S-wave attenuation due to wave-induced fluid flow in heterogeneous, partially saturated porous media

Beatriz Quintal*, Holger Steeb**, Marcel Frehner*, and Stefan M. Schmalholz***

*The Rock Physics Network at ETH Zurich (ROCKETH), Sonneggstrasse 5, 8092, Zurich, Switzerland (beatriz.quintal@erdw.ethz.ch; marcel.frehner@erdw.ethz.ch)
**Ruhr-University Bochum, Bochum, Germany (holger.steeb@rub.de)
***University of Lausanne, Lausanne, Switzerland (stefan.schmalholz@unil.ch)

We study seismic S-wave attenuation caused by wave-induced fluid flow at the mesoscopic scale (Pride et al., 2004). Simple-shear relaxation experiments are performed by solving Biot's (1941) equations for consolidation of 2D poroelastic media with finite-element modelling (Quintal et al., 2011). The experiments yield time-dependent stress-strain relations used to calculate the undrained shear modulus, from which S-wave attenuation is determined. Our model consists of periodically distributed (simple-cubic packing) circular heterogeneities with much lower porosity and permeability than the continuous background medium. The continuous background is fully saturated with oil and the low porosity regions are saturated with water. The background contains 80% of the total pore space of the medium. The total saturation in the medium is then 80% oil, 20% water. Snapshots of the relaxation experiment are shown in Figure 1.

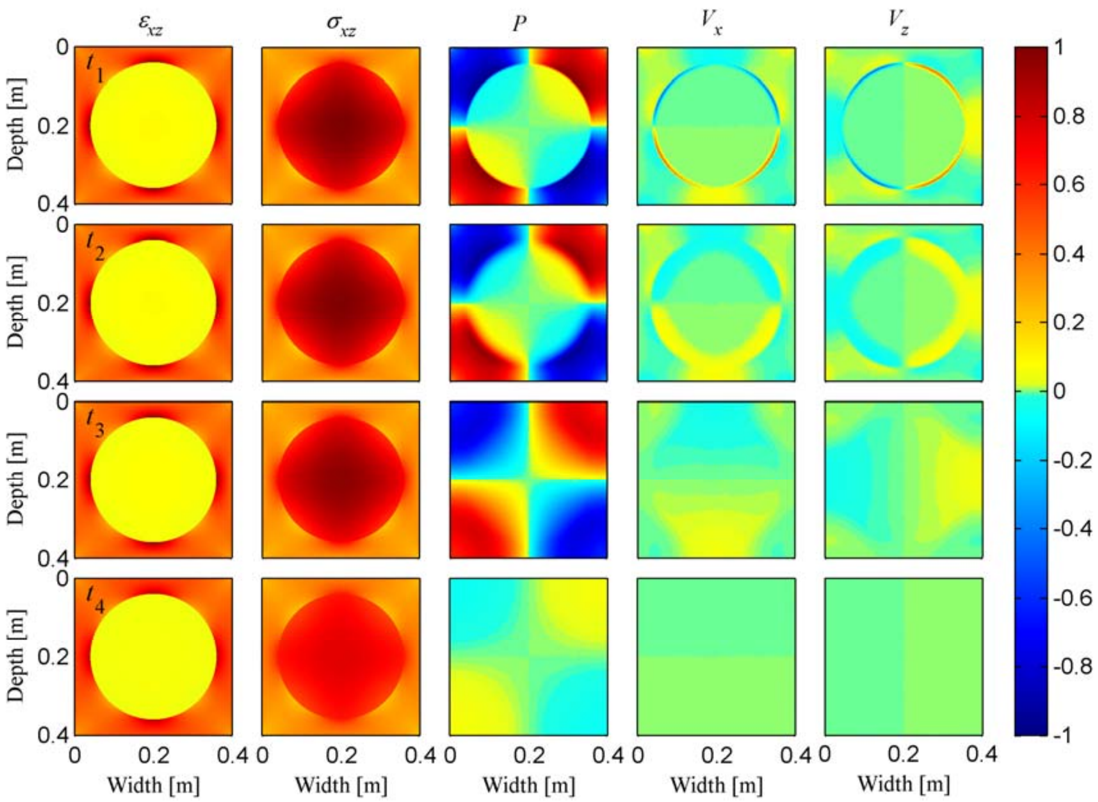

Figure 1. Snapshots at times t_1 = 8.66×10^{-6} s, t_2 = 1.15×10^{-4} s, t_3 = 2.8×10^{-3} s, and t_4 = 0.1 s, of the simple-shear relaxation experiment on the representative elementary volume with a circular heterogeneity saturated with oil. The fields ε_{xz} (shear strain), σ_{xz} (shear stress), P (pore fluid pressure), V_x and V_z (fluid velocity in the x- and z-directions) are normalized by their maximum values. The results are shown in Figure 2 (case A, oil-saturated heterogeneity).

For comparison, we also perform experiments for the background saturated with gas or water, instead of oil. The results are shown in Figure 2, where cases A to D differ in the values of the dry bulk and shear moduli (K and μ, respectively) in the background and in the heterogeneities. In case A, K and μ are, respectively, 36 and 32 GPa in the heterogeneity, and 4 and 2 GPa in the background. In case B, 36 and 32 GPa in the heterogeneity, 14 and 12 GPa in the background. In case C, 12 and 8 GPa in the heterogeneity, 4 and 2 GPa in the background. Case D is the opposite of case A, where K and μ are 4 and 2 GPa in the heterogeneity, and 36 and 32 GPa in the background.

The S-wave attenuation in this study is caused by flow of the pore fluid between the heterogeneity and the background caused by fluid pressure differences (see snapshots for P, V_x and V_z in Figure 1). A consistent tendency is observed in the relative behavior of the S-wave attenuation among the different saturation cases (Figure 2). First, in the gas-saturated media the S-wave attenuation is very low and much lower than in the oil-saturated or in the fully water-saturated media. Second, at low frequencies, the S-wave attenuation is significantly higher in the oil-saturated media than in the fully water-saturated media. Based on these tendencies, we suggest that S-wave attenuation could be used in seismic interpretation as an indicator and discriminator of fluid content in a reservoir, in addition to P-wave attenuation.

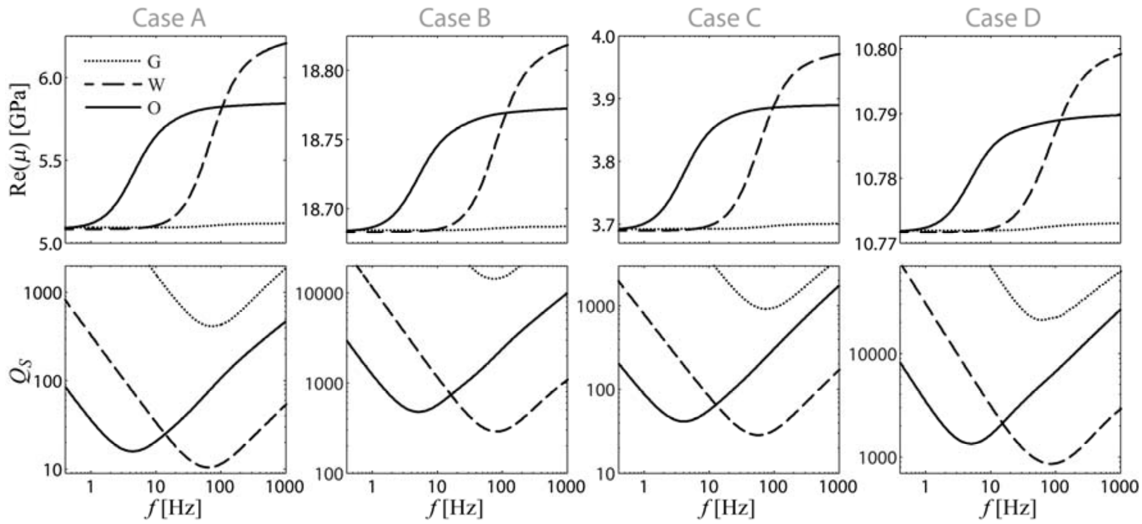

Figure 2. Numerical results for the real part of the undrained shear modulus, μ, and the S-wave quality factor, Q_S. The inverse of Q_S is a measure of S-wave attenuation. The legend terms refer to the fluid in the background: gas (G); water (W); or oil (O).

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