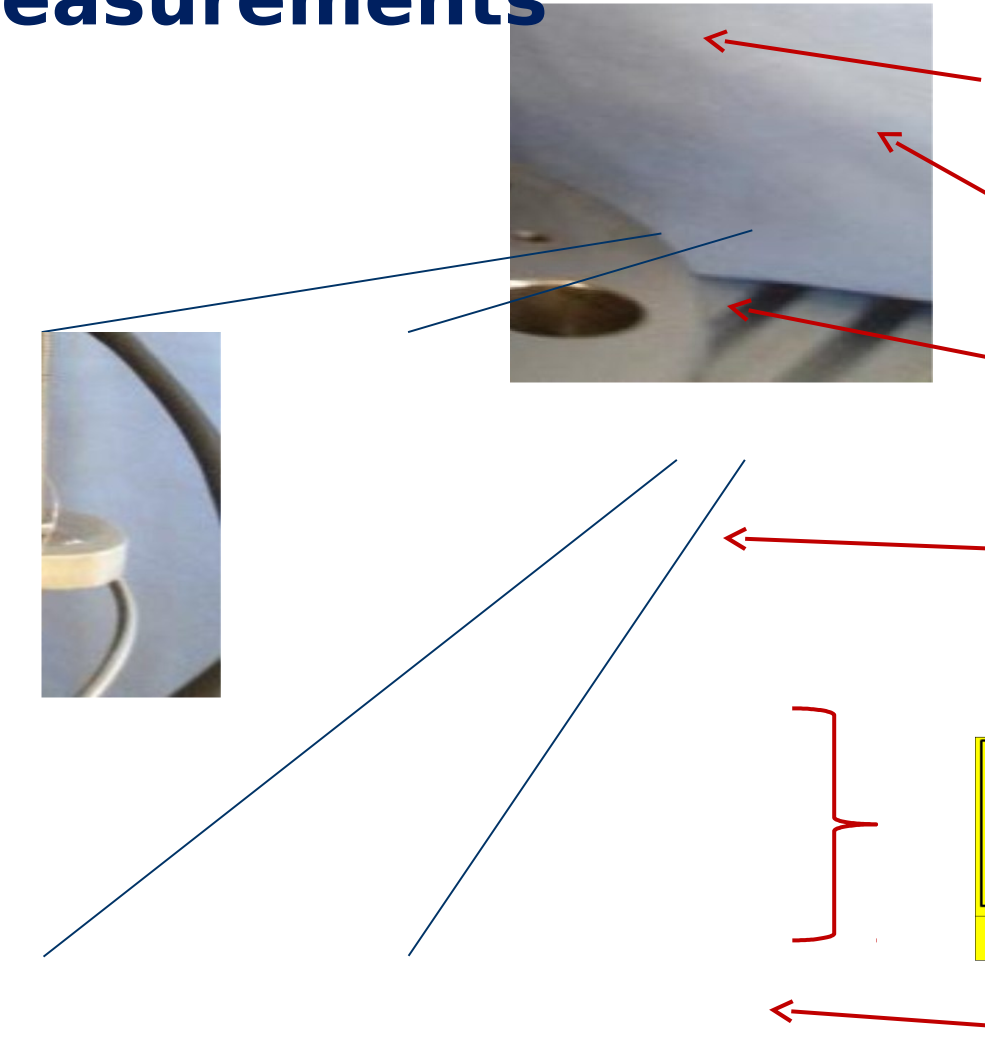
Seismic Dispersion in Mancos Shale

by

Dawid Szewczyk, Andreas Bauer, Rune M. Holt & Jens Hedegaard

ROSE meeting
27th - 30th April 2015
Trondheim, Norway

Triaxial cell for seismic-dispersion measurements



Endcap with ultrasonic transducers (Vp, Vs) and pore-fluid line

LVDT

Rock sample (1" diameter) with 8 strain gages (4 axial, 4 radial) glued to it (rubber sleeve was removed)

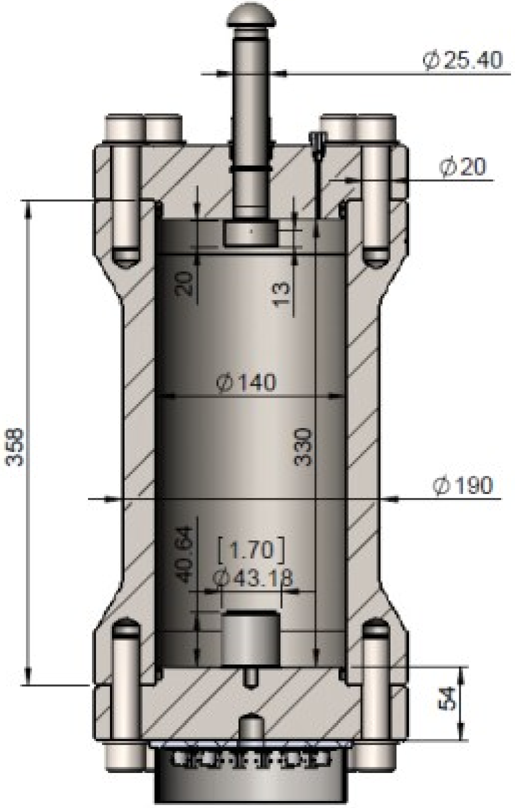
Endcap with ultrasonic transducers (Vp, Vs) and pore-fluid line

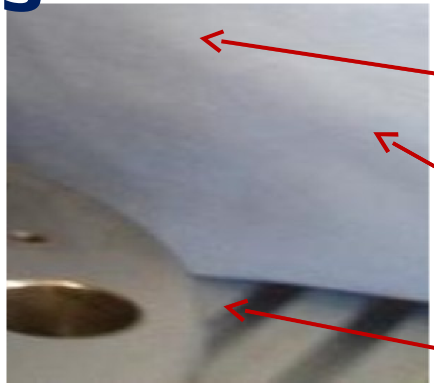
Low-frequency unit consisting of piezoelectric actuator and piezoelectric force sensor, ε~$10^{-7} - 10^{-6}$

force sensor, ε

Internal load cell

Triaxial cell for seismic-dispersion measurements





Endcap with ultrasonic transducers (Vp, Vs) and pore-fluid line

LVDT

Rock sample (1" diameter) with 8 strain gages (4 axial, 4 radial) glued to it (rubber sleeve was removed)

Endcap with ultrasonic transducers (Vp, Vs) and pore-fluid line

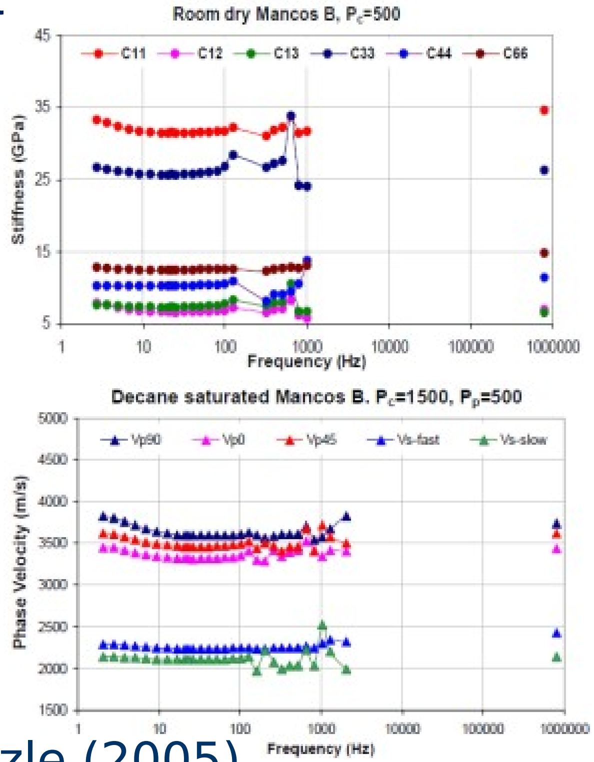
Low-frequency unit consisting of piezoelectric actuator and piezoelectric force sensor, $\varepsilon \sim 10^{-7} - 10^{-6}$

force sensor, ε

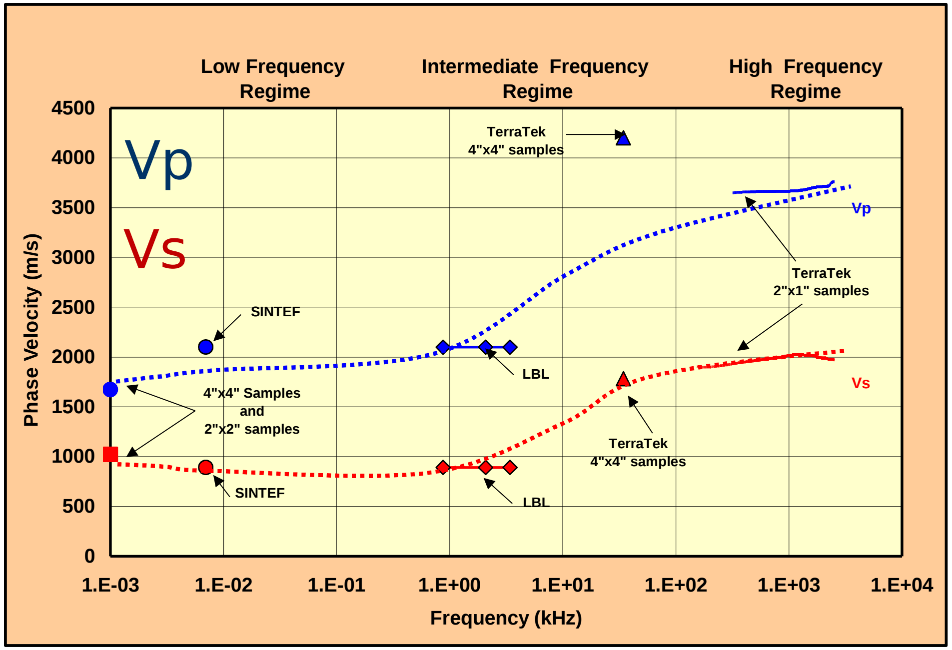
Internal load cell

Mancos shale: Seismic Dispersion – Saturation Effects

- Experimental evidence obtained with Mancos shale shows contradictory results



Sarker, Batzle (2005)



Rivera et al. (2001)

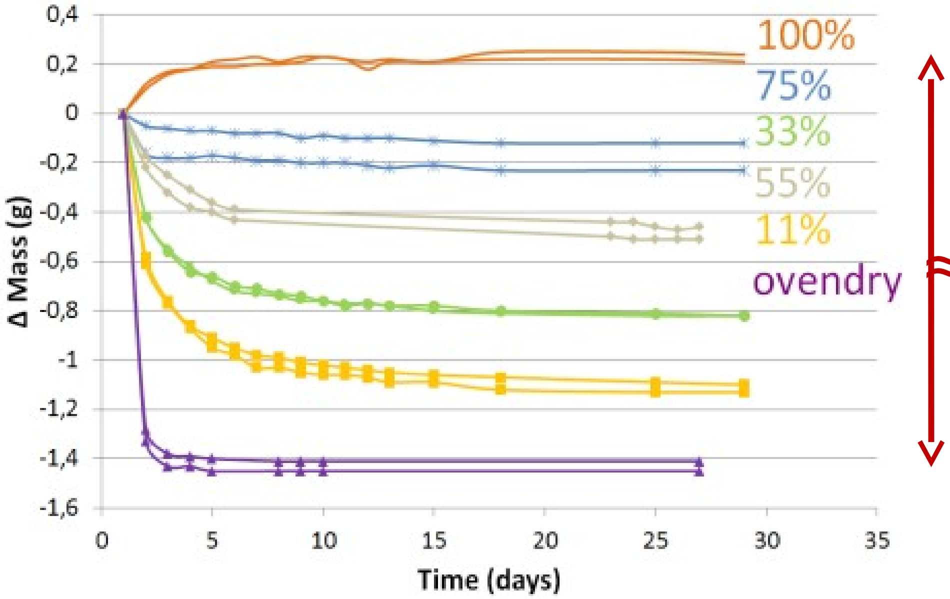
- **Mancos shale**: Static, low-frequency and ultrasonic measurements under deviatoric stress conditions performed on the samples with varying saturation reveals different behaviors in low and high frequency bands and large sensitivity for fluid content.

Mancos shale: Seismic Dispersion – Saturation Effects

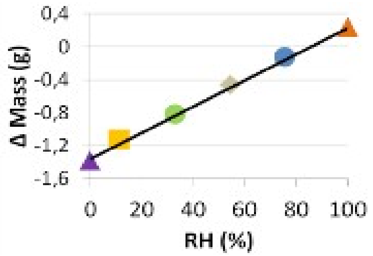
Mancos shale: outcrop, gas shale, preserved in oil, density = 2.57 g/cm³, 6-8% porosity, 20-25% clay, ≈ 1% TOC

Expose samples to different relative humi [RH]:

- 0% [oven-dry]
- 11.3% [LiCl]
- 32.9% [MgCl]
- 54,7% [$Mg(NO_3)_2$]
- 75.4% [NaCl]
- ≈86% [As received]
- 100% [water]



≈6,6% V

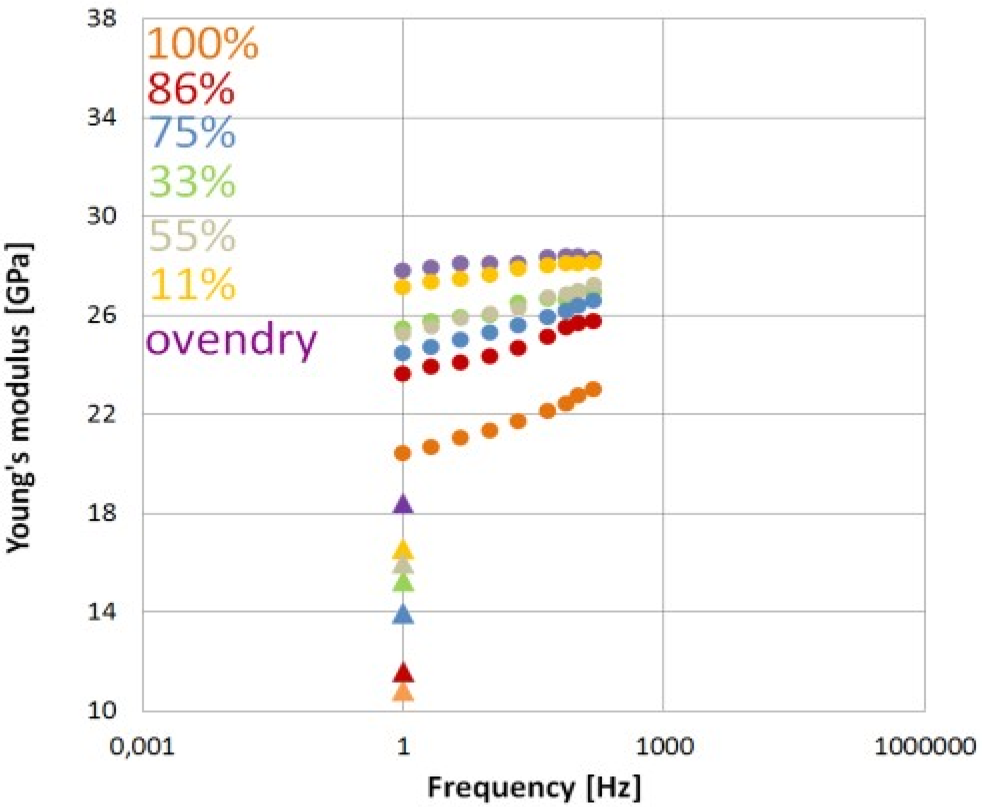


- **RH control → saturated solutions of different type of salts**
- **Total change in water content corresponds to ≈ 6,6% of the sample volume (data available in literature reports range of 6-8%)**
- **Nearly 1 to 1 correspondence between RH and saturation**

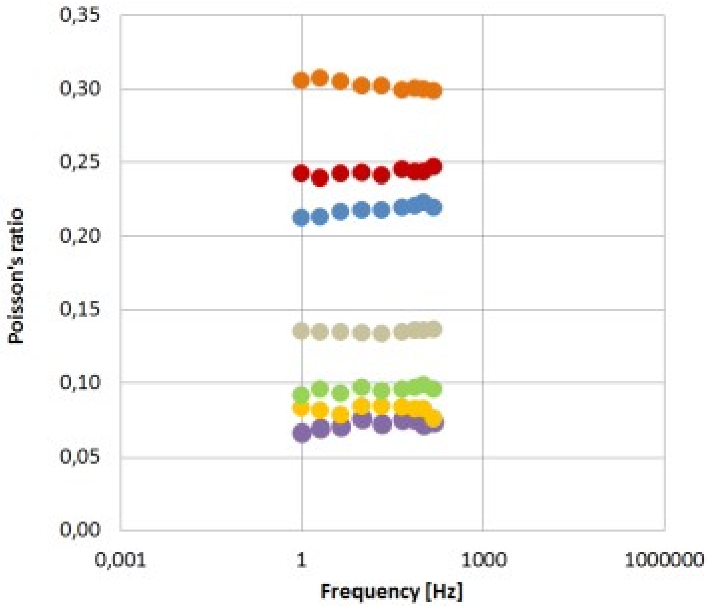
Mancos shale: Seismic Dispersion – Saturation Effects

MPa confining, 26MPa axial

Young's modulus



Poisson's ratio

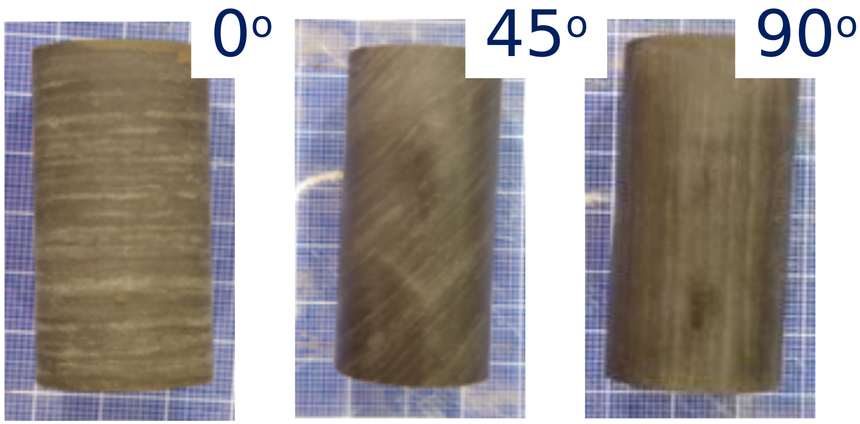


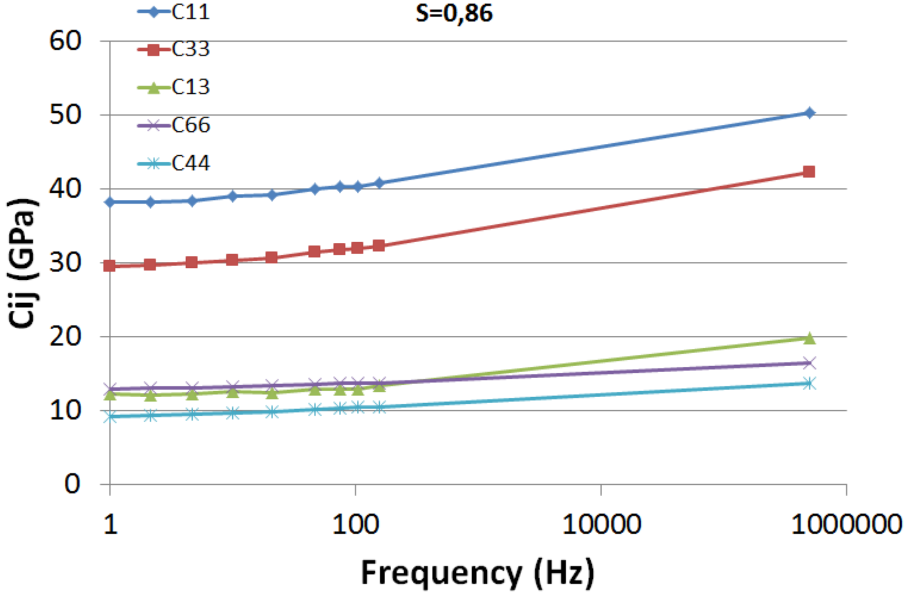
- Increasing saturation → increases Poisson's ratio (fivefold)
- isson's

- Increasing saturation → decrease of static Young's modulus
- Increasing saturation → decrease of dynamic (seismic) Young's modulus
- Increasing saturation → stronger dispersion (seismic range) of Young's modulus

Mancos shale: Anisotropy corrections

- Shales are anisotropic → TI medium → 5 independent stiffness parameters → 3 experiments with differently oriented plugs





- Young's modulus & Poisson's ratio

$$E_{V-Isot} = \frac{\rho V_{SV}^2 (3V_{PV}^2 - 4V_{SV}^2)}{V_{PV}^2 - V_{SV}^2} \rightarrow E_{V-Anisot} = C_{33} - \frac{C_{13}^2}{(C_{11} - C_{66})}$$

$$\nu_{VH-Isot} = \frac{V_{PV}^2 - 2V_{SV}^2}{2(C_{V_{PV}^2} - V_{SV}^2)} \rightarrow \nu_{VH-Anisot} = \frac{C_{13}}{2(C_{11} - C_{66})}$$

$$C_{33} = \rho V_{PV}^2$$
$$C_{11} = \rho V_{PH}^2$$
$$C_{44} = \rho V_{SV}^2$$
$$C_{66} = \rho V_{SH}^2$$
$$C_{13} = \ldots$$

Mancos shale: Anisotropy corrections

- In TI media, the Young's modulus, Ev, for triaxial loading perpendicular to bedding is generally smaller than the Young's modulus obtained from vP and vS (perpendicular to bedding) under the assumption of isotropy. The Poisson's ratio is in general higher.
- Correction factor depends on C_{11}, C_{33}, C_{13} and C_{66} (all three Thomsen anisotropy parameters).

$$\frac{E_{V-Isot}}{E_{V-Anisot}} = \frac{V_{PV}^{2}\left(V_{PH}^{2}-V_{SH}^{2}\right)-C_{13}^{2}}{\left(V_{PH}^{2}-V_{SH}^{2}\right)} \frac{V_{PV}^{2}-V_{SV}^{2}}{\rho V_{SV}^{2}\left(3V_{PV}^{2}-4V_{SV}^{2}\right)}$$

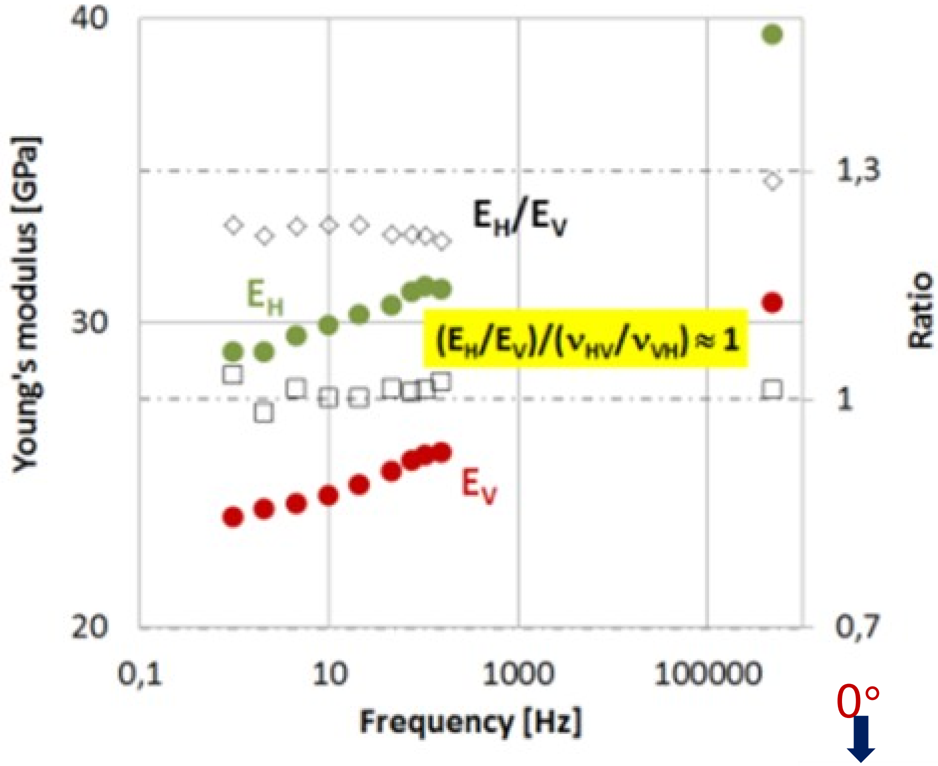
$$\frac{\nu_{VH-Isot}}{\nu_{VH-Anisot}} = \frac{C_{13}}{V_{PH}^{2}-V_{SV}^{2}} \frac{V_{PV}^{2}-V_{SH}^{2}}{V_{PV}^{2}-2V_{SH}^{2}}$$

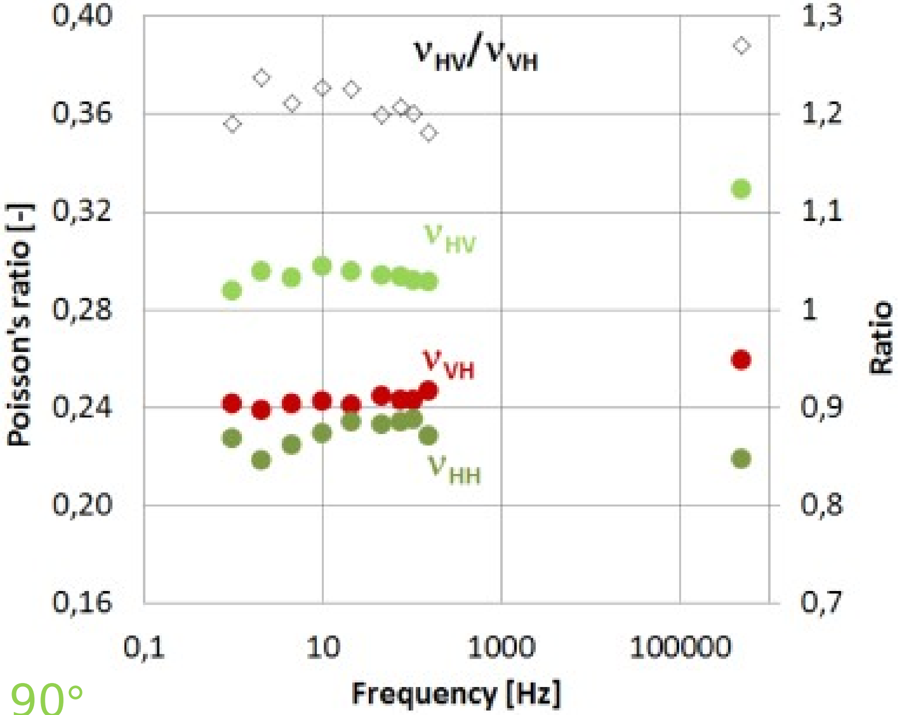
$$C_{13} = \frac{\sqrt{\left(2V_{qP}^{2}-V_{PH}^{2}\sin^{2}\theta-V_{PV}^{2}\cos^{2}\theta+V_{SV}^{2}\right)^{2}-\left(\left(V_{PH}^{2}-V_{SH}^{2}\right)\sin^{2}\theta-\left(V_{PV}^{2}-V_{SV}^{2}\right)\cos^{2}\theta\right)^{2}}}{2\sin\theta\cos\theta}+V_{SV}^{2}$$

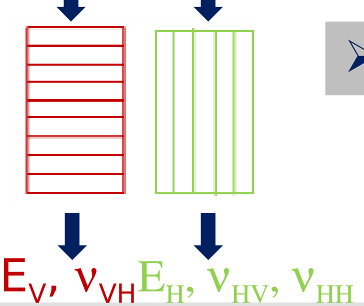
- For our samples correction factor for Ev is equal to 0.93, for Poisson's ratio it is 1,145.

Mancos shale: Anisotropy corrections

- TI symmetry requires: $\frac{\nu_{HV}}{E_H} = \frac{\nu_{VH}}{E_V}$



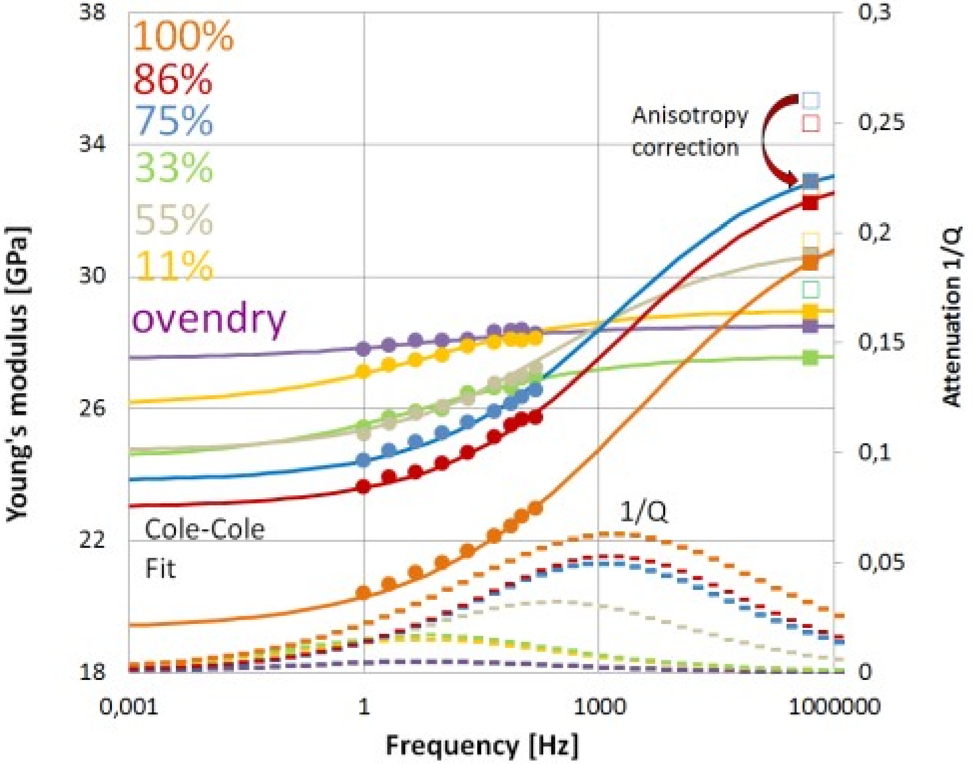




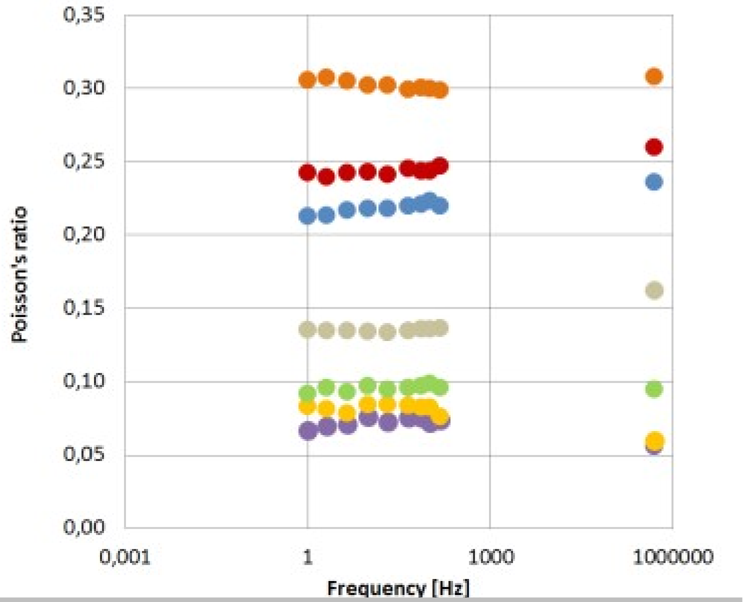
- **Data are valid!**

Mancos shale: Seismic Dispersion – Saturation Effects

Young's modulus: [illegible]MPa confining, 26MPa axial



Poisson's ratio



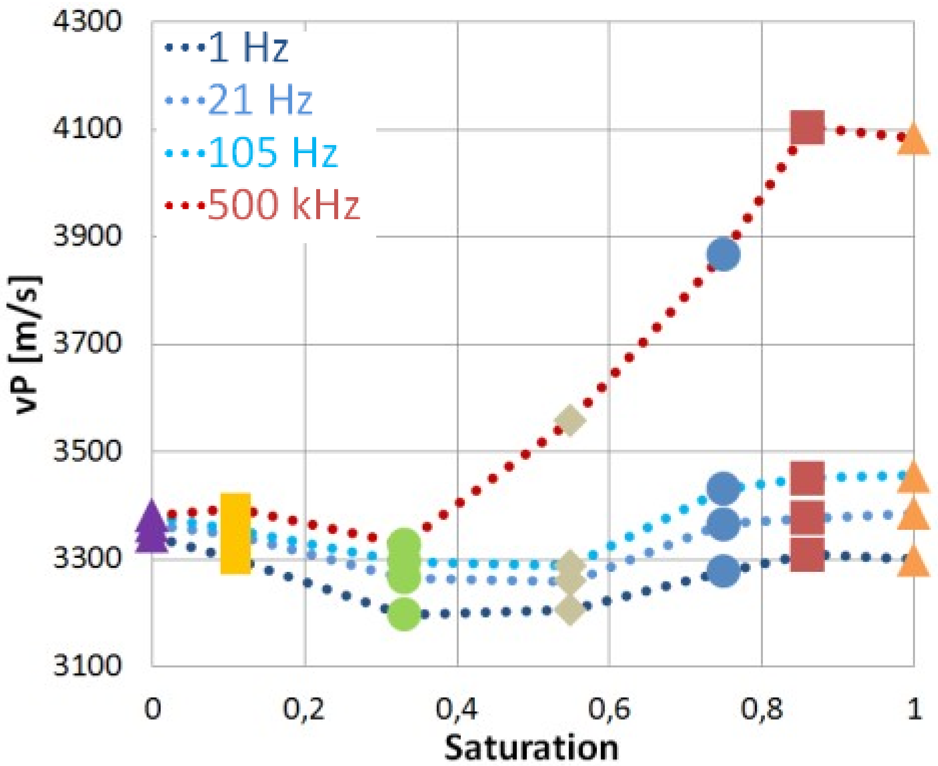
- ➢ **Ultrasonic → Poisson's ratio follow low frequency trend**

- ➢ **Ultrasonic → complex behavior of Young's modulus**
- ➢ **Different saturation effects in seismic and ultrasonic regimes**
- ➢ **Increasing saturation → characteristic frequencies shifted towards higher f**

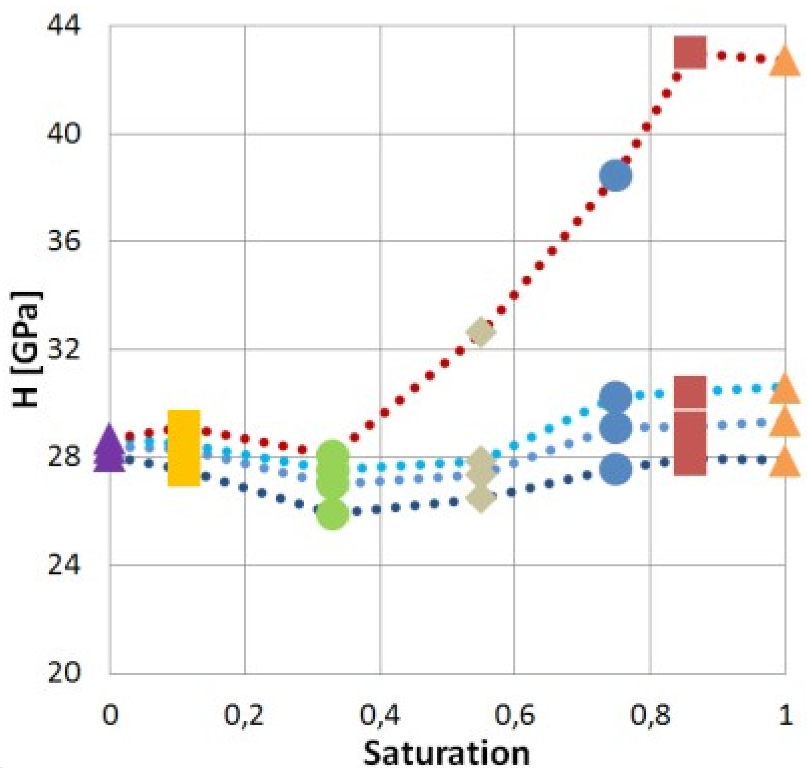
Mancos shale: Seismic Dispersion – Saturation Effects

17MPa confining, 26MPa axial

P wave velocity



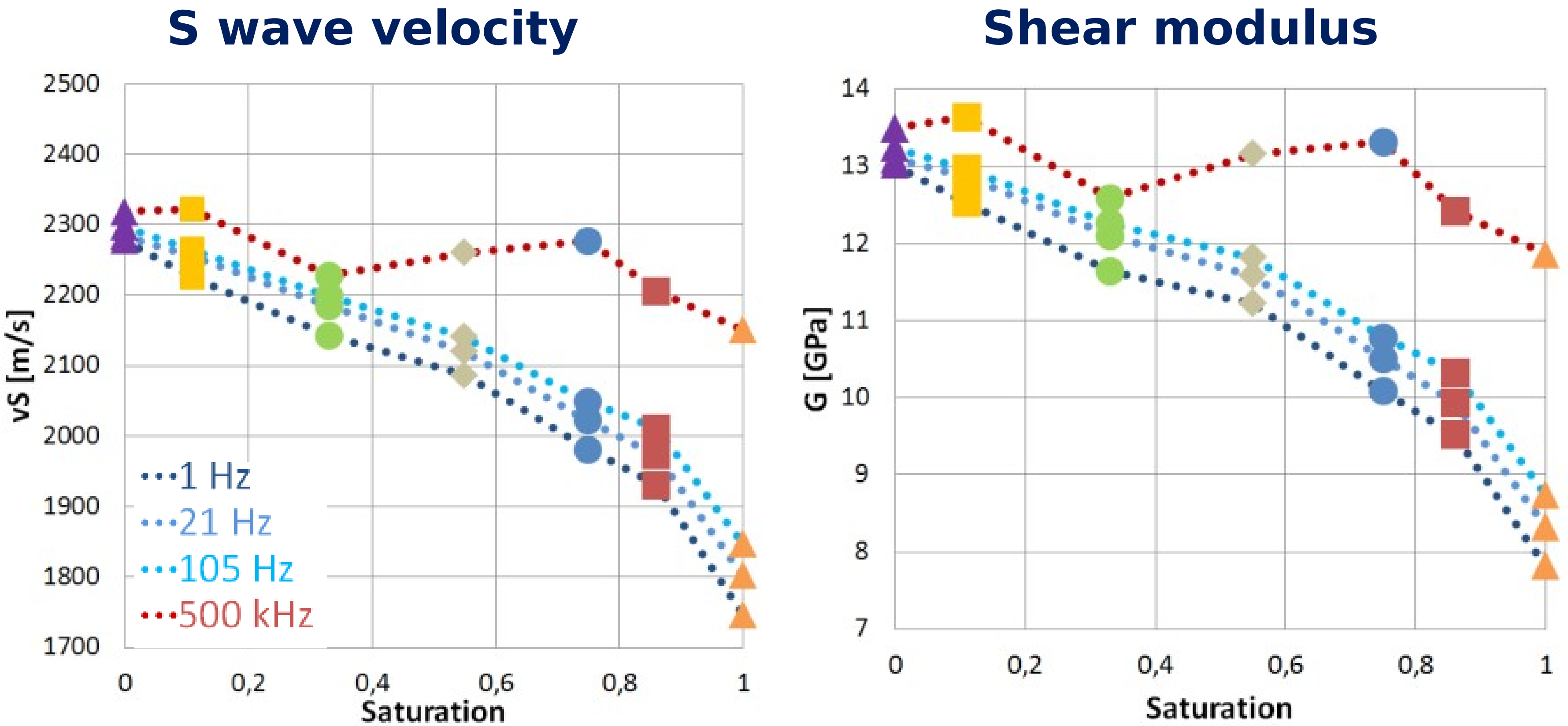
P wave modulus



Varying saturation effects in complex yet different behaviors of low frequency and ultrasonic regimes. Not a density effect.

Mancos shale: Seismic Dispersion – Saturation Effects

17MPa confining, 26MPa axial



S wave velocity

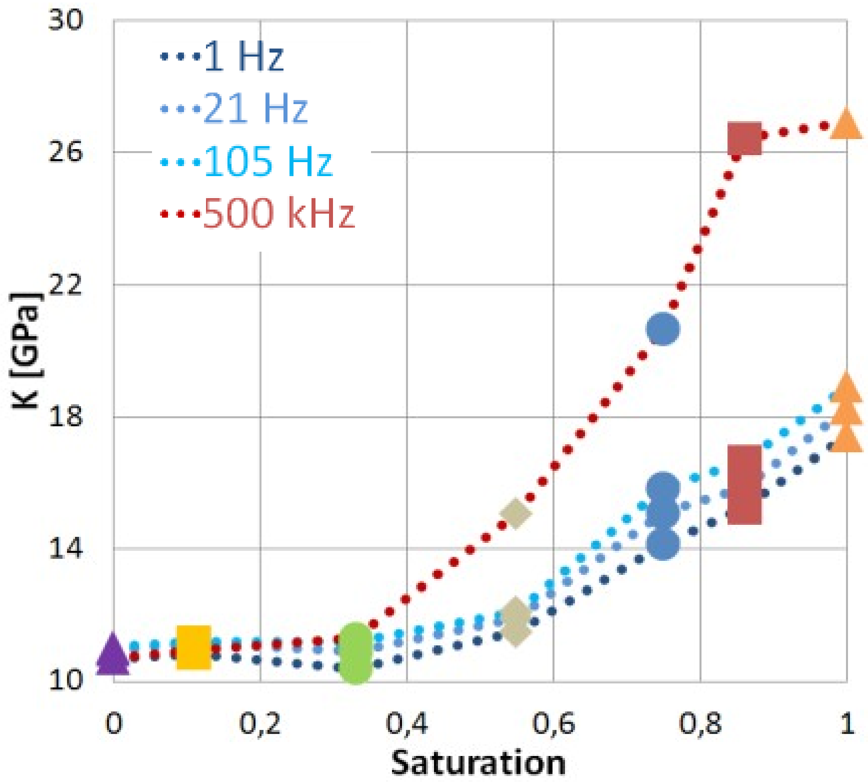
Shear modulus

Increased saturation effects in decrease of S wave velocity in low frequency regime. Ultrasonic regime manifold behavior.
Not a density effect.

Mancos shale: Seismic Dispersion – Saturation Effects

17MPa confining, 26MPa axial

Bulk modulus



- ➢ Increased saturation → Increase of the bulk modulus

Rock-physics models should be able to capture behavior in both seismic and ultrasonic regime.

Mancos shale: Seismic Dispersion – Saturation Effects

How to capture the distinct behaviors in both regimes:

- **Water sensitivity caused by capillary suction pressure**
- **Effects of clay-bound water ?**
- **Budianski, O'Connell and Hudson with drainage parameter D being both saturation and frequency dependent ?**
- **Non homogenous saturation or permeability ?**

Summary

- The results show large dispersion of Young's modulus for highly saturated samples and notably smaller for small saturations.
- Increase in water saturation also results in a gradual, rather strong softening of the shale at seismic frequencies.
- At ultrasonic frequencies, the rock softening is superposed by dispersion effects that results in a more complex water-saturation dependence of the ultrasonic velocities.
- Increase in water saturation causes nearly fivefold increase in Poisson's ratio (Poisson's ratio as possible sensor of saturation).
- **Great care should be taken while applying rock-physics models based on ultrasonic data to seismic frequencies.**