INVERSE Q FILTERING TO ENHANCE SEISMIC RESOLUTION

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1. INTRODUCTION

High resolution seismic profiles are desirable for geological interpretation. However, the resolution of a seismic profile gradually decreases as seismic waves propagate in the earth. This phenomenon is known as the attenuation effect which is caused by medium absorption. Due to absorption, the high-frequency components of seismic waves decay more rapidly than the low-frequency components and hence the resolution is degraded.

Therefore, quantification of medium quality factor Q is important for seismic signal processing. Once Q is known, we can design an inverse Q filter to enhance the resolution of seismic profiles. Furthermore, it can also provide additional information of the subsurface formation. Many works have been done on seismic transmission data whereas only a few works try to estimate Q from seismic reflection data due to its complexity. The accuracy of Q estimation highly relies on the accuracy of the estimated wavelets from the seismic signal.

In this paper, we propose a method for Q estimation and inverse Q filtering using a wavelet extraction method which is based on higher-order-statistics (HOS). The effectiveness of the method has been proved with synthetic and field examples [1]. First, we extract seismic wavelets from seismic reflection data. Second, we estimate Q using the spectra-ratio method [2]. And then we design an inverse Q filter and apply the filter to the seismic trace to recover its high-frequency components.

2. METHOD

Seismic reflection data can be modeled as

$$\mathbf{x} = \mathbf{b} * \mathbf{r} + \mathbf{n}, \tag{1}$$

where $\mathbf{b}$ is the seismic wavelet, $\mathbf{r}$ is the reflectivity sequence, $\mathbf{n}$ is the additive noise, and the operator $*$ denotes 1D convolution. In practice, the wavelet is always changing due to attenuation; however, we still assume that within a short period of time, the changes are negligible.

For two data segments, we estimate two different wavelets using our HOS based wavelet extraction method [1]. The wavelet extracted from a shallow data segment is used as the reference wavelet, denoted by $\mathbf{b}_0$, and the wavelet extracted from a deeper segment is used as the target wavelet, denoted by $\mathbf{b}_1$.

The spectra-ratio method is used to calculate Q between the two data segments. The amplitude spectra of $\mathbf{b}_0$ and $\mathbf{b}_1$, denoted by $|\mathbf{B}_0(f)|$ and $|\mathbf{B}_1(f)|$, are calculated first, and then such an equation is derived[2]:

$$\ln\left(\frac{|\mathbf{B}_1(f)|}{|\mathbf{B}_0(f)|}\right) = -\pi f (t_1 - t_0) / Q \tag{2}$$

where t_0 and t_1 are the two-way traveltimes of the two wavelets. Q can be calculated by curve fitting using the least-squares method within the common bandwidth of the two wavelets.

After Q between two data segments is estimated, an inverse filter can be designed and applied to the attenuated segment to recover its high-frequency components. The reference data segment is denoted by $\mathbf{x}_0$ and the target data segment is denoted by $\mathbf{x}_1$, their two-way traveltimes are denoted by t_0 and t_1. Such an inverse Q filter can be designed:

$$\left|\tilde{\mathbf{X}}_1(f)\right| = \left|\mathbf{X}_1(f)\right| \exp(\pi f (t_1 - t_0) / Q) \quad (3)$$

where $\mathbf{X}_1(f)$ is the spectra of $\mathbf{x}_1$, $\tilde{\mathbf{X}}_1(f)$ is the spectra after filtering, and Q is the medium quality factor between the two segments.

Some measures are taken to improve Q estimates using the spectra-ratio method, such as zero-padding in the time domain, robust-regression in least-squares fitting, and choosing an effective bandwidth for curve fitting. When inverse Q filtering is applied, an effective bandwidth is also chosen to prevent instability.

3. SYNTHETIC EXAMPLES

We generate a synthetic seismic trace using the convolution model, shown in equation 1 and the attenuation effect is taken into consideration when the trace is generated. The trace is shown in Figure1. An ideal trace without attenuation is also generated for comparison, shown in Figure 2.

We apply the proposed method to the synthetic trace to recover its high-frequency components. The recovered trace is shown in Figure 3. We compute the normalized crosscorrelation (NCC) to evaluate the similarity between the traces. The NCC between the synthetic trace and the ideal trace is 0.6823, and the NCC between the recovered trace and the ideal trace is 0.8969.

4. CONCLUSION

The difficult of Q estimation from seismic reflection data lies in that the spectra of seismic waves are distorted by closely spaced reflectors in the formation. By using our HOS based wavelet extraction method which has been proved to be effective even for relatively short seismic data, reliable wavelets are extracted and the tuning effect brought by the reflectors is removed. Synthetic examples have verified the effectiveness of the proposed method.

5. AKNOWLEDGEMENT

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6. REFERENCES

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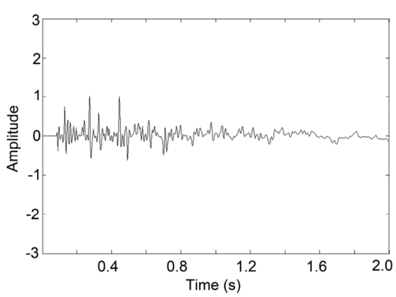

Figure 1. The synthetic trace

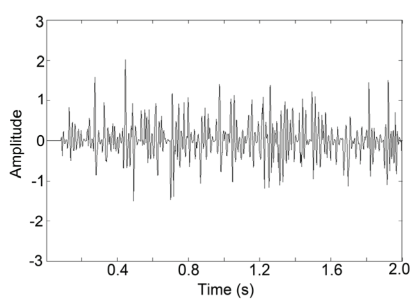

Figure 2. The ideal trace

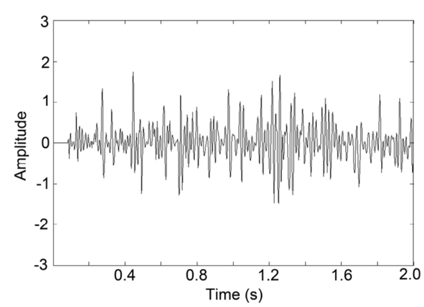

Figure 3. The recovered trace