Numerical tools to model seismic waves in unconsolidated and partially saturated granular media

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In order to accurately study the properties of partially saturated unconsolidated media at the near surface scale, or be able to image deeper structures through them, accurate 2D and 3D wave propagation numerical modelling tools are required. The rheology/mechanical properties of such media are frequently extremely complex (nonlinear, anisotropic, ...), even when considered at dry state and of homogeneous mixture. Experimental observations (both at the laboratory and field scales) show that the seismic wave-field in unconsolidated granular materials remains difficult to interpret within standard methodological frameworks. We present here a numerical study aiming at exploring possible alternative forward modelling approaches to better extract information from recorded signals.

We first present a finite volume method (Asfour et al. 2021) in which exact Riemann solvers are introduced. Solutions are compared to high-order finite-differences (Seismic_CPML code) and spectral finite element (SPECFEM code) solutions. A first series of synthetic cases is shown to benchmark the code at the hundred meters scale with a 100-300Hz wavelet source content. Another synthetic and more realistic case is then presented with a medium affected by a steep nonlinear velocity gradient in depth, typical of an unconsolidated granular medium (as previously considered at laboratory scale). For this model, a 1500Hz dominant frequency point source wavelet is considered and fluid saturation is also tested by applying a fluid-solid coupling. First arrival times and PSV-wave dispersion obtained from the different codes are compared.

In a second step, and considering the real data recorded at the laboratory, we apply a more realistic source wavelet (obtained through signal spectrum ratio) and we perform parallelized high-order finite difference simulations (UNISOLVER code) to compare 2D and 3D elastic as well as
poroelastic solutions on finely discretized meshes. Computed and observed data are compared. The poroelastic rheology provides better amplitudes in the seismograms and better exhibits some PSV modes in the phase velocity dispersion observations. Sensitivity kernels are also shown for the different rheologies. The different results obtained are now paving the way to seismic inversion at the near surface scale and to image shallow fluid/water saturated layers.