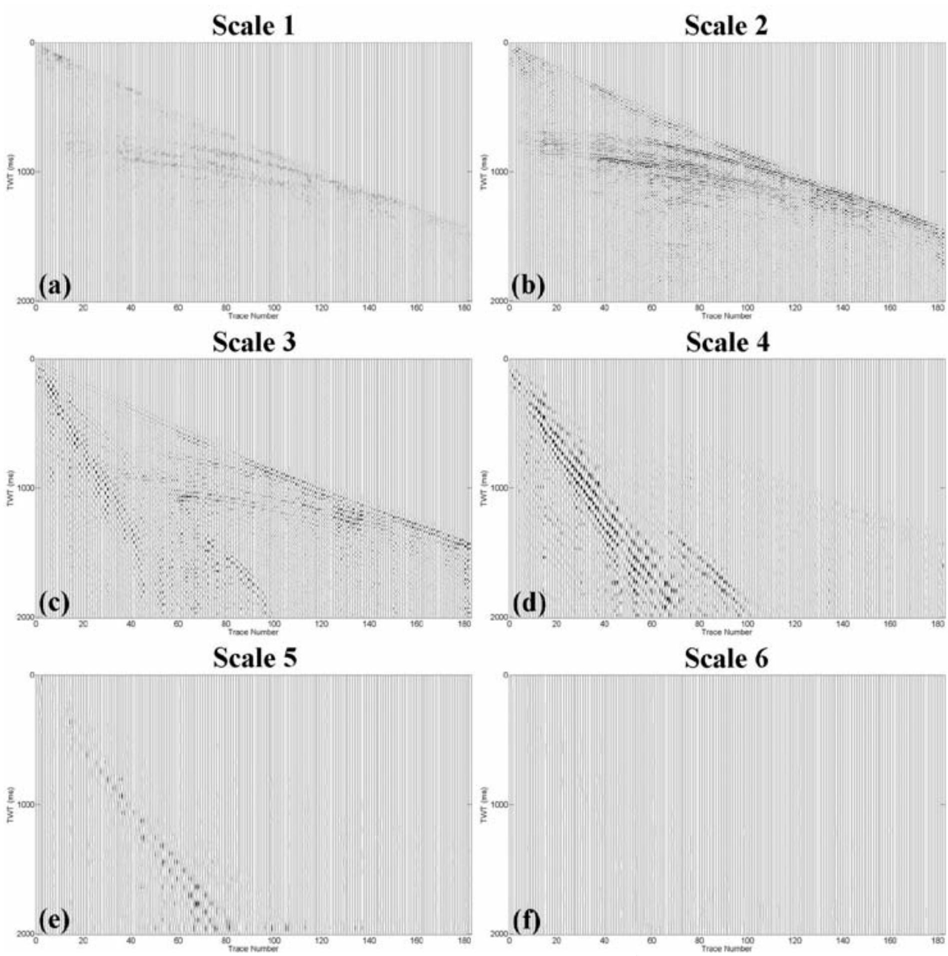
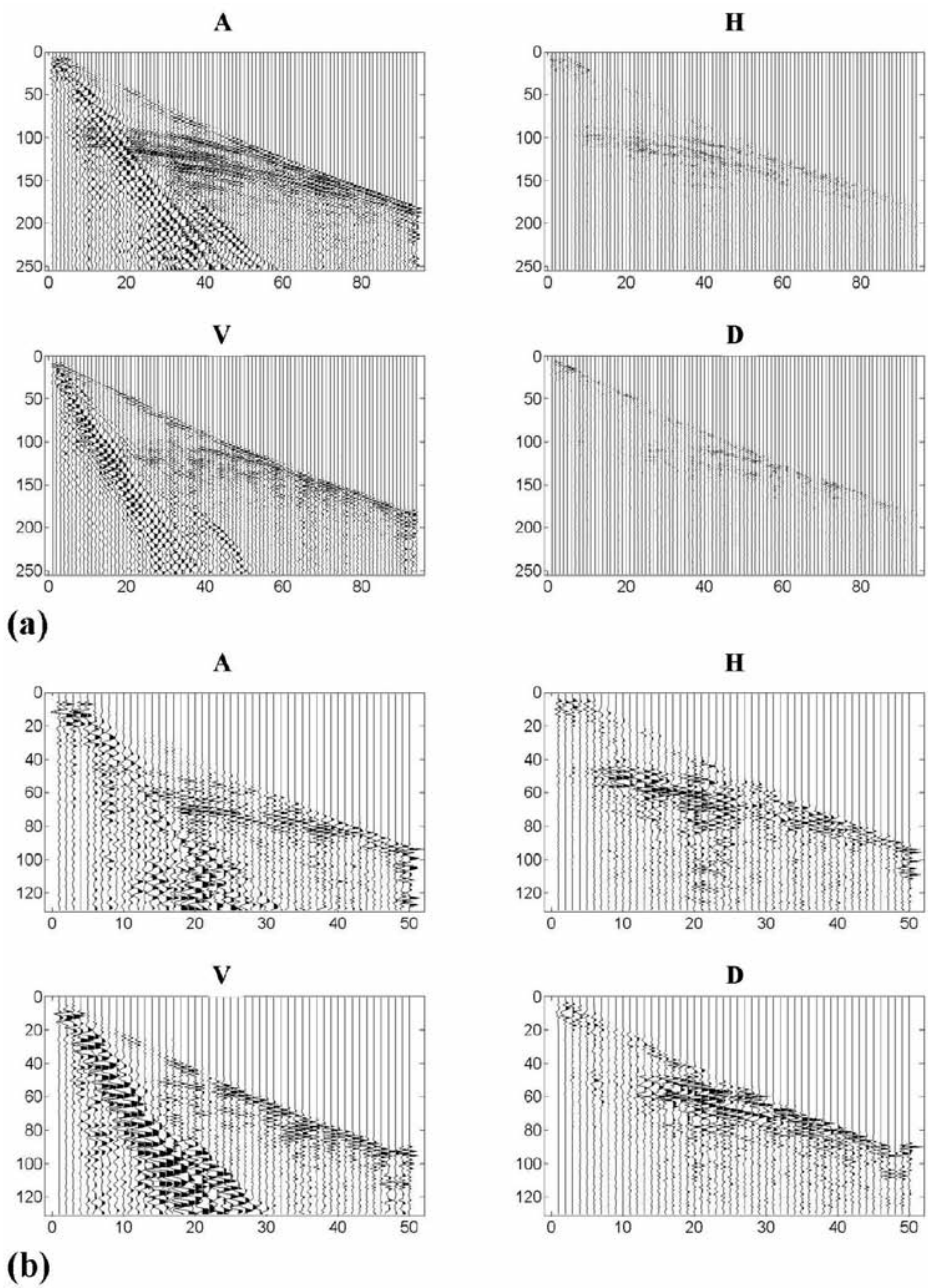
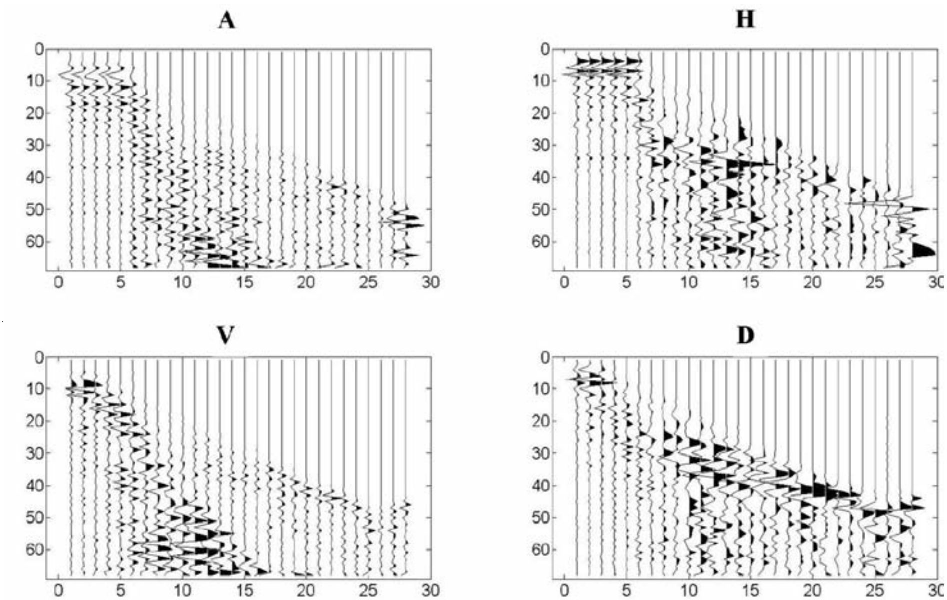


Fig. 8. 1DWT scales of a real shot gather. The ground roll is seen in scales 3, 4, and 5. The noise is extracted using a time boundary at each trace.

of the samples in data was the decisive factor in how many levels of wavelet transform could be applied to the data; first, the maximum number of q was calculated to which number 2 had to be powered to be less than or equal to the number of samples. If the number of samples was a power of 2, q would be the maximum level of decomposition; else the data was padded with zeros until it had 2 to the power of q+1 samples in which case the maximum level of decomposition would be q+1. However, it was not necessary to decompose the trace into the maximum level calculated as there was no seismic event in scales


A
H
V
D
(a)
A
H
V
D
(b)



(c)

Fig. 9. The first three 2DWT levels of the real data decomposition. The ground roll is present in a fanshaped region in the vertical detail coefficients; therefore, it can be attenuated by filtering these coefficients. A, H, V, and D represent approximation and horizontal, vertical, and diagonal details, respectively.

corresponding to frequencies lower than 5 Hz and the decomposition could be stopped there to save time. Selection of the coefficients corresponding to the ground roll was a little different in 1D-and 2DWT techniques. In 1DWT, each scale was analogous to a frequency band; therefore, the scales corresponding to the ground roll frequencies were determined. The frequency band of the ground roll was considered to be 7-15 Hz. Therefore, the time-scale coefficients representing the ground roll were chosen and zeroed. Because of the frequency overlap between basis functions of different scales, simply zeroing all selected scales could affect the reflections. To reduce the reflection suppression, a taper of 2/3 was used for the first and the last scales corresponding to the ground roll. On the other hand, in 2DWT, the seismic events were separated based on their different dips (velocities); for that reason, the ground roll was placed in vertical details. Having the time boundary of ground roll at each trace in the vertical detail coefficients, the noise could be extracted.

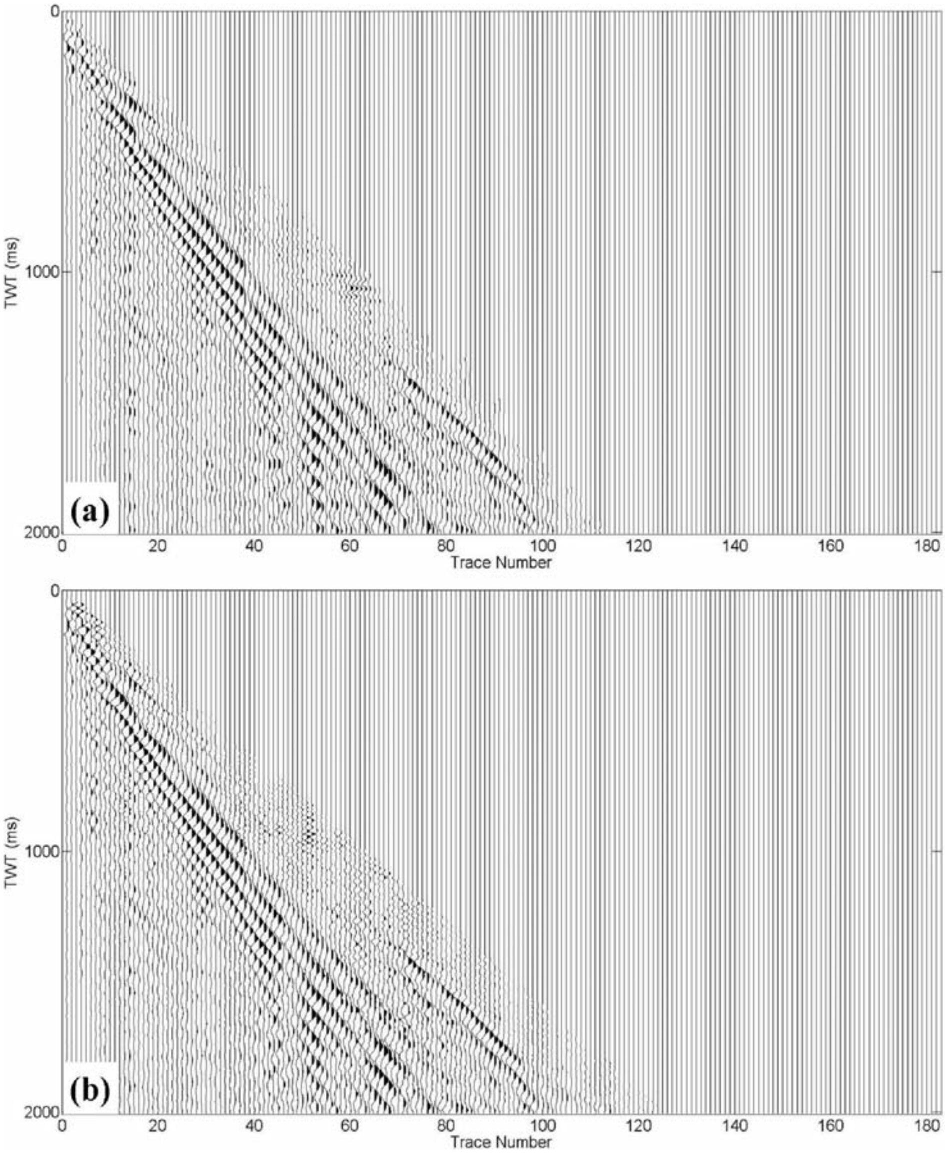


Fig. 10. The extracted ground roll using: (a) 1DWT filter and (b) 2DWT filter.

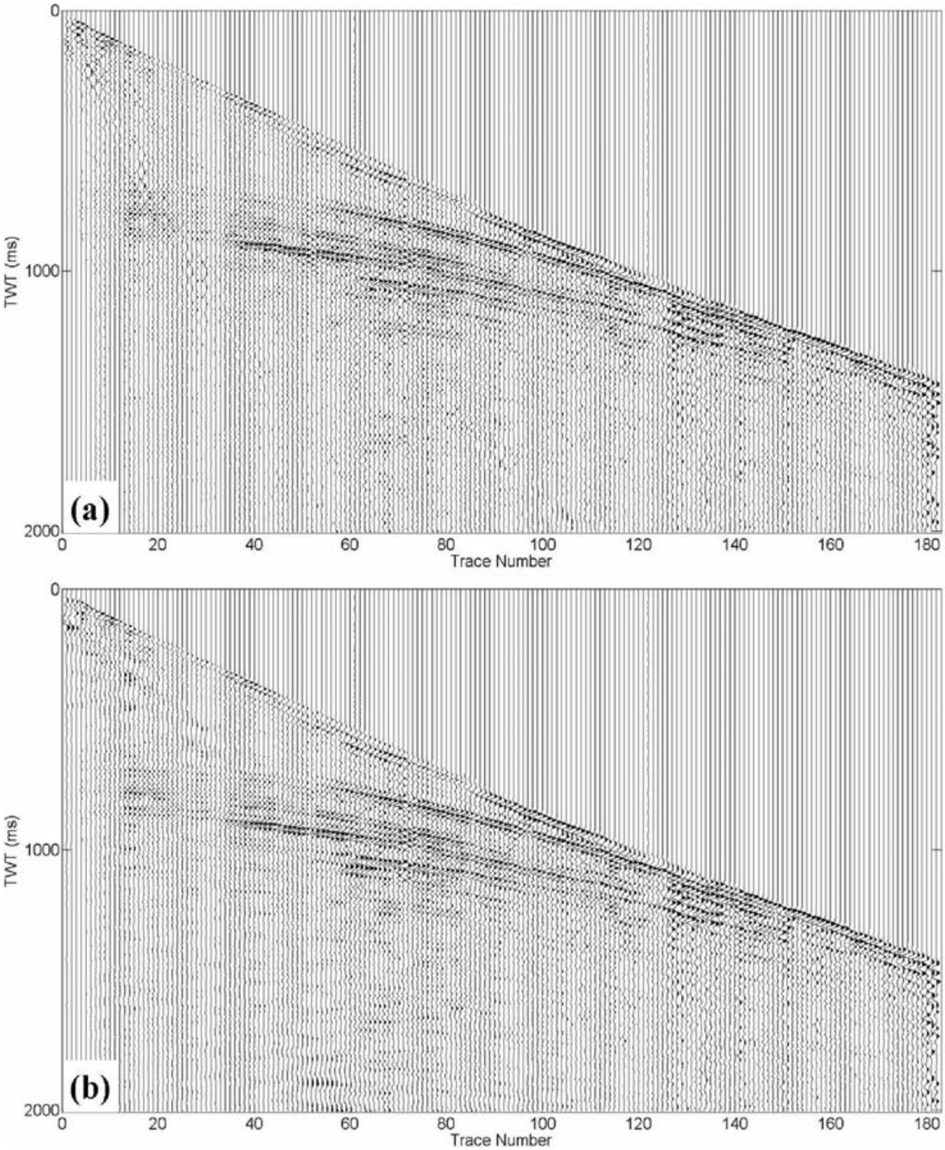


Fig. 11. Results of filtering data using: (a) 1DWT filter and (b) 2DWT filter. Some parts of the noise are remained after filtering via 1DWT while the noise is nearly completely removed in the 2DWT-filtered data.

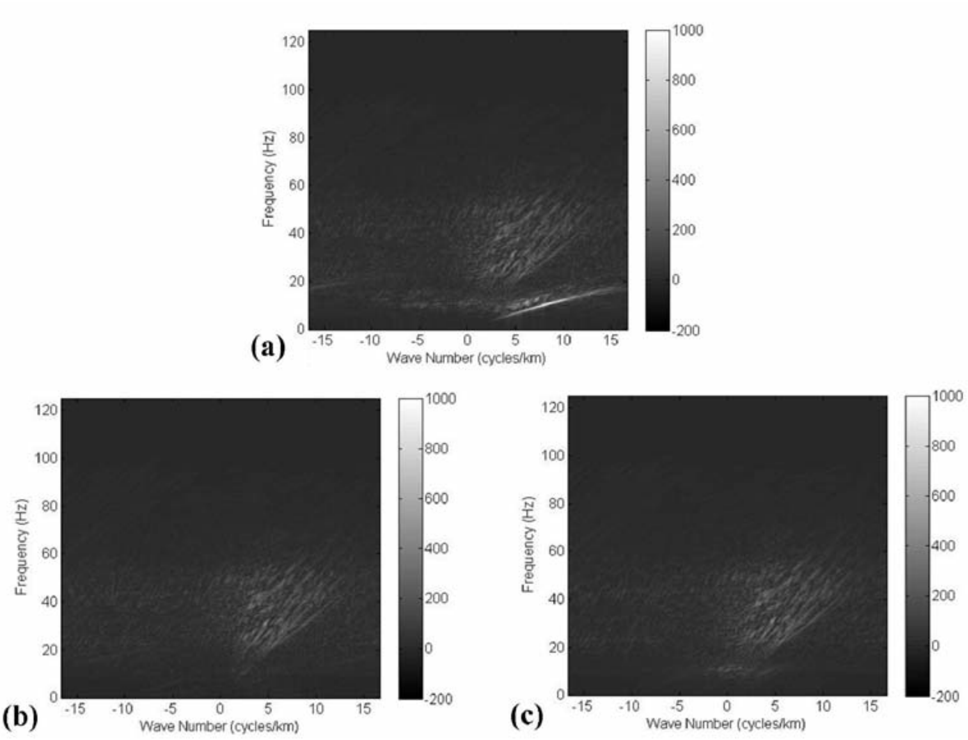


Fig. 12. The amplitude spectrum of: (a) data in Fig. 2, and the filtered data with: (b) a 1DWT filter and (c) a 2DWT filter. The amplitudes of low frequency reflections are better preserved in the 2DWT filter. The 1DWT filter acts based on the frequency-location separation of signal and noise; as a result, the low frequency components are seen to be attenuated. On the other hand, 2DWT acts based on the velocity-location difference between the signal and noise and it is expected to attenuate the components along the velocity lines.

The 1DWT filter transforms each individual trace from the time domain to a time-scale one. As a result, seismic features with the same frequency content but different arrival times and with the same arrival times but different frequency content are separated in different coefficients. The filter zeros coefficients corresponding to unwanted events and preserves the ones for signal. Ground roll usually have low frequency and contaminates a fan-shaped part of data. Therefore, the coefficients of higher scales at specified times had to be selected. Application of an inverse 1DWT extracted the noise from the trace. Finally subtracting this noise from the input data resulted in the filtered data. Since every trace was analyzed separately, the spatial coherency of the ground roll was not considered here.

The 2DWT filter converts a two-dimensional seismic data into four two-dimensional panels with half samples in columns as well as rows; these panels are named *approximation* and *horizontal, vertical* and *diagonal details*. Seismic features were separated based on their different velocities. Ground roll had a low frequency; as a consequence, it was usually represented in the vertical detail panel. Selecting vertical coefficients in a fan-shaped part extracted this type of noise. In this filter, spatial coherency of the ground roll was also considered since the data was analyzed as a 2D data set.

Extracted noise showed that the ground roll extracted in the 2D case was more coherent, since the trace-to-trace correlation of the ground roll was taken into account while in the 1D filter, any trace was analyzed separately. Examination of Trace No. 20 shows that 2DWT has preserved reflection signals even at 850 and 2200 ms where the ground roll completely masks reflections in the input data.

Finally, the filters were applied to real data after applying the automatic gain control (AGC). In addition to the ground roll, refractions were present as linear dipping events. Since the purpose here was to attenuate the ground roll while making the least impact on other events, the refractions were treated as signals to be preserved in the data. Again, the filtered data showed that the 2DWT filter preserved the spatial coherency of the events while the 1DWT filter did not. Considering the amplitude spectra, reflections were mainly unchanged by both filters. The 1DWT filter acted similar to a frequency filter and the 2DWT seemed like a dip filter; but without the distortions caused by frequency and f-k filters. Both 1DWT and 2DWT proved to be strong tools for ground roll suppression.

CONCLUSIONS

Any filter used with the purpose of noise attenuation uses some properties of the noise and signal to separate them. In this study, two filters based on 1DWT and 2DWT were applied to synthetic and real data for the purpose of ground roll suppression. The main steps of these filters can be summarized as follows:

- In these filters, the ground roll contaminated region is determined in the input domain and then it is calculated in each decomposition level.

- The maximum possible level of decomposition is calculated based on the number of samples in the input data.

- Calculation of the scale (in 1DWT) corresponding to the ground roll is made based on the Nyquest frequency at each level.

- Boundaries of the regions of the vertical detail coefficients (in 2DWT) containing the ground roll are calculated based on a determined region in the input data and an increment of the trace and time sampling intervals at each level.

As a result, the parameters affecting the filter performance are: (a) the difference between the frequency bandwidths of the signal and noise for the 1DWT filter, (b) the velocity difference for 2DWT, and (c) the time arrival at each trace in both filters. These parameters depend on the input data and to have an appropriate result, at least one of these factors should be different. In addition, the choice of the mother wavelet can affect the filter performance because different wavelets produce different results in separation of signal and noise in a WT domain. The Daubechies 4 was used here because of its properties which makes it suitable for filtering purposes.

As the results showed, both filters proved to be powerful in noise attenuation; however, some parts of the noise were remained after the one-dimensional filter was applied whereas the two-dimensional one mainly attenuated the noise. Also the signal suppression was minimum in the second filter. This could be due to the fact that the 1DWT filter was applied trace by trace while 2DWT analyzed a 2D seismic data considering all traces; therefore, the spatial coherency of the signals was taken into account.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to NIOC Exploration Directorate, Iran, for the financial support and the data received through the project No. 89235 and to Mrs. M. Vefagh for generating the synthetic data.

REFERENCES

Abdul-Jauwad, S.H. and Khène, K.F., 2000. Two-dimensional wavelet-based ground roll filtering. Expanded Abstr., 70th Ann. Internat. SEG Mtg., Calgary: 2107-2110.

Chen, W.C., Gao, J.H. and Bao, Q.Z., 2009. Adaptive attenuation of ground roll via continuous wavelet transform. Chinese J. Geophys., 52: 2854-2861.

Cohen, J.K. and Chen, T., 1993. Fundamentals of the discrete wavelet transform for seismic data processing, Tech. Rep. CWP-130: Center for Wave Phenomena, Colorado School of Mines.

Daubechies, I., 1988. Orthonormal bases of compactly supported wavelets. Commun. Pure Appl. Mathemat., 41: 909-996.

Daubechies, I., 1992. Ten Lectures on Wavelets. SIAM Publications, Philadelphia.

Deighan, A.J. and Watts, D., 1996. 2D filtering using the wavelet packet transform. Extended Abstr., 58th EAGE Conf., Amsterdam.

Deighan, A.J. and Watts, D., 1997. Ground-roll suppression using wavelet transform. Geophysics, 62: 1896-1903.

Goupillaud, P., Grossmann, P. and Morlet, J., 1984. Cycle-octave and related transforms in seismic signal analysis. Geoexplor., 23: 85-102.
Haar, A., 1909. Zur Theorie der Orthogonalen Funktionensysteme. Ph.D. Thesis, University of Gottingen, Germany.
Herrmann, R.B., 2006. Computer Programming in Seismology. An overview of synthetic seismogram computation. Version 3.30. Dept. of Earth qnd Atmospheric Sciences, University of St. Louis, MO, U.S.A.
Mallat, S., 1989a. A theory for multiresolution signal decomposition: the wavelet representation. IEEE Trans. Patt. Anal. Mach. Intell., 11: 674-693.
Mallat, S., 1989b. Multifrequency channel decomposition of images and wavelet models. IEEE Transact. Acoust., Speech, and Signal Proc., 37: 2091-2110.
Mallat, S., 1999. A Wavelet Tour of Signal Processing. Academic Press, San Diego.
Matos, M.C. and Osório, P.L.M., 2002. Wavelet transform filtering in the 1D and 2D for ground roll suppression. Expanded Abstr., 72nd Ann. Internat. SEG Mtg., Salt Lake City.
Meyer, Y., 1993. Wavelets: Algorithms and Applications. SIAM Publications, Philadelphia.
Osório, P.L. and Costa de Silva, M., 2000. Aplicação de Wavelets na Supressão de Ruído Sísmico. XIII Congresso Brasileiro de Automática: 539-544.
Rioul, O. and Vetterli, M., 1991. Wavelets and signal processing. IEEE Sig. Proc. Mag., 8: 14-38.
Stein, J.A. and Langston, T., 2007. A review of some powerful noise elimination techniques for land processing. Extended Abstr., 69th EAGE Conf., London.
Stollnitz, E.J., DeRose, T.D. and Salesin, D.H., 1995. Wavelets for Computer Graphics: A Primer, Part 1: Tutorial. IEEE Comput. Graph. Applic., 15: 76-84.

APPENDIX A

DAUBECHIES WAVELETS

For a time-frequency analysis, one needs a wavelet optimally localized in terms of both time width and frequency bandwidth. For smooth signals, generally a wavelet is needed which is itself smooth and therefore has a good frequency localization. In contrast, signals that contain discontinuities are better analyzed using wavelets with a good spatial localization to accurately map rapid changes into the signal. For the filtering purposes, Daubechies wavelets make a good basis function. These wavelets have finite support on $[0, 2n-1]$ (Fig. A-1). Thus, the Fourier transforms must have non-finite support. But, this is only a theoretical result. As can be seen in the amplitude plots of Fig. A-2, the Daubechies wavelets fall off rapidly in the frequency domain and therefore they have effectively finite support there as well (Cohen and Chen, 1993).

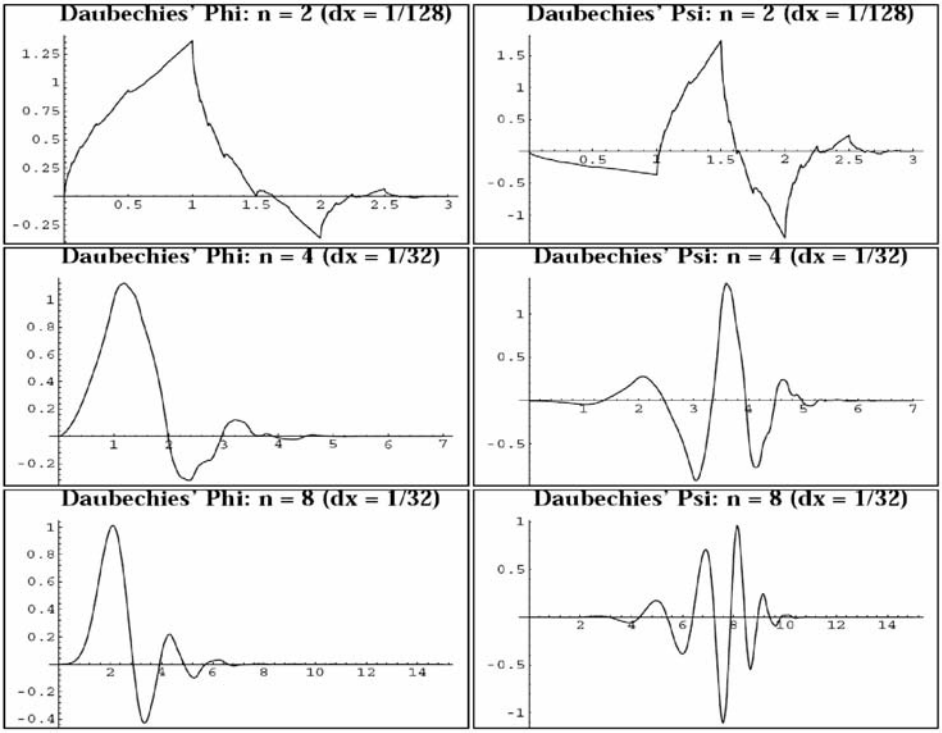


Fig. A-1. Some Daubechies scaling functions and wavelets (Cohen and Chen, 1993).

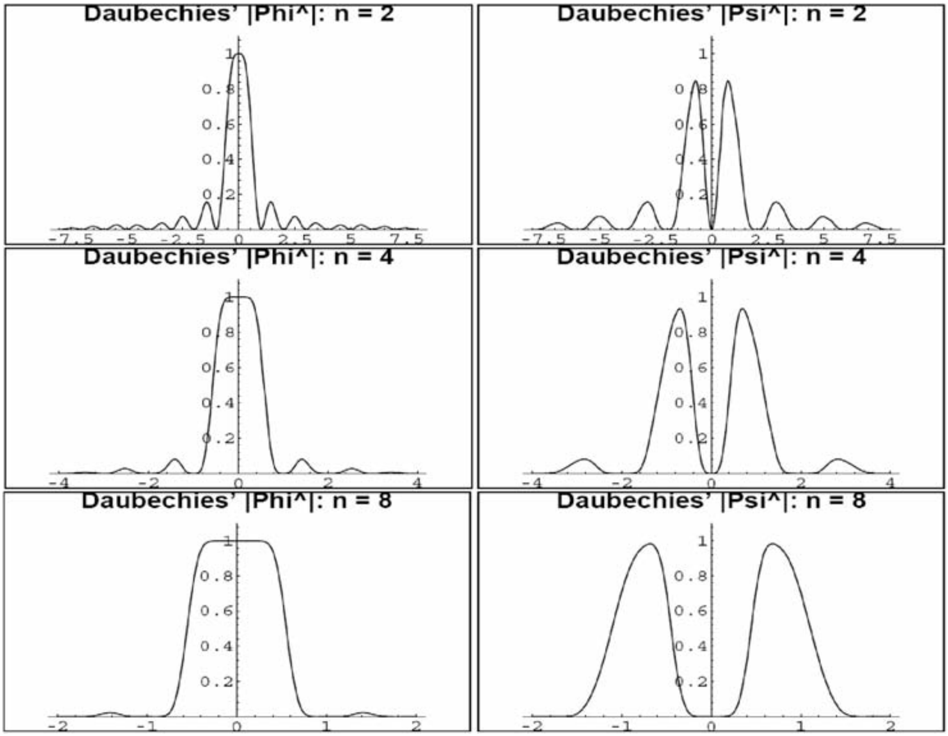


Fig. A-2. Fourier transforms of Daubechies scaling functions and wavelets (Cohen and Chen, 1993).

APPENDIX B

A synthetic data containing four events is used to examine the filters capabilities in separating signals with different properties (frequencies and velocities). These events are as follows: a horizontal event with 1-35 Hz frequencies and three dipping events with 1, 3, and 10 sample/trace velocities and corresponding frequencies of 1-25, 1-15, and 1-10 Hz (Fig. B-1). It consists of 200 vertical and 100 horizontal samples, the sampling interval is 4 ms and the trace interval is 50 m. Data reconstructed by different 1DWT scales are shown in Fig. B-2. The coefficients at each scale are detail coefficients (corresponding to the high pass filter at WT). As a result, the frequency range of the scales corresponds to the maximum of the Nyquest frequency of the previous scale and to the minimum of the Nyquest frequency of that scale. For example, the first scale contains a frequency band of 62.5-125 Hz in this data set and as expected, no frequency is present in the data for this scale. Also, the 2DWT levels of decomposition are presented in Fig. B-3. This transform depends on the velocity difference between the seismic events. The selected wavelet coefficients in the ground roll attenuation are the vertical coefficients which extract the low velocity components of the data.

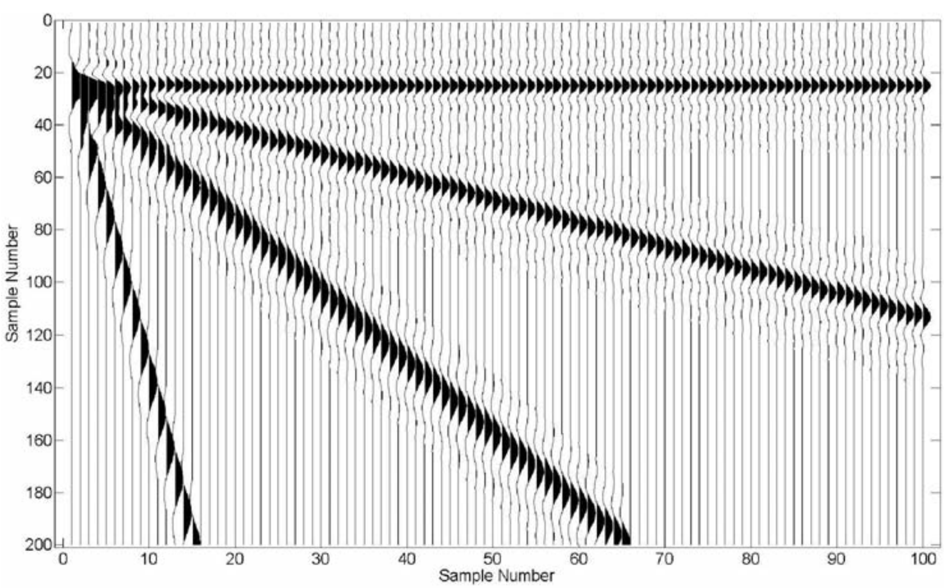


Fig. B-1. Synthetic data containing four seismic events with velocities of 0, 1, 3, and 10 sample/trace. The frequency bandwidths of these events are considered to be 1-35, 1-25, 115, and 1-10 Hz, respectively. To have an idea about the effect of the wavelet decomposition on the number of samples at each level, both horizontal and vertical axes are shown in sample numbers.

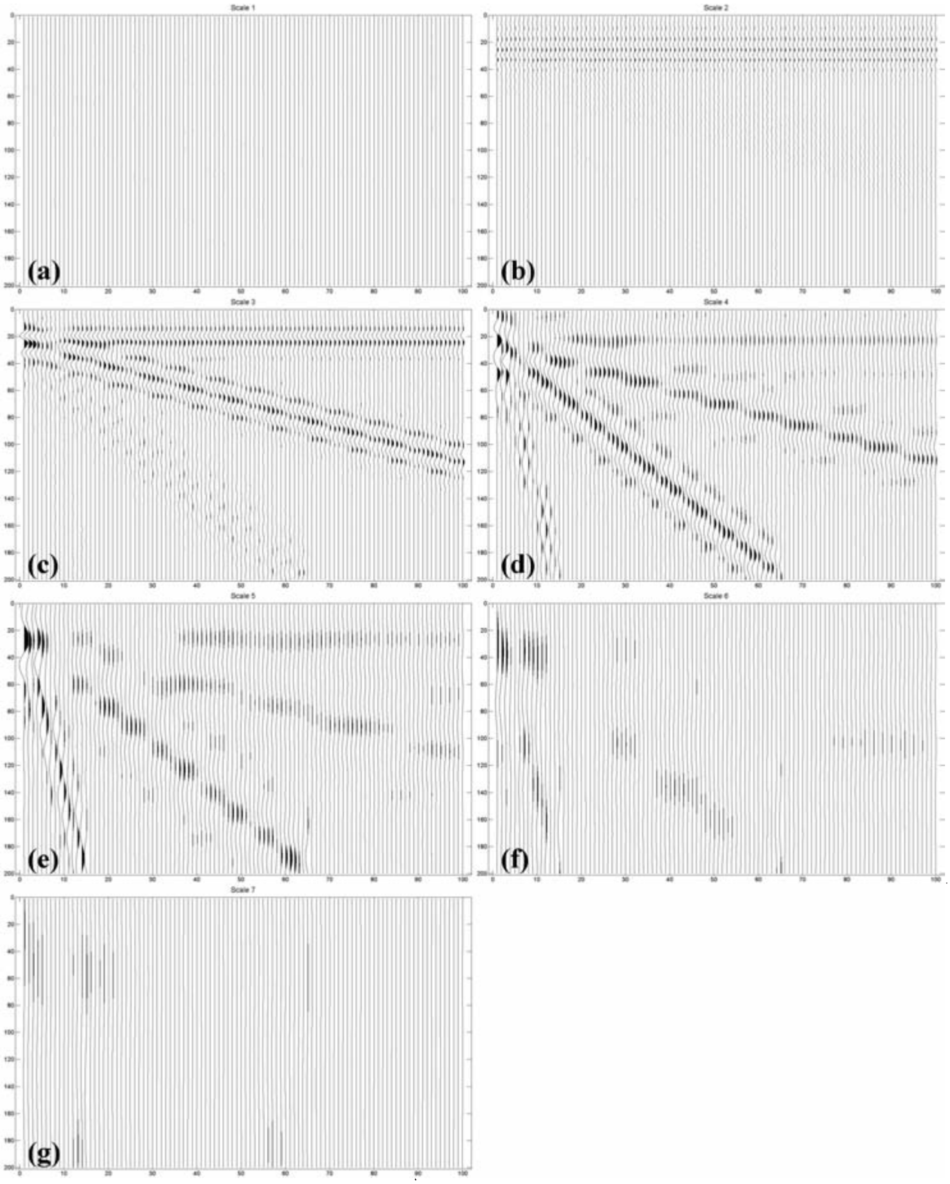


Fig. B-2. Data of Fig. 2 reconstructed using only one scale at a time: (a) scale 1, (b) scale 2, (c) scale 3, (d) scale 4, (e) scale 5, (f) scale 6, and (g) scale 7 of 1DWT. It is seen that how different frequencies are present in different scales.

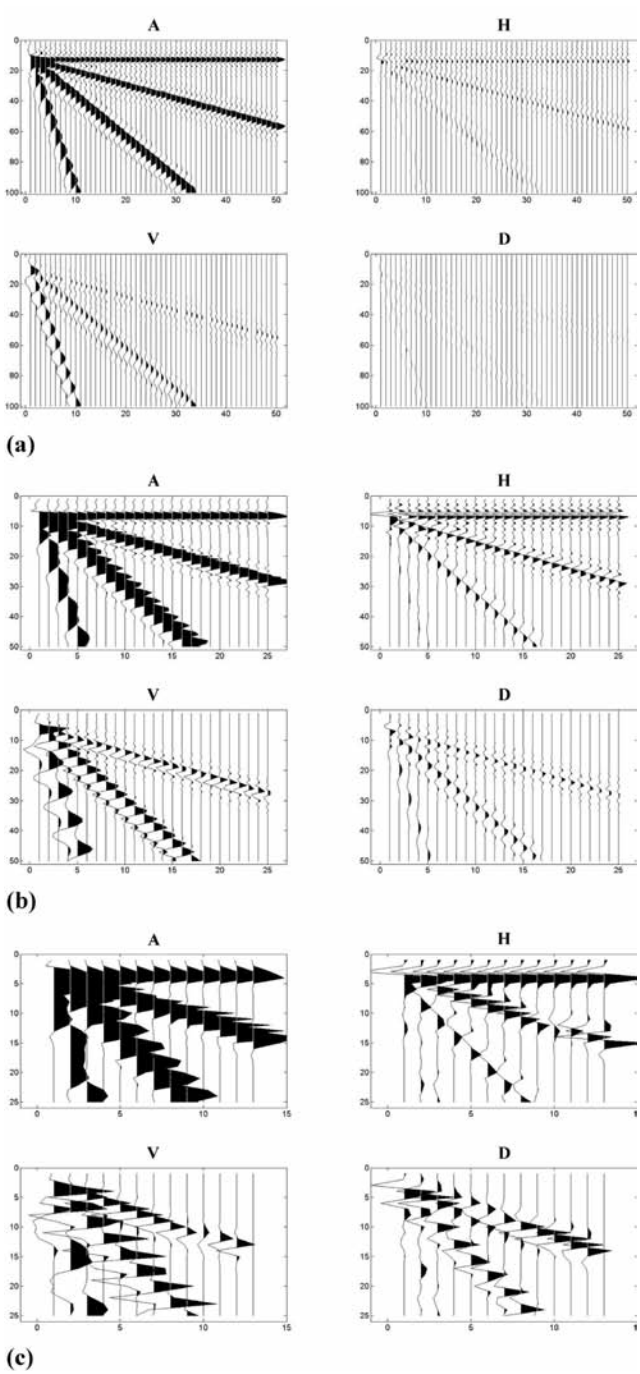


Fig. B-3. The 2DWT domain of the data in Fig. 2. Three levels of decomposition are seen in (a), (b), and (c). A, H, V, and D represent the approximation, horizontal, vertical, and diagonal details, respectively. In this case, events are separated according to their velocities into different details. At each level, the number of samples is halved along each axis.