

# A New Method to Invert Time-lapse Impedance Using Hybrid Data Transformation

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## Abstract

Time-lapse inversion is preferably performed on the difference data that is made between the monitoring and reference seismic data. When the difference data is sparse and spiky, spike deconvolution is possibly utilized to invert reflectivity. Logarithmic impedance can be further recovered from this inverted reflectivity. However, limitation exists, especially for the ramp and thin layer structures, the inverted reflectivity might be incorrectly located using such deconvolution method. The authors of this paper propose a new four-step method to deal with this situation. The first step is to integrate or derive the seismic difference data depending on the type of the structure. The second step is to use spike deconvolution algorithm to invert reflectivity. The third step is to derive or integrate reflectivity back to get the real reflectivity. The final step is to compute impedance from the previously inverted reflectivity.

## Introduction

The final purpose of reflection seismic exploration is to obtain logarithmic impedance as a function of two-way traveling time. Several assumptions have been imposed on seismic data, for example, no multiples, no transmission losses, zero-phase wave shape. Logarithmic impedance can be approximately expressed as a function of reflectivity (Peterson, et al., 1955; Oldenburg, et al., 1983). If the inverted reflectivity is within the range of 0.3, the error of estimated impedance is about 3% (Oldenburg et al., 1983). If the reflectivity were less than 0.2, the resultant impedance would be less than 1.37% (Hardage, 1987; Ghosh, 2000). So if the optimal reflectivity can be inverted from the seismic difference data, meaningful impedance can be further computed using the logarithmic formula.

If the inverted data is sparse, i.e., only limited randomly located samples have non-null values, spike deconvolution can be used to locate the spike positions and the corresponding amplitudes. The commonly used methods include the single most likely replacement (SMLR) (Kormylo, et al., 1980), iterated conditional modes (ICM) (Lavielle, 1991), iterated window maximization (IWM) (Kaarensen, 1998), simulated annealing (SA) (Ingber, 1989) and L1-based simplex algorithm (Press, et al., 1992). These methods usually work well for the thick-bed structures whose dimensions are within the resolution limit. However these methods are invalid for the thin-bed structure and for the thick ramp structure. For the thin-bed structure, the reflectivity is too close and its thickness is below the resolution limit. In this case, the spike of the reflectivity will be located in the wrong position, as will be the peak of the amplitude. The response wave shape is identical to that of the 1<sup>st</sup> derivative of the basic wavelet (Widess, 1973). For the thick ramp structure, the reflectivity is no longer a spike, and the corresponding response is identical to that of the integral of the basic wavelet at the ramp boundary and close to zero inside the ramp structure (Hilterman, 2001). So, the question here is: can we transform the data whose reflectivity is sparse and spiky so that we can utilize spike deconvolution methods to invert reflectivity? And how? In this paper, we will try to answer these questions.

The motivation of this paper is to attempt to invert impedance, especially for the thick double-ramp structure and thin layer structure from the post stack time-lapse seismic data since these two types of structure are the commonly encountered in the practical time-lapse seismic monitoring. The difference between monitoring and reference seismic data will be used to invert impedance. There are two advantages to do so. One advantage is that less data will be involved in the inversion. The other advantage is that the changes in the rock and reservoir properties are concentrated in only small region; and the non-uniqueness of the inverted solution will be significantly reduced (Sarkar, et al., 2003; Gluck, et al., 2000). Three synthetic examples will be given here to demonstrate how to invert impedance from the post-stack time-lapse seismic data whose structure is thick-bed, thick double-ramp, and thin-bed, respectively.

## Methodology

First we will examine two predictable wavelet shapes with the zero-phase Ricker wavelet as the basic wavelet. The first predicted wavelet shape is the 1<sup>st</sup> derivative of the basic wavelet. The second one is the integral to the basic wavelet. The center of the basic wavelet is set zero in time and the amplitude reaches maximum at this position. It is observed that amplitudes of both the 1<sup>st</sup> derivative and the integral zeros. These wave shapes can be correlated to some physical structures. According to Hilterman (2001), the wave shape of the response is identical to the basic wavelet for the thick-bed structure, quite similar to the 1<sup>st</sup> derivative of the basic wavelet for the thin-bed structure, and close to the integral of the basic wavelet for the ramp structure (see Figure 1, 2). Therefore, the wave shape should be modified to match the thick-bed structure wave shape. In this paper, a new method of hybrid data transformation is proposed to correctly invert time-lapse impedance from post stack seismic data.

## Examples and Discussion

Here three synthetic examples are given to show how to invert impedance using the methods described in the previous section. The first example is made for the thick-bed structure, the second example for the double-ramp structure with and without noise, and the third for the thin-bed.

The first synthetic example is for the noise free thick-bed structure shown in figure 3. The central frequency of Ricker wavelet used is 30 Hz and the sample interval 2 ms. Same parameters are used in all the other numerical examples. In Figure 3, figure (a) shows the monitor trace, (b) the reference trace, and (c) their difference. The purpose of this exercise is to simulate time-lapse seismic monitoring situations in which the variations involved in the difference trace theoretically should only contain the fluid flow caused variations. Since the thickness of the structure is within the resolution limit, spike positions and their amplitudes can be correctly located and determined by using spike deconvolution directly to the difference trace (c). The exact and the inverted logarithmic impedance are shown in (d). To compare with the exact impedance, we can see that the impedance has been perfectly recovered.

It should be noted here that the impedance is inverted nearly correctly even in the presence of 20% Gaussian noise. Such data and the inverted impedance are shown in figure 3-1. As the noise level increases, the accuracy of spike locations will be affected and the detected amplitudes will be contaminated with noise. The degree to be affected depends on the noise level.

The second synthetic example is for the double-ramp velocity model with constant of density. The synthetic data and the inverted impedance are shown in figure 4. In this figure, frame (a), (b), (c) have the same meaning as in figure 3. Frame (d) represents derivative of the difference data in (c). Frame (e) shows the exact and the inverted impedance. We can see from frame (c) that the magnitude of amplitude at the transition point is zero. We can't directly apply spike deconvolution algorithm to this kind of data. Now examine the derivative data. Quite different feature appears in (d). The local extrema of the amplitudes exist at the transition points. At this stage, it seems promising to apply spike deconvolution to this data and invert for reflectivity. Using the method described in the previous section, we obtained the final impedance shown in frame (e) together with the exact impedance. It is obvious that the transition points have been accurately located and the impedance amplitudes are also quite close to the exact impedance. This example shows that the method described in the previous section is effective and has the potential to be applied to impedance inversion from time-lapse ramp structures.

The final example is generated for the thin-bed (figure 5). Frame (a) to (c) have the same meaning as that in figure 3 and figure 4. Response in frame (d) is the integral of response in frame (c). The final inverted impedance is shown in frame (e) together with the exact impedance. From frame (c), it is observed that the positions of the minimum and maximum amplitudes differ from the boundaries of the thin-bed. The distance between the maximum and minimum amplitudes is greater than the real thin-bed thickness. This artifact is caused by the tuning effect. The zero amplitude is located in the middle of the maximum and minimum amplitude and corresponds to the mid-position of the thin-bed. It is invalid to apply spike deconvolution directly to this data. However, the response from frame (d) shows different features. The response wave shape is identical to the basic wavelet wave shape. The condition is satisfied in applying spike deconvolution to this data to recover the reflectivity. The final inverted impedance is shown in (e) together with the exact impedance. We can see that accurate thin-bed boundaries have been located and only very small deviations of impedance amplitude exist. This example shows that this method works well for the thin-bed structure.

## Conclusions

In this paper, we proposed a new method to invert impedance from time-lapse seismic data. This new method is applicable for the thick-bed, ramp, thin-bed structures and even with the presence of high-level noise. No external constraints are required in the inversion itself. This method provides great potentiality to invert impedance for the practical time-lapse seismic data, especially for the ramp and thin-bed structures that are commonly encountered in the practical situations.

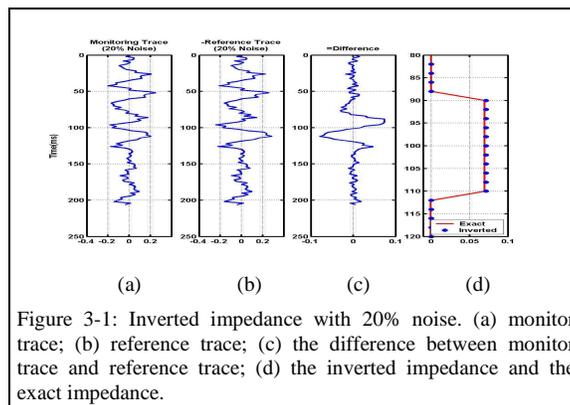
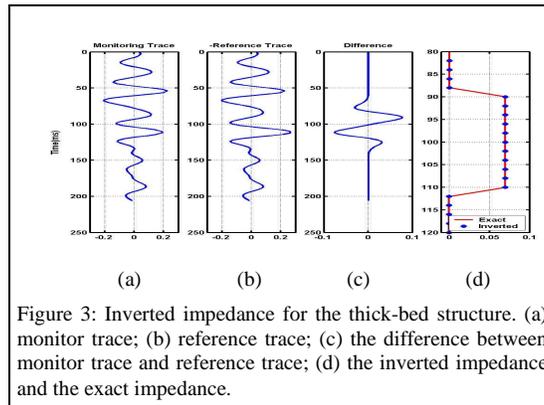
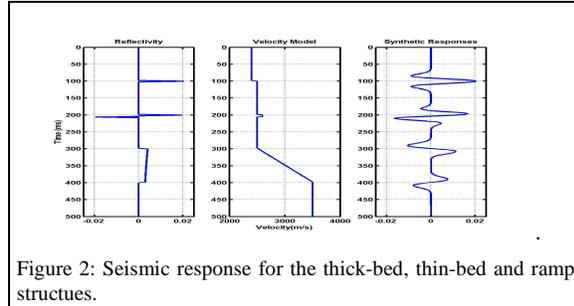
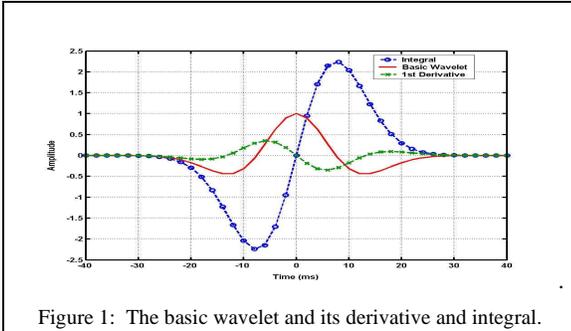
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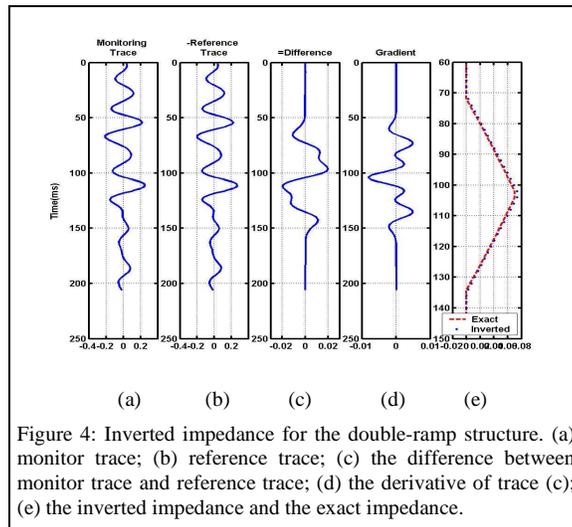


Figure 4: Inverted impedance for the double-ramp structure. (a) monitor trace; (b) reference trace; (c) the difference between monitor trace and reference trace; (d) the derivative of trace (c); (e) the inverted impedance and the exact impedance.

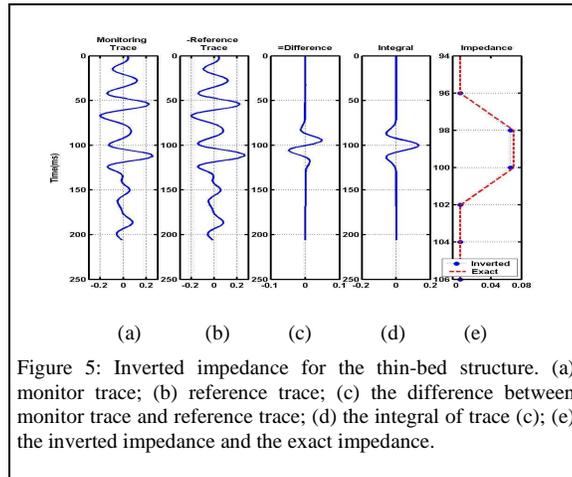


Figure 5: Inverted impedance for the thin-bed structure. (a) monitor trace; (b) reference trace; (c) the difference between monitor trace and reference trace; (d) the integral of trace (c); (e) the inverted impedance and the exact impedance.