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Numerical modeling of wave propagation and scattering in heterogeneous and poroelastic rocks

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Scattering of elastic waves in heterogeneous elastic and poroelastic rocks is investigated with numerical wave propagation simulations on the macro- and microscale. Different combinations of finite difference and finite element methods for space and time discretization are used to numerically solve the elastodynamic wave equation in two dimensions. The different numerical algorithms are applied to an elastic scattering problem, i.e. a mechanically weak circular inclusion embedded in a mechanically stiffer elastic medium. The numerical results are compared with an analytical scattering solution for a plane wave hitting the circular inclusion where the diameter of the circular inclusion is of the same order than the wavelength of the plane wave. Staircase-like discretization of the circular shape with the spatial finite difference method prevents calculation of accurate velocity and displacement fields very close to the boundary of the inclusion and may even lead to misinterpretation of the results. The finite element method using an unstructured, triangular mesh is able to provide accurate solutions very close to the inclusion boundary. Away from the circular inclusion all numerical methods give similar results. Waves are trapped inside the inclusion and excite resonant oscillations. The fundamental oscillation frequency of the inclusion can be measured inside and away from the inclusion and does not depend on the central frequency of the incoming plane wave. Scattering simulation in poroelastic rocks on the pore scale uses a three-dimensional microscopic model, which resolves the complex three-dimensional pore geometry and the boundaries between the elastic skeleton and the pore fluid. This is compared with the one-dimensional macroscopic

Biot model that superposes the continuum solid and fluid velocity fields and is based on the effective medium theory. In both cases the finite difference method is applied for the numerical simulation in which a plane P-wave with a wavelength about an order of magnitude larger than the characteristic pore size propagates through the poroelastic rock. Results show that first order transmission and reflection phenomena are captured with both models. However, a significant loss of amplitude of a plane P-wave occurs in the three-dimensional microscopic model due to scattering attenuation on the pore scale, which is not included in the macroscopic Biot model. The applicability and computational advantages and disadvantages of the different numerical algorithms are discussed.