Numerical simulation of seismic wave propagation in media with discrete fractures

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Seismic wave propagation in naturally fractured rocks is strongly affected by the different scale length (size) and spatial distributions of fractures. In this study, we present a numerical method that simulates the wavefield propagation in fractured media. We examine the various effects of fractures on the wavefield characteristics. To represent accurately the elastic wave calculations, we use the pseudospectral method. The implementation of fractures with a vanishing width in the 2D finite difference grids is done using an effective medium theory. Fractures are treated as highly compliant interfaces inside a solid rock mass. Following the concept of the linear slip deformation or displacement discontinuity model (DDM) of Schoenberg (J. Acoust. Soc. Am., 1980), a fracture can be represented as a boundary across which the displacements are discontinuous whereas the stresses remain continuous. To first order the displacement discontinuity and the tractions are linearly related, i.e. $[u] = Z\tau$, where $[u]$ is the average displacement discontinuity, $\tau$ is the traction on the fracture, and $Z$ is called the fracture compliance tensor. According to the DDM theory, the effective compliance of a rock mass with one or several fracture sets can be found as the sum of the compliances of the host (background) rock and those of all the fractures (Coates and Schoenberg, Geophysics, 1995, and Liu et al., J. Geophys. R., 2000). Furthermore, the background rock and fracture parameters can be related to the effective anisotropic coefficients, which govern the influence of anisotropy on various seismic signatures.

The validity of the method has been tested and the accuracy examined by comparing synthetic seismograms with corresponding theoretical ray traveltimes. We examine different scale lengths of fractures as well as various spatial distributions. Our results indicate that the behaviour of fractures varies from a single scatter to an interface, depending on the ratio of the fracture length to the wavelength. Equally important is the spatial distribution of fractures that controls the formation of clusters. Our results show that in areas with fracture clustering, there is strong and coherent energy. Numerical modelling techniques, like the one presented here, can be a useful tool in the understanding of the important role of fractures and their effects on wave propagation. The knowledge gained by such studies, may ultimately lead to the extraction of valuable information about the fracture distributions in natural rocks, directly from seismic data.