Ground Roll Suppression using Wigner Distribution

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ABSTRACT

A data processing strategy to suppress seismic noises by Wigner Distribution (WD) method through signal decomposition in time-frequency domain is demonstrated. The 48 WDs are used for a profile with 48 channel vertical component geophone records. The level seismograms from the 48 WDs of these geophones records are built. There are 256 Level Seismograms, but only some level seismograms in a certain level range can be used. From some reasonable approach that in the level range 70 to 100 the reflected wavephases dominate. Then the level seismograms from Level 70 to Level 100 are composed to get de-noised seismogram. The effects of the de-noising are better than the results of discrete wavelet transform (DWT), and the clear reflected wavephases are got. Therefore the WD- method has its advantage than others in this case.

Keywords: Wigner Distribution (WD), Ground Roll, Level Seismograms, Discrete Wavelet Transform (DWT

INTRODUCTION

Some methods were used to denoise seismic data e.g. the time-frequency analysis (Cohen, 1995) (Wu et al. 2011). The ground roll is mainly Rayleigh wave with low frequency and high amplitude which is a type of coherent noise in seismic data. The wavelet transform was used to suppress this noise (Corso et al. 2003; Deighan & Watts, 1997), however different mother wavelets result in different analysis results, and thus the usefulness of the wavelet transform are limited. A method called Karhunen-Loève transform (KL) was used to suppress the ground roll (Londoño et al., 2005), but using this transform only principal (largest) eigenvector usually was used, and other smaller eigenvectors were not used (Lin, 2010a; 2010b), and therefore the accuracy is limited due to lost information with ignoring the small eigenvectors. A type of time-frequency representation optimal with respect to time-frequency localization is the Wigner Distribution (WD) (Cohen, 1995; Dragoman, 2005; Ozaktas et al., 2001). The WD is already used to enhance the seismic event (Tobback et al., 1996). The goal of this paper is to reduce ground roll using the WD.

WIGNER DISTRIBUTION (WD)

When a function is $f(t)$, and t is the time scale, then the Wigner Distribution (WD) under transformed scale t is defined as follow (Ozaktas et al., 2001);

$$W_f(t,f) = \int f(t+\frac{t'}{2}) \int f^*(t-\frac{t'}{2}) e^{-i2\pi f t'} dt' \qquad (1)$$

The WD analysis is similar to the continue wavelet transform, and the decomposed time sequence at each frequency scale is the "Wigner Component". A straight forward physical interpretation of the WD is that the waveform of the recorded seismic wave is analyzed in the

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time-frequency plane called the "Wigner Plane". The mathematical meaning of WD is that the waveform can be decomposed via time-frequency representation. Parameter t in the equation (1) is the time scale and f is the frequency scale in the Wigner Plane.

FIELD DATA EXAMPLE

In order to perform the WD, a data set of the 48 channel vertical component geophone records in Jiayi, Taiwan shown in Fig.1. These field records were generated by a sledgehammer. The first source-to-geophone offset is 5 m with 5 m geophone spacing, and the time sampling interval is 2ms.

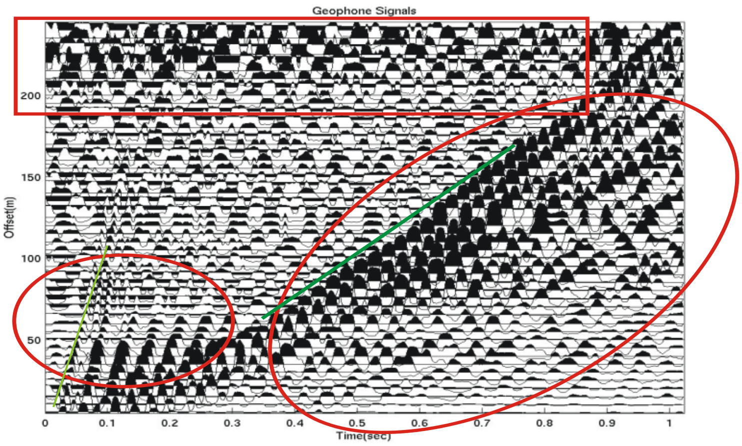

Figure 1. This figure shows a data set of 48- channel vertical component geophone records

The geological background at the recording site has obvious near-surface effects which make the interpretation and data processing more difficult. For example the travel-time curve of ground roll is not line. It shows that the near-surface of first layer may be flabby and gradually hard (velocity gradient medium). As the offset increases the quality of the records is not good. The relatively strong signals exist before more coherent first arrives at far offset indicate an obvious reason for careful processing strategy when propagation distance become large, therefore noises exist with large amplitudes in the top rectangle area of Fig.1. In the bottom-right ellipse area the energy is mainly from ground rolls using green line as the sign. In the other part the signals of the reflected waves are not clear. Only the clear wavephases with the curve as the sign can be seen in the bottom-left ellipse area, and a wavepahse with the green line as the sign on the left has apparent velocity about 1400m/s, this should be direct P wave. The direct SV wave cannot be observed.

DEFINITION OF LEVEL

Figure 2(a) shows the geophone record of figure1 with the offset being 5 m. Figure 2(b) shows it's Wigner Distribution (WD). The "Level" in the WD is defined. This WD has the dimensions with 256 rows (frequency scale) and 512 columns (time scale). A row trace represents a level trace (basis), and thus it has 256 level traces. For example the figures (c) (d) are the first and 100th levels of the WD. The concept of "level" likes the "scale" of the Wavelet Transform (Mallat, 1999). The 48 geophone records haves 48 WDs, and here only the WDs of the some geophone records with the offset being 10m, 50m, 100m, 150m, 200m and 240m are shown in figure 3. From the figures of figure 3, it is not easy to pick up a certain wavephase e.g. reflected phasewave with these irregular energy distributions in WD domains as the offset variances and therefore direct analysis of WD domains is unsuitable.

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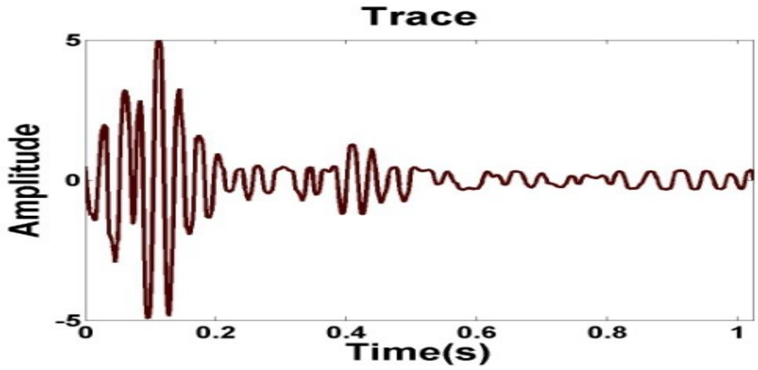
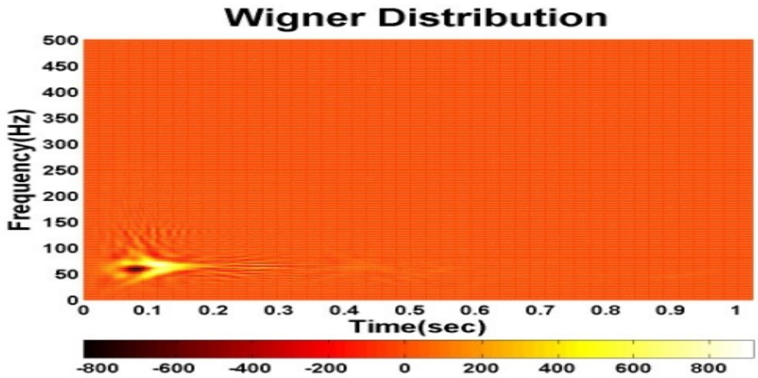
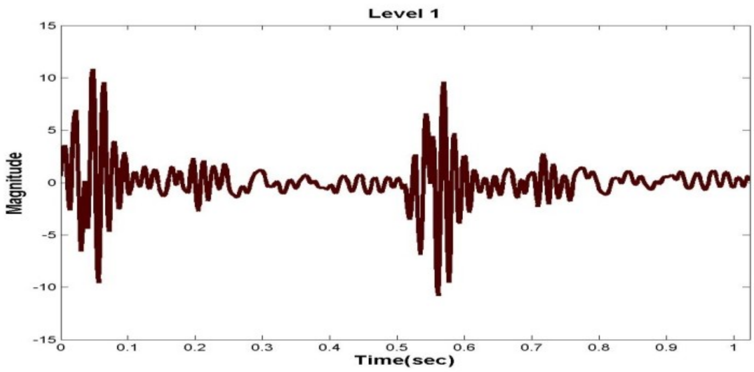


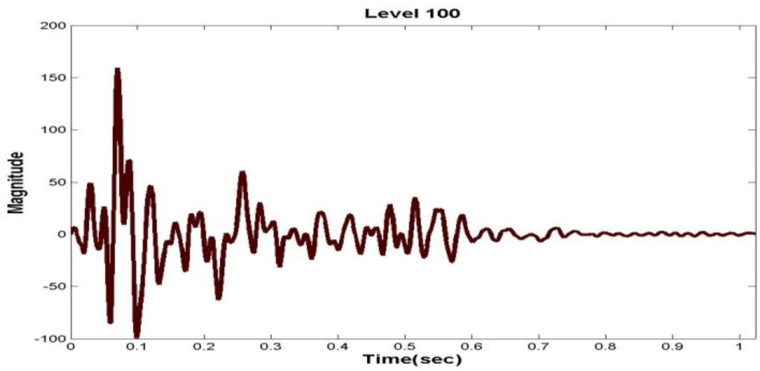
(a)



(b)

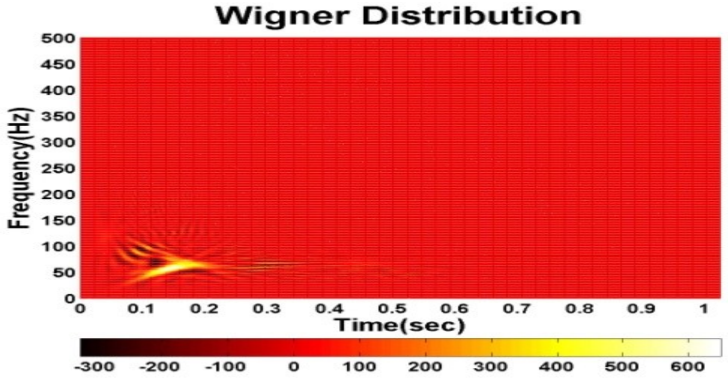


(c)

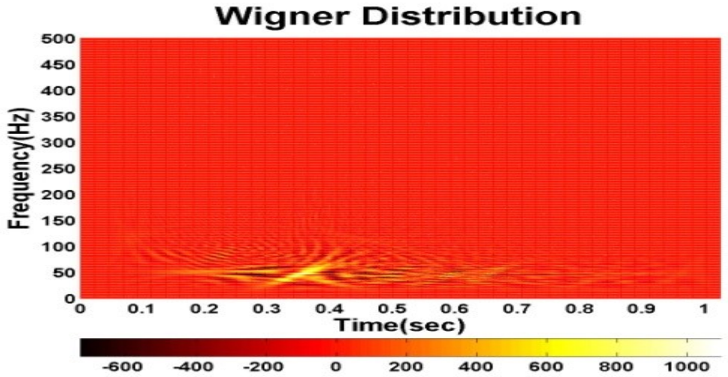


(d)

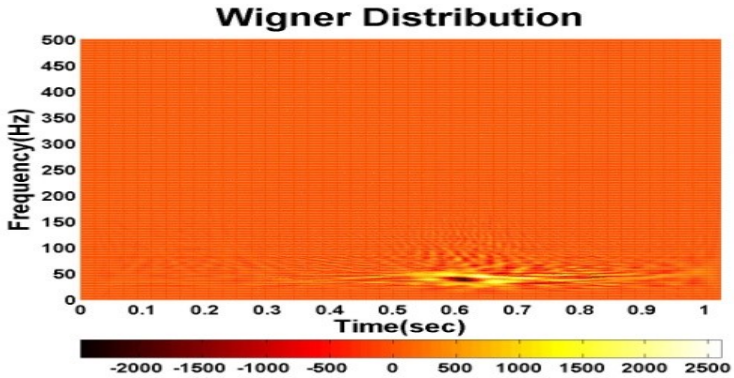
Figure 2. The figure (a) shows the geophone record with the offset being 5 m. The figure (b) shows its WD. The figure (c) shows first level trace (first basis), and figure (d) shows 100^{th} level trace (100^{th} basis).



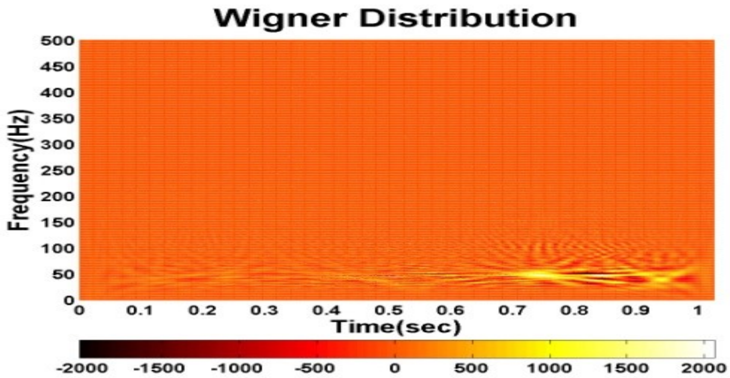
10m



50m



100m



150m

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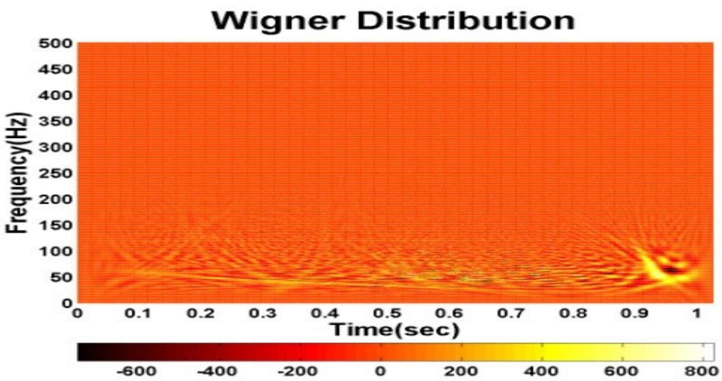
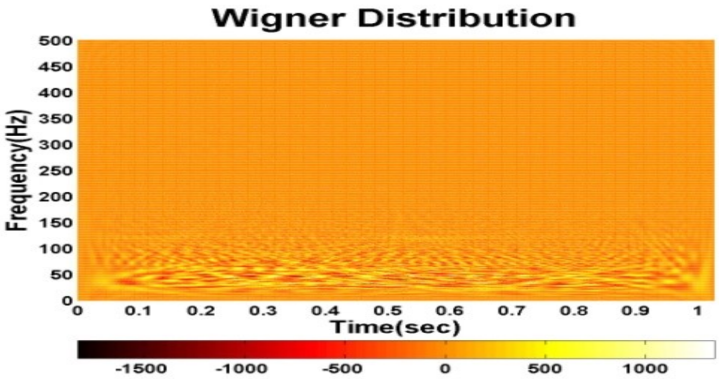


200m

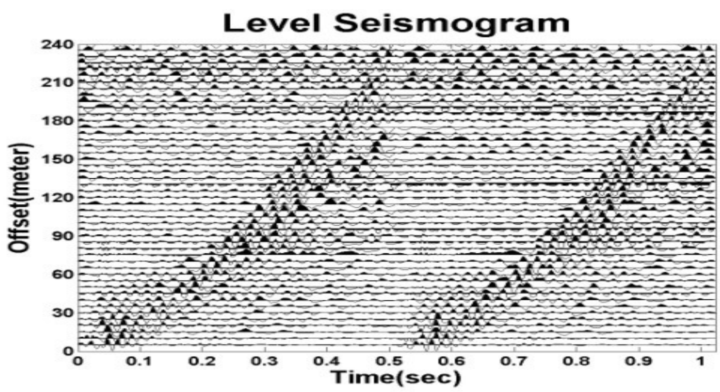


240m

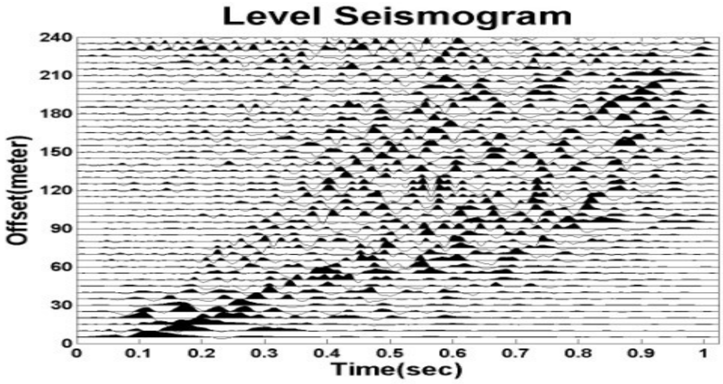
Figure 3. Shows the WDs of some geophone records in Fig.1. The offset is written below each WD figure.

DEFINITION OF LEVEL SEISMOGRAM

Now the "Level Seismogram" for level one using these 48 WDs of the records with the offset from 5m to 240m is built. The first level trace from each WD of each record with different offset is taken out, and therefore there are 48 time sequences (trace) with different offsets. They are also the first bases in WD domains. Let the vertical axis be the offset from 5 to 240 m and the horizontal axis be the time axis from 0 to 1.024 sec. These time sequences related to corresponding offset are composed as "Level Seismogram" shown in Fig.4. There are 256 levels (traces as in Fig.2c,d) in the WD of each record and therefore 256 level seismograms are built. Fig.4 shows the level seismograms of level 1 (a) and 69 (b). Later these level seismograms will be added to get the denoising seismogram in a certain level range which the reflect wavephases dominate.



(a)



(b)

Figure 4. This figure shows “Level seismogram” for level 1 (a) and 69 (b)

AN APPROACH TO SELECT USEFUL LEVEL RANGE TO REMOVE GROUND ROLL

There are 256 level seismograms, however, only some level seismograms could be used in a certain level range which the reflected waves dominate. When the suitable range for reflected wavephases could be found, and level seismograms in this range will be synthesized to get the denoising seismogram. This is an important issue of this paper. Usually noises increase as the offset increases in the geophone records. They include ground rolls and multiples and noises without clear wavephase, and cover the reflected wavephase.

The geometric spreading amplitude of ground roll is proportional to $\frac{1}{\sqrt{r}}$ for homogenous and isotropic medium, here r is offset. Figure 5(a) shows the theoretical energy distribution by red curve. However the real layer model may be inhomogeneous and anisotropic, and therefore the real behavior of energy (using Parseval theorem) spreading is different from the green curve when considering other physical attenuation factors e.g. scattering and other wavephases e.g. multiple. Therefore the real energy curve should decrease quickly as the offset increases compared with figure 5(a) by red curve. The synthesized level seismogram in the level range from 1 to 69 is defined to add the level seismogram from level 1 to 69 together shown in figure 6. In this synthesized level seismogram the ground rolls cannot be reduced compared with Fig.1, and therefore selecting this level range is unsuitable. From the shape of real total energy distribution by green curve in the level range from 1 to 69, it is fitted this situation, which the energy decreases quickly, compared with red curve due to other physical attenuation factors and wavephase. It implies that in this level range the ground rolls dominate. Now the behavior of the body wave is thought. When the geometric spreading is considered, then the amplitude of the body wave is proportional to $\frac{1}{s^2}$ in homogenous and isotropic medium, and s is the passing routine. The theoretical energy distribution as the offset increases is shown in Fig.5 (b) by red curve when only considering about geometric spreading. When other physical attenuation factors are also considered e.g. multiple and thus the passing routine will be longer, therefore the amplitude of curve should decease quickly with some attenuation factors e.g. scatting as in Fig.5 (b) by black curve. From the shape of real total energy distribution by green curve in the level range from 70 to 100, it is also fitted this situation compared with red curve except at the offset about from 15 to 55m. It has no wonder that in the synthesized level seismogram of the level range (Fig.7) the amplitudes of ground rolls from 15 to 55m are larger. In this level range the reflected

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wavephases dominate, however the part of ground rolls in Fig.1 could not be entirely removed. Compared with Fig.1, the effect of denoising is good.

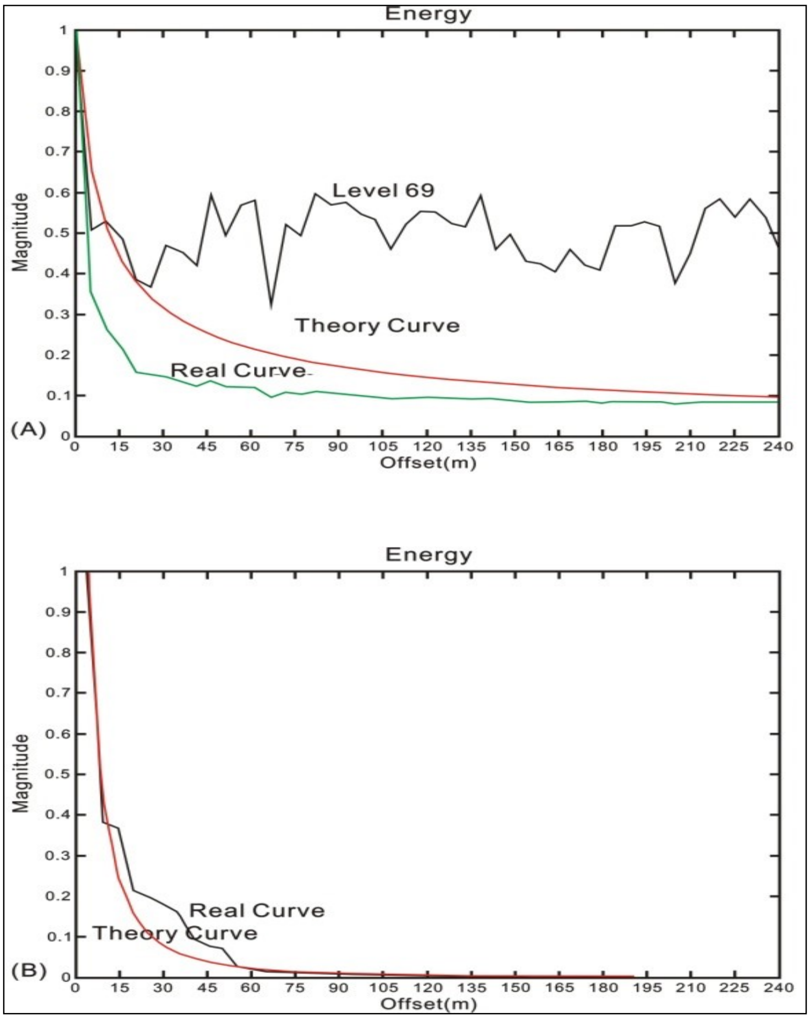

Figure 5(a) shows the energy change only with geometric spreading of the ground roll as offset increases by red curve. The energy distributes as the offset increases for the synthesized level seismogram in the level range from 1 to 69 by green curve. Black curve is the energy distributes as the offset increases for the level 69. Figure 6(b) shows the energy change only with geometric spreading of the body wave as the offset increases by red curve. The energy for the synthesized level seismogram in level range 70 to 100 distributes by black curve. The difference of both curves is small compared with Fig.6 (a) except the offset about from 15 to 55m. In these figure the amplitudes are normalized through dividing their maximum values.

DE-NOISED SEISMOGRAM

The synthetic level seismogram in the level range from 1 to 69 is shown Fig.6. The ground rolls still dominate. In the level range from 70 to 100 the energy of the reflected wavephases should dominate. The synthetic level seismogram in the range from the level 70 to 100 is shown in Fig.7. The ground rolls cannot be removed but about 40 percent reduced in the ellipse area in the mitten, and other ground rolls and noises are almost reduced.

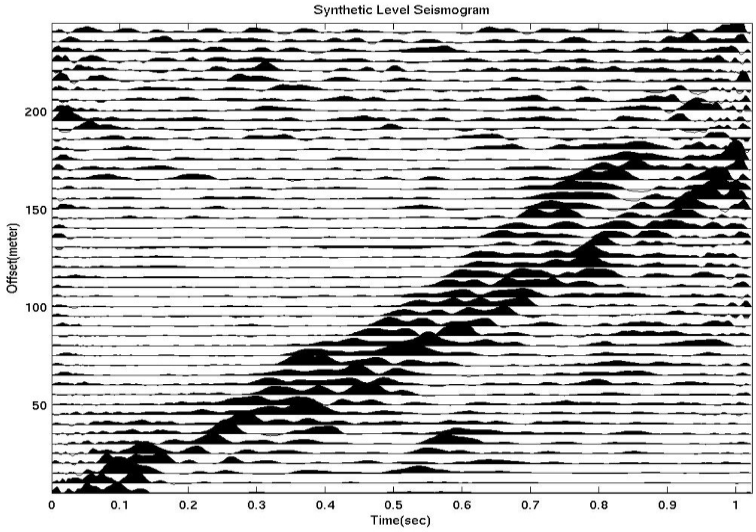

Figure 6. This figure shows the synthetic level seismogram (Level 1 to 69)

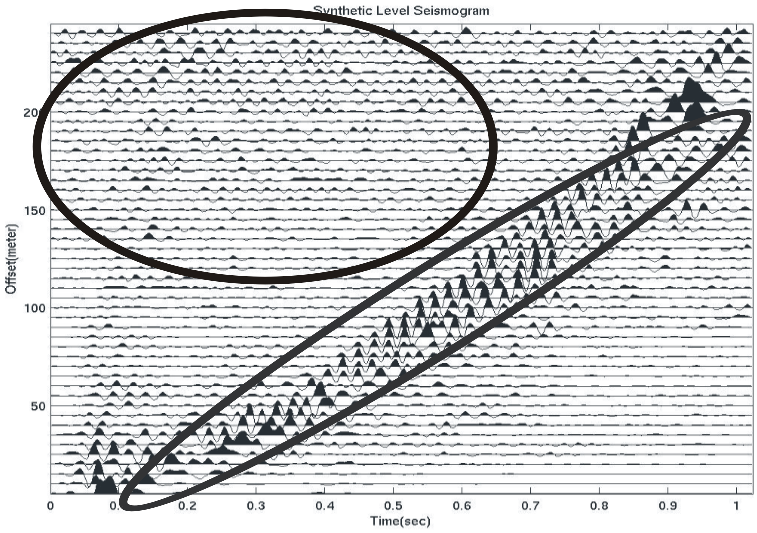

Figure 7. This figure shows the synthetic level seismogram (Level 70 to 100)

DISCUSSION

Figure 6 shows the synthetic level seismogram from Level 1 to 69 and the ground rolls and noises with low frequency dominate in this range. In Fig.7 the ground rolls are reduced and the reflected wavephases in the ellipse area is clear compared with same area in Fig.1. The ground rolls cannot be entirely removed with large amplitudes in the black area in the mitten and some reflected wavephases are over-reduced, and therefore WD has these disadvantages. Referred to Fig.5 (b) the red and black curves have clear difference for the offset 15m to 55m, and the clear large amplitudes of ground rolls are shown. It can be understand the reason why the black curve is higher than the red curve in this offset range, that is; the ground rolls in this offset range are a little reduced compared with other range. For comparison the ground rolls are suppressed using Discrete Wavelet Transform (DWT) (Stollnotz et al., 1995) (Deighan & Watts, 1997) (Mallat, 1999) (Cohen, 1995) shown in Fig.8. The result of DWT is dependent of the mother wavelet choosing and scale, therefore this is a large disadvantage using DWT. The quality of the de-noising seismogram is not better than using WD method.

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The energy of ground rolls is although reduced to 30 percent but the ground rolls in the ellipse area can not be reduced. Finally the WD-method has a disadvantage. That is; the computing time will be longer as the dimension of the data is larger, however this problem is already solved (Garcia et al., 1997) (Aykut, 2005).

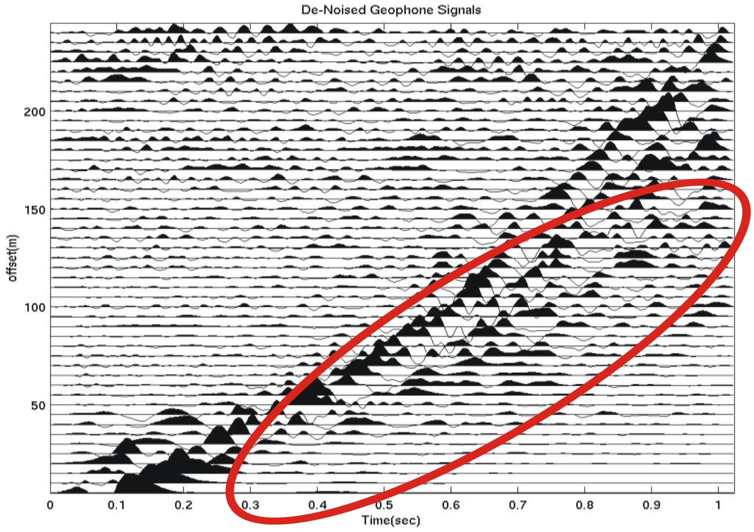

Figure 8. This figure shows the de-noising seismogram using Discrete Wavelet Transforms (DWT). The ground rolls in the red ellipse area are not reduced.

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