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A synoptic approach to the seismic sensing of heterogeneous fractures: from geometric reconstruction to interfacial characterization

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Abstract. A non-iterative waveform sensing approach is proposed toward (i) geometric reconstruction of penetrable fractures, and (ii) quantitative identification of their heterogeneous contact condition by elastic waves in the frequency domain. To this end, the fracture support Γ (which may be non-planar and unconnected) is first recovered without prior knowledge of the interfacial condition by way of the recently established approaches to non-iterative waveform tomography of heterogeneous fractures, e.g. the methods of generalized linear sampling and topological sensitivity. Given suitable approximation $\breve{\Gamma}$ of the fracture geometry, the jump in the displacement field across $\breve{\Gamma}$ i.e. the fracture opening displacement (FOD) profile is computed from remote sensory data via a regularized inversion of the boundary integral representation mapping the FOD to remote observations of the scattered field. Thus obtained FOD is then used as input for solving the traction boundary integral equation on $\breve{\Gamma}$ for the unknown (linearized) contact parameters. In this study, linear and possibly dissipative interactions between the two faces of a fracture are parameterized in terms of a symmetric, complex-valued matrix $\boldsymbol{K}(\boldsymbol{\xi})$ collecting the normal, shear, and mixed-mode coefficients of specific stiffness. To facilitate the high-fidelity inversion for $\boldsymbol{K}(\boldsymbol{\xi})$, a 3-step regularization algorithm is devised to minimize the errors stemming from the inexact geometric reconstruction and FOD recovery. The performance of the inverse solution is illustrated by a set of numerical experiments where a cylindrical fracture, endowed with two example patterns of specific stiffness coefficients, is illuminated by plane waves and reconstructed in terms of its geometry and heterogeneous (dissipative) contact condition.

Keywords: inverse scattering, elastic waves, fractures, heterogeneous contact condition, specific stiffness, hydraulic fractures.

1. Introduction

Geometric and interfacial properties of fractures in rock and like quasi-brittle solids (e.g. concrete and composites) are the subject of critical importance to a wide spectrum of