Ultrasonic Studies of Stressed **Sand** and Clay

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Motivation

- Explore the effect of fluid substitution on anisotropic parameters
- Explore the behavior of v_p/v_s for sand and clay

Impact of fluid substitution on Anisotropy?

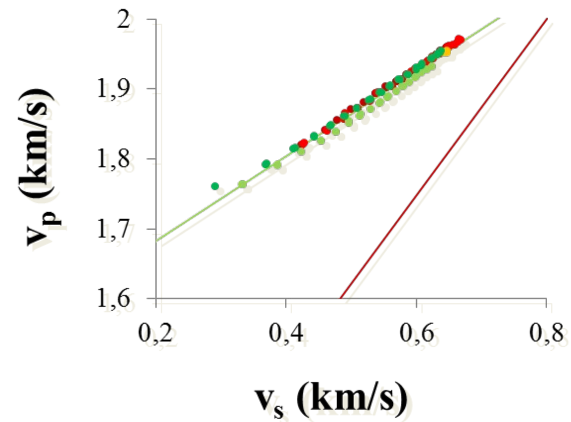
(Collett & Gurevich, 2013; Thomsen, 2012)

$$\varepsilon^{sat} = \frac{L}{L^{sat}}\varepsilon + \frac{\alpha_0}{L^{sat}}\frac{((\delta - 4\varepsilon)L + 4\gamma\mu)M}{3K_g}.$$

In a similar way, δ^{sat} is given by

$$\delta^{sat} = \frac{L}{L^{sat}}\delta + \frac{\alpha_0}{L^{sat}}\frac{((\delta - 4\varepsilon)L + 4\gamma\mu)M}{3K_g}.$$

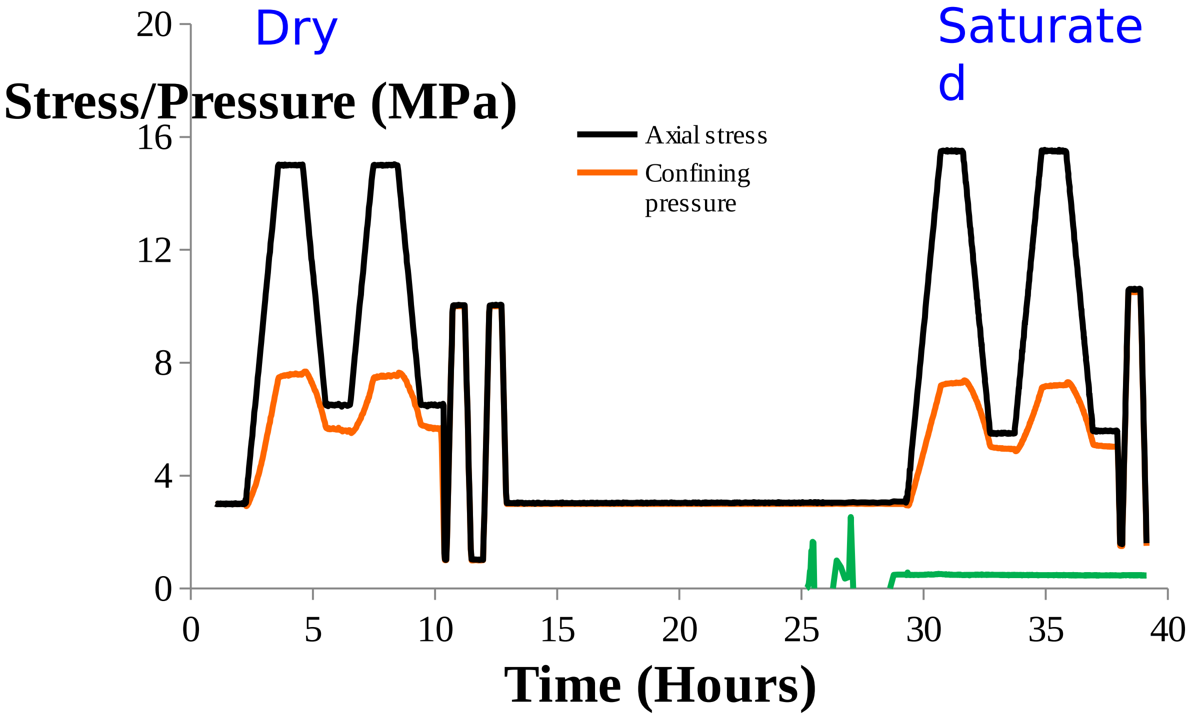
How well known v_p/v_s trends does not works for uncosolidated sediments?



Effect of fluid on anisotropic parameters

Lab tests in triaxial set-up

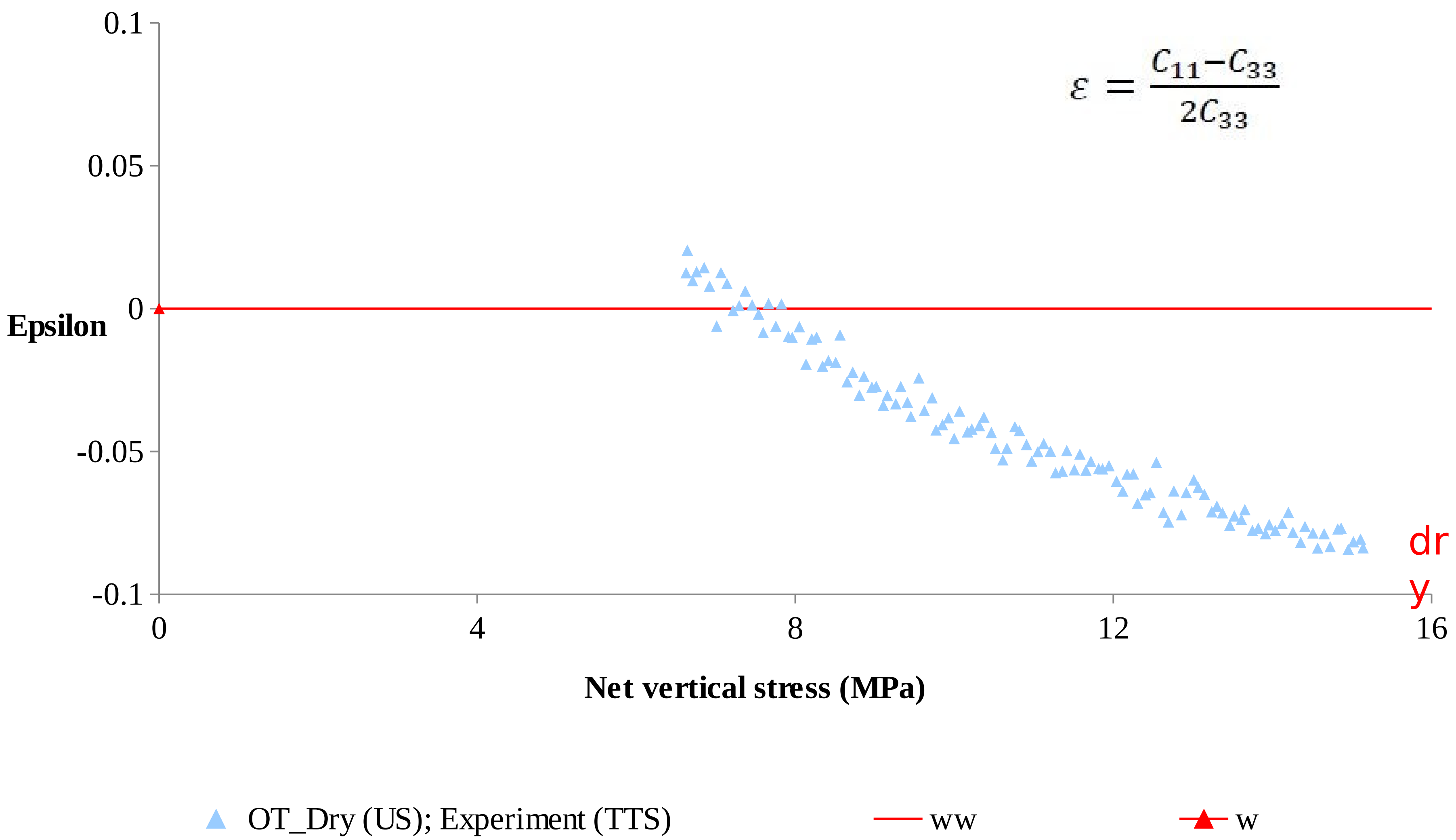
(only unsorted Ottawa sand)



Saturated with 3,5wt% NaCl

Multi-directional P- & S-wave velocity measurements permit determination of all 5 TI elastic stiffness parameters => Thomsen's ε, γ, δ (+ η)

Effect of fluid on Epsilon (Uniaxial strain condition)



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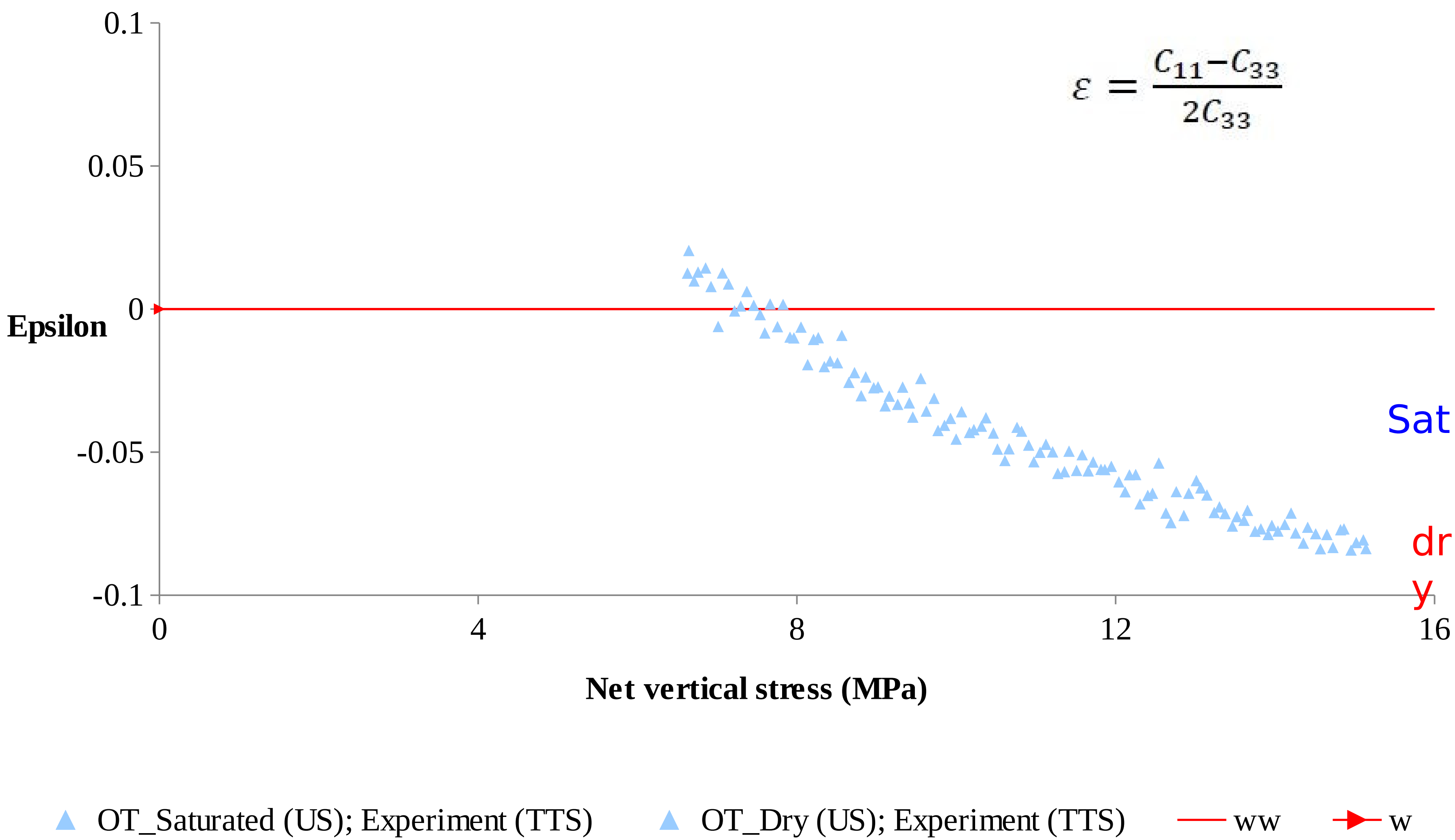

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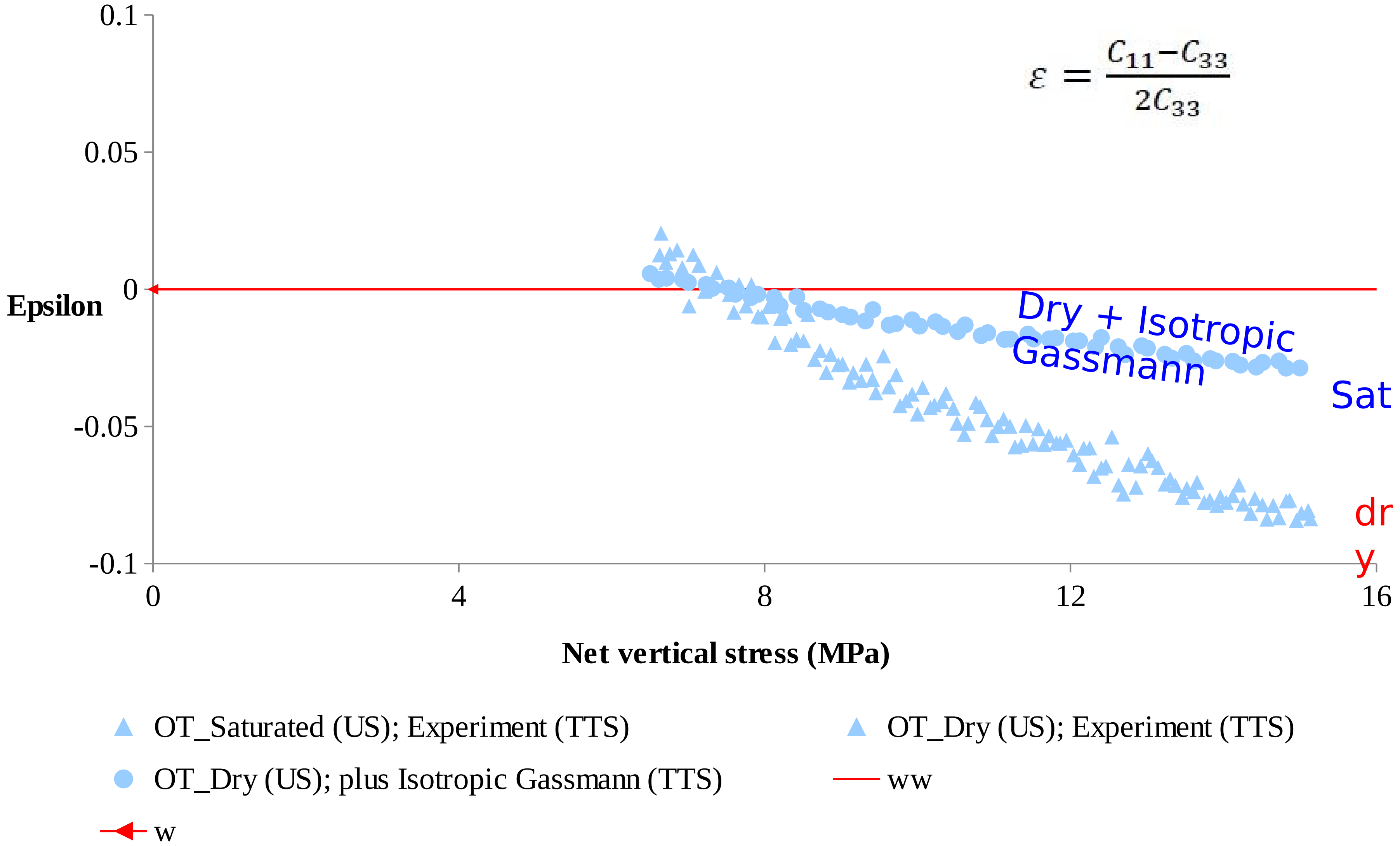

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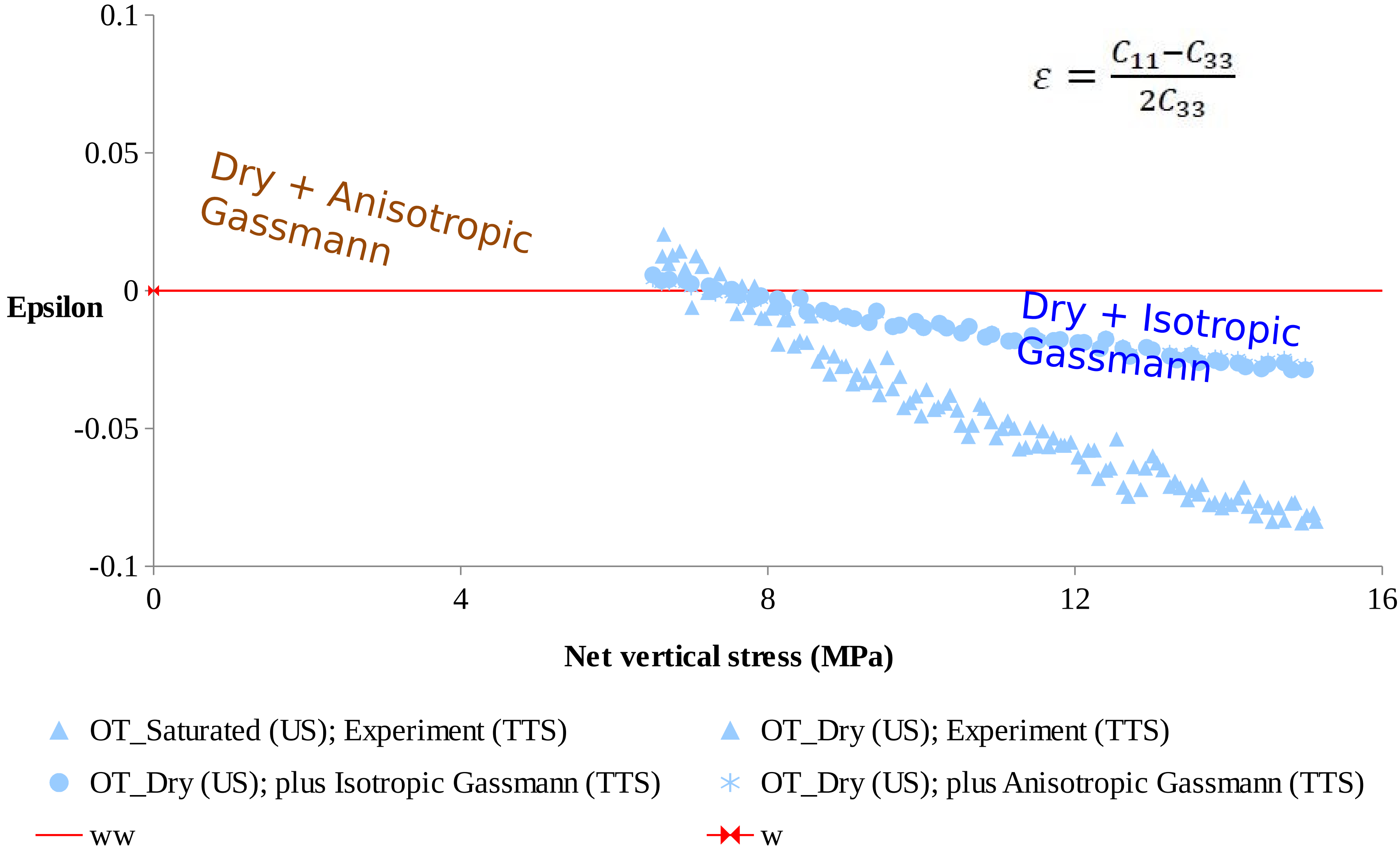
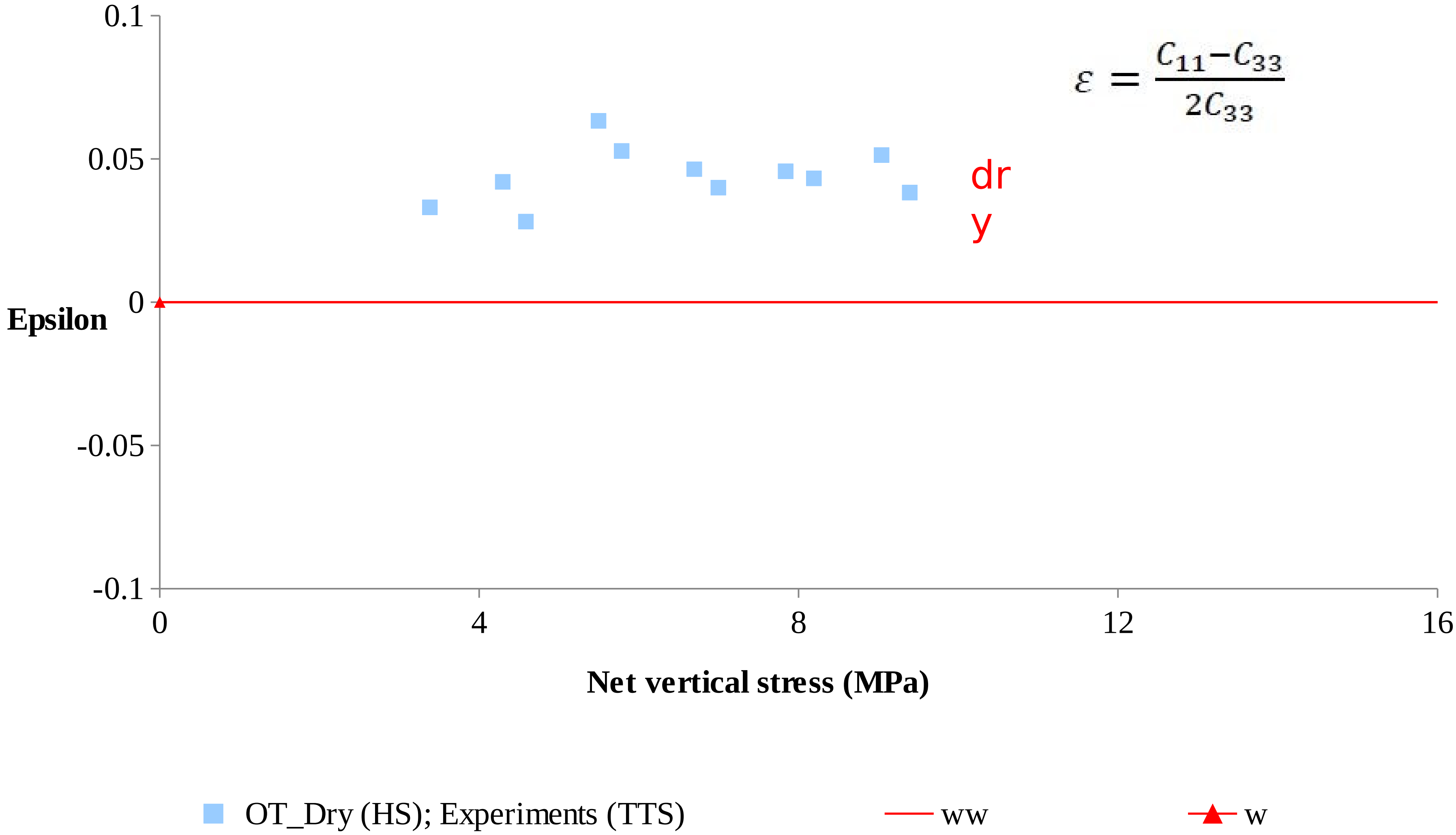


Effect of fluid on Epsilon (Hydrostatic stress)



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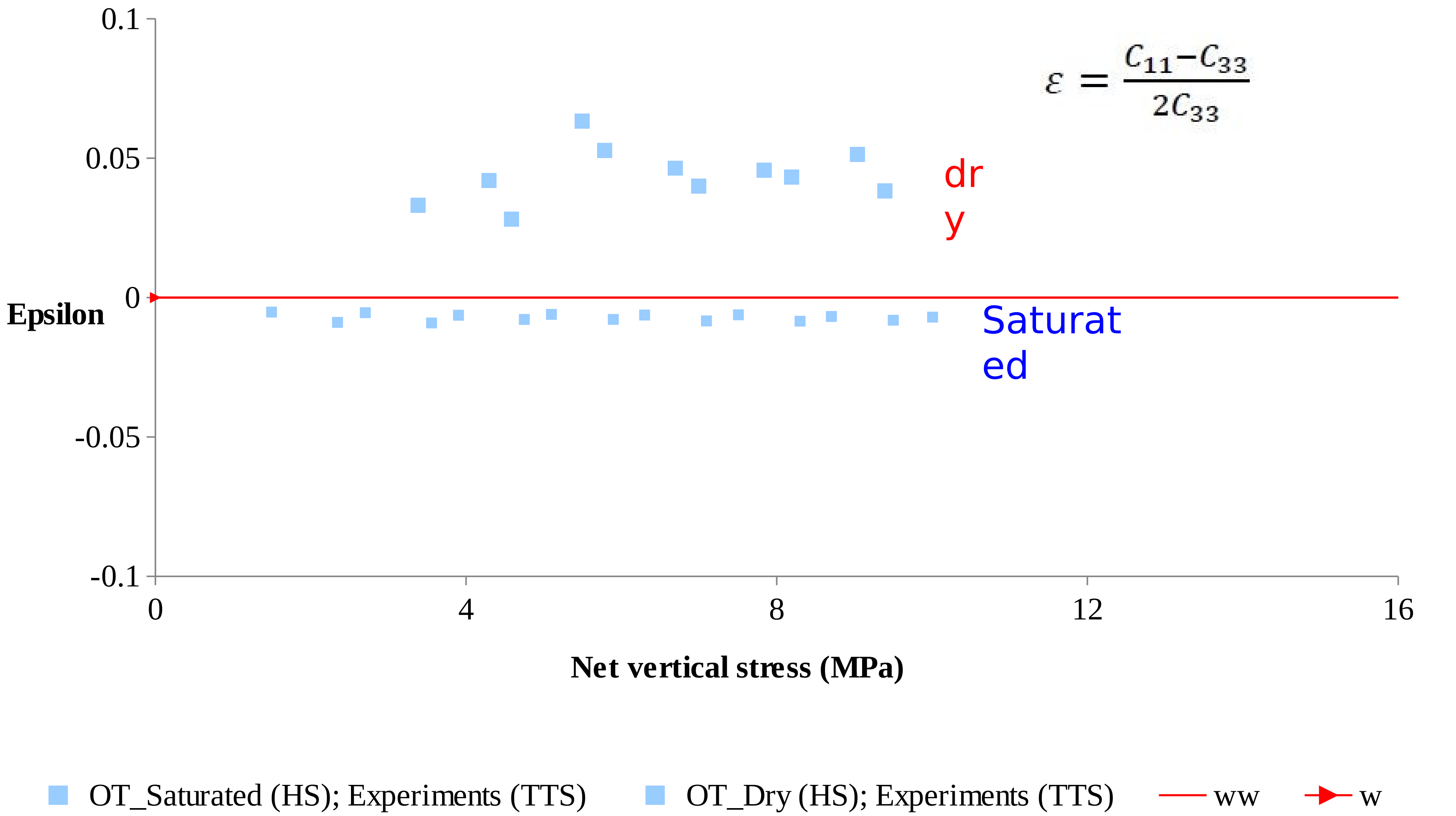

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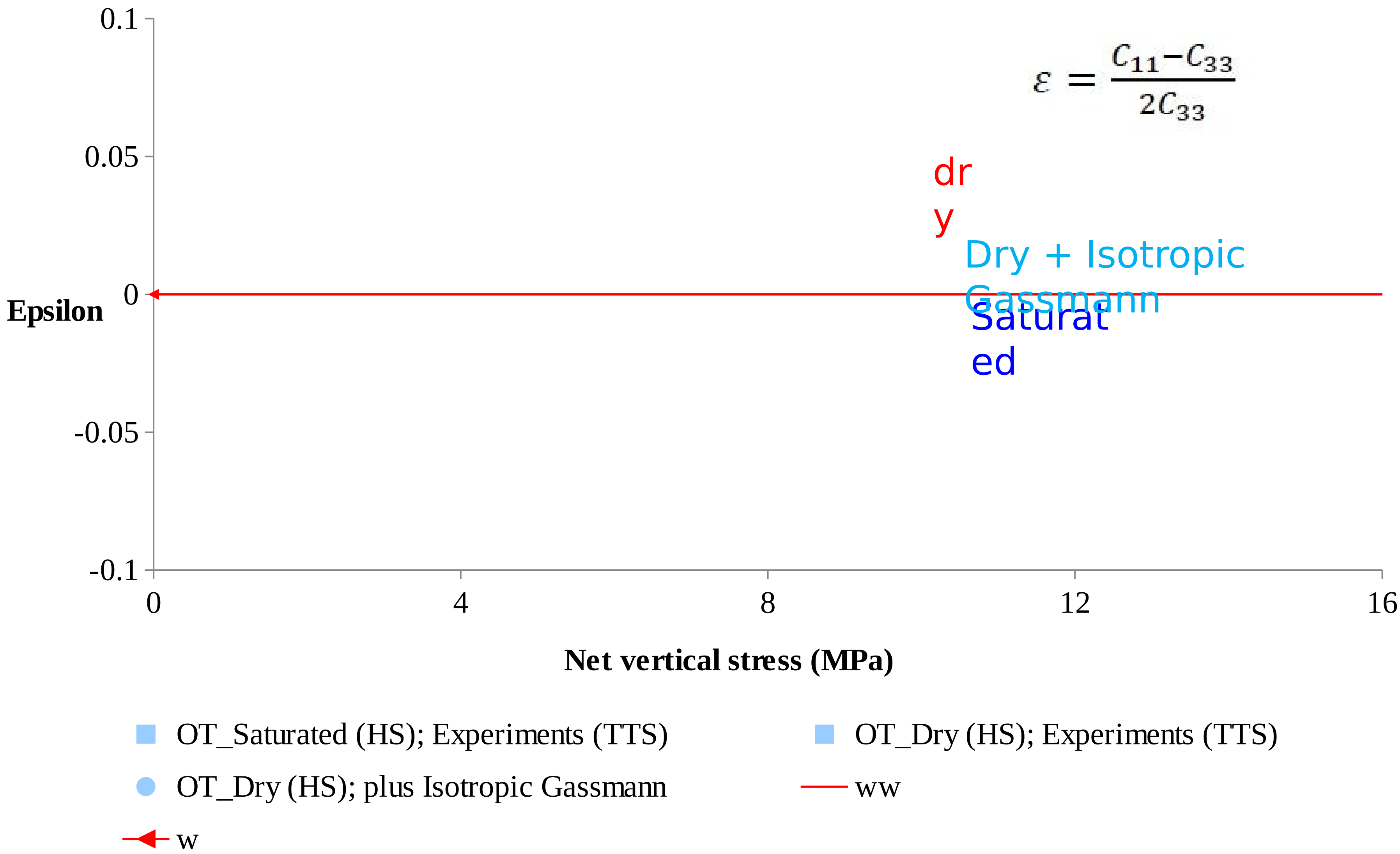

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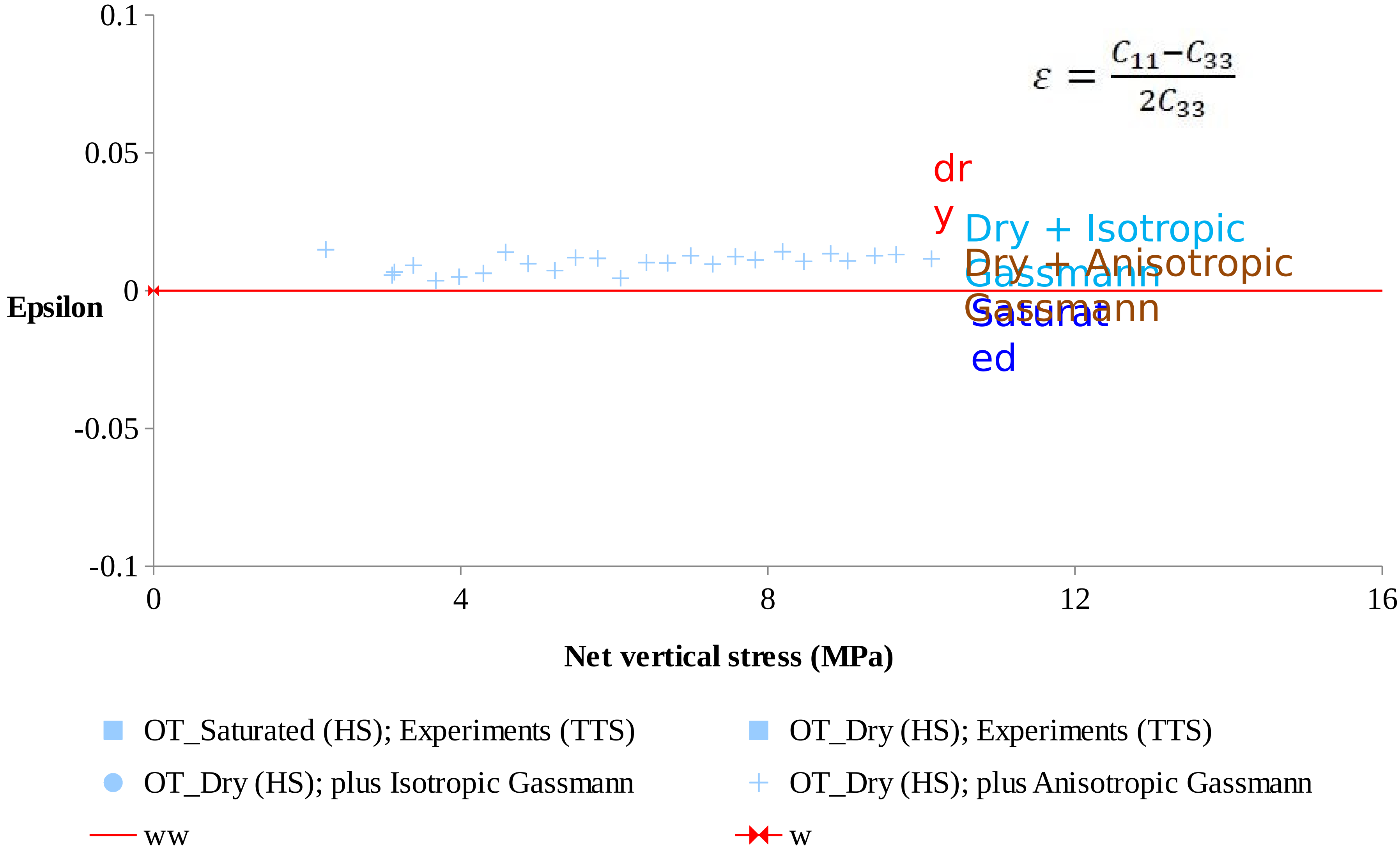
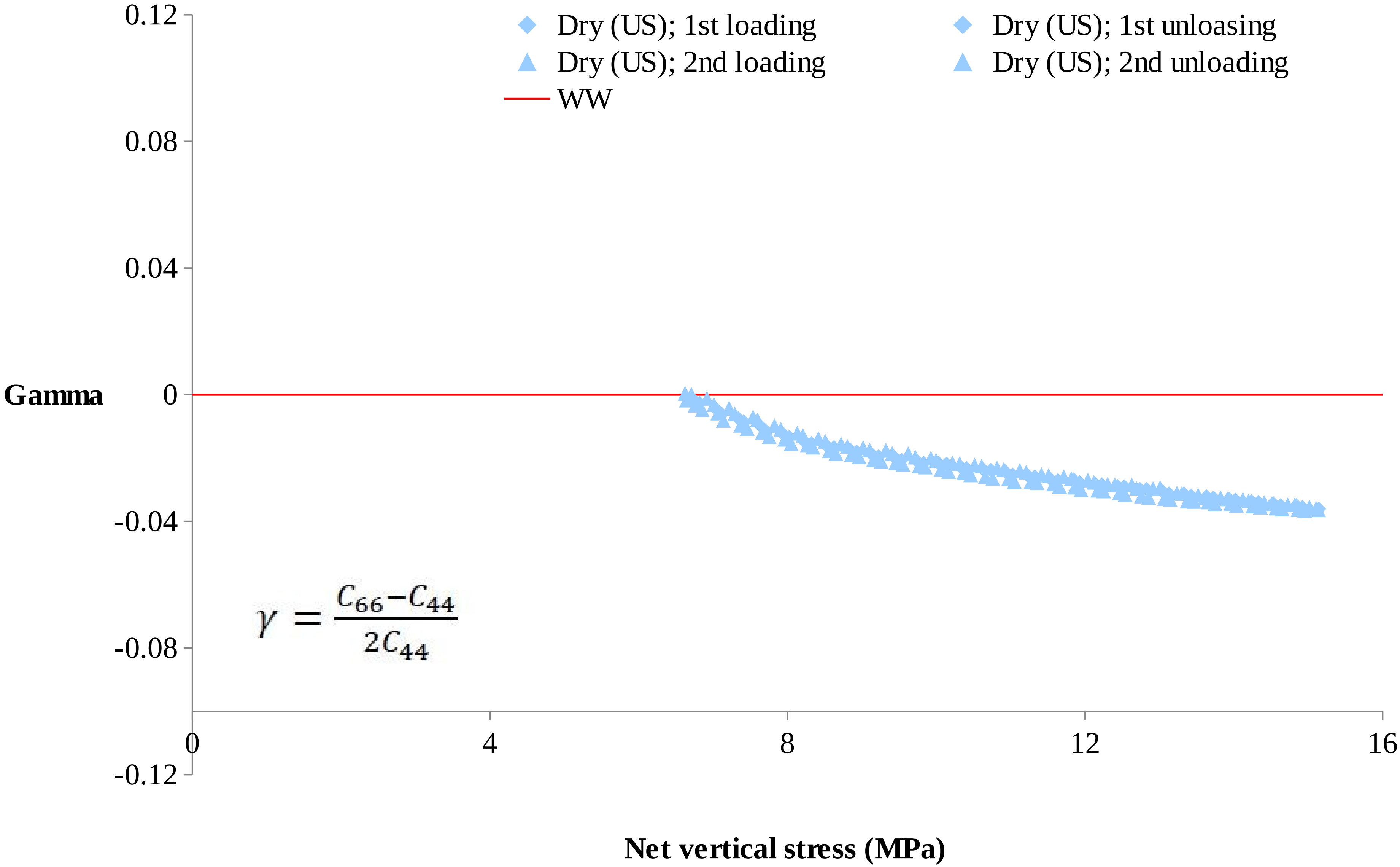


Effect of fluid on Gamma (Uniaxial strain condition)



$$\gamma = \frac{C_{66} - C_{44}}{2C_{44}}$$

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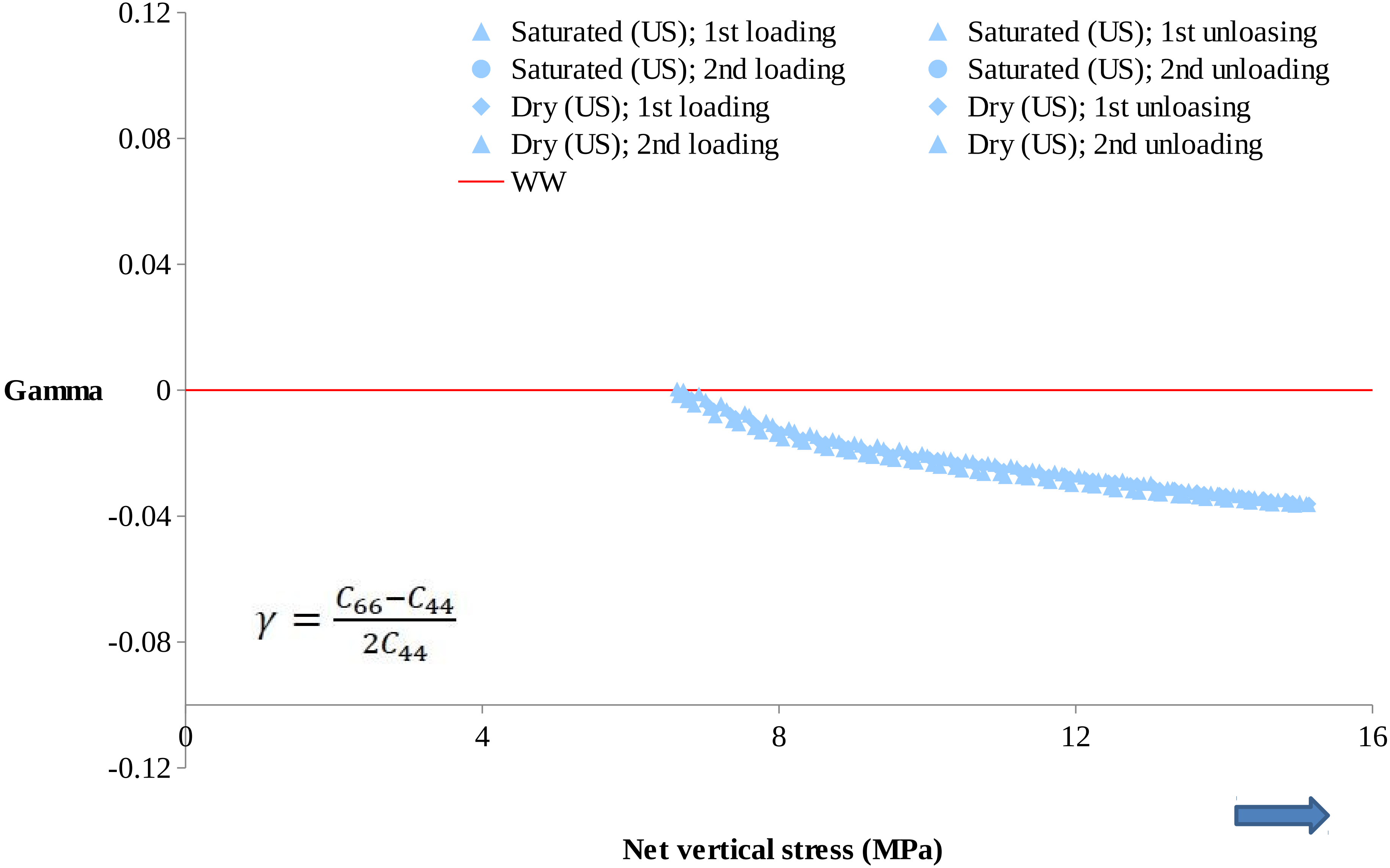

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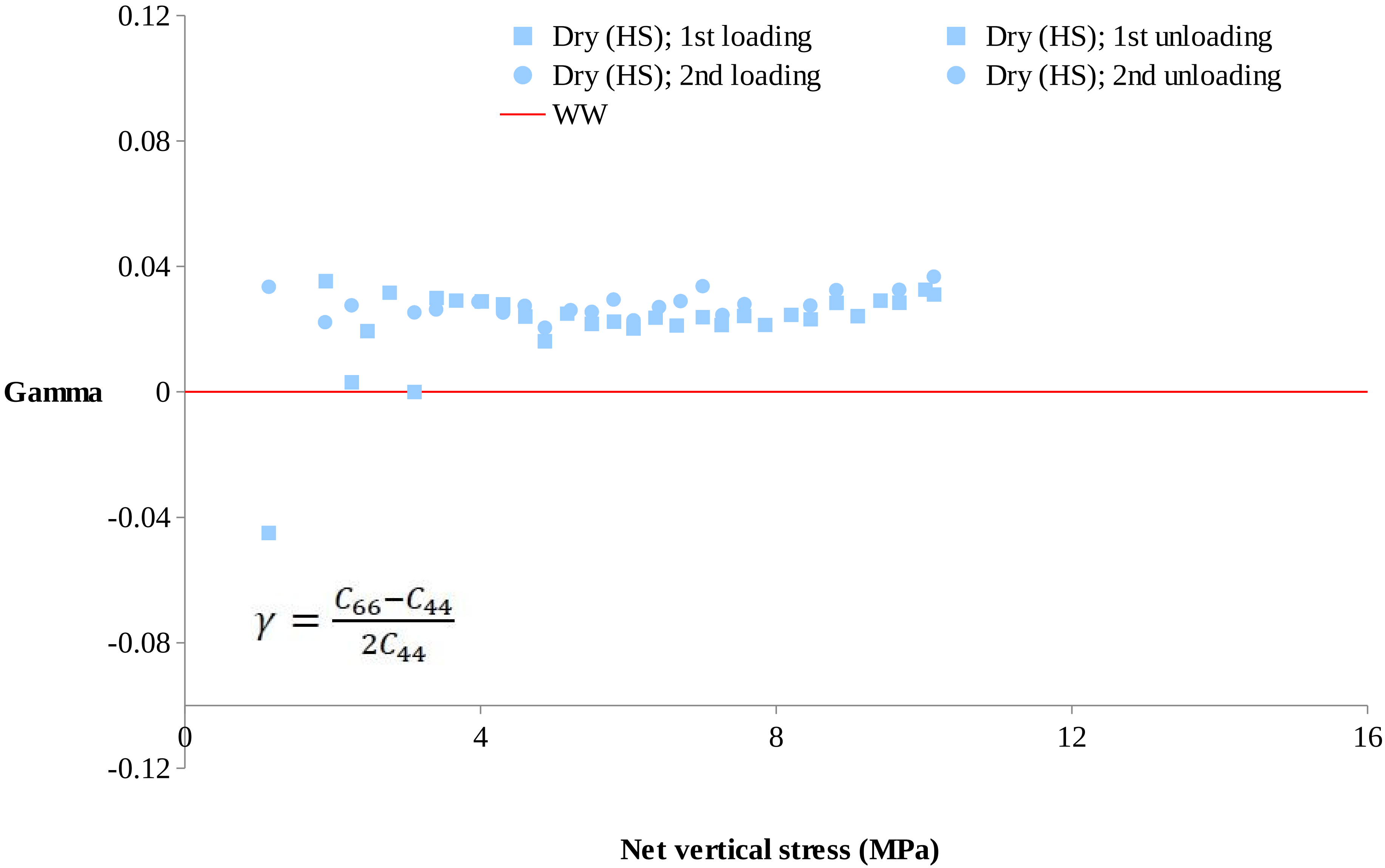

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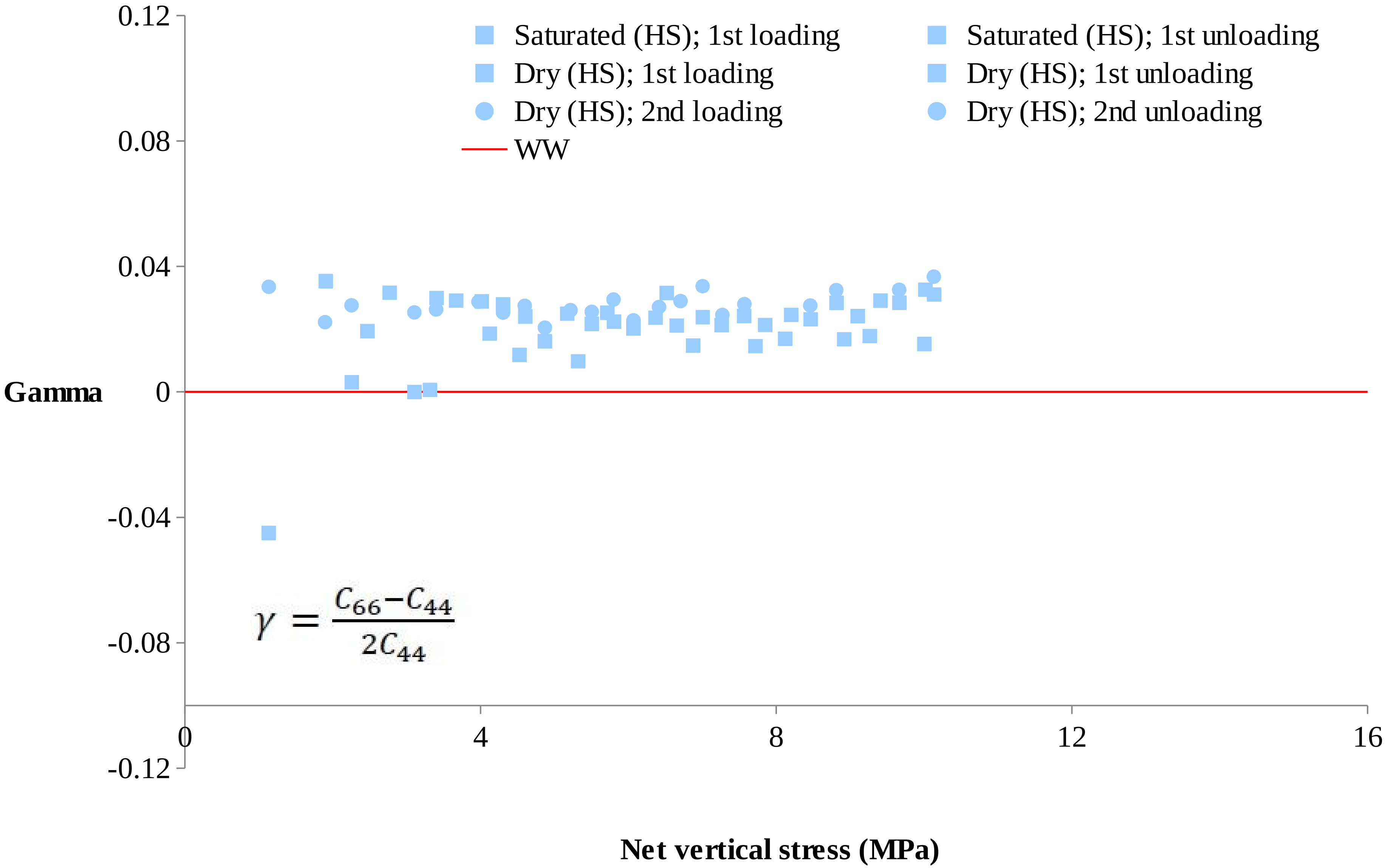
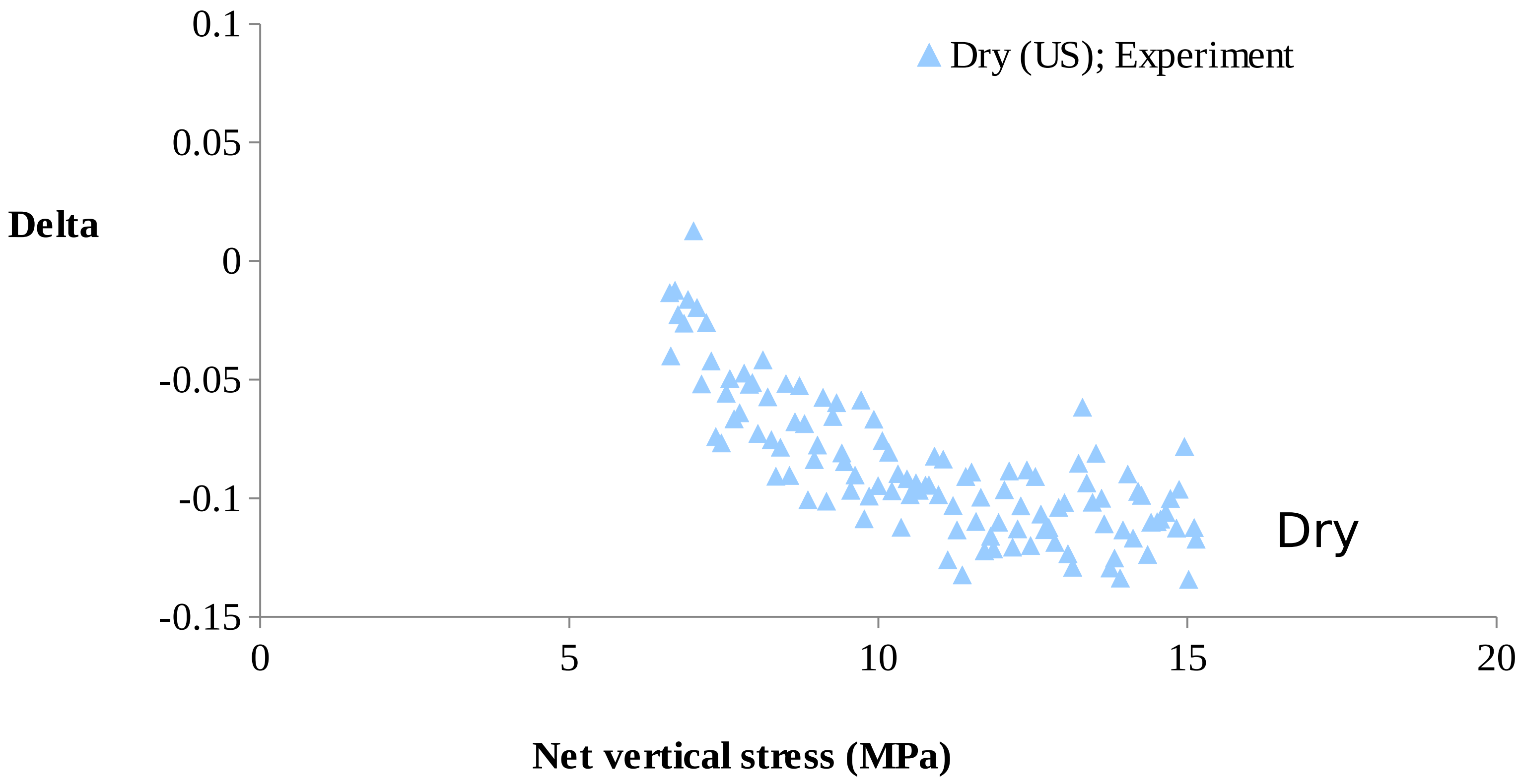


$$\gamma = \frac{C_{66} - C_{44}}{2C_{44}}$$

Effect of fluid on Delta (Uniaxial strain condition)

$$\delta = \frac{(C_{13}+C_{44})^2-(C_{33}-C_{44})^2}{2C_{33}(C_{33}-C_{44})}$$



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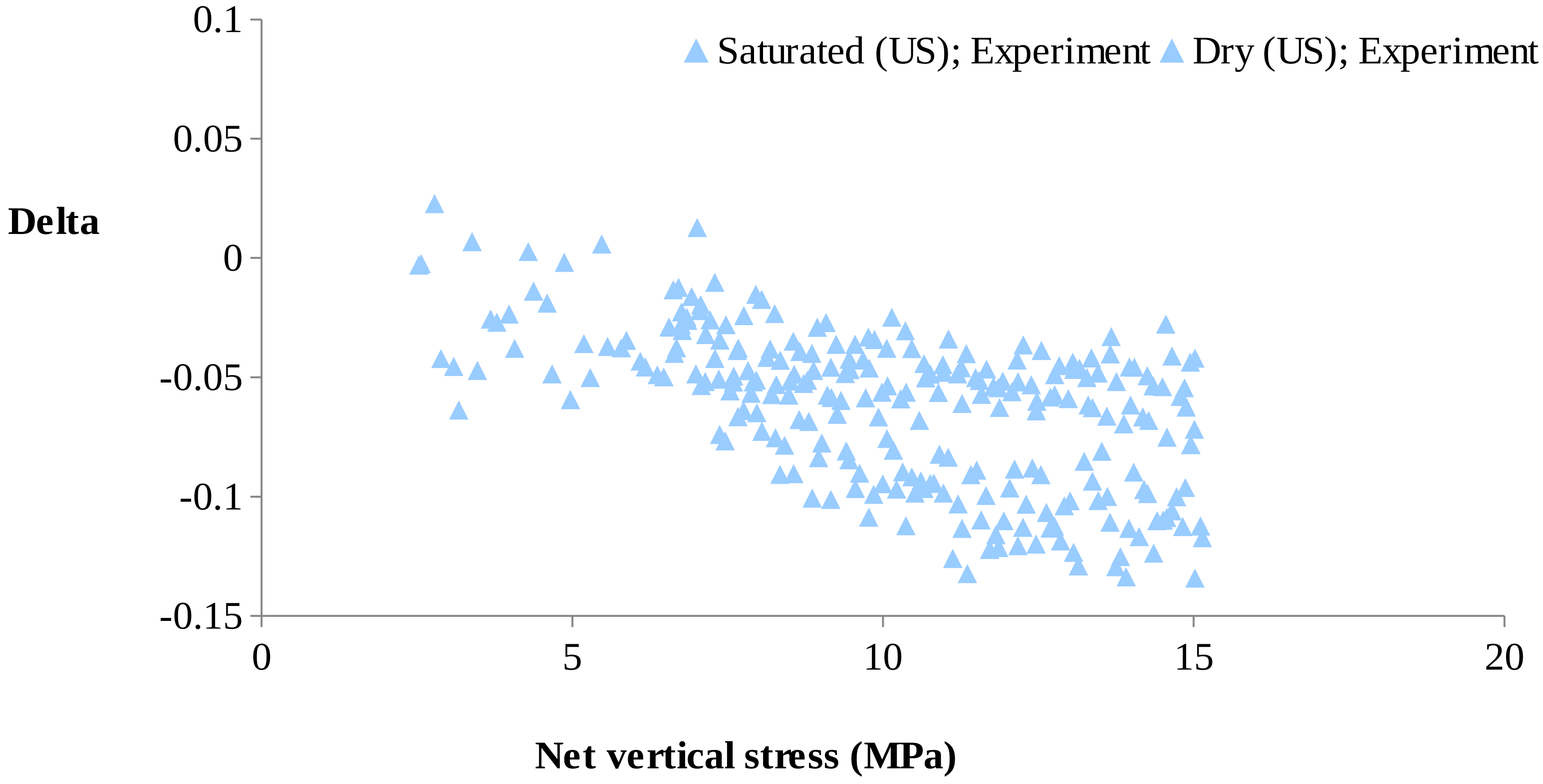

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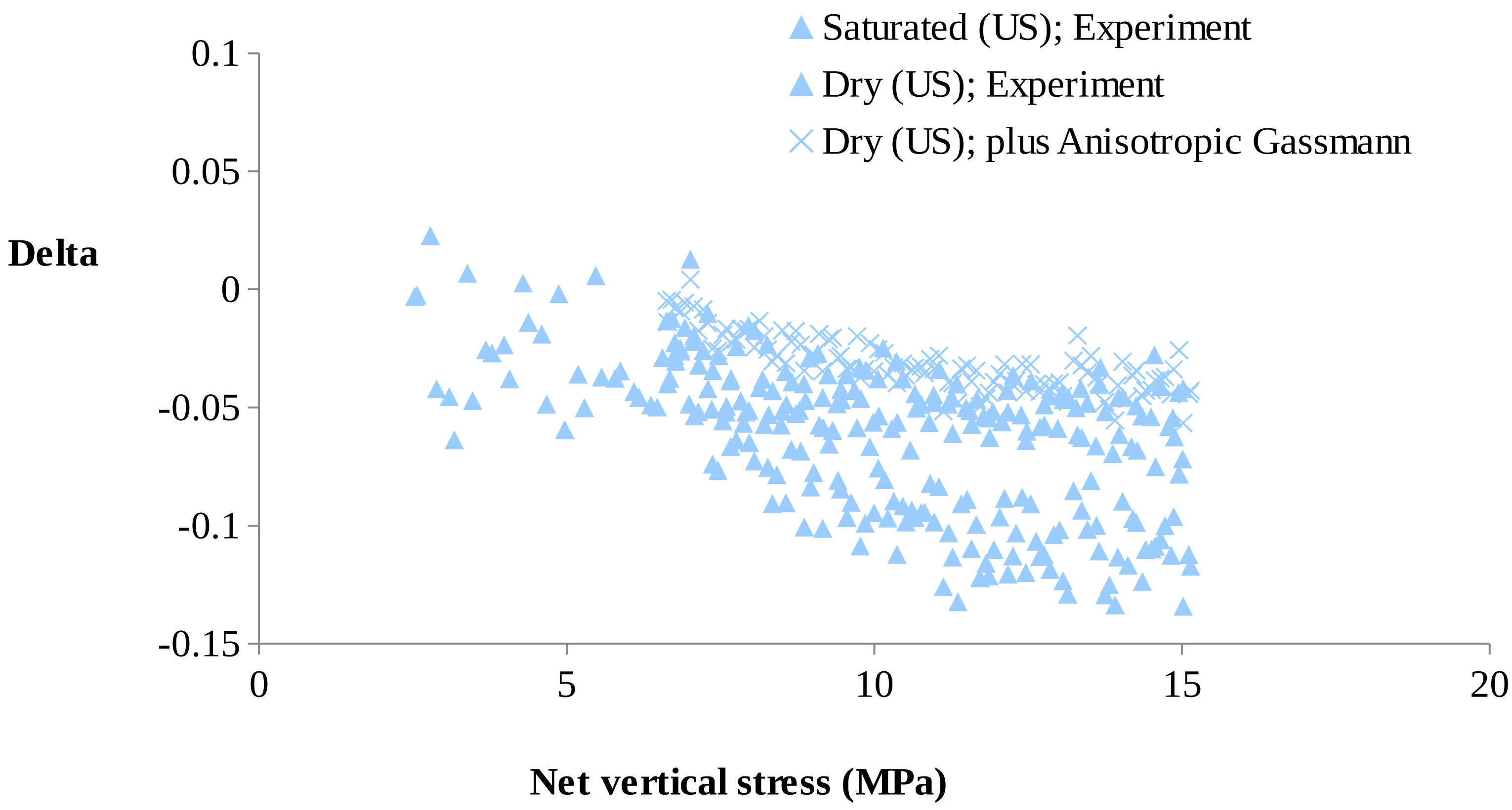
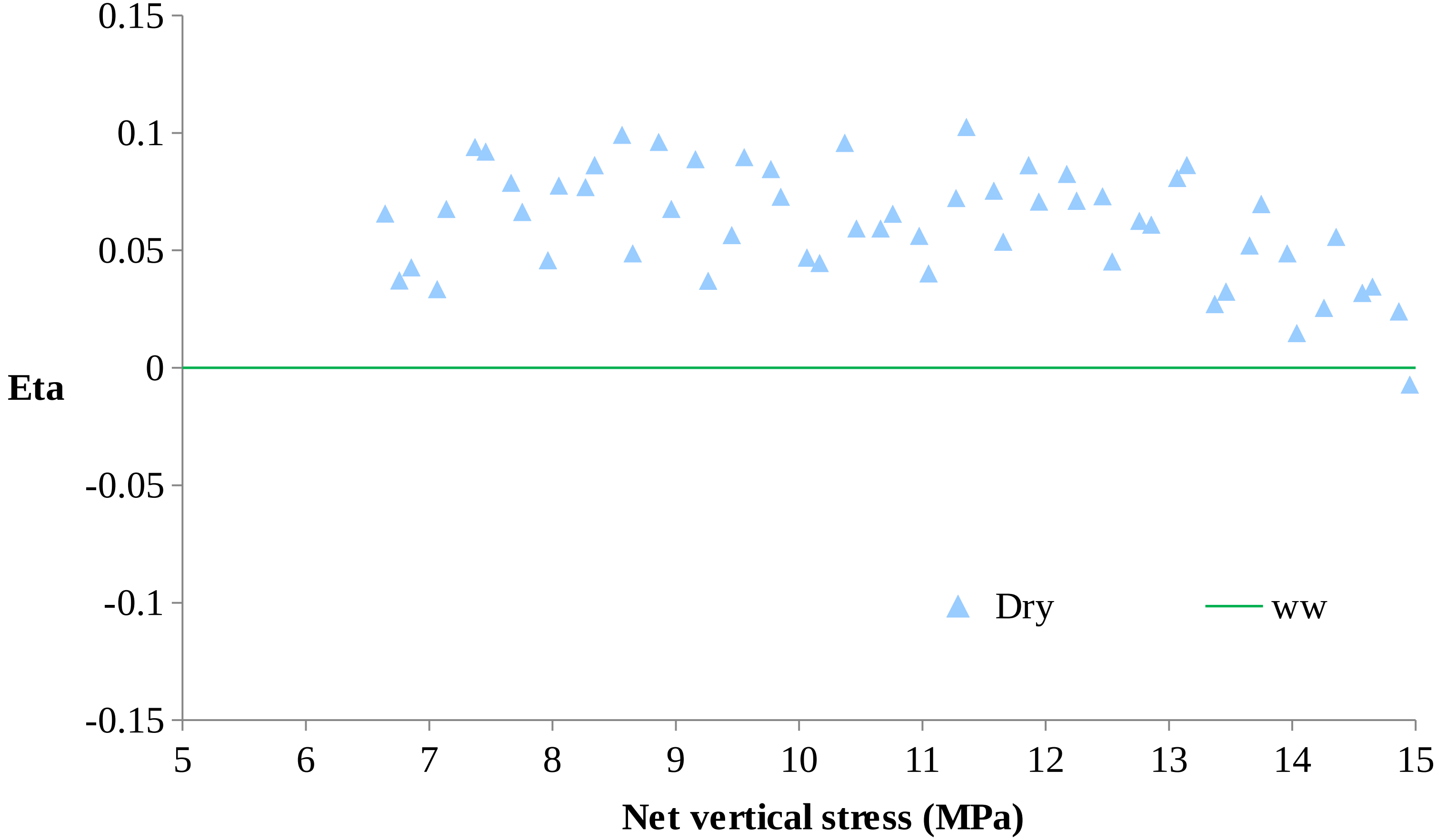


Effect of fluid on Eta (Uniaxial strain condition)

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



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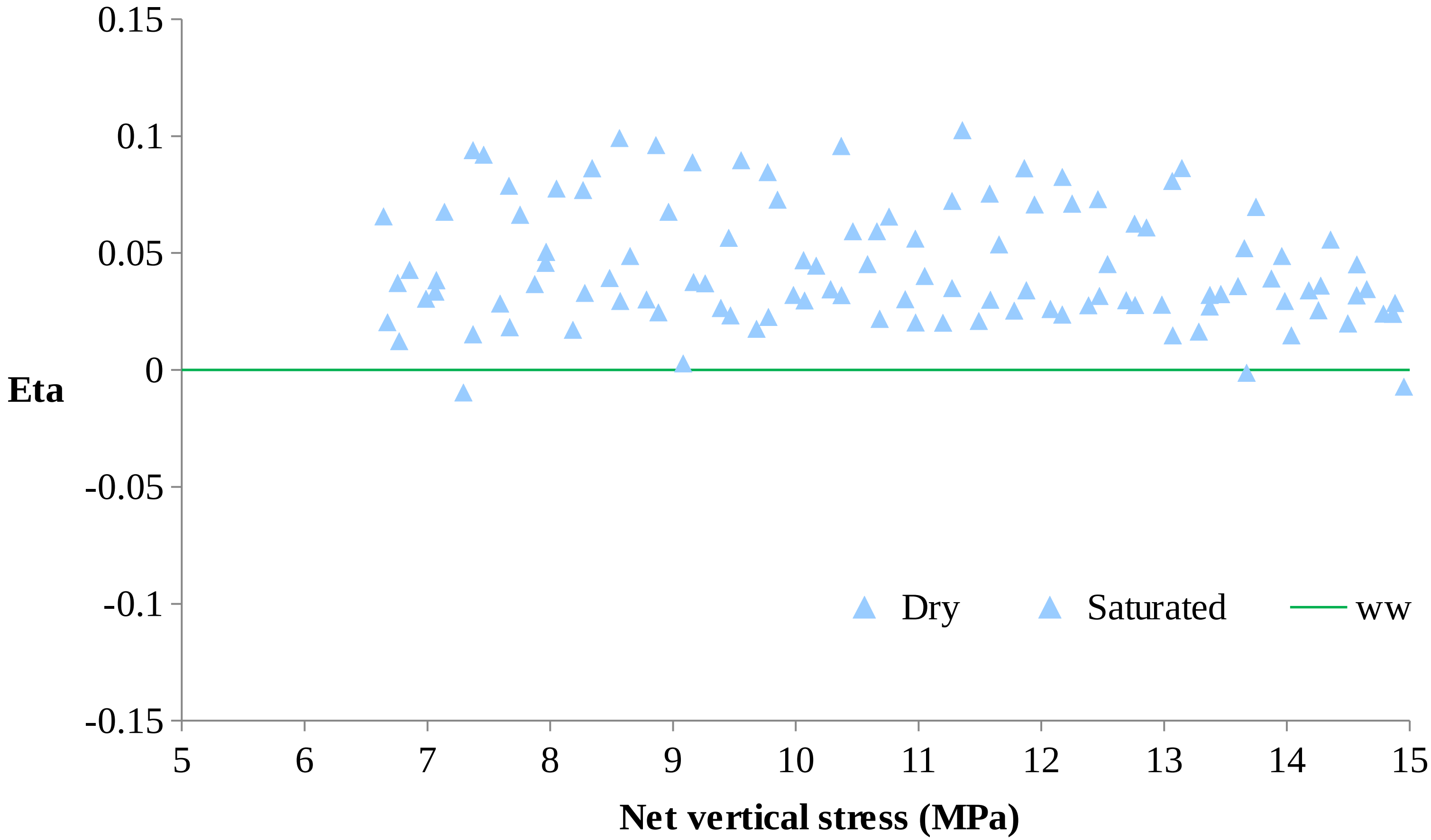
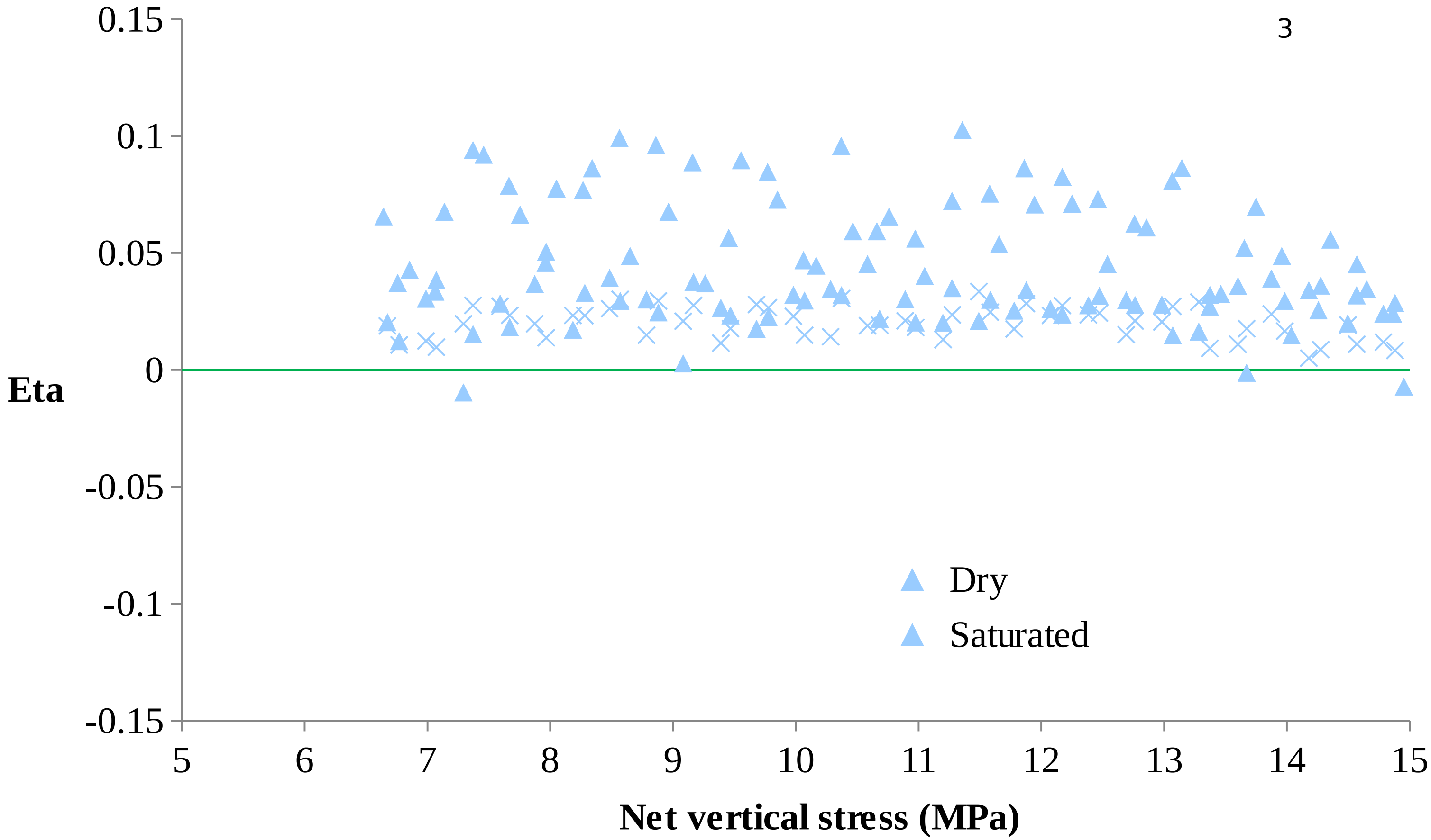


Effect of fluid on Eta (Uniaxial strain condition)

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

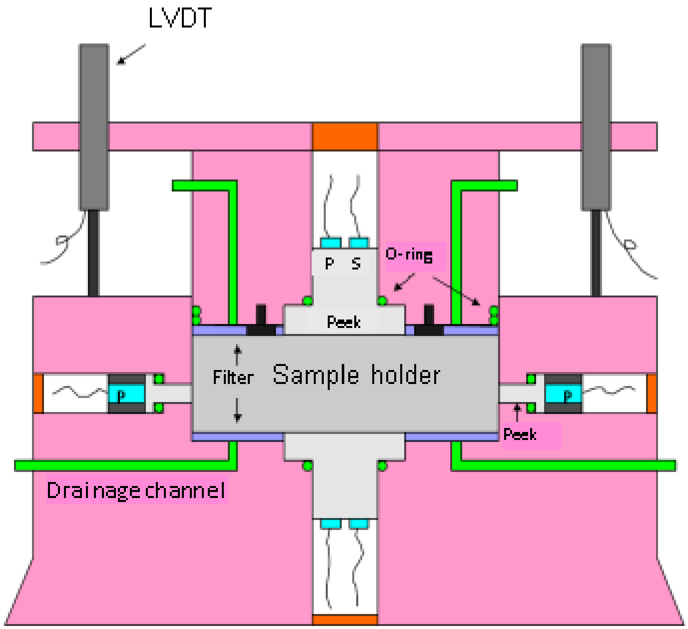
$$\eta^{sat} = \frac{C_3}{C_3} \eta$$

3

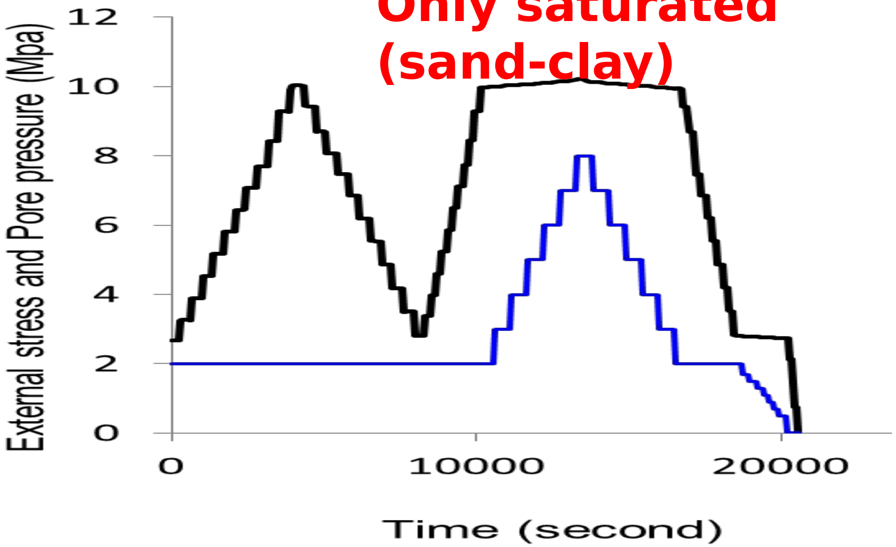


Vp-Vs
(sand-clay)

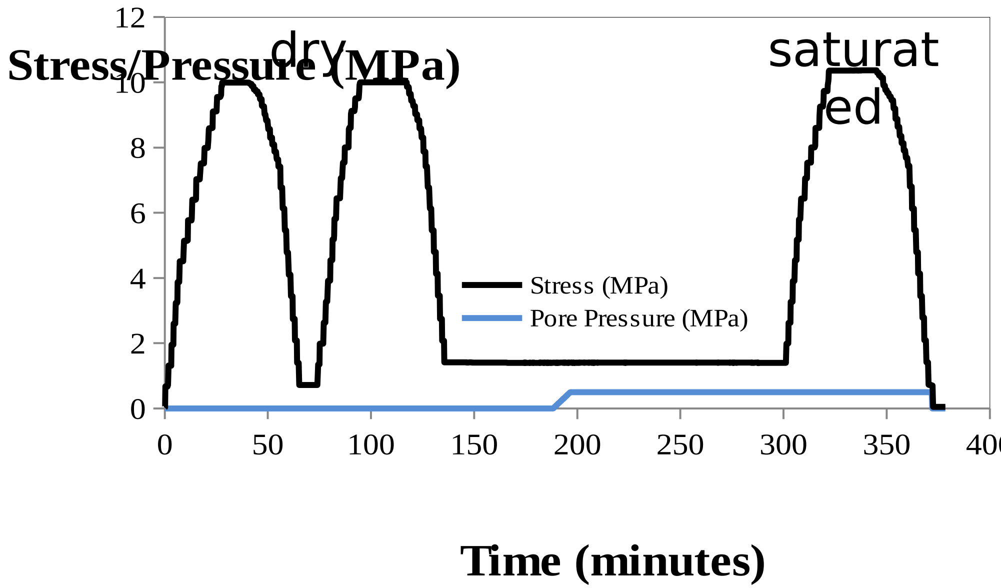
Lab tests in Oedometer



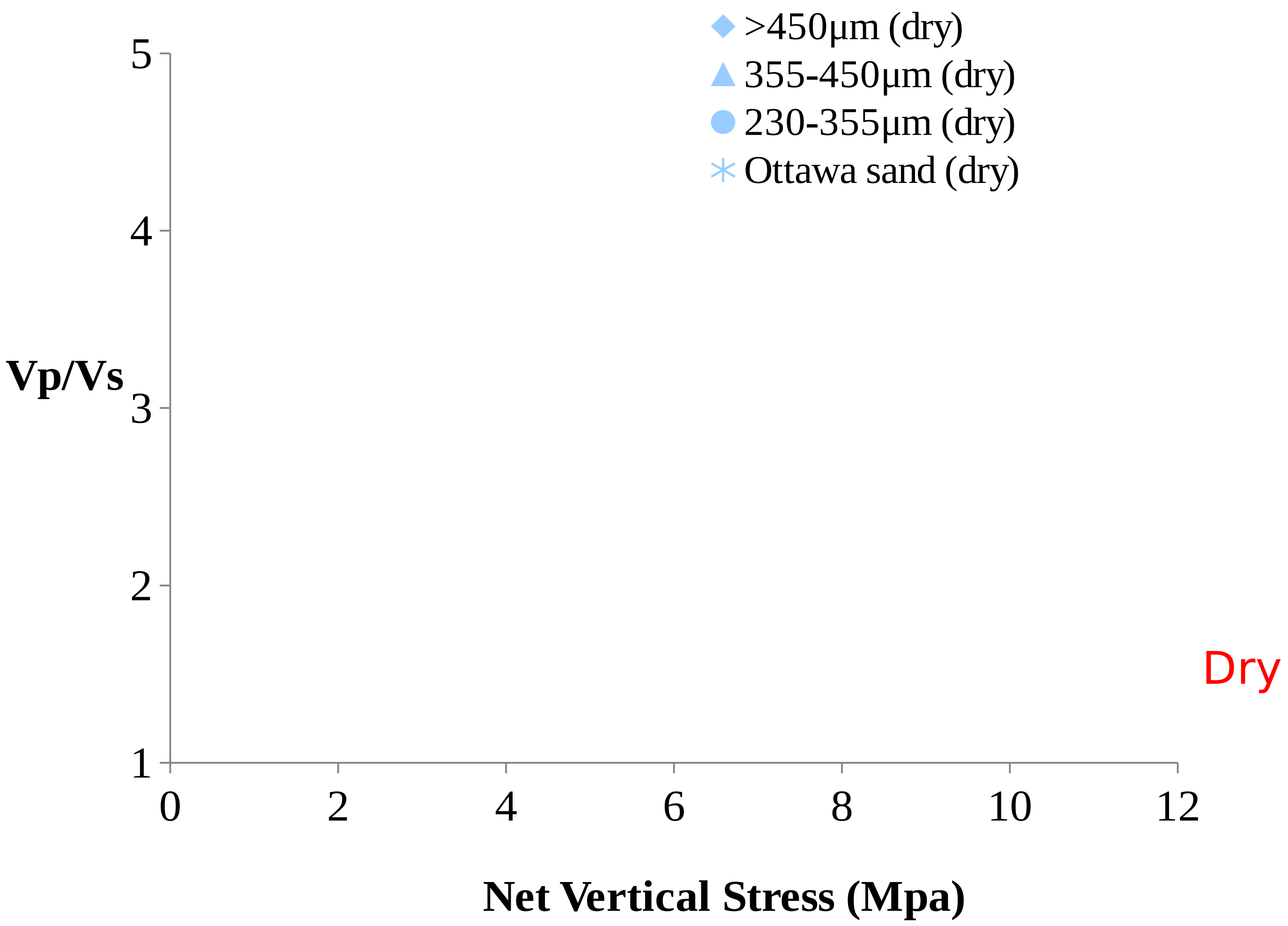
Only saturated (sand-clay)



Fluid effects (only sand) →

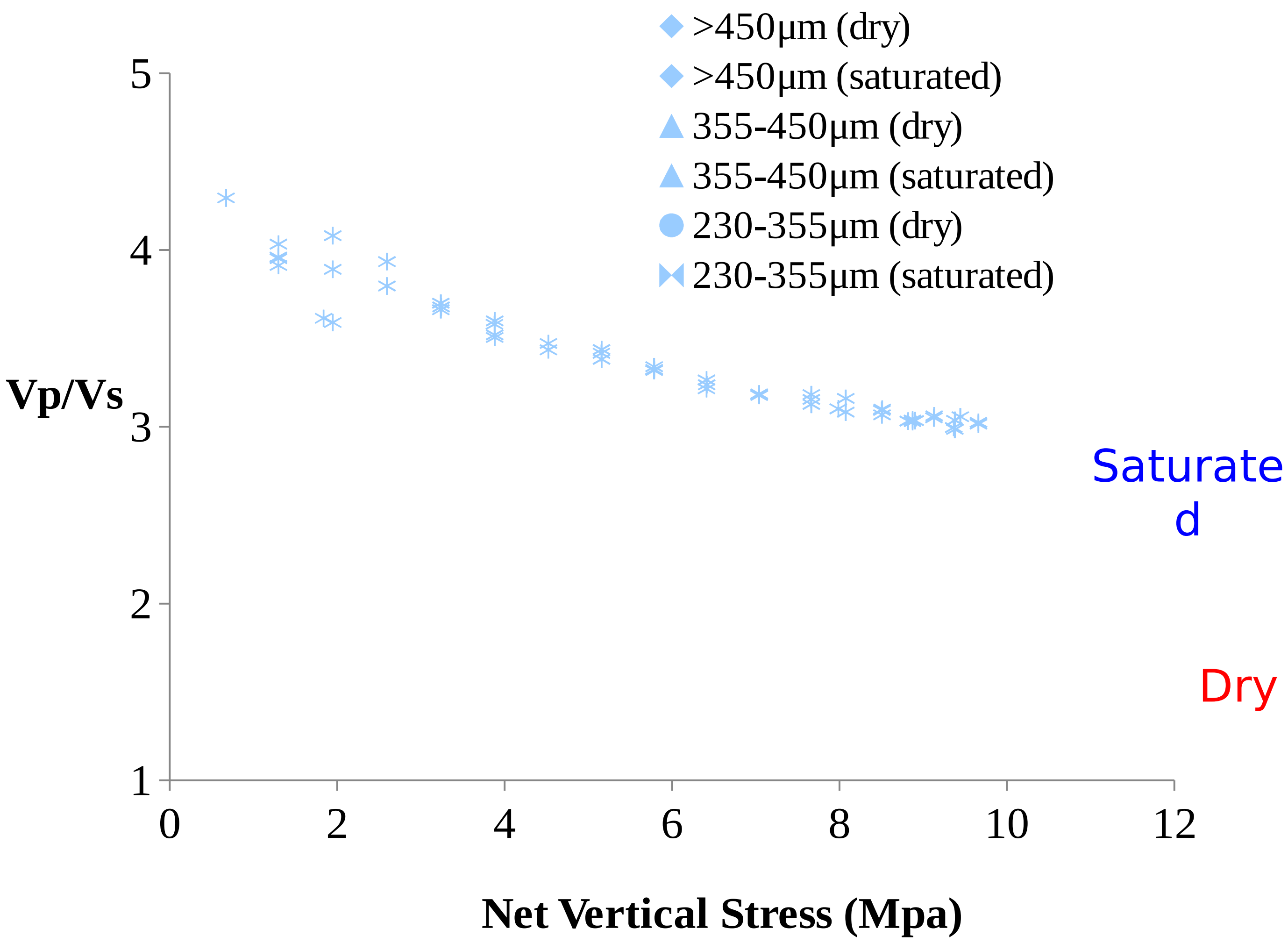


Vp/Vs: Role of fluid (only sand data)



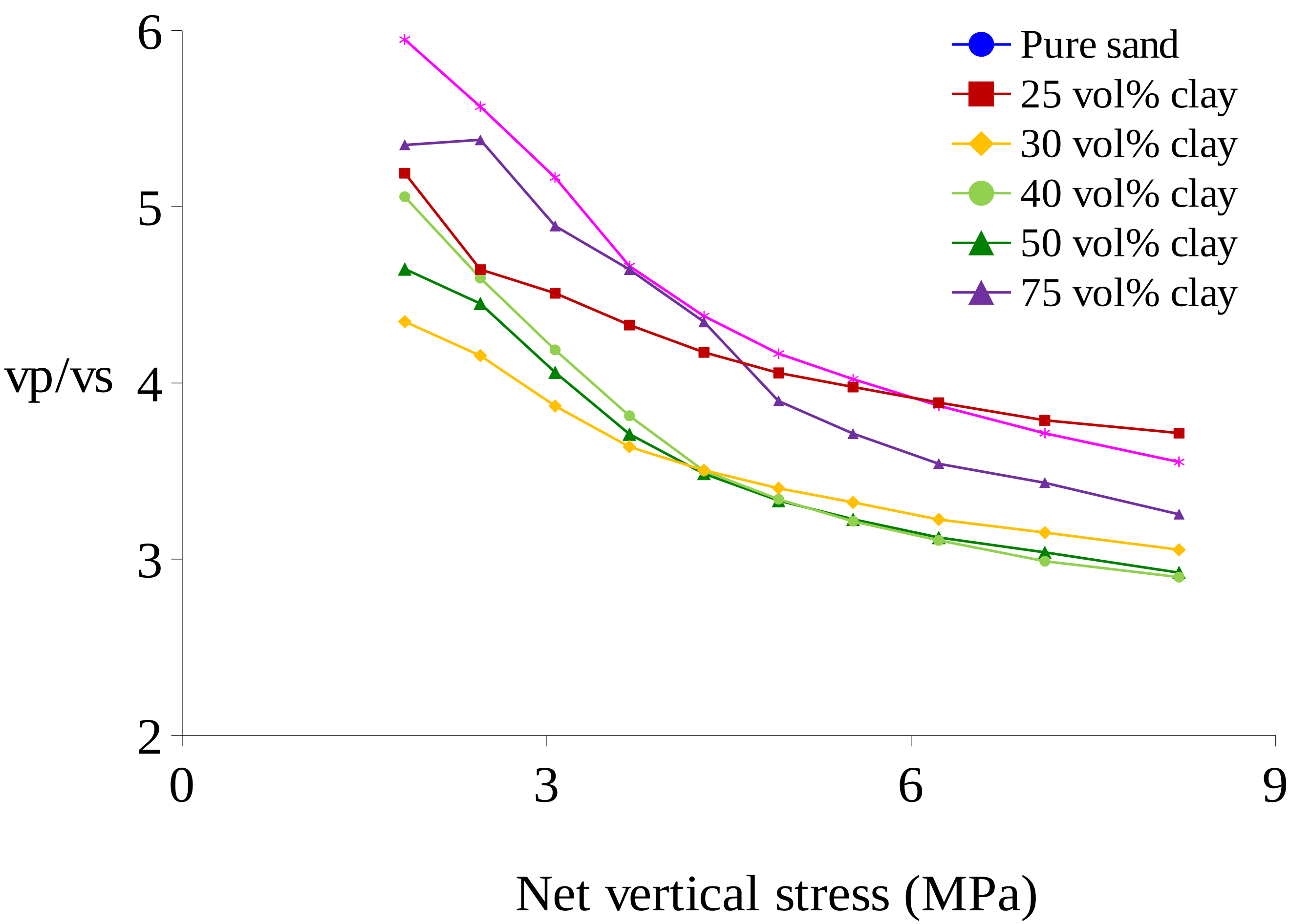
Data from Oedoemeter

Vp/Vs: Role of fluid (only sand data)



Data from Oedoemeter

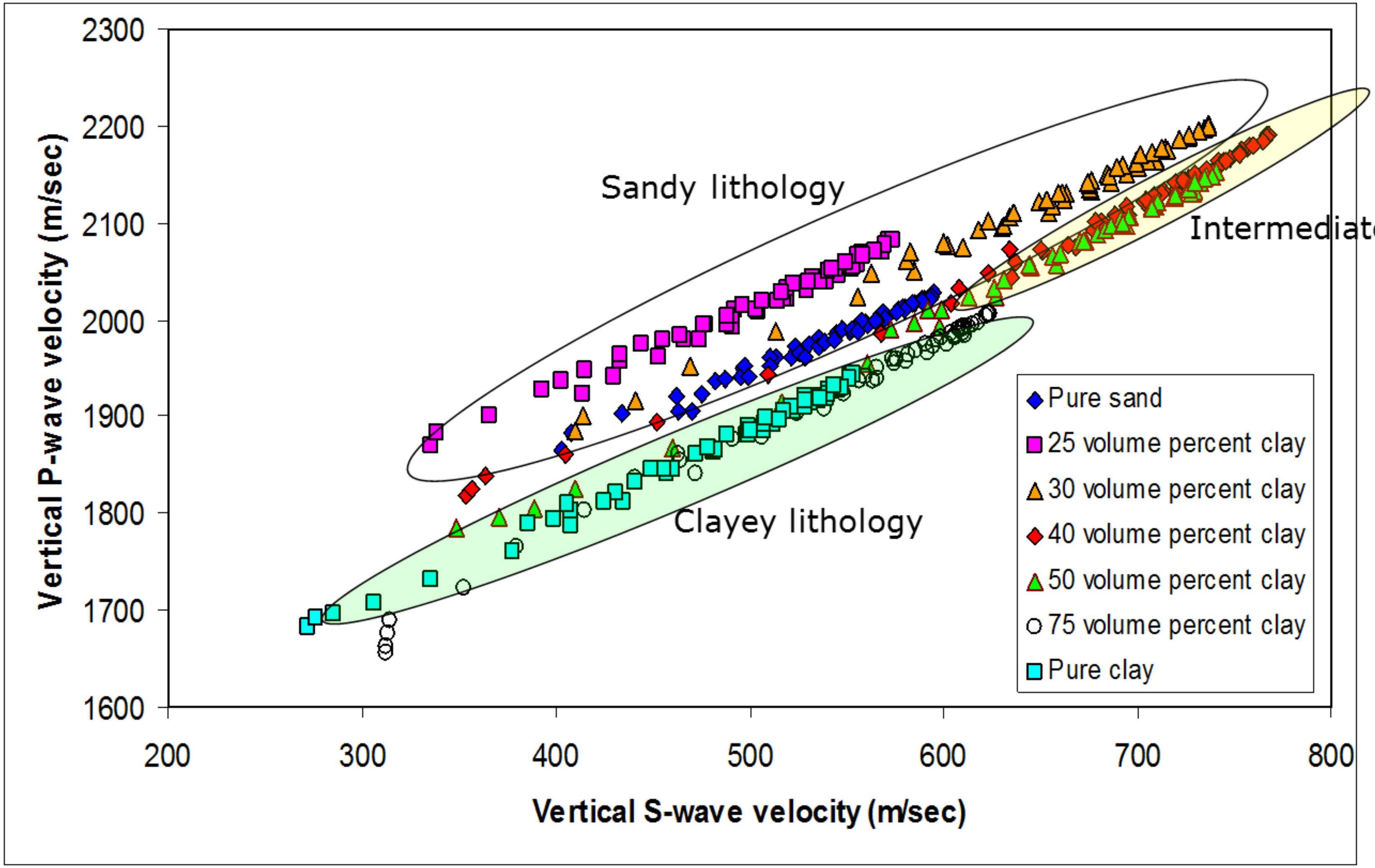
Vp/Vs: The role of clay content and stress



Data from tests with brine-saturated sand, clay (kaolinite) and sand:clay mixtures

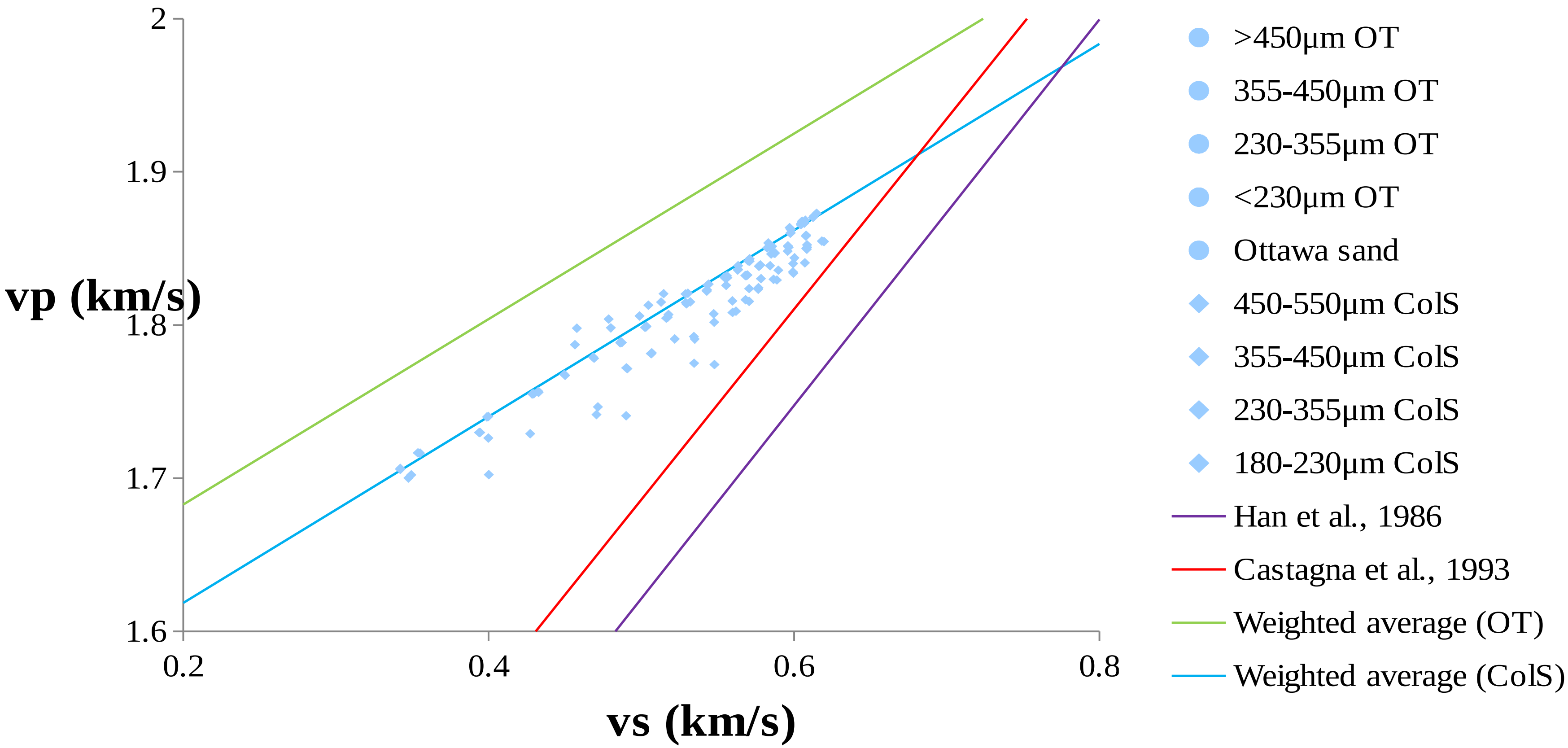
v_P/v_S decreases with stress, more in clay than in sand

Vp/Vs trends



Oedometer tests performed with brine-saturated sand, clay (kaolinite) and sand:clay mixtures have been used to address v_P *vs.* v_S trends (here: only axial velocities)

v_P/v_S: trends for sand

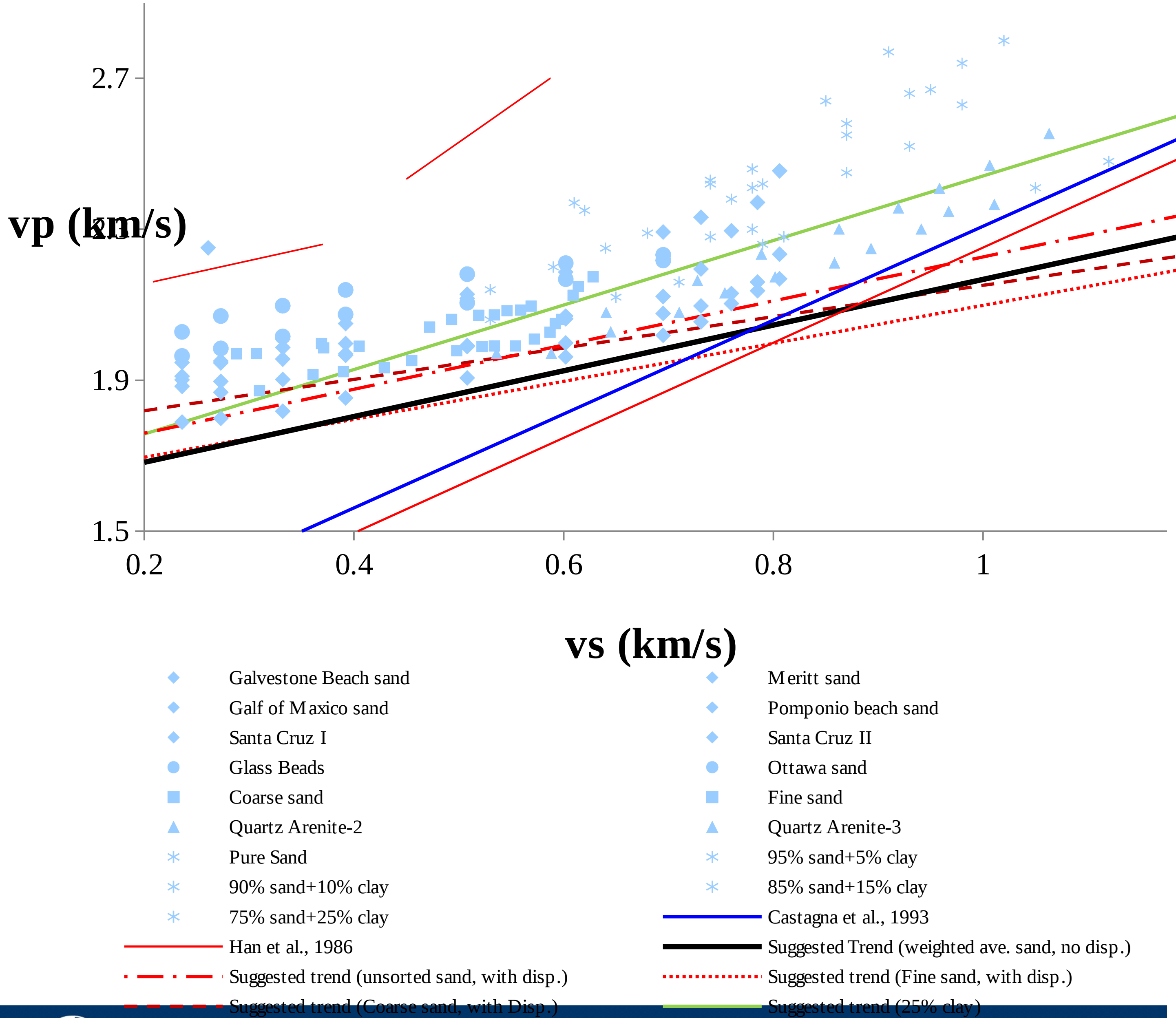


Higher velocities for Ottawa than for angular Columbia sand, but similar v_P-v_S trends

Plotting v_P vs v_S gives a better picture than showing v_P/v_S alone

No obvious effect of grain size

v_P/v_S: global trends for sand



The trends are different from data at low stress (< 10 MPa) and above

Data from Zimmer, 2003 (Diamond); Domenico, 1977 (circular), Prasad, 1988 (square); Mondol et al., 2010 (triangle) and Yin, 1992 (star)

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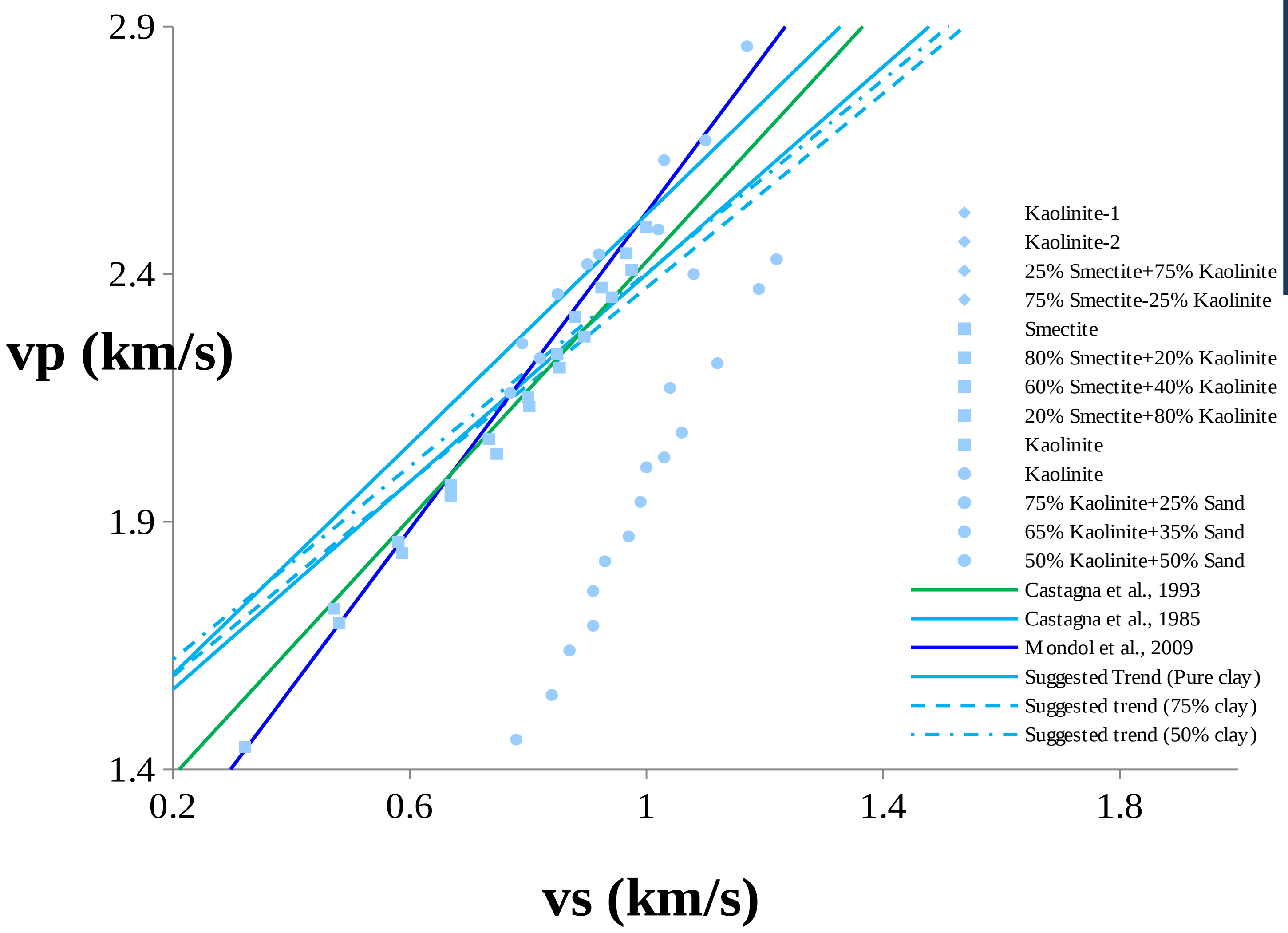
v_P/v_S: trends for clays



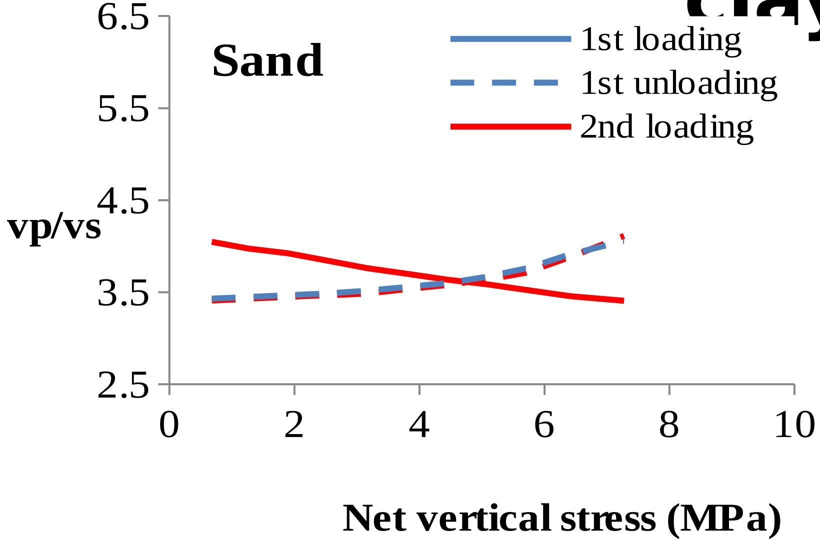
The trends are different from sand + again for data at low stress (< 10 MPa) vs. above

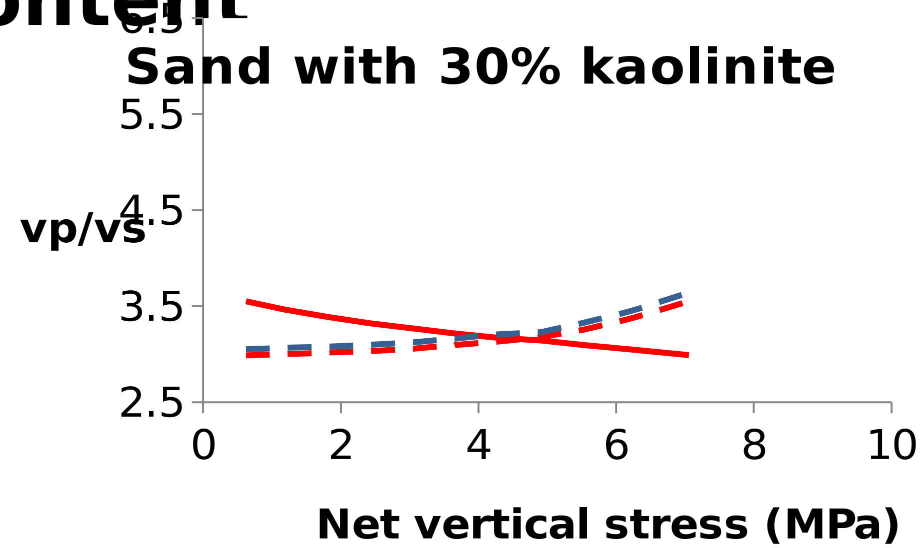
Diamonds: This study

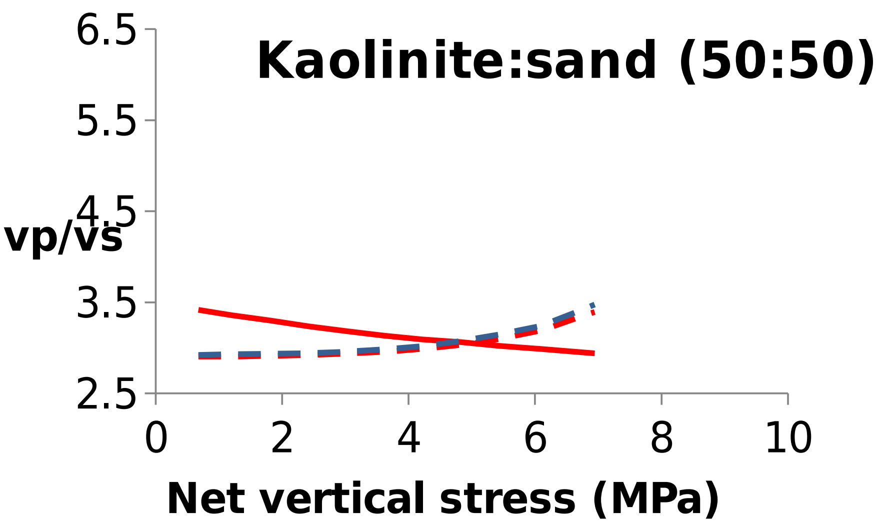
Squares: Mondol et al. (2009)

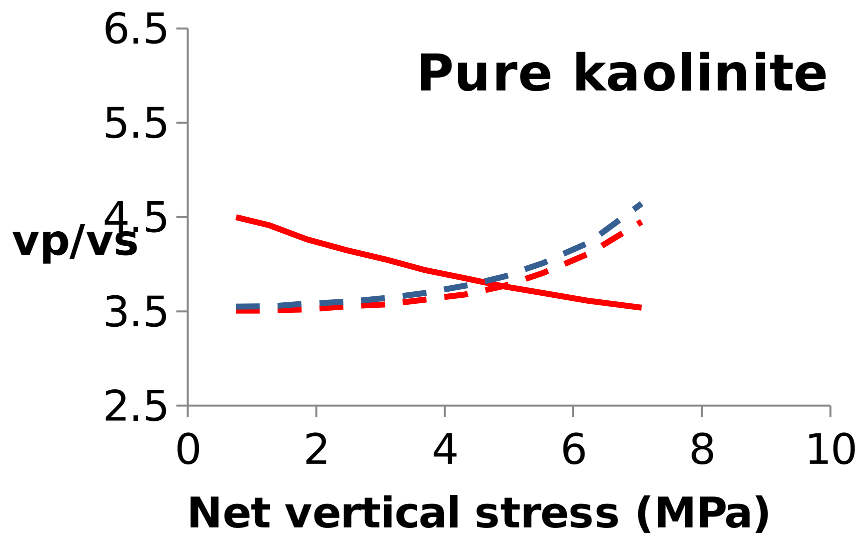
Circles: Yin (1992) (hydrostatic data)

Vp/Vs: Role of state of consolidation and clay content

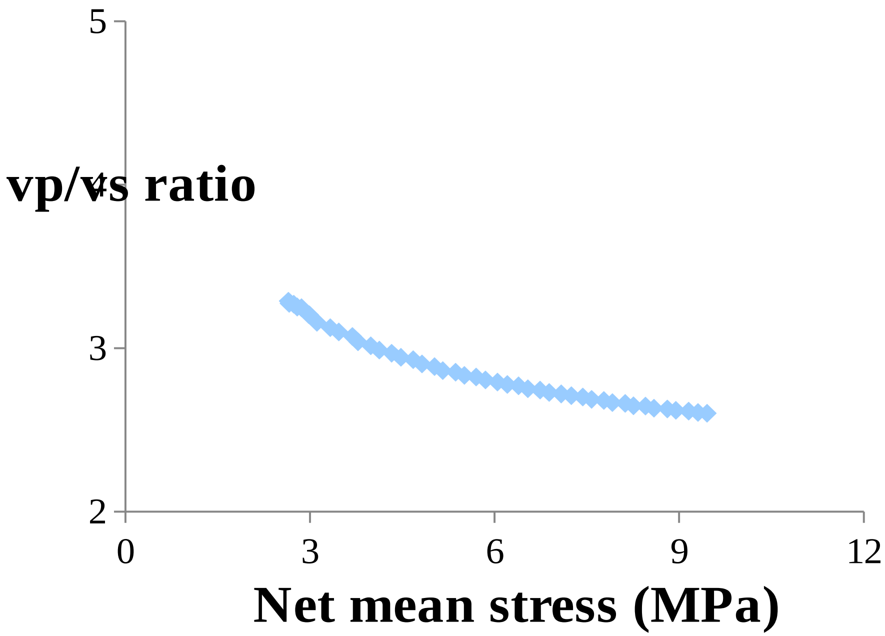


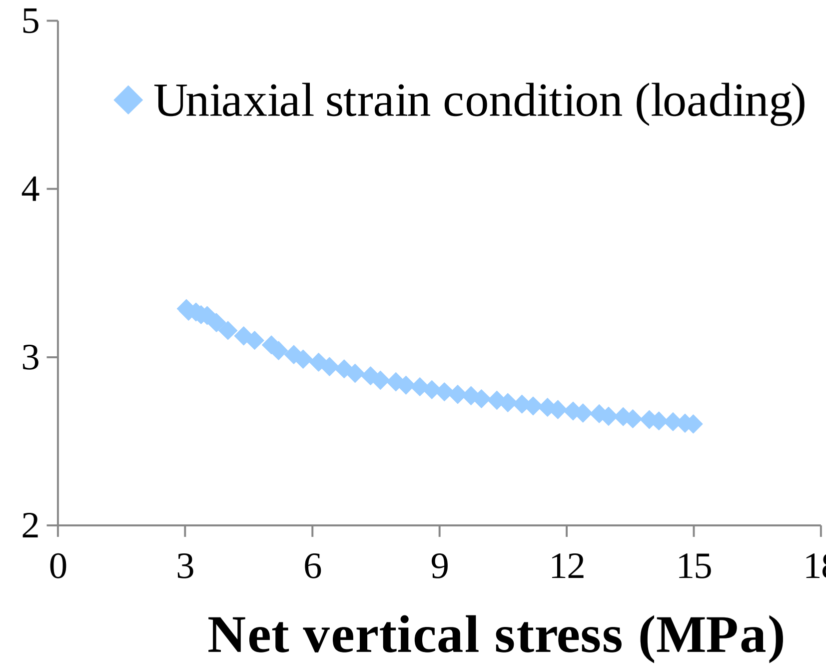






v_P/v_S: The role of Stress Path (only for sand)





Ottawa sand data from triaxial set-up, showing apparent data collapse when v_P/v_S is plotted against net mean stress

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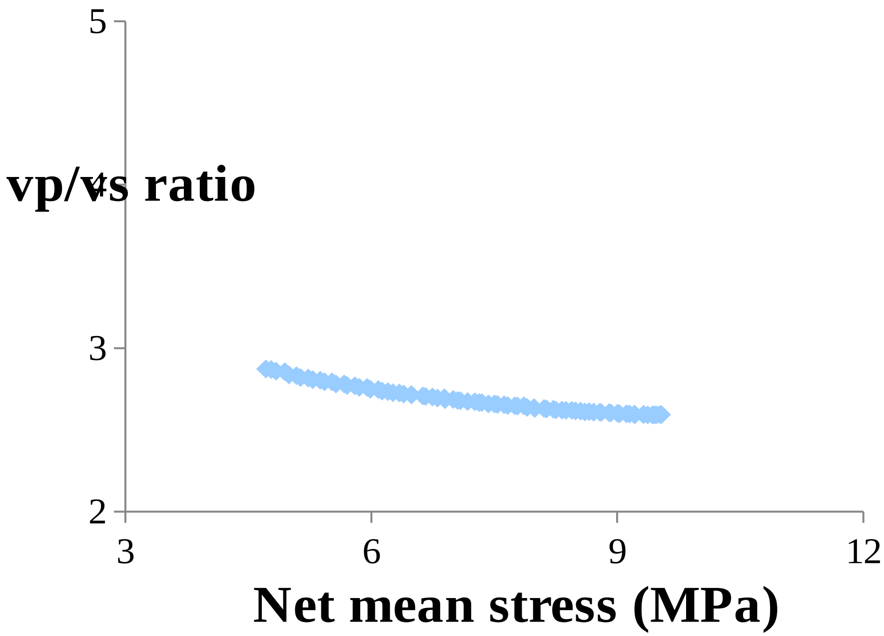

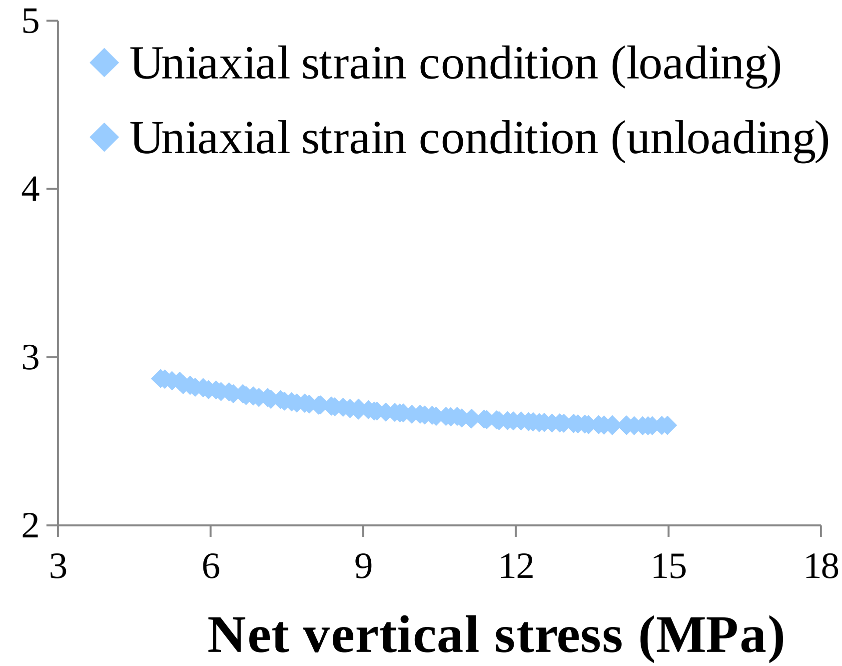

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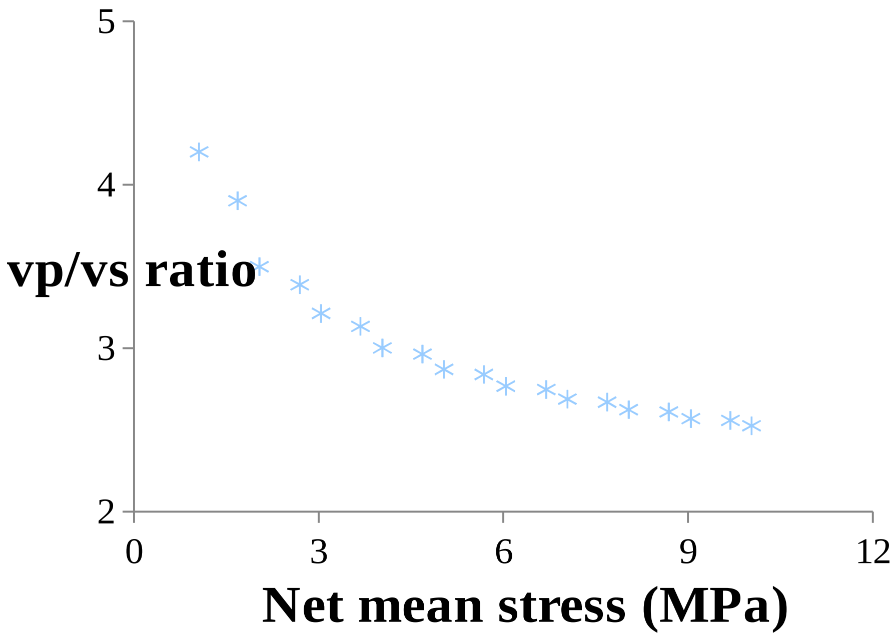

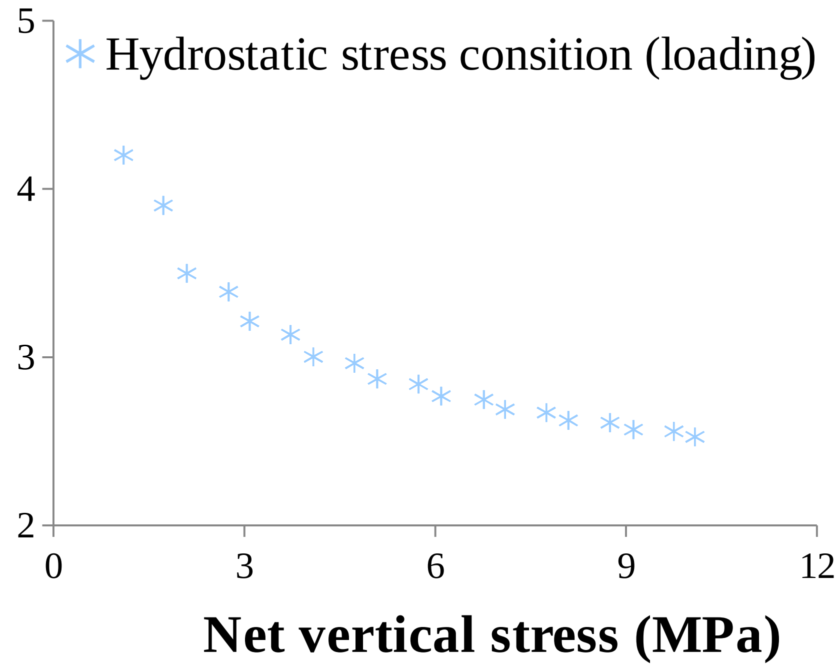

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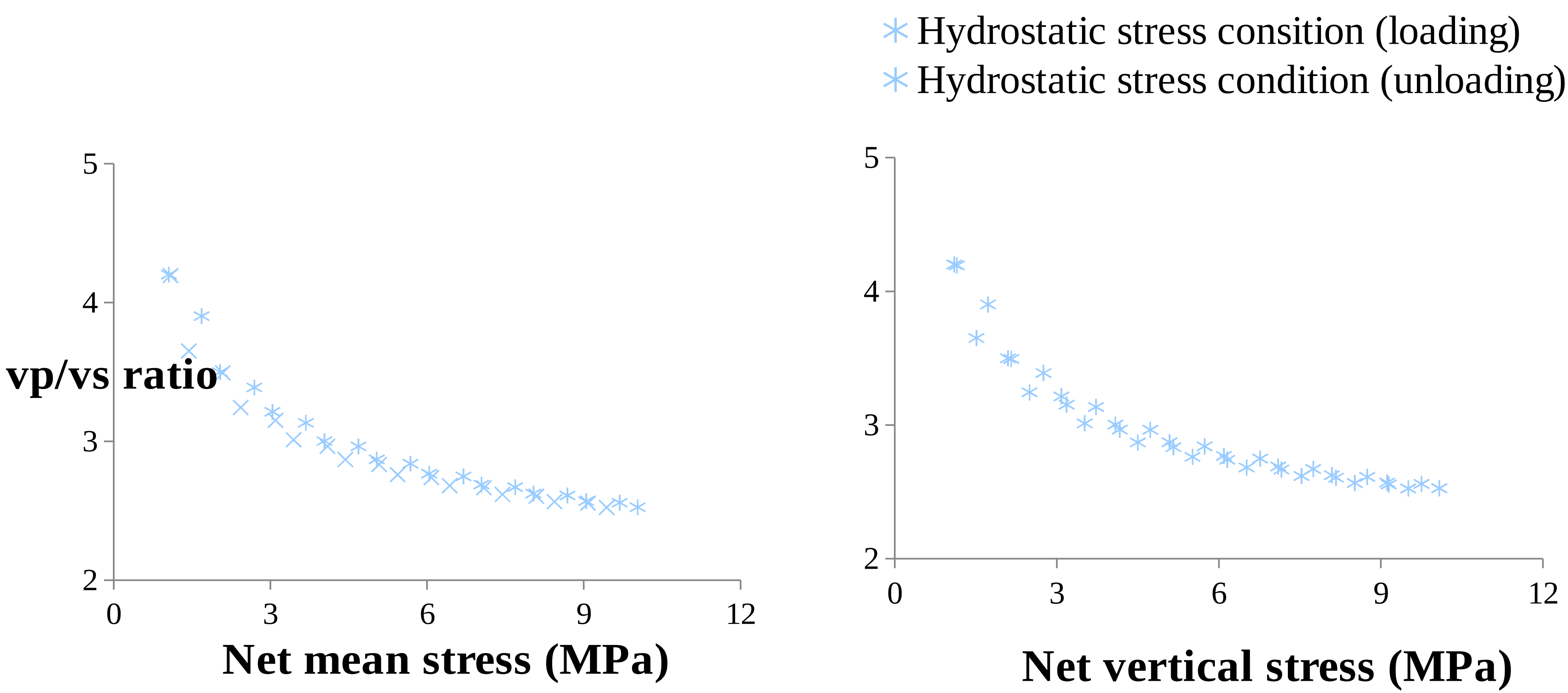

Ottawa sand data from triaxial set-up, showing apparent data collapse when v_P/v_S is plotted against net mean stress

Conclusions

- Comparison between measured dry and saturated anisotropy parameters are conformable with theory within experimental uncertainty
- v_P/v_S relation is sensitive to fluid saturation, stress, lithologies and state of consolidation.
- Well known v_p/v_s trends fail to explain v_p/v_s relation for uncosolidated sandy lithologies but fairly capture for clayey lithologies.

Acknowledgements

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Jørn Stenebråten & others in the Formation Physics Laboratory at SINTEF & NTNU