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Effects of the Near Field on Source-independent Q Estimation

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SUMMARY

We consider the problem of Q estimation from microseismic and from perforation shot data. Assuming that the source wavelet is not well known, we focused on the spectral ratio method and on source-independent viscoelastic full waveform inversion. We derived 3-D near-field approximations of monopole and dipole Green's tensors in a homogeneous viscoelastic medium. We show that the spectral ratio method is not applicable in the near-field region, but a two-step source-independent viscoelastic full waveform inversion strategy applied to synthetic data can first recover the purely elastic velocities and then provide an attenuation estimate.

Introduction

This work is motivated by the problem of attenuation estimation from microseismic and perforation shot data. Usually, the source wavelet is not well known, so we focus on Q estimation techniques that can handle this problem. Earlier, we revisited the spectral ratio method and checked the capabilities of source-independent full waveform inversion in a layered viscoelastic medium under the far-field assumption (Shigapov et al., 2013). However, sometimes Q estimation in the near field of a source is required. Mangriotis et al. (2011) analyzed the effects of the near field on shallow seismic studies. They considered 3-D purely elastic monopole Green's function and investigated the effect of apparent attenuation in the near field when estimated by the spectral ratio and amplitude-decay method. They found that, even in a lossless homogeneous elastic medium, the near-field effect can be poorly suppressed by frequency-domain or polarization filtering. To take into account the near-field effect in a heterogeneous medium, they proposed to use full 3-D modelling. In this work, we consider the effect of the near field on the effectiveness of source-independent Q-estimation techniques in a viscoelastic medium.

Analysis of the near-field effects

In a small area around a source, the near-field approximations of monopole G_{np} and dipole $G_{np,q}$ Green's tensors in a homogeneous viscoelastic medium (Wu and Ben-Menahem, 1985) can be obtained from the corresponding exact formulas using series expansions of exponential functions over the small parameter $i\omega r/\beta$ in the usual notation (Aki and Richards, 2002):

$$G_{np}(\mathbf{x},\omega) \approx \frac{F_p(\omega)}{8\pi\rho\beta^2 r}\cdot\left[\left(1+\frac{\beta^2}{\alpha^2}\right)\delta_{np}+\left(1-\frac{\beta^2}{\alpha^2}\right)\gamma_n\gamma_p\right], \tag{1}$$

$$G_{np,q}(\mathbf{x},\omega) \approx \frac{M_{pq}(\omega)}{8\pi\rho\beta^2 r^2}\left[\left(1-\frac{\beta^2}{\alpha^2}\right)(3\gamma_n\gamma_p\gamma_q-\gamma_n\delta_{pq}-\gamma_p\delta_{nq}-\gamma_q\delta_{np})+2\gamma_q\delta_{np}\right], \tag{2}$$

where complex velocities α and β contain Q_α and Q_β. As a first experiment, we consider the monopole Green's function as a simple model of a perforation shot in a perfectly vertical well, with a horizontal force source $\mathbf{F}=(1,0,0)^T$ and two 3-component receivers at $\mathbf{x}_A$ and $\mathbf{x}_B$ in the same well. Then, $\gamma_1^{A,B} = \gamma_2^{A,B} = 0$ and $\gamma_3^{A,B} = 1$. Consequently, $G_{11}^A/G_{11}^B = r_B/r_A$, whereas $G_{j1}^{A,B} = 0$ for $j = 2,3$. As a second experiment, we assume that the perforation shot is a dipole with only one non-zero component of the moment tensor $M_{11} = 1$. Then, $G_{31,1}^A/G_{31,1}^B = (r_B/r_A)^2$ and $G_{j1,1}^{A,B} = 0$ for $j = 1,2$. Because these ratios do not depend on Q's values, we cannot estimate attenuation with the conventional spectral ratio method under these assumptions. Fortunately, the validity of the presented Green's tensors is restricted to a very small sphere around the source. This is why these formulas do not explain the results of Mangriotis et al. (2011) in a purely elastic homogeneous medium. We therefore generalize the results of Wu and Ben-Menahem (1985) and derive the additional terms in the near-field Green's tensor. Then, the ratio G_{11}^A/G_{11}^B of the first components of a monopole perforation shot from the first experiment is given by

$$G_{11}^A/G_{11}^B = \left[\frac{1}{4r_A}\left(1+\frac{\beta^2}{\alpha^2}\right)-\frac{i\omega}{3\beta}\left(1-\frac{\beta^3}{\alpha^3}\right)\right]\Big/\left[\frac{1}{4r_B}\left(1+\frac{\beta^2}{\alpha^2}\right)-\frac{i\omega}{3\beta}\left(1-\frac{\beta^3}{\alpha^3}\right)\right]. \tag{3}$$

Because the logarithm of this ratio has a complicated dependence on the attenuation, the conventional spectral ratio method applied to the data corresponding to the wave fields in the equation 3 cannot be used. The same conclusion can be drawn after analyzing the exact Green's functions.

Source-independent viscoelastic full waveform inversion in the near field

The spectral ratio method is restricted to far-field VSP data in a laterally homogeneous viscoelastic medium. To overcome this restriction, we propose to use viscoelastic full waveform inversion with a source-independent misfit function. Based on the spectral ratios from the previous section we can construct logarithmic and deconvolution-based misfit functions (Shigapov et al., 2013). Here we restrict ourselves to a convolution-based misfit function, $E_{1SI} = \sum_{i=1}^{N_s}\sum_{j=1}^{N_r}\sum_{k=1}^{3}\frac{1}{2}\left|\left|D_{nk,ref}^{i}U_{nk}^{ij}-U_{nk,ref}^{i}D_{nk}^{ij}\right|\right|_{\ell_2}^2$, because it does not require additional regularizations. Here, we abbreviated the modelled field $U_{nk}(\mathbf{x}_{si},\mathbf{x}_{rj},\omega)$ with U^{ij}_{nk} ($n = P$ or S and $k = 1,2,3$), the observed wave field $D_{nk}(\mathbf{x}_{si},\mathbf{x}_{rj},\omega)$ with D^{ij}_{nk}; N_s is the number of sources, $D^{i}_{nk,ref}$ is the k-th component of the observed reference wave field averaged over the all N_r receivers from the i-th source, and $U^{i}_{nk,ref}$ stands for the corresponding modelled reference wave field. First, we have shown on the near-field synthetic data that this misfit function has its minimum in the correct place if all the other parameters are exactly known (Figure 1, left). If the velocity model has errors, then inversion of only Q fails even with an accurate source wavelet (Figure 1, centre). Assuming that the 'real' and modelled source-wavelets differ by a phase shift, the misfit function has its minimum in the correct place (Figure 1, right). We should mention that the choice of reference traces affect the misfit function and, in some cases, a conventional misfit function with source wavelet estimation may be preferable.

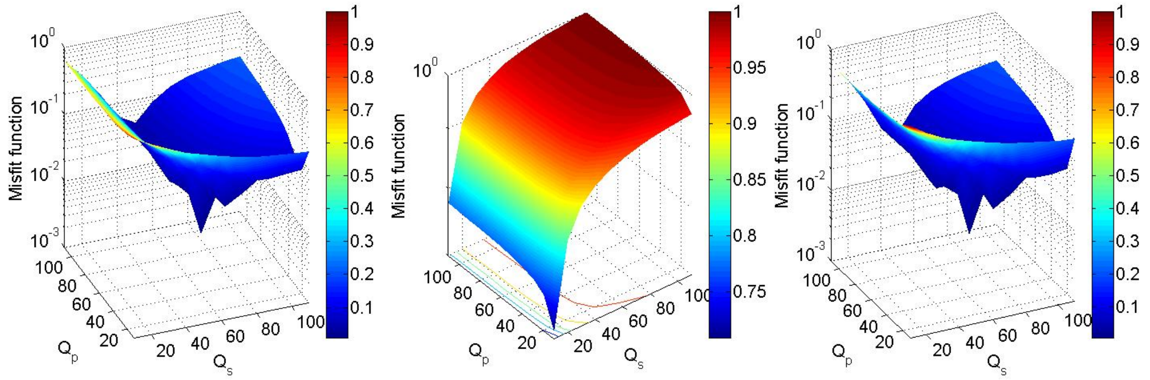

Figure 1 *Values of misfit functions when the Q's are the only unknowns (left), when the velocity model is also unknown (centre), and when 'real' and modelled source wavelets differ by a phase shift of* $\frac{\pi}{3}$ *(right).*

Conclusions

We considered the problem of Q estimation from synthetic microseismic and from perforation shot data. Assuming that the source wavelet is not well known, we focused on the spectral ratio method and on source-independent viscoelastic full waveform inversion. Following Wu and Ben-Menahem (1985), we derived 3-D near-field approximations of monopole and dipole Green's tensors in a homogeneous viscoelastic medium. We have shown that the spectral ratio method is not applicable in the near-field region, but that a two-step source-independent viscoelastic full waveform inversion strategy, where first the purely elastic velocities are reconstructed and then Q inversion is applied, can be used for attenuation estimation in the near field.

Acknowledgements

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