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Numerical procedure to obtain the effective dynamic permeability of heterogeneous poroelastic media

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We propose a numerical upscaling procedure to infer the effective dynamic permeability of heterogeneous poroelastic media. To do so, we apply an oscillatory homogeneous solid displacement field at two opposite sides of a sample while, at the remaining boundaries, (a) the components of the solid ($\mathbf{u}$) and fluid relative ($\mathbf{w}$) displacements normal to the imposed displacement are set to zero and (b) the fluid relative displacement parallel to the imposed displacement is periodic. Under these conditions, we numerically solve the coupled dynamic equations of poroelasticity in the space-frequency domain[1]. Next, we evaluate the ratio between the components of $\mathbf{w}$ and $\mathbf{u}$ in the direction of the imposed displacement ($\hat{x}$) averaged over the sample's volume. When the fluid pressure gradients (∇p_f) induced in the sample can be neglected, the obtained ratio can be related with an effective dynamic permeability ($\kappa(\omega)$) using the generalized Darcy's law for the overall relative fluid motion in the sample as follows

$$\kappa(\omega) = \frac{i\eta w_x}{\omega \rho_f u_x}, \tag{1}$$

where i is the imaginary unit, ω is the angular frequency, and η and ρ_f are the fluid shear viscosity and density, respectively. Fig. 1 shows a validation of the numerical procedure for homogeneous and layered media (varying permeability).

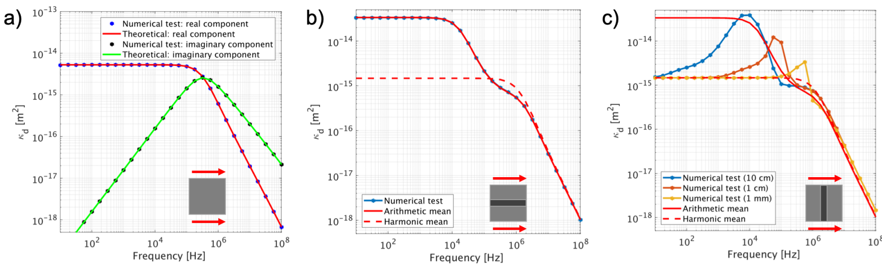

Figure 1: Numerically inferred effective permeability for (a) homogeneous and (b and c) layered sandstones compared with pertinent analytical models. Note that an acceleration applied perpendicular to the layering (c) results in a propagating slow P-wave inside the mid layer for which $\nabla p_f \neq 0$ and Eq. 1 is not valid anymore. Consequently, the numerical results deviate from the theoretical solution (red dashed line). The characteristic frequency of this process depends on the slow P-wavelength and mid-layer size.

[1]Biot, M. A. (1962). *Mechanics of deformation and acoustic propagation in porous media. Journal of Applied Physics, 33, 1482-1498.*