Thomsen anisotropy parameters for unconsolidated sands under stress

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Objectives

- Quantifying the full polar anisotropy (transverse isotropy) of sand by measuring the Thomsen parameters ε, γ and δ.

- Attempt to validate that 'Eta (η)'

$$\eta = \frac{\varepsilon - \delta}{1 + 2\delta}$$

is insensitive to the state of fluid saturation

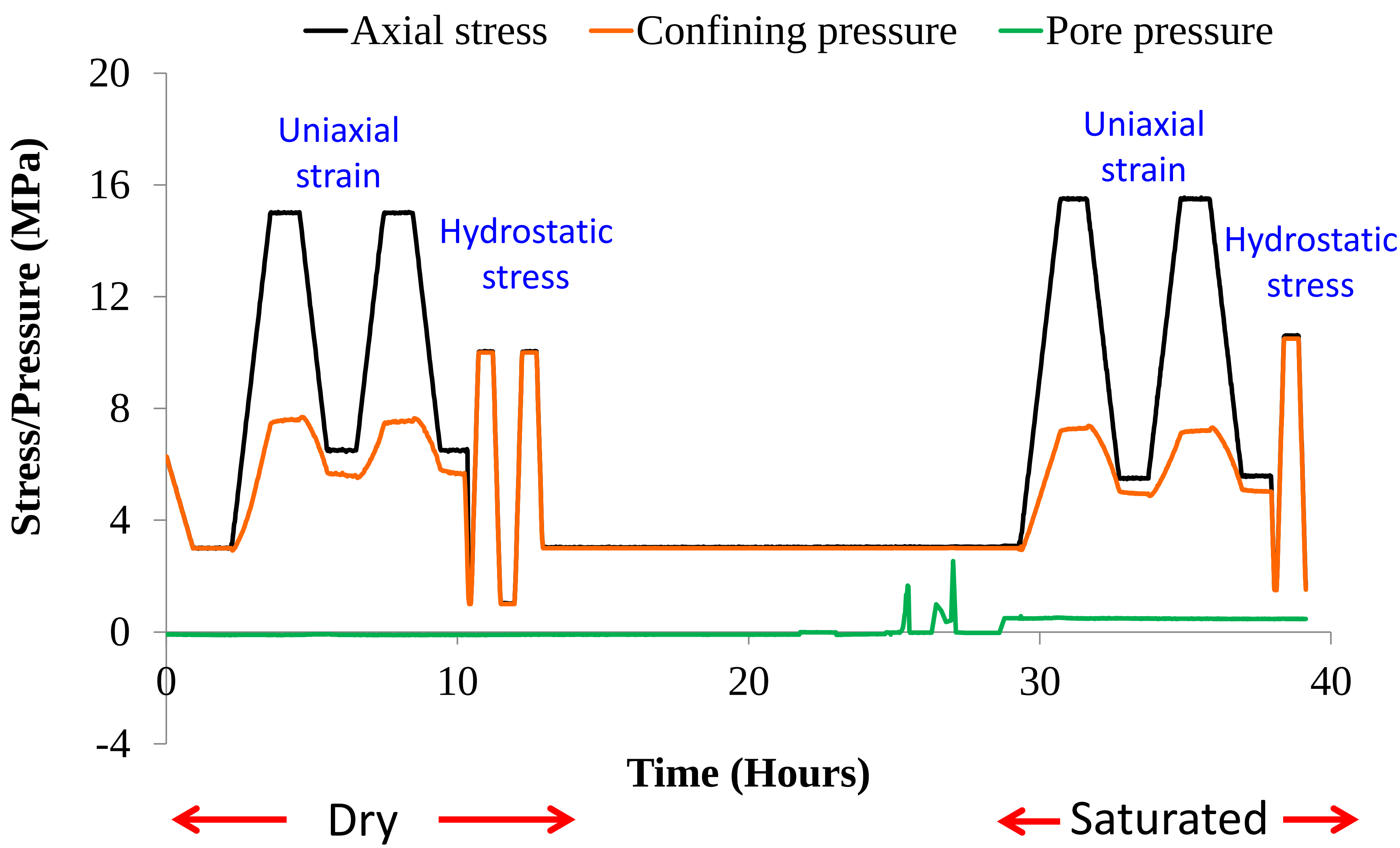
Sample

Sample: Ottawa sand (40/70)

Dry sample: Oven dried at 110˚C and vacuumed during test

Saturated sample: Saturated with 3.5wt% NaCl brine

Stress Path



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Triaxial Setup

- Confining pressure monitored
- P-wave transducer at 0˚, 20˚, 37˚, 47˚, 68˚ and 90˚ along with S-wave transducer at 0˚ and 90˚.
- Dimension of the sample:
  - Diameter: 38mm
  - Height: 60-65mm

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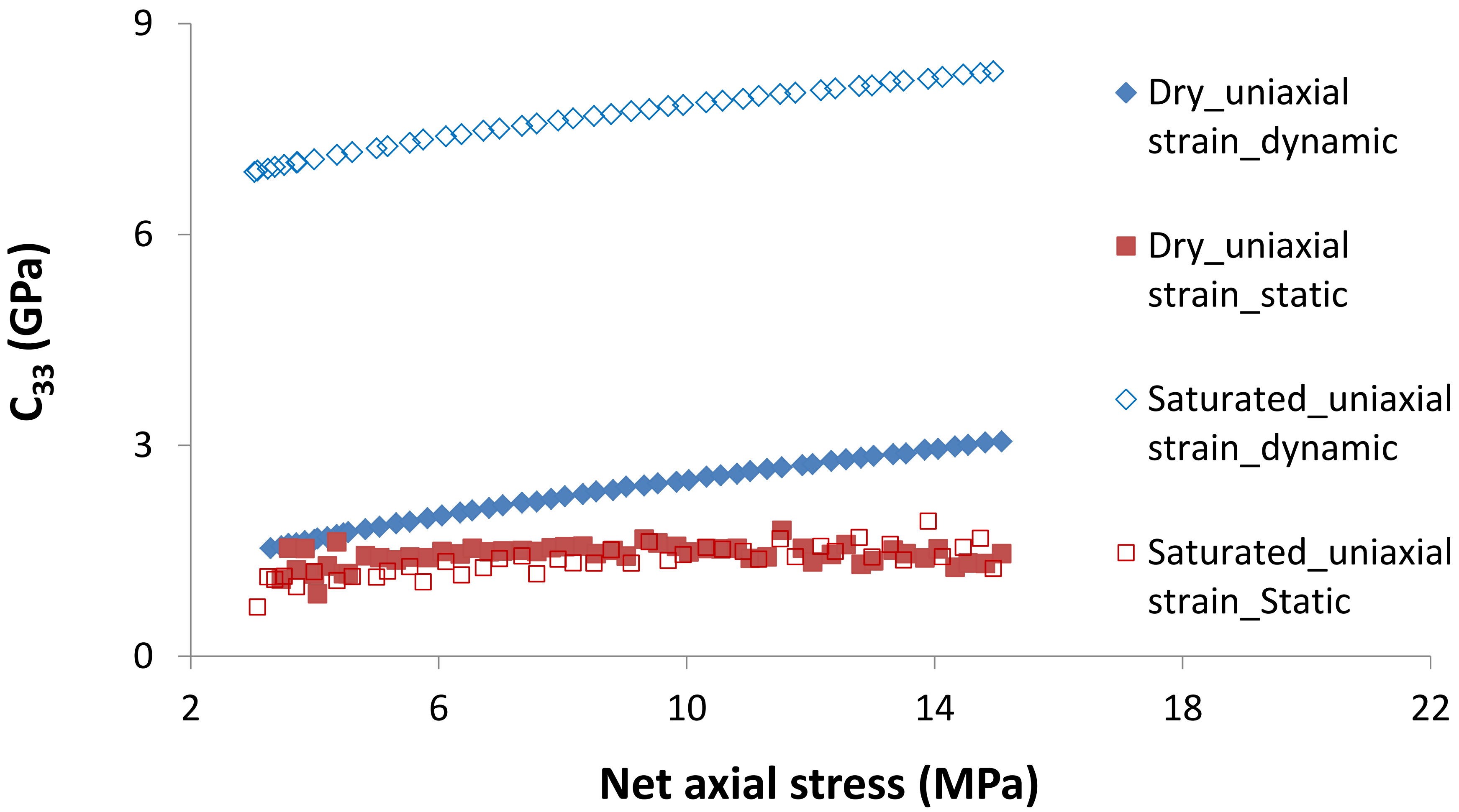
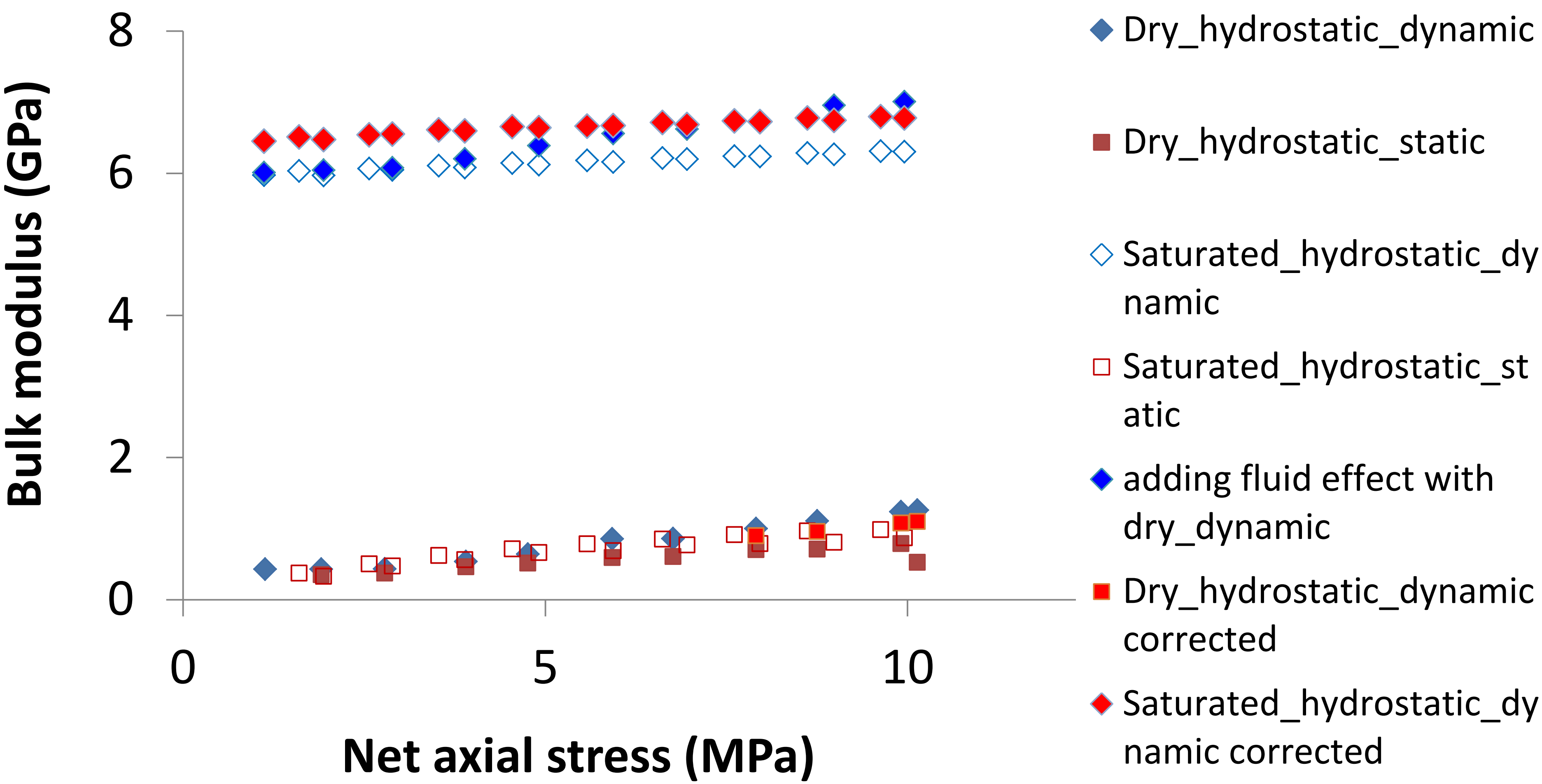
Results

C_{33} : Under uniaxial strain condition



- ✓ Static stiffness is independent of saturation
- ✓ Dynamic stiffness is strongly dependent of saturation

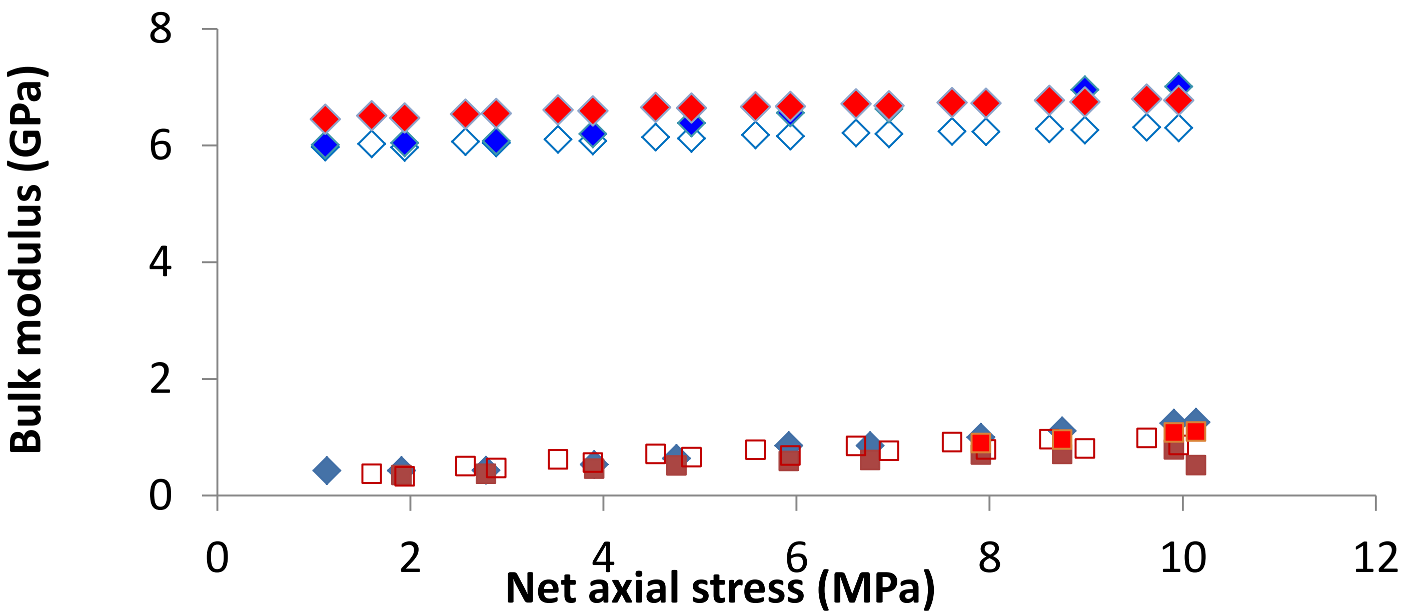
K (Bulk modulus) : Under hydrostatic stress



$$K_{dyn} \approx \rho\left[(v_{Pz}^2 - \frac{4}{3}v_{Sz}^2) + \frac{4}{9}\{(2\varepsilon+\delta)v_{Pz}^2 - 2\gamma v_{Sz}^2\}\right]$$

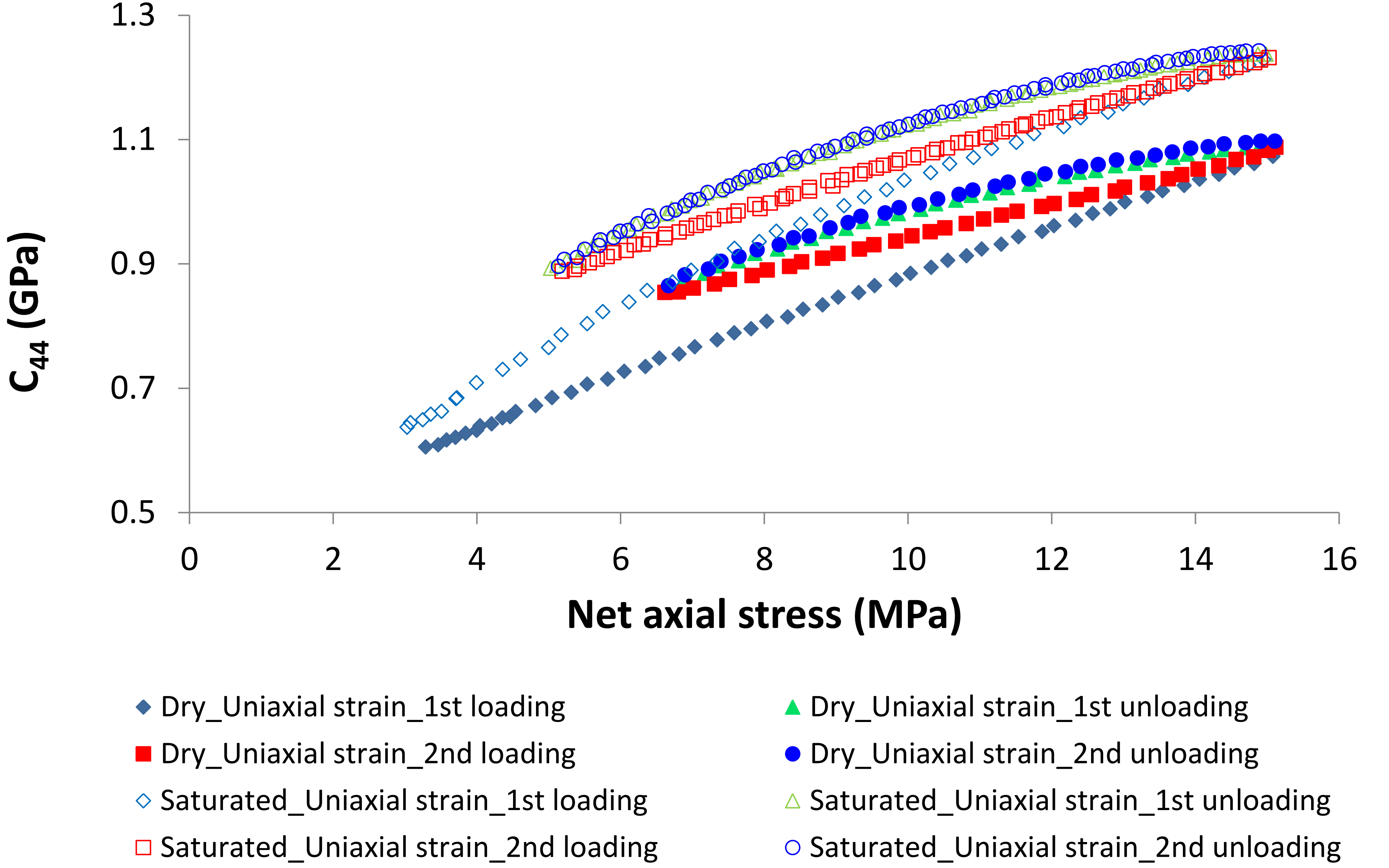
Holt et al, 2013

K (Bulk modulus) : Under hydrostatic stress

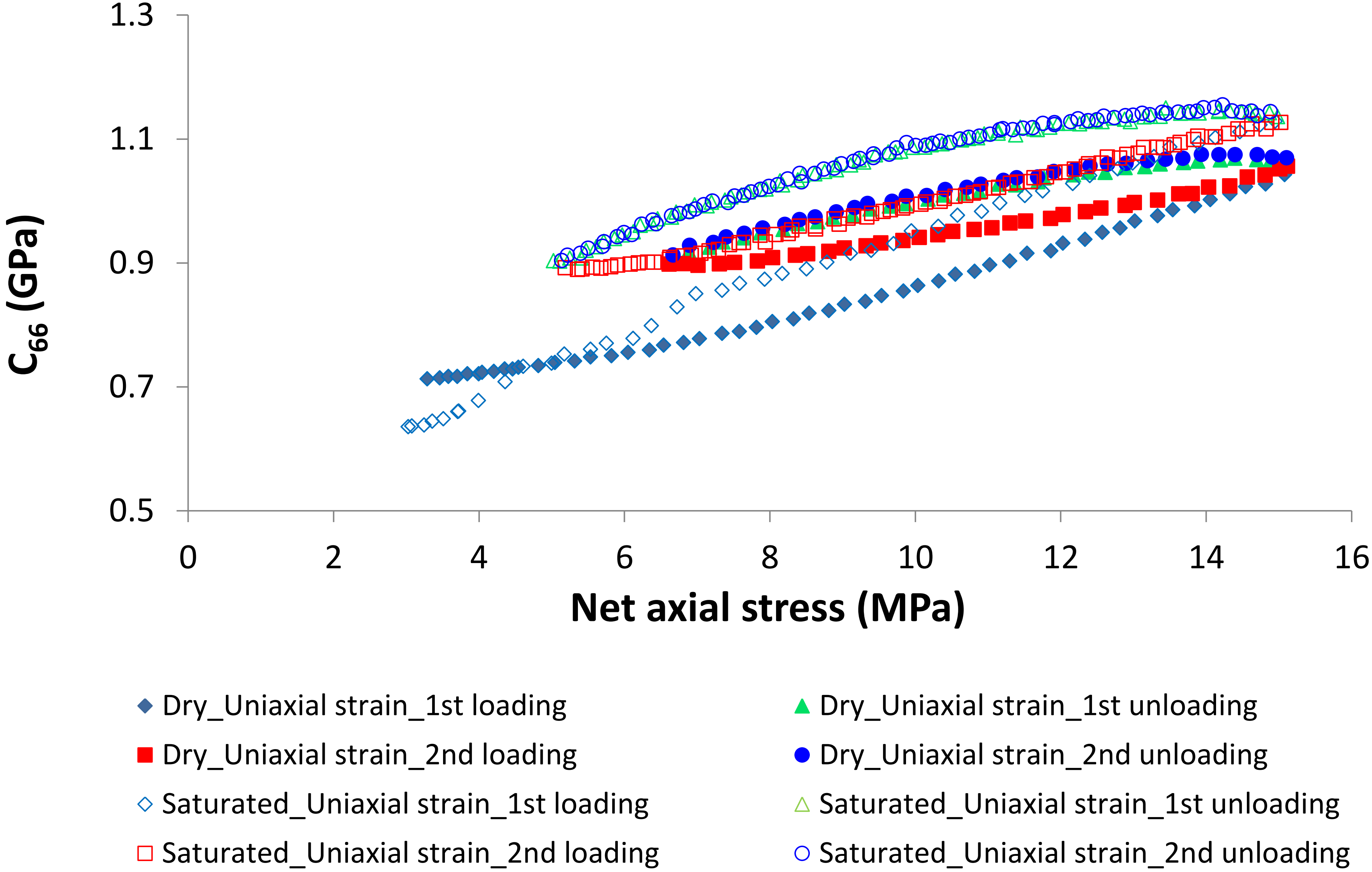


- Static stiffness is independent of saturation
- Dynamic stiffness is strongly saturation dependent
- Adding fluid effect using Biot, with static bulk modulus corresponding to the dynamic bulk modulus.
- Correcting bulk modulus for anisotropy have little effect.

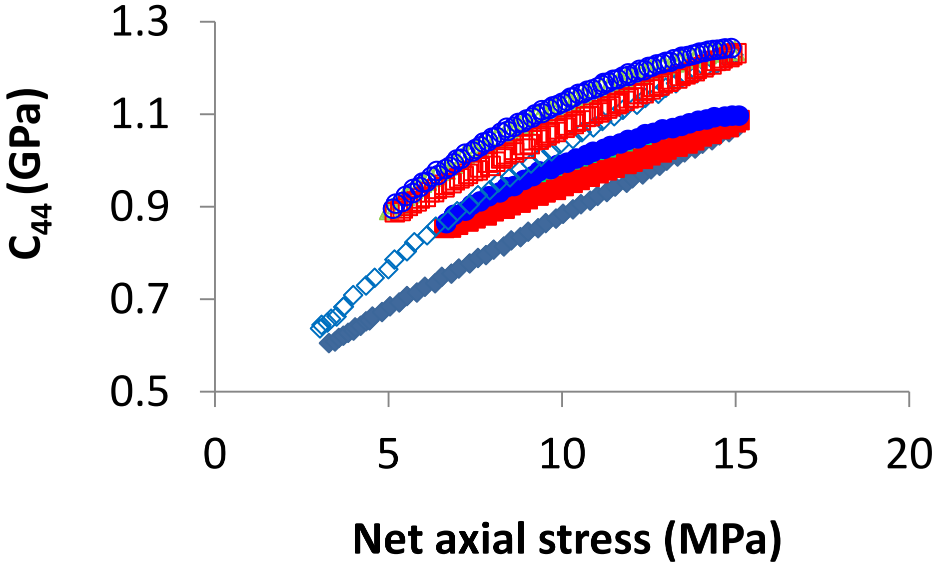
C_{44} : Under uniaxial strain condition

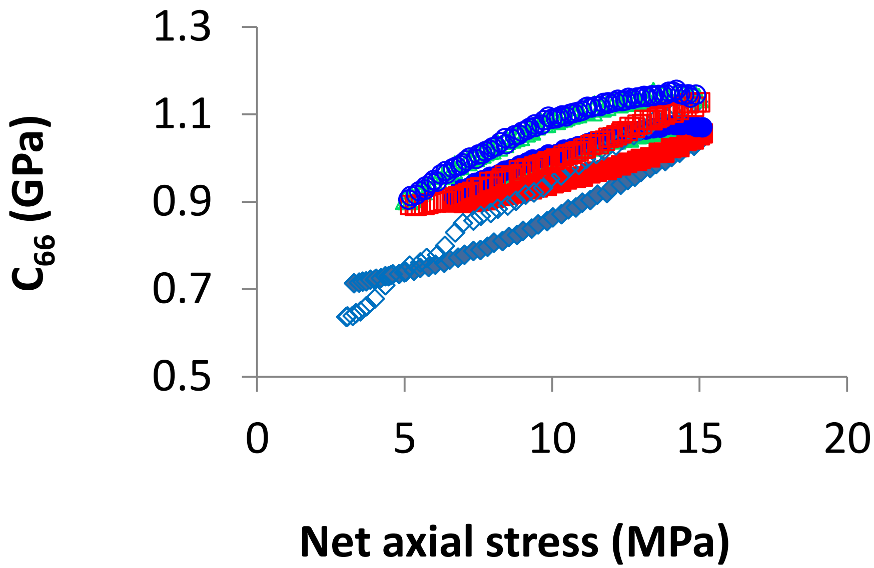


C_{66} : Under uniaxial strain condition



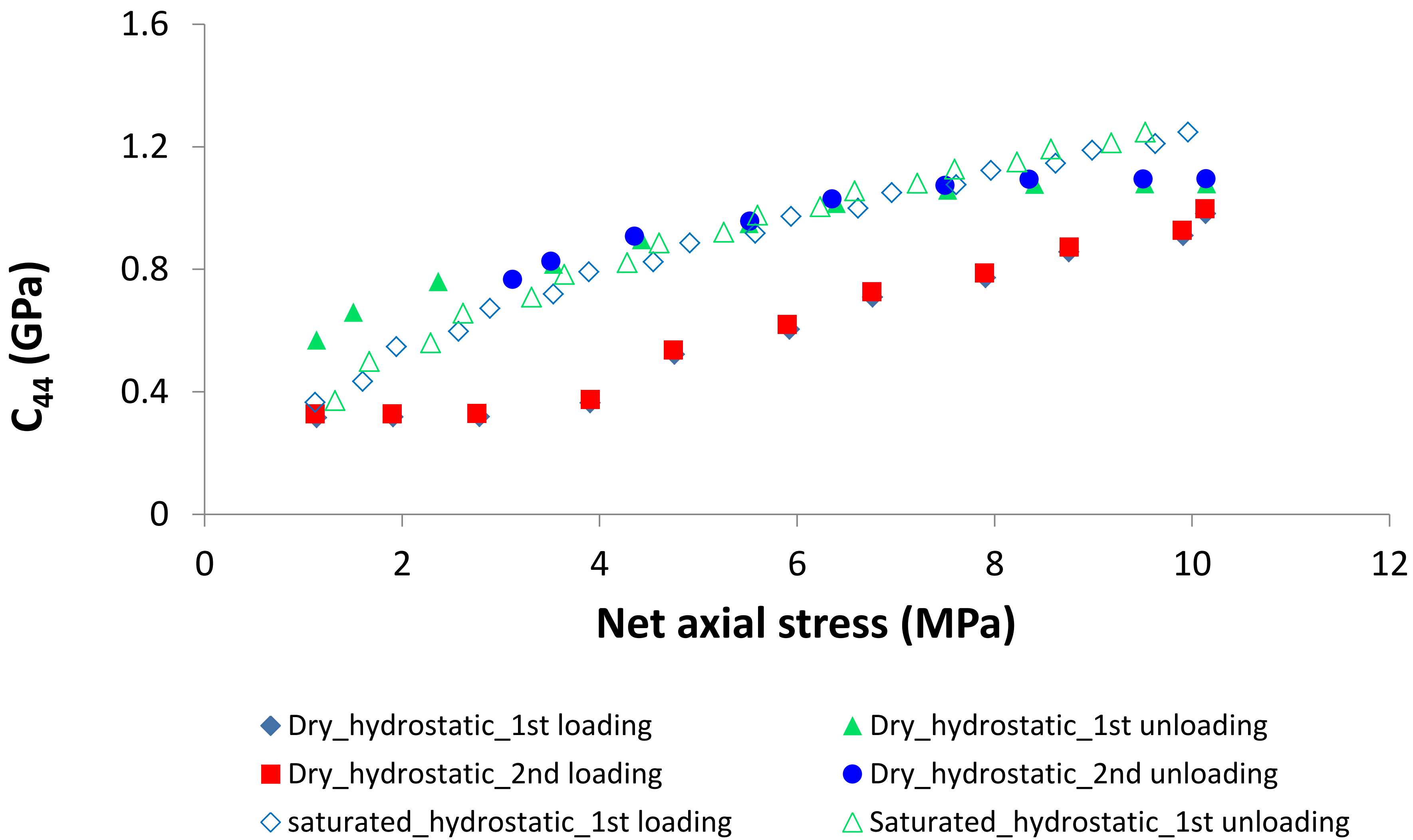
Shear stiffness : Under uniaxial strain condition





- ✓ Shear stiffnesses are not independent of saturation
- ✓ The difference in stiffness between dry and saturated is higher for axial shear stiffness.

C_{44} : Under hydrostatic stress



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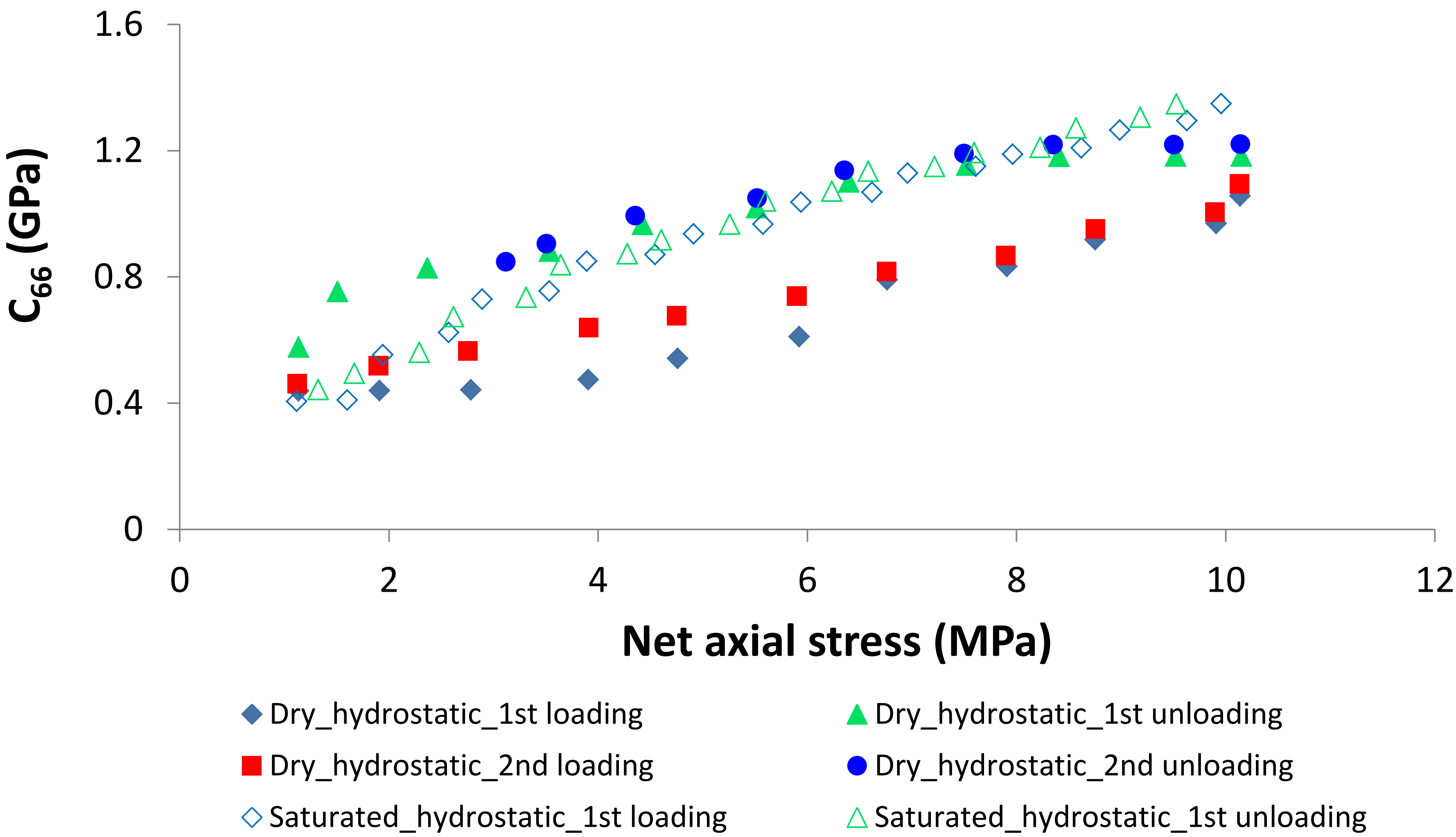
C_{66} : Under hydrostatic stress



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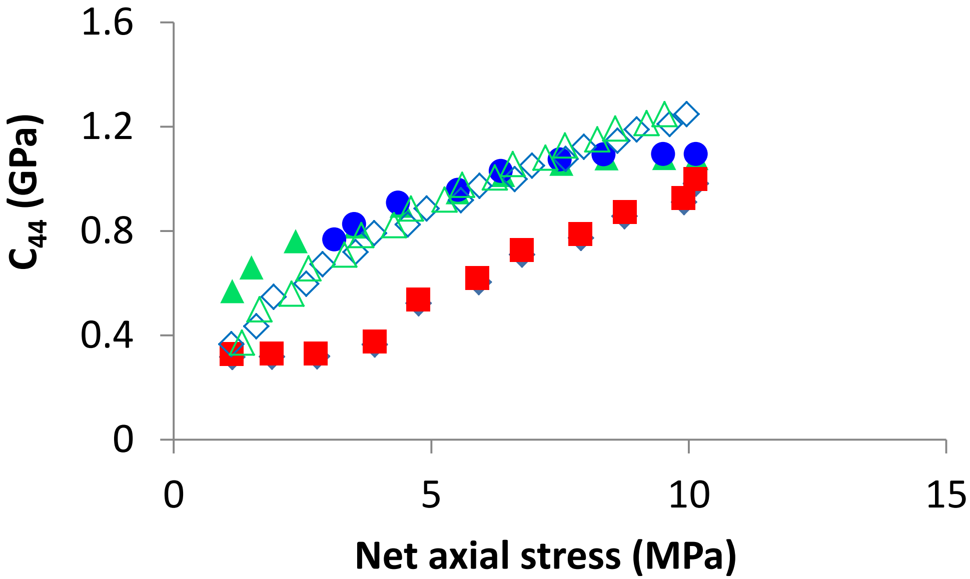
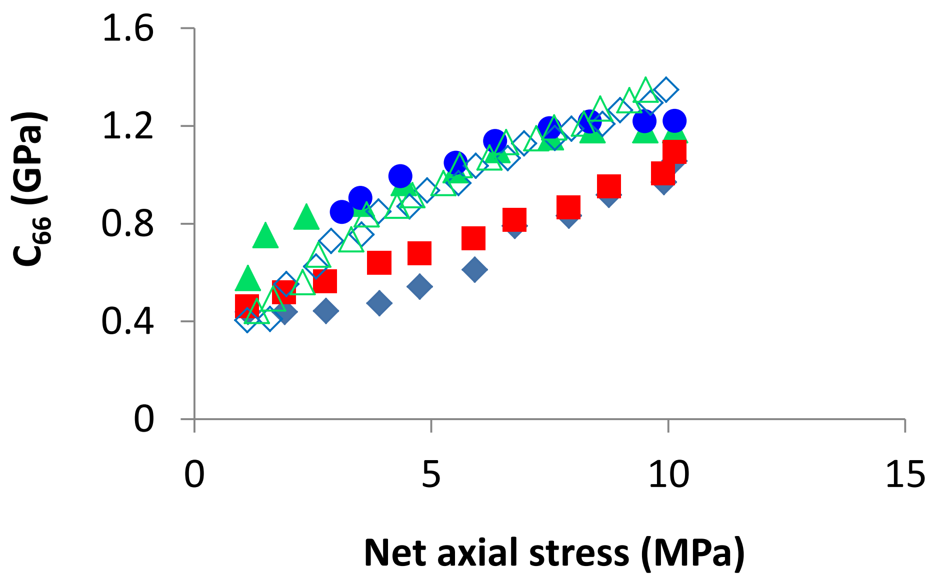
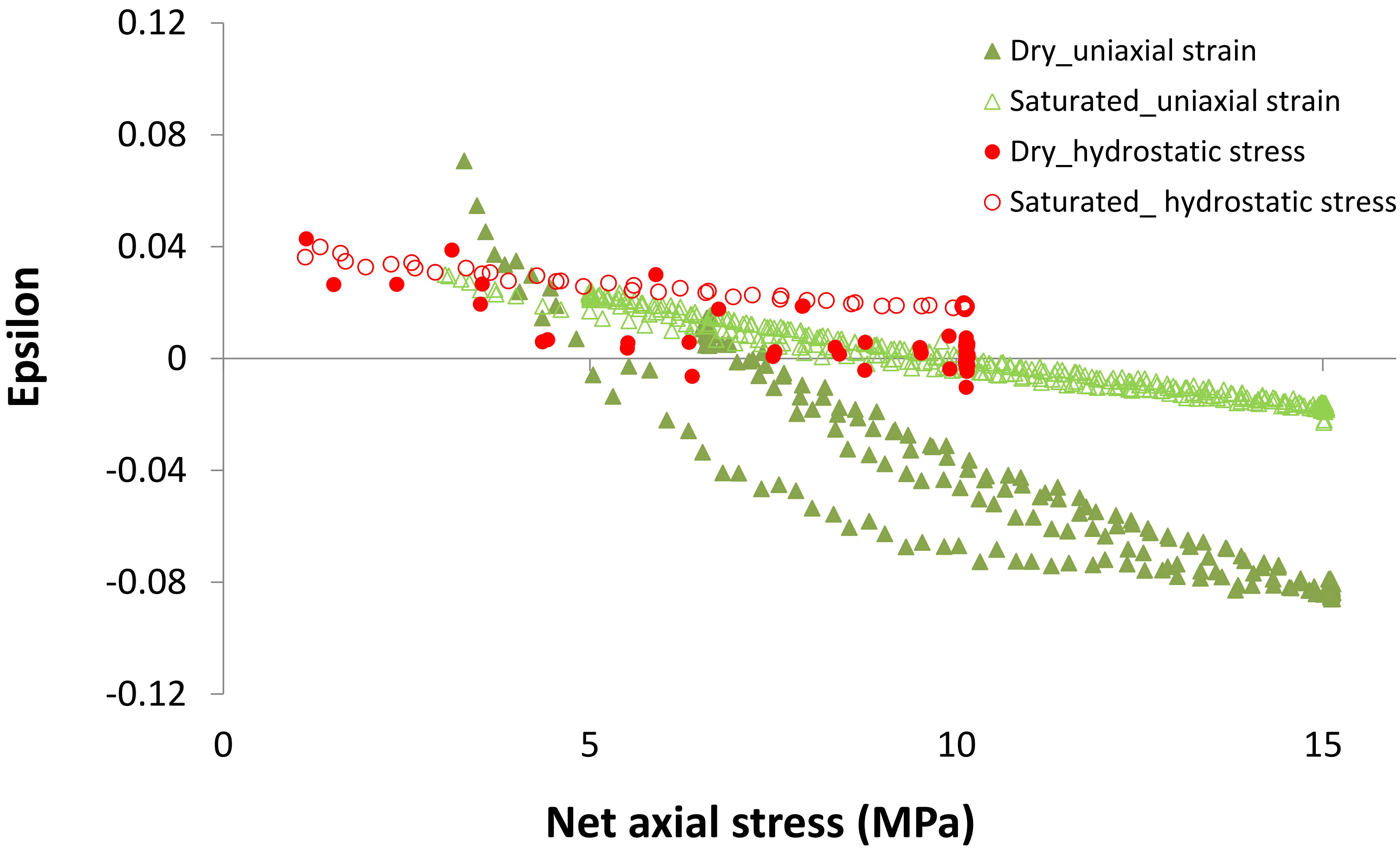
C_{66} : Under hydrostatic stress





- ✓ Unlike uniaxial strain condition, Shear stiffness for both loading and unloading for dry sands are identical.
- ✓ Stiffness during Loading and unloading is identical for saturated sand
- ✓ Shear stiffnesses during loading are not same for dry and saturated sand. However, they are quite close during unloading.

Epsilon



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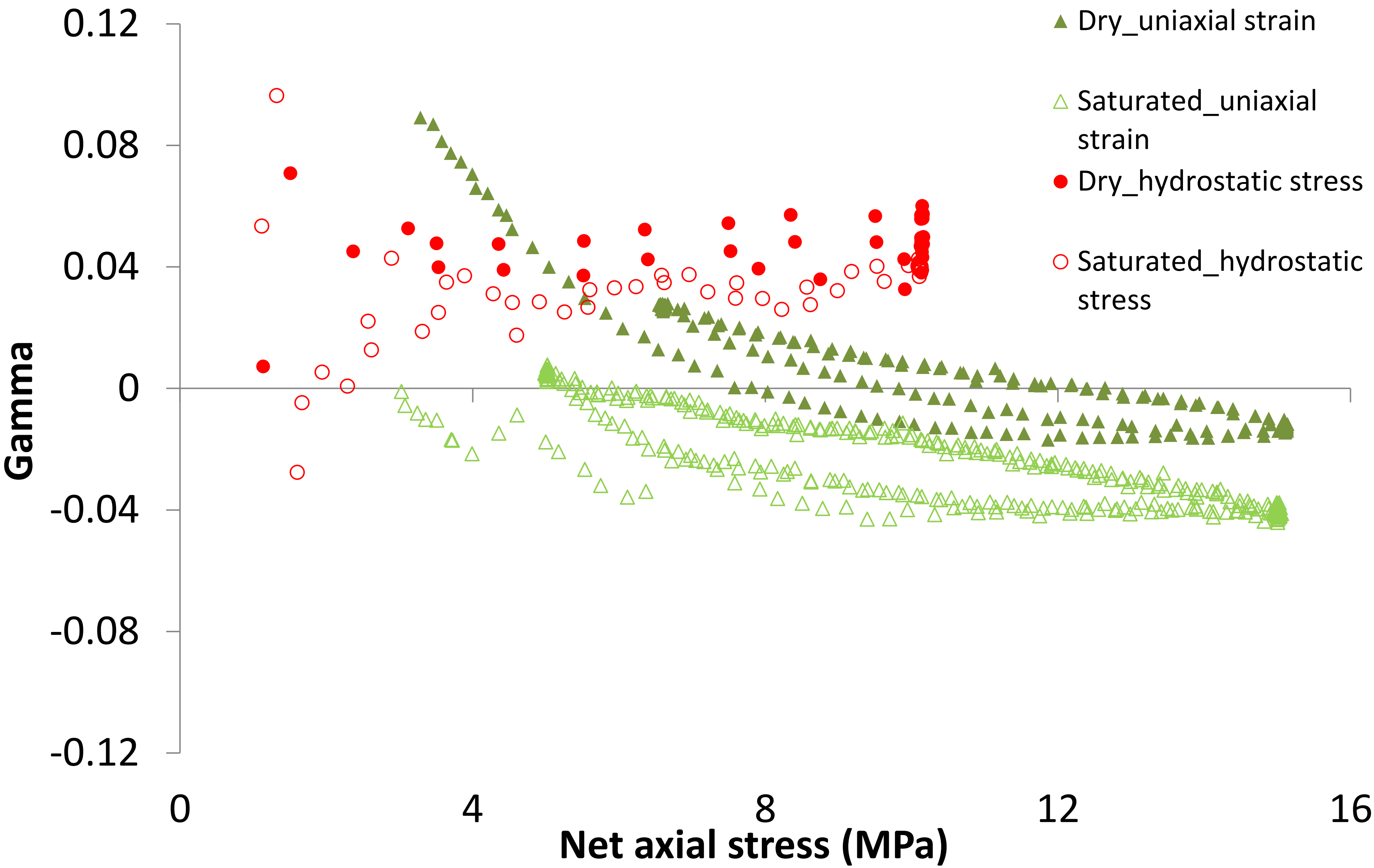
Gamma



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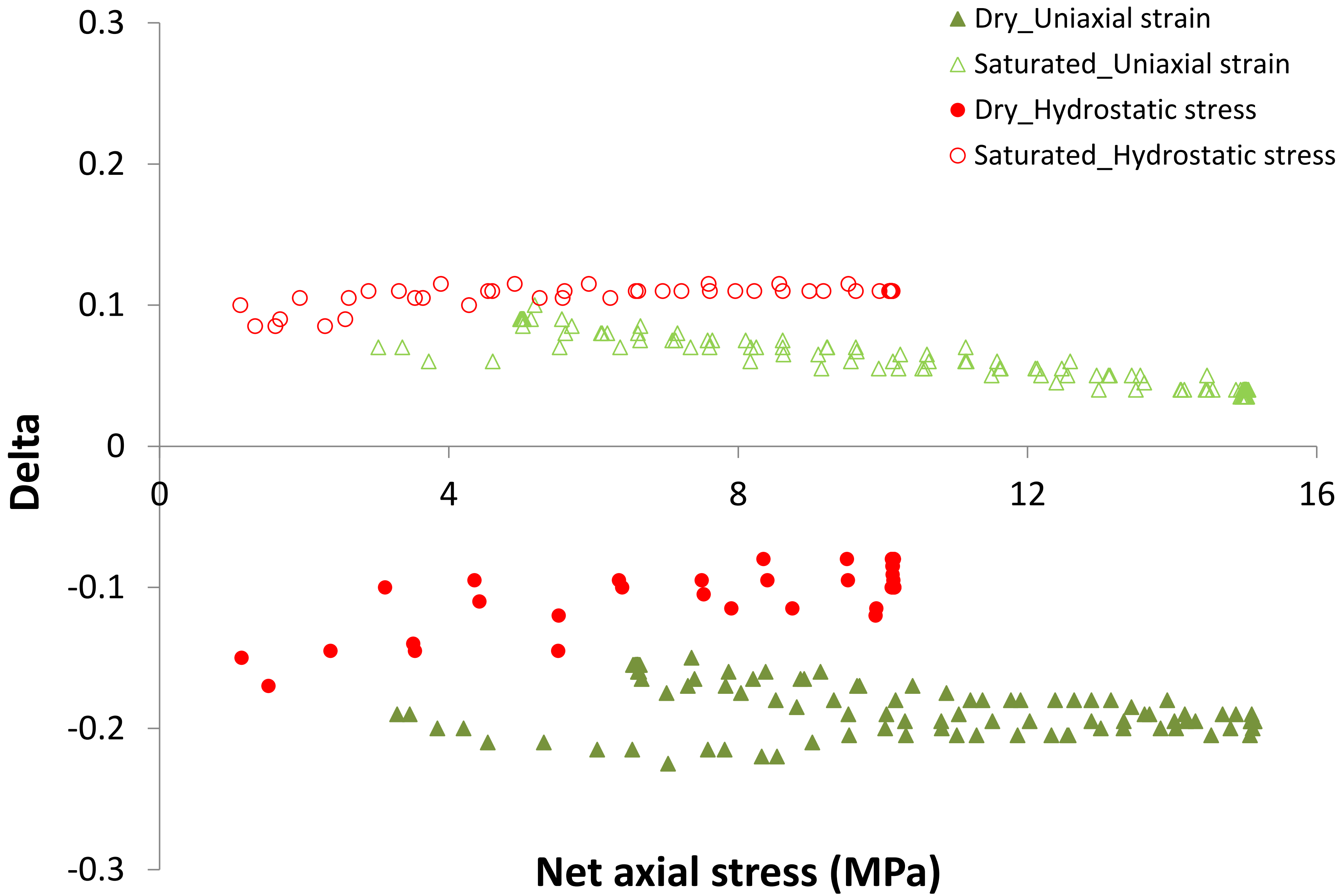
Delta



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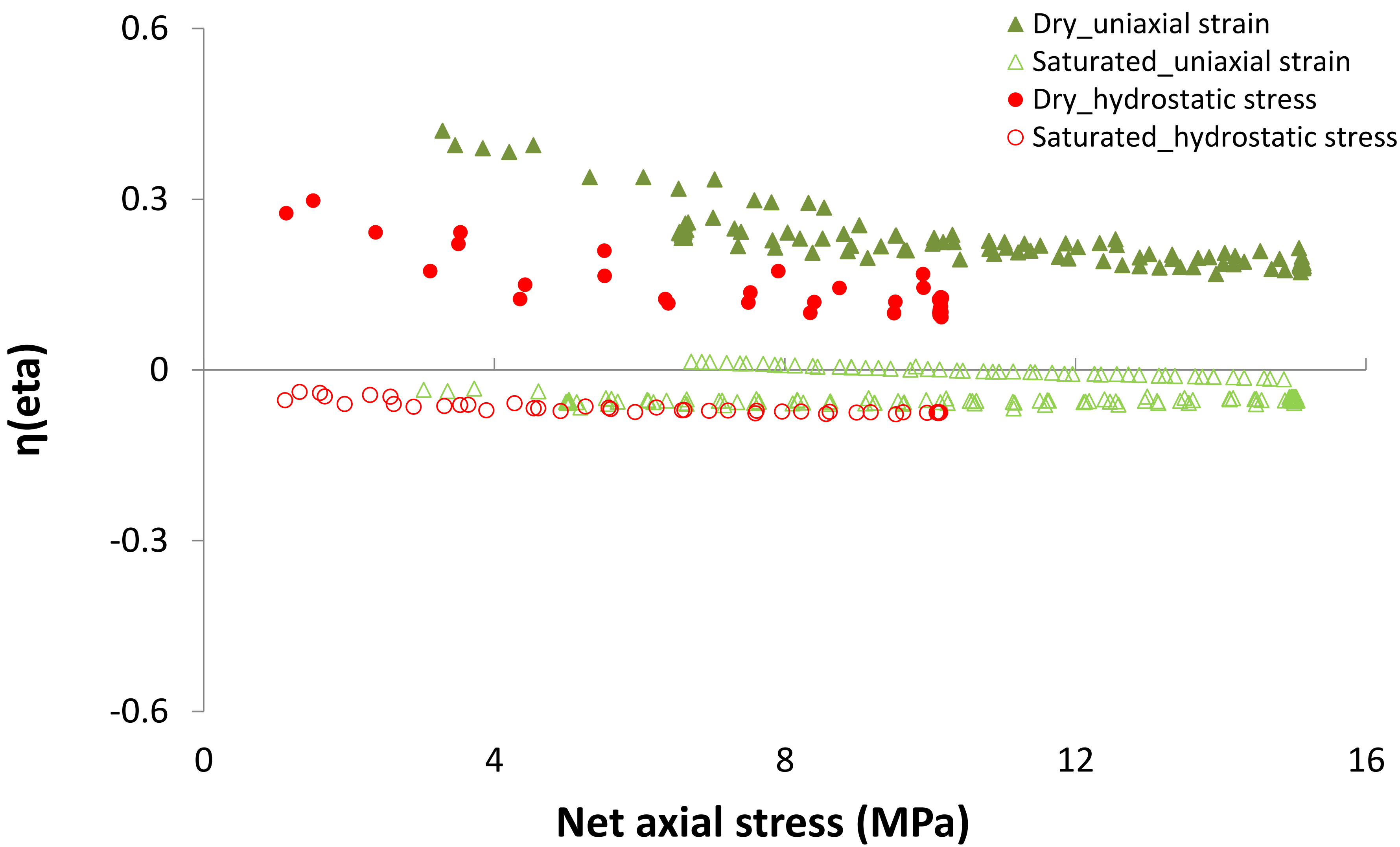
Eta



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Conclusions

- ✓ Under hydrostatic stress, anisotropic parameters are moderately or not sensitive to stress, indicating lithological origin of anisotropy.

- ✓ Under uniaxial strain condition, stress induced velocity anisotropy is strongly evident.

- ✓ Saturation appear to have unexpected influence on gamma and eta. The epsilon reduced by saturation.

Conclusions

- ✓ Saturation dependent shear moduli remains unexplained. This could also be the cause of the discrepancy between the observed saturation dependence of η and the insensitivity suggested by Thomsen (2012).

- ✓ Further work is required to investigate various possible sources of discrepancy between the experiment and the theory.

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Thank You