Active seismic imaging and characterization of fractures

In recent years, major strides have been made toward the simultaneous geometric reconstruction and interfacial characterization of fractures via seismic waveform tomography. So far the proposed methods, often reliant upon a rudimentary parameterization of the fracture geometry (e.g. planar fractures) and nonlinear minimization, entail a number of impediments including: i) high computational cost; ii) sensitivity to the assumed parametrization resulting in multiple sets of “optimal” solutions and thus the ambiguity of such obtained information; iii) computational instabilities requiring multiple stages of regularization, and iv) major restrictions in terms of the seismic sensing configuration, namely the location of sources and receivers relative to the (planar) fracture surface.

The goal of this study is to establish a comprehensive platform for the 3D reconstruction and mechanical characterization of arbitrarily-shaped, distinct fractures in quasi-brittle materials. In particular, the focus will be on i) developing a robust framework for geometric reconstruction of fractures from the scattered field data using a carefully designed indicator functional that features low sensitivity to measurement noise and imposes no major restrictions on the illumination frequency or the sensing configuration, and ii) recovering the fracture's heterogeneous boundary condition.

Over the past decade, research in applied mathematics and engineering has produced a suite of non-iterative approaches to inverse scattering, such as the linear sampling method (LSM), that are capable of accurately recovering the 3D geometry of subsurface anomalies. In the present work, this goal is accomplished via an extension to the so-called generalized linear sampling method (GLSM) to enable geometric reconstruction of fractures regardless of their interfacial condition. With such result at hand, the proposed inverse solution will entail a 3-step hybrid approach where: 1) the fracture surface is reconstructed without the knowledge of interface; 2) given the geometry, the fracture opening displacement (FOD) profile is recovered from an integral transform relating FOD to the observed seismic waveforms; and 3) given FOD, the spatial distribution of specific stiffnesses is resolved from the boundary integral equation for fracture, incorporating its (inhomogeneous) elastic contact condition. This scheme is integrated into a recently developed BEM code. The proposed developments will then be verified in a laboratory setting, making use of the recently acquired Scanning Laser Doppler Vibrometer (SLDV) that is capable of monitoring triaxial waveforms on the specimen's surface.