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Multiphase flow, deformation and wave propagation in porous media

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Our goals are to determine some of the most important macroscopic properties of porous media whether they are dry or saturated by one or two fluids such as permeabilities, solid deformations and acoustic velocities. Therefore, one needs to calculate fluid flow through the pores and the deformation of the solid matrix.

Single and multiphase flows are determined by Lattice Boltzmann Models (LBM) where fluid motion is described in terms of a discretized particle distribution function which obeys a Lattice Boltzmann Equation equivalent to the Navier-Stokes equations at the macroscopic level. Complex boundary conditions can be easily treated by LBM which makes it convenient for flow simulations in porous media. Applications to the determination of the absolute permeability and of the relative permeabilities in complex media are given as well as examples of transient phenomena.

Elastic deformations of the solid matrix whether they are static or time dependent can be determined by Lattice Spring Models (LSM). The solid matrix is represented by a regular cubic lattice whose points are connected by springs which are either linear (between the lattice points) or angular (between the linear springs). The spring set is selected in order to obtain an equivalent isotropic solid. The elastic properties of the medium can be calculated from the elastic energy stored in the elementary cell. A mass can be assigned to the lattice points. Applications to the determination of the macroscopic Young modulus and Poisson ratio of porous solids are given as well as direct simulations of wave propagation through dry porous solids.

In order to study wave propagation in porous media containing one or two fluids, the LBM and LSM codes are coupled by using a momentum exchange algorithm which equates the velocities and the normal stresses at the solid-fluid interface. Then, two different methods can be used to study wave propagation.

In the first direct method, a pressure variation is induced at a given set of points and one determines how this variation propagates through the fluid and the solid. The precision and some basic phenomena such as the decomposition of a compression wave propagating through the fluid into a shear and a compression wave at an oblique solid-liquid interface, are illustrated.

The second indirect method is based on the homogeneization theory valid when the wave lengths are much larger than the pores and much smaller than the medium. Successive expansions of the local Navier-Stokes equation in the fluid and of the local elasto dynamic equation in the solid coupled as before show that the velocities of the acoustic waves can be obtained in four steps. First, the dynamic permeability is determined; second the macroscopic stiffness tensor is calculated for a dry medium; third, two coefficients characterizing the solid matrix reaction to fluid pressure are calculated; fourth, a Christoffel equation which contains all these quantities is solved in order to calculate the four wave velocities. Various applications illustrate the possibilities of this second method. A few comparisons with analytical solutions or results obtained by different numerical methods are given.

Some possibilities and extensions of these codes are discussed.