The Application of Wiener Optimum Deconvolution Filter (WODF) with Frequency Analysis to Suppress Ground-roll in Seismic Data

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SUMMARY

Basically, ground-roll noise causes signal quality information decrement in land seismic data. Ground-roll is the main type of Rayleigh-wave that is characterized with low velocity, low frequency and high amplitude. Separating them by using frequency filtering, like (*f,k*) filtering, causes signal distortion due to overlapping signal with ground-roll in time and frequency domain. To solve this problem, we proposed a redesigned Optimum Wiener filter method. The basis of the proposed method is estimating ground-roll in contaminated data by using a reference noise trace, sweep signal. By Wiener filtering, the reference noise is then adjusted to match the ground-roll noise in contaminated data. The adjusted reference noise then subtracted from the seismic trace to obtain the signal. In this research, we also give objective analysis to find the best parameter in maximizing the obtained result whereas the frequency interval is likely the most influenced parameter in Wiener filtering. The obtained results show that Wiener filtering can suppress ground-roll without disturbing the signal while the signal is overlap with ground-roll.

Key words: Optimum Wiener Filtering, Sweep Signal, Ground-roll, (*f,k*) Filtering

INTRODUCTION

The proposed method, Optimum Wiener filtering, has been applied formerly in deconvolution purpose by developing least square algorithm. The special feature of Wiener filtering is we can derive filter coefficient that convert the input signal to any desired outputs (Robinson dan Treitel, 1980). In this research, Wiener filtering for suppressing ground-roll is done by separating signal from ground-roll, which had been used before by Karslı and Bayrak (2003). They concluded that this method effectively estimates ground-roll within the seismic data. This redesigned Wiener filtering can estimate ground-roll by creating a reference noise trace in the first instance.

METHOD

In ground-roll extraction using Wiener filtering, we use sweep signal both linear and nonlinear as the reference noise trace. To build the reference noise trace we need to estimate the frequency interval of the ground-roll within seismic trace by considering its amplitude spectrum. The amplitude spectrum of a signal shows what frequencies exist in the signal. The amplitude spectra as seen in Figure 1, show that for the same frequency interval, the amplitude value of a seismic trace after interfered with ground-roll (Figure 1b) has a bigger value than the amplitude value of a seismic trace without ground-roll interference (Figure 1a).

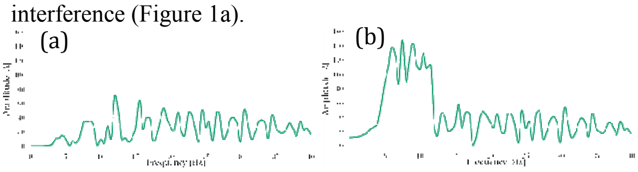

Figure 1. Amplitude spectra (absolute) from synthetic data (a) Only contains signal (b) Interfered with ground-roll

The reason why we have preferred sweep signal as the reference noise trace to extract ground roll is that its frequency varies with time such as ground-roll. A sweep signal s_t is formulated as (Buttkus, 2000):

$$s_t = \begin{cases} \sin(2\pi F(t)) & \text{for } 0 \le t \le T \\ 0 & \text{for } t<0 \text{ and } t>T \end{cases} \tag{1}$$

where $F(t)$ is a function which determines the character of sweep as follow,

$$F(t) = \begin{cases} fb + \frac{fe-fb}{2T}t & \text{for Linear} \\ fb + \frac{fe-fb}{(2T)^N}t^N & \text{for Nonlinear} \\ & N=DBO/6+1 \end{cases} \tag{2}$$

The frequencies fb and fe are respectively the beginning and ending frequencies of sweep. T is signal duration and N is the slope of sweep power spectrum, DBO (dB/Octave).

In the next step we try to obtain filter coefficient, f_τ. When f_τ is convolved with s_t, the amplitude and phase of the reference noise trace is adjusted to match the actual ground-roll noise in the seismic trace. The estimated ground-roll noise from seismic trace s'_t is defined as:

$$s'_t = \sum_{\tau=0}^{n-1} f_\tau s_{t-\tau} \qquad (\tau = 0, 1, \ldots, n-1) \tag{3}$$

Wiener filtering is defined as a least square error function L. But unlike the conventional procedure, here, this function is known as a cost function (Linville and Meek, 1992) between seismic trace z_t and estimated ground-roll noise s'_t. Cost function L can be written as:

$$L = \sum_t (z_t - s'_t)^2 \tag{4}$$

By substituting Equation (3) into Equation (4) we get:

$$L = \sum_t (z_t - \sum_\tau f_\tau s_{t-\tau})^2 \tag{5}$$

The minimum amount of L is attained by setting the variation of L with respect to f_i to zero, so we get new equation:

$$\sum_\tau z_t s_{t-i} = \sum_\tau f_\tau \sum_t s_{t-\tau} s_{t-i} \qquad (i = 0, 1, \ldots, n-1) \tag{6}$$

In Equation (6), on the left is the cross-correlation between seismic trace z_t and the reference noise trace s_t. On the right is convolution of the autocorrelation of the reference noise trace s_t with filter coefficient f_τ. Simplifying Equation (6) we get:

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$$Ci = \sum_{\tau} f_\tau R_{\tau-i} \qquad (7)$$

The general form of matrix equation for Equation (7):

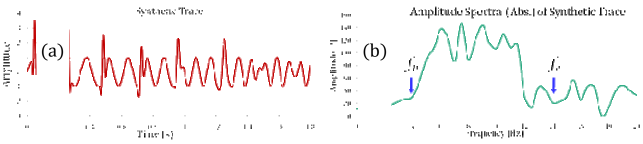
$$\begin{bmatrix} R_0 & R_1 & R_2 & \cdots & R_{n-1} \\ R_1 & R_0 & R_1 & \cdots & R_{n-2} \\ R_2 & R_1 & R_0 & \cdots & R_{n-3} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ R_{n-1} & R_{n-2} & R_{n-3} & \cdots & R_0 \end{bmatrix} \begin{bmatrix} f_0 \\ f_1 \\ f_2 \\ \vdots \\ f_{n-1} \end{bmatrix} = \begin{bmatrix} C_0 \\ C_1 \\ C_2 \\ \vdots \\ C_{n-1} \end{bmatrix} \qquad (8)$$

Here we have filter coefficient f_τ. Using Equation (3), we get s'_t as the estimated ground-roll from seismic trace. Finally we obtain a seismic trace that is free from ground-roll by subtracting the estimated ground-roll noise, s'_t, from the seismic trace.

RESULTS

Application on synthetic data

Synthetic data is used to test the performance of the ground-roll suppression using redesigned Optimum Wiener filtering (Figure 2a). The synthetic data is created by combining a signal trace which is resulted from seven Ricker signals that is assumed as earth's reflectivity, with a sweep signal that represents a dispersive ground-roll noise. Sweep signal is characterized as linear with 5-14 Hz frequency interval. Frequencies between reflectivity and ground-roll are designed as overlap. The synthetic trace is 1800 ms long and is sampled at 2-ms interval. To simulate using this filter, we assume that the precise frequency interval of the noise trace is unknown.



Fi e 2. (a) Synthetic trace (c) (Z n out from Figure 1b) mplitude spectrum (absolute om synthetic trace containing ground-roll

By quick examination in the amplitude spectrum of synthetic trace (Figure 2b), the frequency interval that meets the ground-roll character is approximately determined to be 4-14 Hz. From the initial frequency estimation, we make four various frequency intervals, a) 5-14 Hz, b) 4-14 Hz, c) 5-13 Hz, and d) 4-13 Hz, to construct linear sweep signals as the reference noise with T=1800 ms. After using Wiener filtering, we compare the derived result from each frequency intervals (Figure 3). Here, ground-roll is more successfully suppressed using 5-14 Hz frequency interval than other intervals.

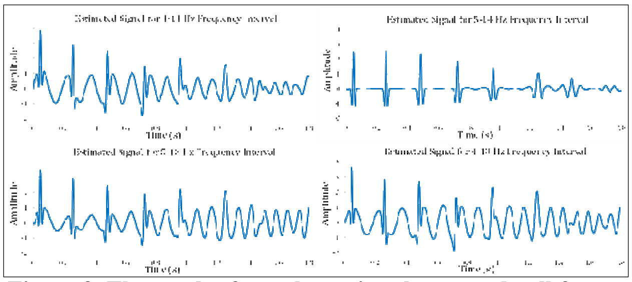


Figure 3. The result after subtracting the ground-roll from synthetic data using four various frequency intervals derived by Wiener filtering

Here, we can conclude that the beginning and the ending frequencies of sweep, f_b and f_e, which are used in synthetic data for Wiener filtering application, have affected the estimated ground-roll results. Thus in applying Wiener filtering, we should more concern in determining frequency interval that is used for estimating ground-roll.

Application on Field Data

In this study we also examine the effect of applying Wiener filtering in field data. We use a 21-traces CDP gathers from Indonesia (Figure 4a). The data are 3000 ms long and are sampled at a 2-ms interval. By applying Wiener filtering in this data, we expect to see its performance in estimating ground-roll, and finally to obtain a clearer image.

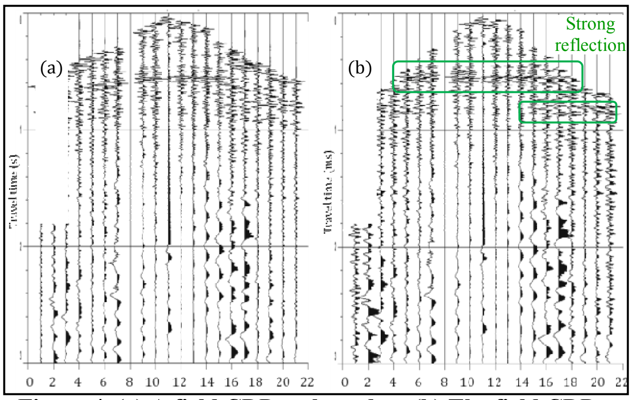


Figure 4. (a) A field CDP gathers data (b) The field CDP gathers data after NMO process

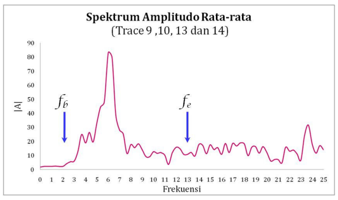


Figure 5. Average amplitude spectrum (absolute) from trace number 9, 10, 13 and 14

According to the amplitude spectrum that is seen in Figure 5, the frequency interval of ground-roll to create reference noise trace is approximately determined to be 2-13 Hz. Hence, here we make six various frequency intervals, respectively are a) 2-11 Hz, b) 5-11Hz, c) 2-12 Hz, d) 5-12 Hz, e) 2-13 Hz, and f) 5-13 Hz. The ground-roll noise in the field data is assumed to have a linear character. Reference noise trace is chosen to be linear with T = 3000 ms duration.

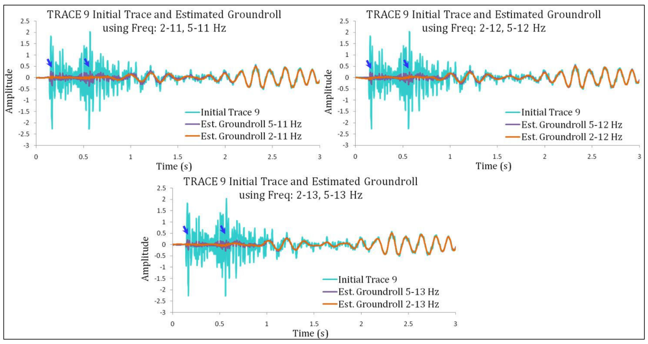


Figure 6. The extracted ground-roll of trace number 9 in the field CDP gathers data using Wiener filtering for various frequency intervals

As seen in Figure 6, the sections which are pointed by blue arrow indicate a strong earth reflectivity (at the initial trace). In a section of seismic trace that contains a strong reflection, the shape of extracted ground-roll noise should not follow the reflection. By meeting this requirement, the signal that is consisted in the seismic data will distort much lesser. The strong reflections might give us information about the edge of subsurface layers. Thus, the coherency between the extracted ground-roll noise with the strong earth reflectivity should have a smaller amount. Considering this condition, from Figure 6 we conclude that the extracted ground-roll noise from 2-13 Hz frequency interval is able to estimate ground-roll better than other frequency intervals. The Wiener filter result using 2-13 Hz frequency interval shows that the ground-roll in the field data is successfully suppressed (Figure 7a).

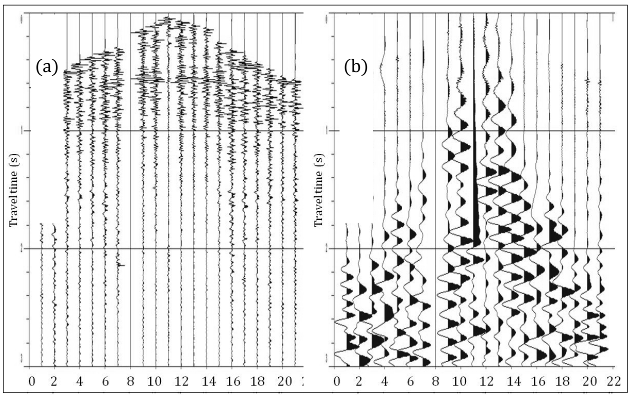


Figure 7. Result from Wiener filtering using field CDP Gathers data with 2-13 Hz frequency interval (a) After subtracting the ground-roll from data (b) The extracted ground-roll

The field CDP gathers data that has been used previously is now applied NMO, resulting the second field data (Figure 4b). In order to make the effectiveness of the Wiener filter method more clear, a comparison is done by applying (*f,k*) filter to this data. According to the application in the previous field data we have already known that 2-13 Hz is the most appropriate frequency interval to be applied in the data. Because we use a same initial field data, the application of Wiener filtering at this data will use 2-13 Hz frequency interval. Reference noise trace is chosen to be linear with T = 3000 ms duration.

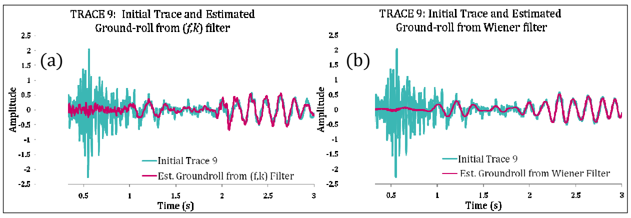


Figure 8. The extracted ground-roll from trace number 9 in the CDP gathers data after being NMO using (a) (*f,k*) filter (b)Wiener filter

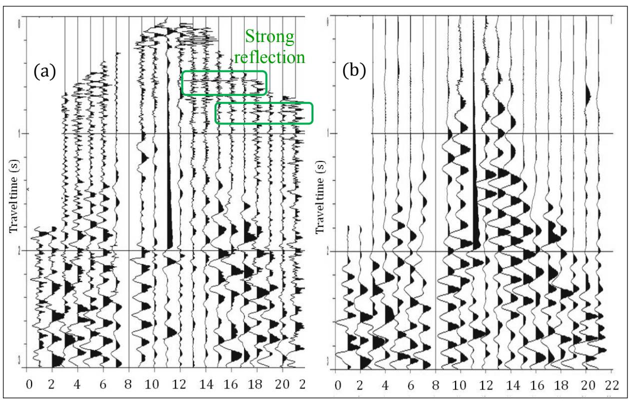


Figure 9. The extracted ground-roll from CDP gathers data after being NMO using (a) (*f,k*) filter (b) Wiener filter

The extracted ground-roll noise that is given by trace number 9 (Figure 8) show that Wiener filtering gives a better estimation than (*f,k*) filter. As seen in this figure, the extracted ground-roll from Wiener filtering is likely more precise and perfectly coherent with the only part that is containing ground-roll of the trace, thus the possibility of distortion occurrence becomes much lesser. The distortion is seen clearly in Figure 9a where several traces of the extracted ground-roll that are given by (*f,k*) filtering still consist strong reflections which are indicating the carried signals from the filtering process.

FREQUENCY ANALYSIS

Ground-roll frequency interval is a main parameter in designing Wiener filtering, besides we do not have the exact information about ground-roll frequency interval in seismic data. By this reason, although we have already concluded the best frequency interval using the extracted ground-roll visualization, we need to do a further consideration using objective analysis to know the precise frequency interval.

Cost-Function

Wiener filtering is defined as a least square error function L, that is called as a cost function (Linville and Meek, 1992). Cost function L is formulated by Equation 4 where the obtain value of L is expected to be minimum.

FREK. EST	5-14 Hz	4-14 Hz	5-13 Hz	4-13 Hz
Energy of Error	144.17	457.95	476.39	563.03
Avg. Energy of Error	0.16	0.51	0.53	0.62

Table 1. The cost-function result in the synthetic trace

In synthetic trace application of Wiener filtering, both the derived cost-function and its average for four frequency intervals (Table 1) show that the minimum value is given by 5-14 Hz. From the explanation above we may conclude that 5-14 Hz is the most appropriate frequency interval for estimating ground-roll. This conclusion has similar conclusion that is given previously, according to visualization of Wiener filter result in synthetic trace (Figure 3).

From the derived cost-function and its average for six frequency intervals that are used to extract ground-roll in the field data (before NMO process), show that the minimum value is given by 5-11 Hz (Table 2). Although the minimum value is given by 5-11 Hz, we consider the overall values of average cost-function for all interval frequencies are nearby zero. According to this condition we conclude that the usage of cost-function in determining the best frequency interval for estimating ground-roll seems less effective.

Frek. Est	2-11	2-12	2-13	5-11	5-12	5-13
Energy of Error	166.715	167.626	167.337	124.628	131.964	137.974
AVERAGE	0.1111	0.1117	0.1115	0.0830	0.0879	0.0919

Table 2. The cost-function result in the field CDP gathers data for trace number 9

Amplitude Spectra of Estimated Ground-roll

By examining the amplitude spectrum (dB) of the extracted ground-roll noise, there are several condition that should be fulfilled thus we can conclude a certain frequency interval as the most appropriate frequency for estimating ground-roll noise. The amplitude in ground-roll frequency area should gives the highest amplitude, and outside the ground-roll frequency area should gives the lowest amplitude than the derived amplitude from other frequency interval. These conditions are expected to be fulfilled by considering the amplitude spectrum that about to be visualized here is ground-roll noise. In ground-roll frequency area, the high value of amplitude is explaining that the domination of ground-roll is very high in this frequency. On other hand, outside the ground-roll frequency area where we assumed as signal frequency, the existence of ground-roll should be the minimum. This condition is reflected as low amplitude within the signal frequency area. If the extracted ground-roll amplitude has a high frequency in this area, it leads to the occurrence of signal distortion.

The amplitude spectra of estimated ground-roll in synthetic data (Figure 10) show that 5-14 Hz frequency interval gives the highest amplitude (dB) in ground-roll frequency area (defined as N.G) and also gives the lowest amplitude (dB) in signal or outside ground-roll frequency area (defined as SIG). According to this explanation we may conclude that from the Wiener filtering results, 5-14 Hz has a better ability in extracting ground-roll than other frequency intervals.

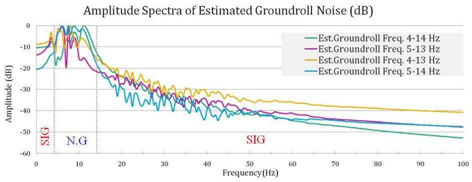


Figure 10. Amplitude spectra (dB) of estimated ground-roll noise from four various frequency intervals in synthetic data

The amplitude spectra of estimated ground-roll in field CDP gathers data (before NMO) (Figure 11) shows that 2-13 Hz and 5-13 Hz frequency intervals give the highest amplitude (dB) in ground-roll frequency area (defined as N.G) and also give the lowest amplitude (dB) in signal or outside ground-roll frequency area (defined as SIG). Through the derived result then we try to compare the estimated ground-roll amplitude spectra between 2-13 Hz and 5-13 Hz. As shown in (Figure 12) the amplitude spectrum of 2-13 Hz frequency interval seems more appropriate than 5-13 Hz. Thus, we conclude that 2-13 Hz frequency interval is the best frequency interval for estimating ground-roll in the field data.

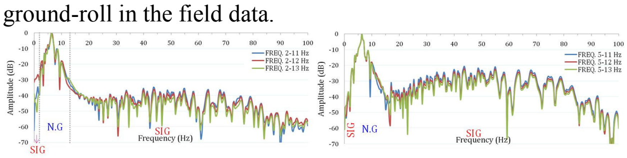


Figure 11. Amplitude spectra (dB) of estimated ground-roll noise from Wiener filter using six various frequency intervals in the field CDP gathers data for trace number 9

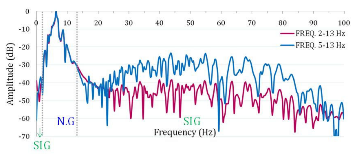


Figure 12. Amplitude spectra (dB) of estimated ground-roll noise from Wiener filter for 2-13 Hz and 5-13 Hz in the field CDP gathers data for trace number 9

The usage of amplitude spectra also possible to be applied as an objective method to determine the effectiveness between Wiener filter method and (f,k) filter, where both methods have been applied in the previous field data. From the derived amplitude spectrum for each method (Figure 13), we see that (f,k) filtering gives higher amplitude for signal or outside the ground-roll frequency area. This condition explains that estimated ground-roll noise that is given by (f,k) filtering has higher potency to distort signal than Wiener filtering. The distortion occurs because the extracted ground-roll from (f,k) filtering is not only coherent with the part that is containing ground-roll but also with some part that is containing signal. From here, we may conclude that the result given by (f,k) filtering does not meet a satisfaction because the occurrence of signal distortion. The difficulty in finding the best polygon which defines the signal or the noise area in (f,k) mapping is one of the main problem. Selecting a wrong polygon may causes distortion either a huge signal removal.

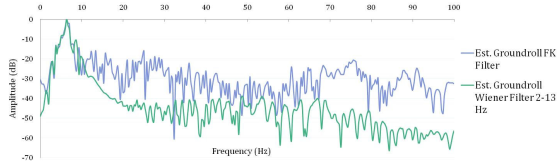


Figure 13. Amplitude spectra (dB) of estimated ground-roll noise from (f,k) and Wiener filter in trace number 9

CONCLUSIONS

The proposed method in this study is a redesigned Optimum Wiener filtering method that is used to extract ground-roll noise. For estimating ground-roll in seismic data, we create a reference noise trace as the initial model of ground-roll, using a sweep function. The success level of using this method depends on the parameters that are used in building the reference noise trace, especially frequency interval. For this reason, we should consider the amplitude spectra of extracted ground-roll noise that are derived from various frequency intervals to know the most appropriate frequency interval.

Comparison between the result that was given by (f,k) filtering and Wiener filtering, shows that although the reflection and ground-roll overlap in frequency domain, the reflectivity distortion can be minimized using the proposed method, Wiener filtering. The extracted ground-roll noise that is obtained from Wiener filtering is coherent with the only part containing ground-roll of the trace. The advantage of using Wiener filtering to suppress ground-roll is this method tries to preserve the signal by operating filter in certain frequency interval that is defined as ground-roll. The only disadvantage in applying Wiener filtering is that it requires more time because it is applied on a trace-to-trace basis.

ACKNOWLEDGMENTS

The author wishes to thank Geophysical Engineering Program, Bandung Institute Technology, for their support and computer facilities.

REFERENCES

Buttkus, B., 2000, Spectral Analysis and Filter Theory in Applied Geophysics, Springer-Verlag, Germany.

Gouppilaud, P.L., 1976, Signal design in the ‘‘Vibroseis’’ technique: Geophysics 41, 1291– 1304.

Karslı H., Bayrak Y., 2003, Using the Wiener–Levinson algorithm to suppress ground-roll: Journal of Applied Geophysics 55, 187– 197.

Levinson, N., 1947, The Wiener rms (root mean square) error criteria in filter design and prediction: J. Math. Phys. 25, 261– 278.

Linville, A.F., Meek, R.A., 1992, Canceling stationary noise: Geophysics 57, 1493–1501.

Yilmaz, O., 1987, Seismic Data Processing, Society of Exploration Geophysicists, Tulsa.