Effects of fractures and background porosity on seismic dispersion and attenuation: theory versus numerical simulations

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Introduction

Recent numerical simulations show that fracture intersections may have a significant effect on elastic properties of fractured reservoirs (Rubino et al., 2016), which provides a possibility of seismic detection and characterization of these intersections. To gain more physical insights into these effects, Guo et al. (2016) proposed a theoretical approach to predict the elastic properties of rocks with intersecting and non-intersecting fractures in different frequency regimes, and showed that the theoretical predictions are in good agreement with the numerical simulations. In this paper, we extend the theoretical predictions of the elastic properties to the full frequency range, computing dispersion and attenuation due to wave induced fluid flow (WIFF) using a branching function formulation of a dynamic theoretical model for poroelastic interaction between pores and fractures (Gurevich et al., 2009; Galvin and Gurevich, 2009).

Method

The frequency-dependent stiffness coefficients due to the WIFF between pores and fractures can be expressed using the branching function, which has the following form (Gurevich et al., 2009):

$$\frac{1}{c^{sat}} = \frac{1}{C_1}\left[1 + \left(\frac{C_1 - C_0}{C_0}\right) \Big/ \left(1 - \zeta + \zeta\sqrt{1 - i\frac{\omega\tau}{\zeta^2}}\right)\right], \qquad (1)$$

where C_0 and C_1 are the elastic moduli in the low and high frequency limits, respectively, while ζ and τ are shape parameters controlled by the fracture shape and defined by poroelastic interaction between pores and fractures (Galvin and Gurevich, 2009). Here, both the frequency-dependent stiffness coefficients caused by the WIFF between the fractures and the background porosity and that within the fractures are expressed by equation (1). Due to the much lower permeability of the background medium than the fractures, the WIFF between the fractures and the background porosity occurs first at lower frequencies. Then, with the increase of the frequencies, the fluid in the fractures doesn’t have enough time to communicate with that in the background porosity. However, it can still communicate with the fluid in the other fractures. Hence, the fluid flow within the fractures occurs. These two types of fluid flow thus result in two stages of seismic dispersion and attenuation. For each stage, the corresponding

C_0, C_1, ζ and τ can be obtained from the properties of the background medium and the fractures. The frequency-dependent stiffness coefficients can then be obtained from equation (1).

Results

One 2D synthetic sample with intersecting fractures is studied. Both theoretical predictions and numerical simulations (Rubino et al., 2016) are carried out and the results are shown in Figure 1. It can be seen that, two stages of seismic dispersion and attenuation exist due to both the WIFF between the fractures and the background porosity (first stage) and that within the fractures (second stage). Good agreement is shown between the theoretical predictions and the numerical simulations for the first stage. However, the frequency shift is observed for the second stage. This may be due to the change of the effective permeability of the fractures, which is not considered in theoretical predictions.

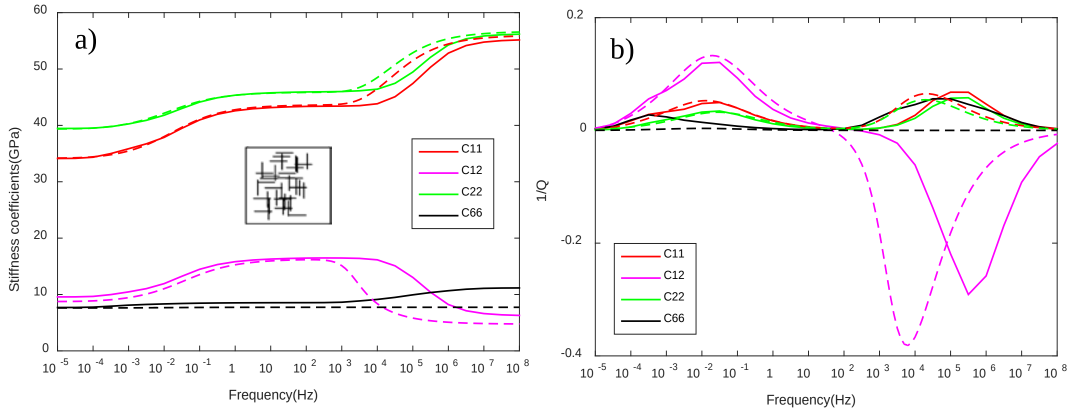

Figure 1: Numerical simulations (solid lines) and theoretical predictions (dashed lines) for the stiffness coefficients. a) Dispersion. b) Attenuation. The sample geometry is shown in the centre of Figure 1a.

Conclusions

Theoretical predictions using a branching function formulation of a dynamic theoretical model for poroelastic interaction between pores and fractures show reasonable agreement with numerical simulations for rocks with intersecting fractures. This work demonstrates a potential for detection and characterization of fracture intersections from seismic data.

Acknowledgements

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