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Pore-scale simulations of resonances using full-waveform finite-difference numerical modeling

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Full-physics numerical simulations using pore-scale models derived from microscopic image data have allowed geoscientists to probe a variety of issues in effective medium theory without relying on theoretical or empirical simplifications. Although the full-physics approach was initially adopted for fluid-flow simulations, it has recently been applied to studies of wave propagation.

Our method utilizes full-waveform, finite-difference modeling of wave propagation and is related to the resonant bar technique. During a full-waveform simulation, resonances, or standing waves, form along a single axis of a numerical model derived from microscopic image data. For example, the size of one of these models, based on Castlegate sandstone, is 424x424x460 samples in the xyz-directions. These microscopic image data are the result of X-ray CT at the GSECARS 13-BM beam line at the Advanced Photon Source. We take such a volume of microscopic image data and initiate a broadband planar source of energy on one of the two boundaries perpendicular to the z-axis, which are both stress-free. We set the other four boundaries to be periodic and allow the wave to bounce between the two free surfaces for a long period of time. By Fourier-transforming the mean displacement field at the stress-free boundary opposite of the source, we study resonances in the amplitude spectrum, in a way analogous to normal-mode seismology.

From the numerical simulations, we observe a transition in the wave propagation properties of the pore-scale models from an effective medium description to a regime of strong pore-scale scattering as a function of frequency. We are able to extend our initial results, obtained for acoustic wave propagation in the presence of a single fluid phase, to include elastic and anacoustic rheologies saturated by multiple fluid phases.

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