Laboratory Measurements of Seismic Attenuation

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April 23, 2018

Outline

Motivation

Laboratory measurements of seismic attenuation on fluid-saturated rocks are important because many amplitude and frequency attributes are used to infer information about the subsurface from seismic data sets. For example, these measurements are used as reference values to check the validity of FWI models.

Objective

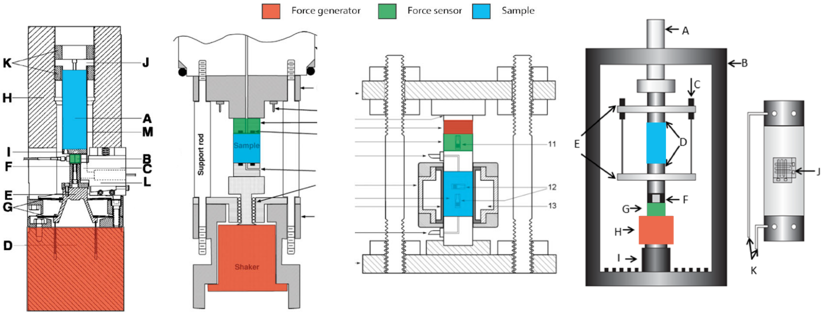
- Szewczyk et al. (2016) and Lozovyi et al. (2018) demonstrated the ability of the low-frequency apparatus at SINTEF to measure the dynamic elastic constants (i.e. Young's modulus and Poisson's ratio) at seismic frequencies.
- However, thus far, we have been unable to perform reliable attenuation measurements (i.e. $1/Q_E$) on rock samples at these frequencies.
- That being said, we have obtained attenuation measurements on standard test materials (e.g. aluminium, plexiglas, and PEEK) that are comparable to that of others.

Literature

Table 1: Comparison of forced-deformation setups based on longitudinal, torsional, and volumetric mode. Partly based on Subramaniyan et al. (2014).

Mode	Author(s)	Sample material	Force generator	Force sensor	Displacement sensor	Frequency [Hz]	Strain amplitude [V]	Parameter(s)
Longitudinal	Batzle et al. (2006)	Various	Shaker	Aluminium STD	Strain gauge	5-2500	10^{-7}	E, $1/Q_E$, ν
	Borgomano et al. (2017)	Limestone	PZT actuator	Aluminium STD	Strain gauge	0.01-10	$\sim 10^{-6}$	E, $1/Q_E$, ν
	Bruckshaw et al. (1961)	Various	Coils	-	-	40-120	-	E, $\Delta W/W$
	Lienert et al. (1990)	Berea	Shaker	PZT transducer	Capactative probe	0.1-100	10^{-7}	E, $1/Q_E$
	Huang et al. (2015)	Various	PZT actuator	Aluminium STD	Strain gauge	2-800	10^{-7}-10^{-6}	E, ν, A, θ
	Madonna et al. (2013)	Berea	PZT actuator	Aluminium STD	LVTDs	0.01-100	10^{-6}	E, $1/Q_E$
	Mikhaltsevitch et al. (2014)	Sandstone	PZT actuator	Aluminium STD	Strain gauge	0.1-400	10^{-8}-10^{-6}	E, $1/Q_E$, ν
	Paffenholz et al. (1989)	Various	PZC transducer	PZT transducer	Inductive transducer	0.003-300	10^{-8}-$5 \cdot 10^{-6}$	E, $1/Q_E$
	Spencer (1981)	Various	Shaker	PZT transducer	Capacitive transducer	4-400	10^{-6}	E, $1/Q_E$
	Szewczyk et al. (2016)	Shales	PZT actuator	PZT transducer	Strain gauge	1-155	$> 10^{-6}$	E, ν
	Tisato et al. (2012)	Berea	Motor	Load cell	Strain gauge cantilever	0.1-100	10^{-6}	E, $1/Q_E$
	Usher (1962)	Various	Vibrators	-	Optical	2-40	10^{-6}-10^{-5}	E, $\Delta W/W$
Torsional	Behura et al. (2007)	Carbonate	Spindle	-	Transducer	0.01-80	$6 \cdot 10^{-7}$-$8 \cdot 10^{-5}$	G, $1/Q_S$
	Paffenholz et al. (1989)	Various	PZC transducer	Aluminium STD	Inductive transducer	0.003-100	$2 \cdot 10^{-7}$-10^{-5}	G, $1/Q_S$
Volumetric	Pimienta et al. (2015)	Sandstone	Confining pump	Pressure sensor	Strain gauge	0.005-0.5	$5 \cdot 10^{-7}$-10^{-5}	K, $1/Q_K$

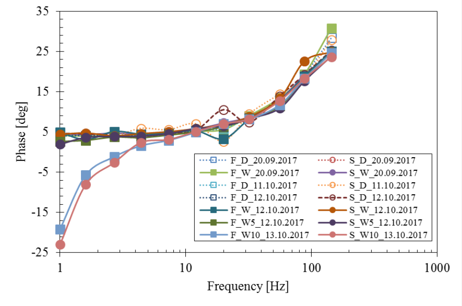
Different Setups



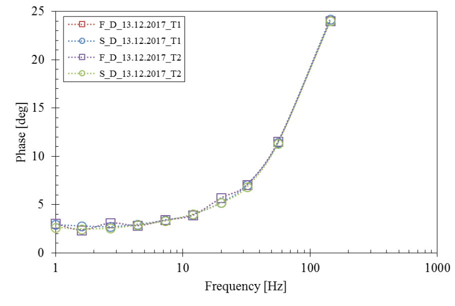
Spencer (1981) Batzle et al. (2006) Mikhaltsevicth et al. (2014) Szewczyk et al. (2016)

Figure 1: Four different forced-deformation setups in which the force generators, force sensors and samples are highlighted. Partly based on Subramaniyan et al. (2014).

Foil Gauges vs. Semiconductors



(a) Aluminium.



(b) PEEK.

Figure 2: Foil gauges (squares) and semiconductors (circles) are put to the test in terms of stability in the absence (open) and in the presence (filled) of a confining fluid.

Foil Gauges vs. Semiconductors

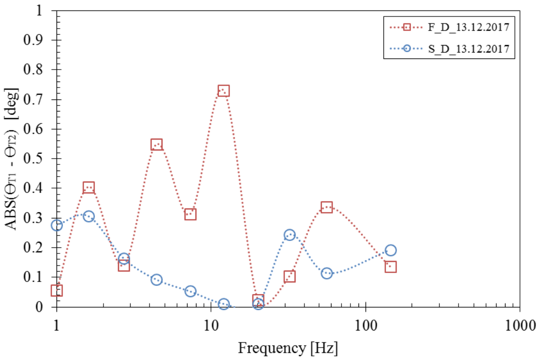


Figure 3: Repeatability of foil gauges (squares) and semiconductors (circles) as a function of two tests performed under identical conditions.

Equations

Since aluminium is non-dispersive, its strain is in phase with the applied force, and the attenuation ($1/Q_E$) may be obtained from the phase shift ($\Delta\theta$) between the stress and the strain response via

$$\frac{1}{Q_E} = tan(\Delta\theta) = tan(\theta_{std} - \theta_{sam}), \tag{1}$$

whereas the Young's modulus is defined as

$$E = \frac{\sigma}{\epsilon}, \tag{2}$$

which leaves the Poisson's ratio

$$\nu = \frac{\epsilon_{rad}}{\epsilon_{ax}}. \tag{3}$$

Plexiglas

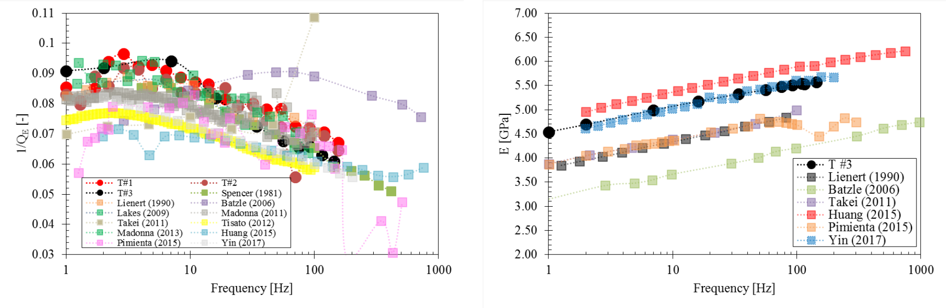


Figure 4: Our experiments (circles) compared to data digitized from various sources (squares) in the absence of a confining fluid.

Aluminium

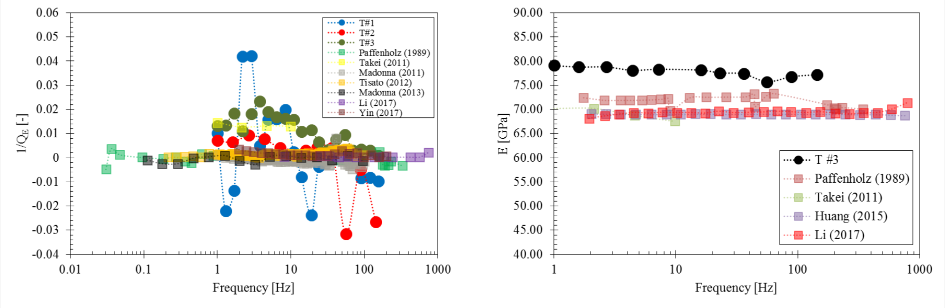


Figure 5: Our experiments (circles) compared to data digitized from various sources (squares) in the absence of a confining fluid.

Comments

- Truth be told, our measurements appears to be more reliable for softer materials, as the data is more scattered for harder materials.
  - In the words of Spencer (1981): "errors in the Young's modulus are generally larger for stiff materials like aluminum, low-porosity carbonates or igneous rocks than for rocks with lower moduli."
  - Rocks exhibit moduli in the region of plexiglas, and it is therefore better to compare it with this material.
- New aluminium standards that has been designed to protect the semiconductors from any fluid interactions are to be tested.

Current Status and Future

- We are currently investigating the temperature dependence of elastic properties of shales at seismic frequencies.
- Bauer et al. (2013) enclosed reasons to believe that the temperature dependence of acoustic velocities is frequency dependent:
    - seismic dispersion is an evident feature in shales, and it is likely that the dispersion is temperature dependent;
    - and the static rock stiffness of shales has been found to be more or less temperature independent while the dynamic stiffness decrease with temperature.

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Acknowledgement