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Wave velocity dispersion and attenuation in media exhibiting internal oscillations

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Understanding the dynamical and acoustical behavior of porous and heterogeneous rocks is of great importance in geophysics, e.g. earthquakes, and for various seismic engineering applications, e.g. hydrocarbon exploration. Within a heterogeneous medium oscillations with a characteristic resonance frequency, depending on the mass and internal length of the heterogeneity, can occur. When excited, heterogeneities can self-oscillate with their natural frequency. Another example of internal oscillations is the dynamical behavior of non-wetting fluid blobs or fluid patches in residually saturated pore spaces. Surface tension forces or capillary forces act as the restoring force that drives the oscillation. Whatever mechanism is involved, an oscillatory phenomena within a heterogeneous medium will have an effect on acoustic or seismic waves propagating through such a medium, i.e. wave velocity dispersion and frequency-dependent attenuation.

We present two models for media exhibiting internal oscillations and discuss the frequency-dependent wave propagation mechanism. Both models give similar results: (1) The low-frequency (i.e. quasi-static) limit for the phase velocity is identical with the Gassmann-Wood limit and the high-frequency limit is larger than this value and (2) Around the resonance frequency a very strong phase velocity change and the largest attenuation occurs.

(1) Model for a homogeneous medium exhibiting internal oscillations
We present a continuum model for an acoustic medium exhibiting internal damped oscillations. The obvious application of this model is water containing oscillating gas bubbles, providing the material and model parameters for this study. Two physically based momentum interaction terms between the two inherent constituents are used: (1) A purely elastic term of oscillatory nature that scales with the volume of the bubbles and (2) A viscous term that scales with the specific surface of the bubble. The model is capable of taking into account an arbitrary number of oscillators with different resonance frequencies. Exemplarily, we show a log-normal distribution of resonance frequencies. Such a distribution changes the acoustic properties significantly compared to the case with only one resonance frequency. The dispersion and attenuation resulting from our model agree well with the dispersion and attenuation (1) derived with a more exact mathematical treatment and (2) measured in laboratory experiments.

(2) Three-phase model for residually saturated porous media
We present a three-phase model describing wave propagation phenomena in residually saturated porous media. The model consists of a continuous non-wetting phase and a discontinuous wetting phase and is an extension of classical biphasic (Biot-type) models. The model includes resonance effects of single liquid bridges or liquid clusters with miscellaneous eigenfrequencies taking into account a visco-elastic restoring force (pinned oscillations and/or sliding motion of the contact line). In the present investigation, our aim is to study attenuation due to fluid oscillations and due to wave-induced flow with a macroscopic three-phase continuum model, i.e. a mixture consisting of one solid constituent building the elastic skeleton and two immiscible fluid constituents. Furthermore, we study monochromatic waves in transversal and longitudinal direction and discuss the resulting dispersion relations for a typical reservoir sandstone equivalent (Berea sandstone).