Frequency-dependent Elastic Moduli and Attenuation of Sandstone and Carbonate Rocks

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Abstract

Elastic moduli and attenuation in a fluid-saturated and heterogeneous porous media depend on wave propagation frequency. At high frequencies, wave propagation induces local fluid flow in the pore space and creates decoupled processes between solid and fluid phases. The major implication of this frequency dependency is velocity dispersion and related variations in elastic moduli (e.g., Young's modulus). Because frequency ranges in the field are different compared to those in the lab, reconciling results from core specimens with field conditions and properly predicting rock and fluid behavior is a challenge. This study aims to circumvent this difficulty by analyzing in the laboratory elastic moduli, acoustic velocities and associated attenuation of intact rocks as a function of frequency with a focus on seismic frequencies.

To meet the study objectives, we use three laboratory experiment methods: First, a custom-designed and manufactured resonance column that generates longitudinal, flexural and torsional vibration modes below 50 Hz. We mount two proximity sensors to separate one vibration mode data to another mode. Second, cyclic loading tests using a triaxial compression frame, which allows us to generate low-frequency oscillation on the specimen under confined and fluid-saturated conditions. Third, the ultrasonic method provides a high-frequency wave propagation which gives an upper limit of the P and S-wave velocities and calculated moduli. The tested rocks include Berea sandstone and Jurassic carbonate specimens.

Results reveal: 1) the attenuation and stiffness in the resonance column test reach an asymptote or linear viscoelastic behavior when the maximum strain is below 10-5. 2) The cyclic loading and ultrasonic measurements show almost constant elastic moduli and velocities as a function of frequency for dry rock specimens. By contrast, the compressional velocity increases by 15% and Young’s modulus rises by 36% for oil-saturated sandstone specimens. 4) The analytical Biot’s, squirt flow and Greetsma-Smit’s models fit the experimental data and help to understand the underlying mechanism of dispersion behavior and predict the elastic moduli in the intermediate frequencies. The cyclic loading and ultrasonic techniques offer a wide spectrum of elastic moduli study for intact rock. The new custom-made resonance column provides robust and easy attenuation measurement from its decaying amplitude over time in comparison to hysteresis curve and phase shift methods in a typical cyclic loading test. The new combination of these three methods provides a comprehensive and comparable dataset that emulates subsurface reservoir conditions and simulations