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Motional Modes of Dilatational Waves in Elastic Porous Media Containing Two Immiscible Fluids

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Although numerical simulations indicate that three modes of dilatational wave motion exist in an elastic porous medium containing two immiscible, viscous, compressible fluids, the modes of relative motion among the three constituents have remained uncharacterized. In the present paper, normal coordinates describing independent dilatational wave motions in an unsaturated porous medium are derived based on the coupled poroelasticity equations of Lo et al. [2005]. These coordinates provide a theoretical foundation to characterize the motional modes using six coefficients depending in a well defined way on inertial drag, viscous drag, and elasticity properties. Using Lincoln sand as a representative example to characterize the motional modes as functions of water saturation at low wave excitation frequencies, we show that the P1 wave, whose phase velocity is greatest, corresponds to the motional mode in which the solid framework and two pore fluids always move in phase, regardless of water saturation. For the P2 wave, which propagates second fastest, the solid framework moves in phase with water, but out of phase with air, if the water saturation is below 80 to 90 %, whereas the solid framework moves out of phase with both pore fluids at near 100 % water saturation. Only this latter motional mode corresponds to the slow compressional wave in the classic Biot theory for a water-saturated system. For the P3 wave, which has the smallest speed, the solid framework undergoes negligibly small displacements; thus, this dilatational mode is due mainly to motions of the two pore fluids, which are always out of phase, a result that is consistent with the proposition that the P3 wave results from capillary pressure fluctuations. For the P2 and P3 waves, the physical variable controlling the dilatational motions of the pore fluids is the ratio of their relative saturations, and in the case of the P2 wave, the relative motion of the pore fluids and the solid framework is governed by an effective dynamic shear viscosity.