Variation of shear and compressional wave modulus upon saturation for pure pre-compacted sands

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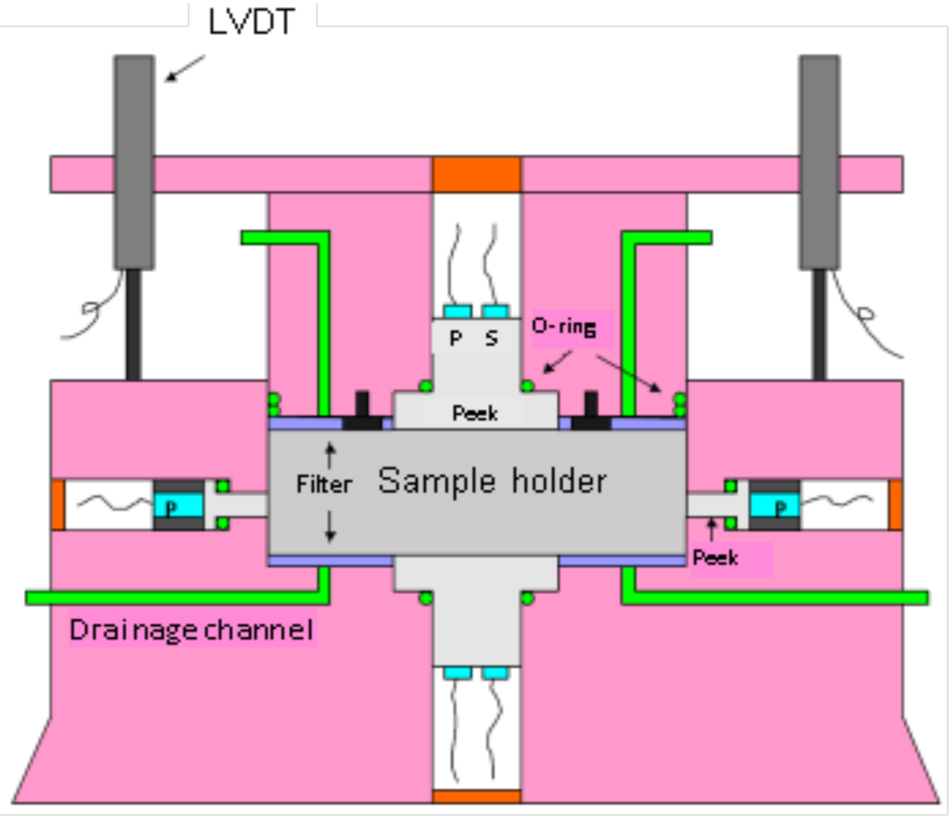
Objectives

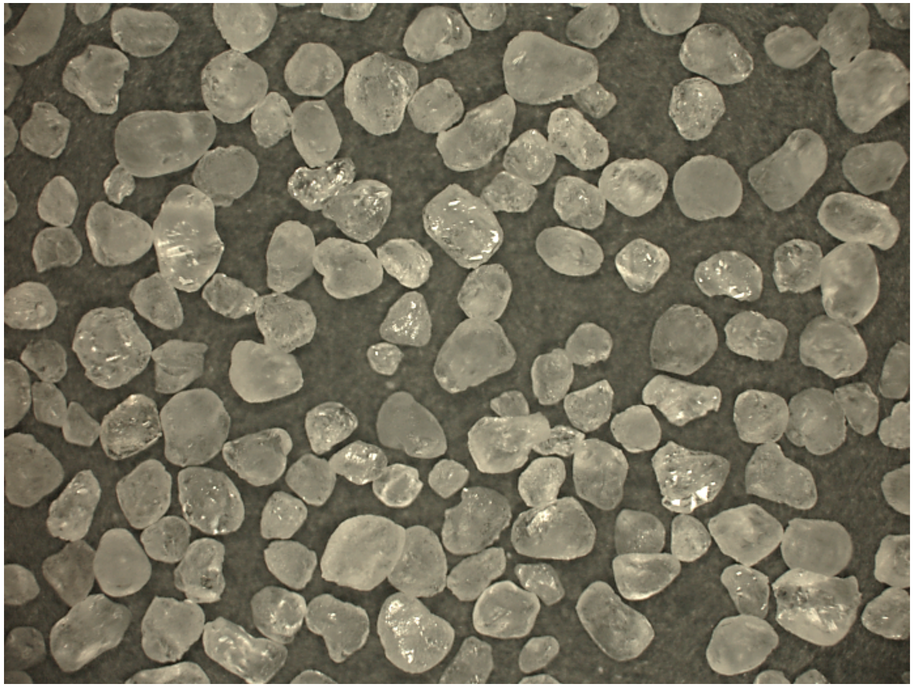
- To investigate the behavior of the shear and compressional wave modulus upon saturation.
- Find out the possible mechanisms for shear and/or compressional wave modulus hardening or softening.

Experimental Setup: Oedometer

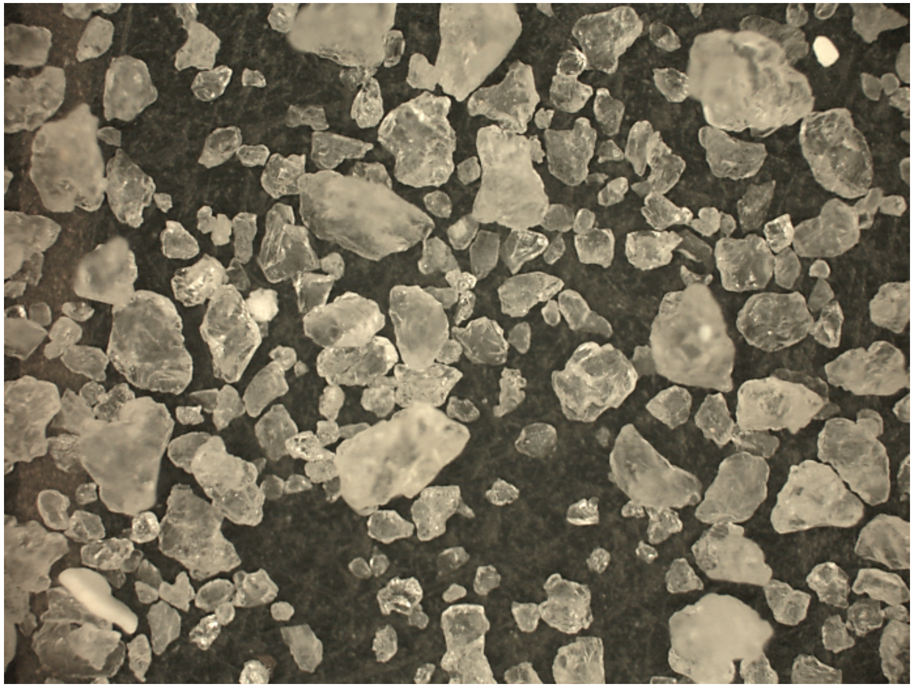


Samples

Ottawa sand (30-70)

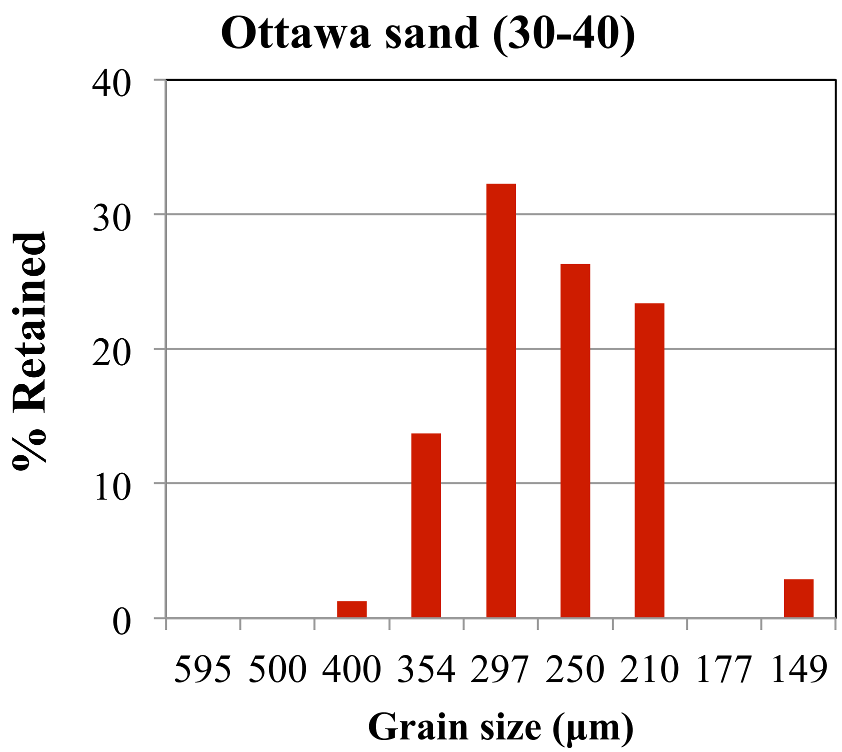


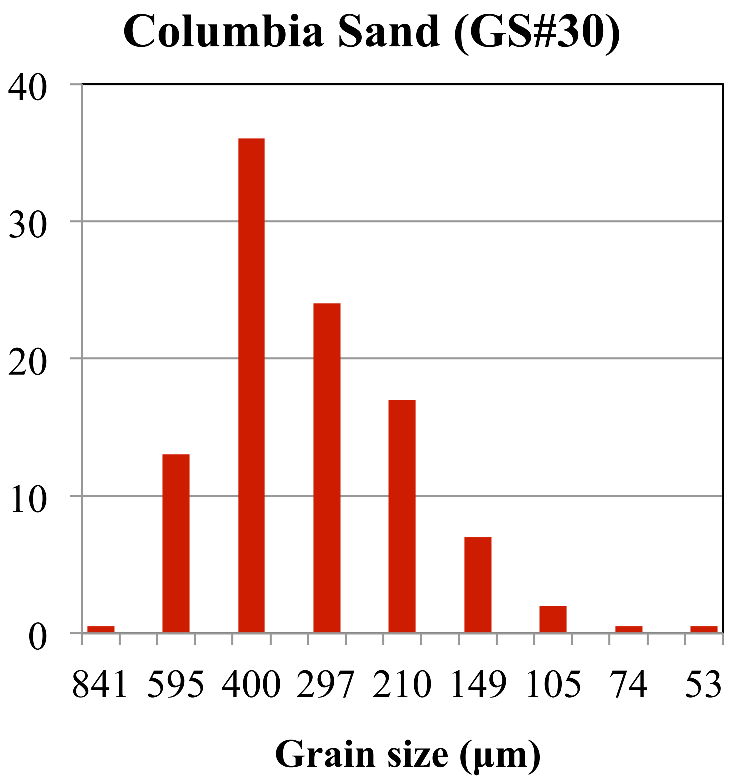
Columbia sand (GS#30)



Photomicrographs under microscope showing grain size and shape

Grain Size Distribution

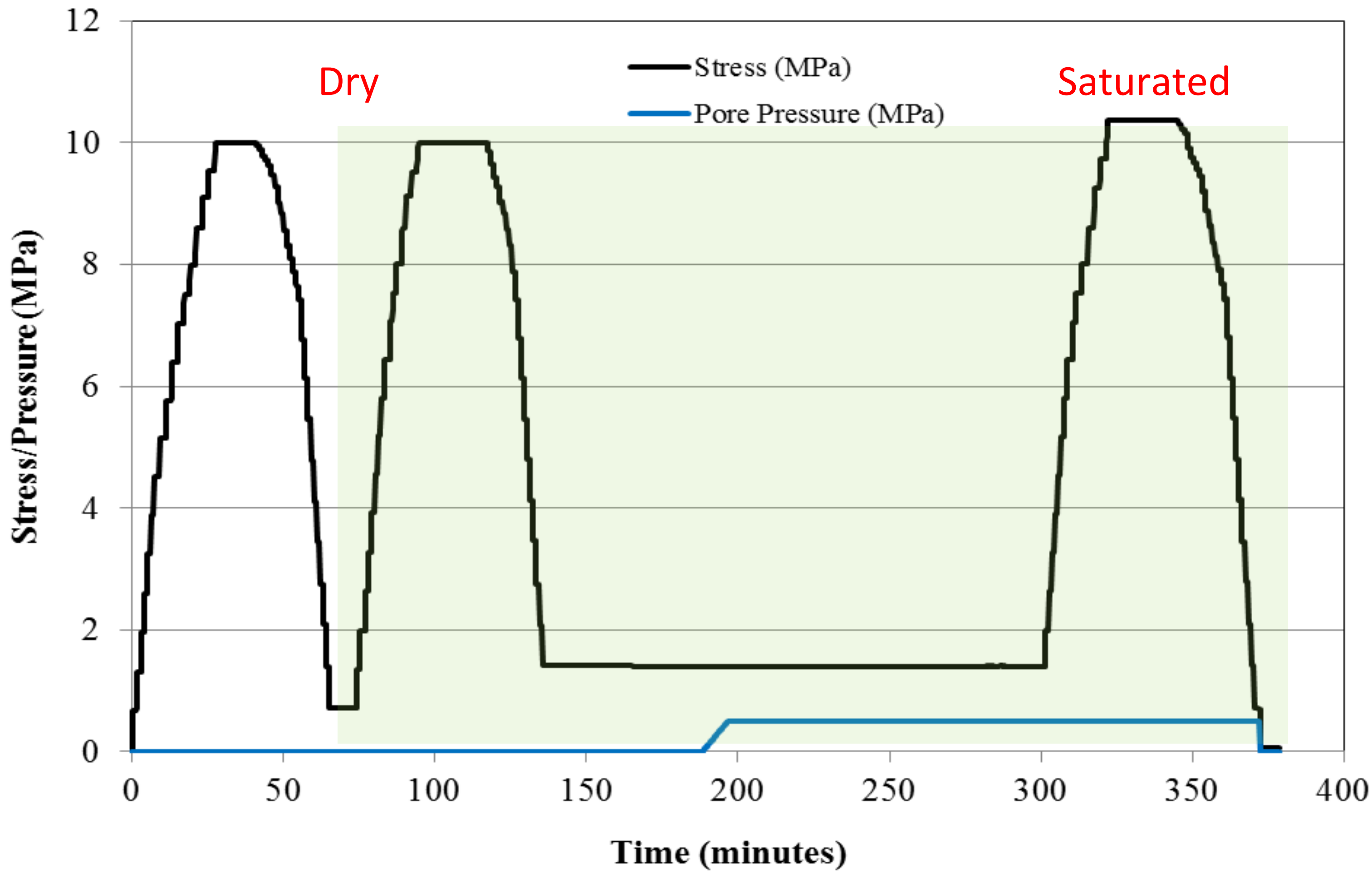




Samples

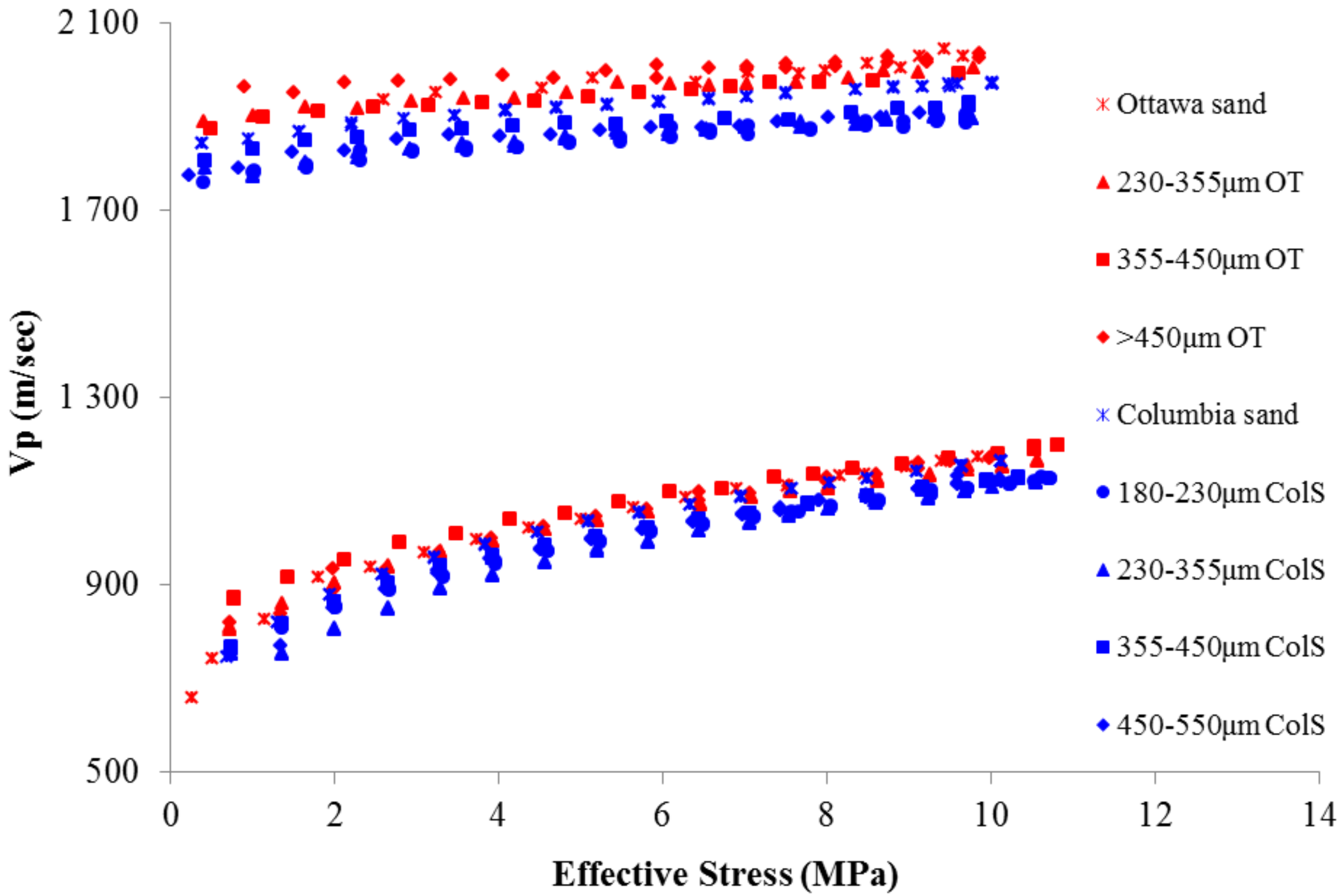
Name	Grain Size	Grain shape	Initial porosity (%)
Ottawa Sand	450-210 µm	Sub-rounded to rounded	37.4
Ottawa Sand	< 230 µm	Sub-rounded to rounded	38.2
Ottawa Sand	355-230 µm	Sub-rounded to rounded	37.2
Ottawa Sand	450-355 µm	Sub-rounded to rounded	37.0
Ottawa Sand	> 450 µm	Sub-rounded to rounded	36.8
Columbia Sand	600-100 µm	Angular	41.8
Columbia Sand	230-180 µm	Angular	44.4
Columbia Sand	355-230 µm	Angular	43.7
Columbia Sand	450-355 µm	Angular	43.0
Columbia Sand	550-450 µm	Angular	42.3

Test Procedure



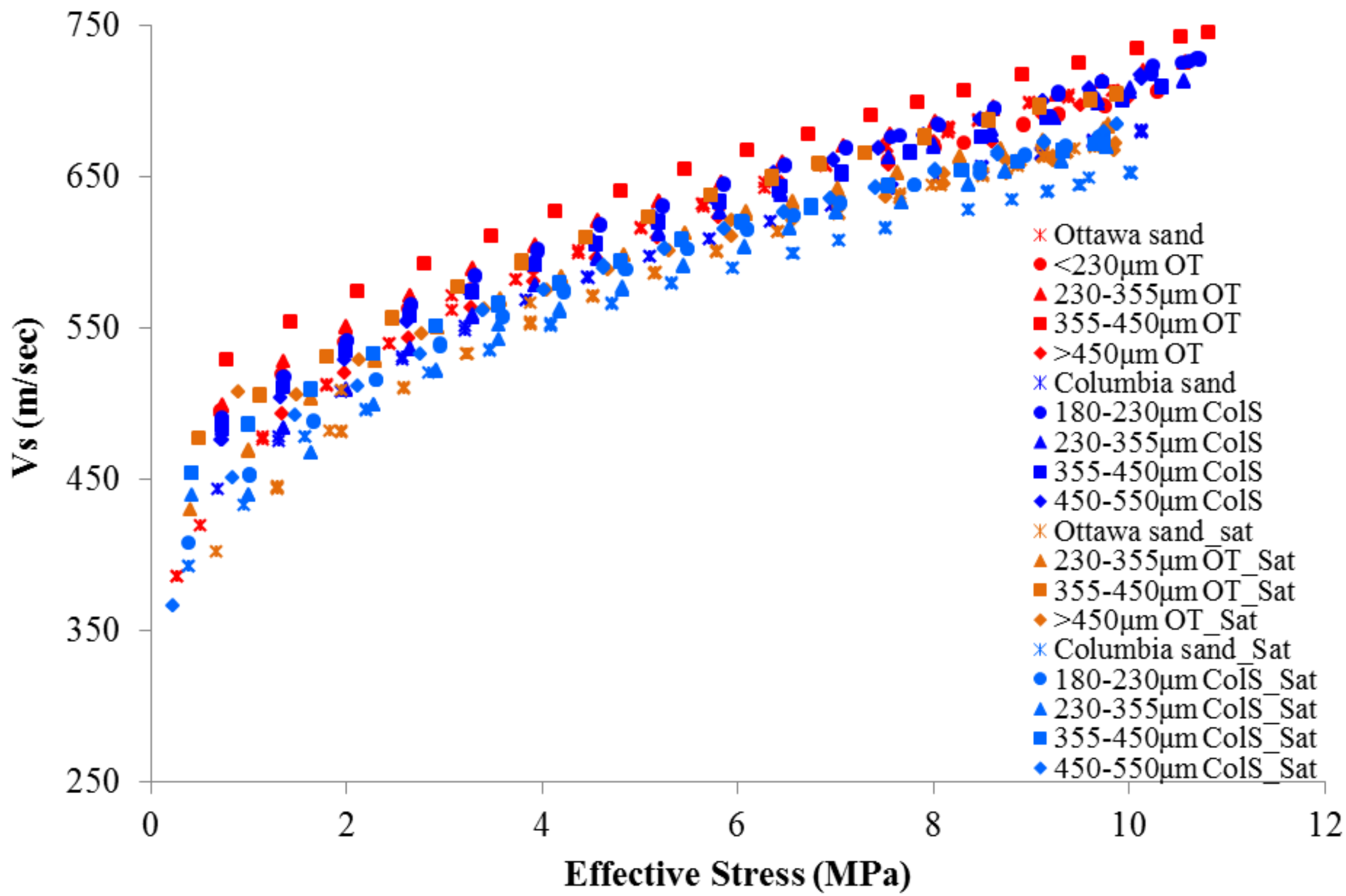
- 3.5wt% NaCl brine used as saturating fluid

Vert. Vp of dry and Saturated Ottawa and Columbia sand



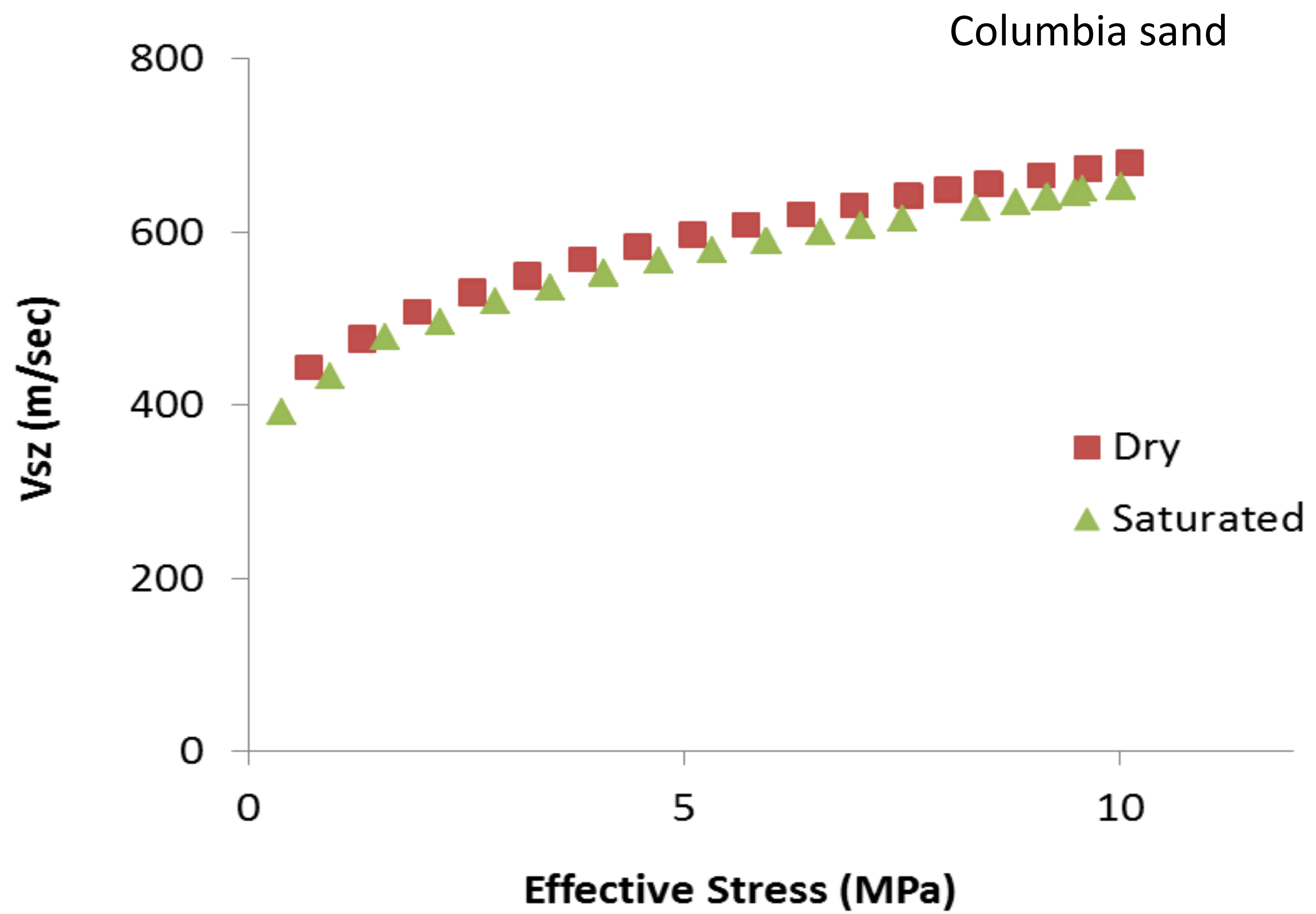
- Rounded sand has higher velocity than angular sand
- Increase in velocity and decrease in stress sensitivity upon saturation

Vert. Vs of dry and Saturated Ottawa and Columbia sand



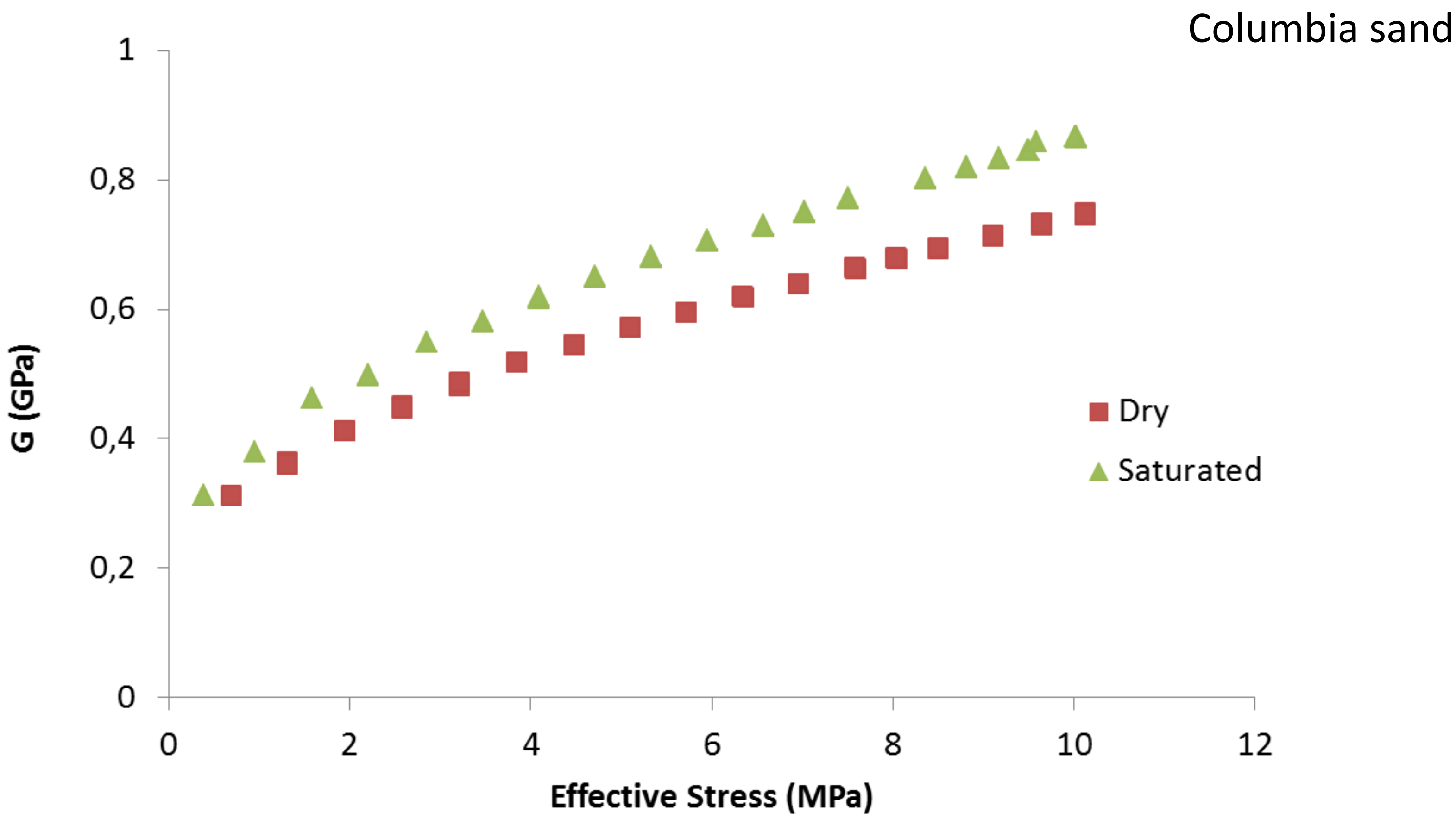
- Rounded sand has higher velosity than angualra sand
- Unchanged stress sensitivity upon saturation

Vert. Vs of dry and Saturated Ottawa and Columbia sand



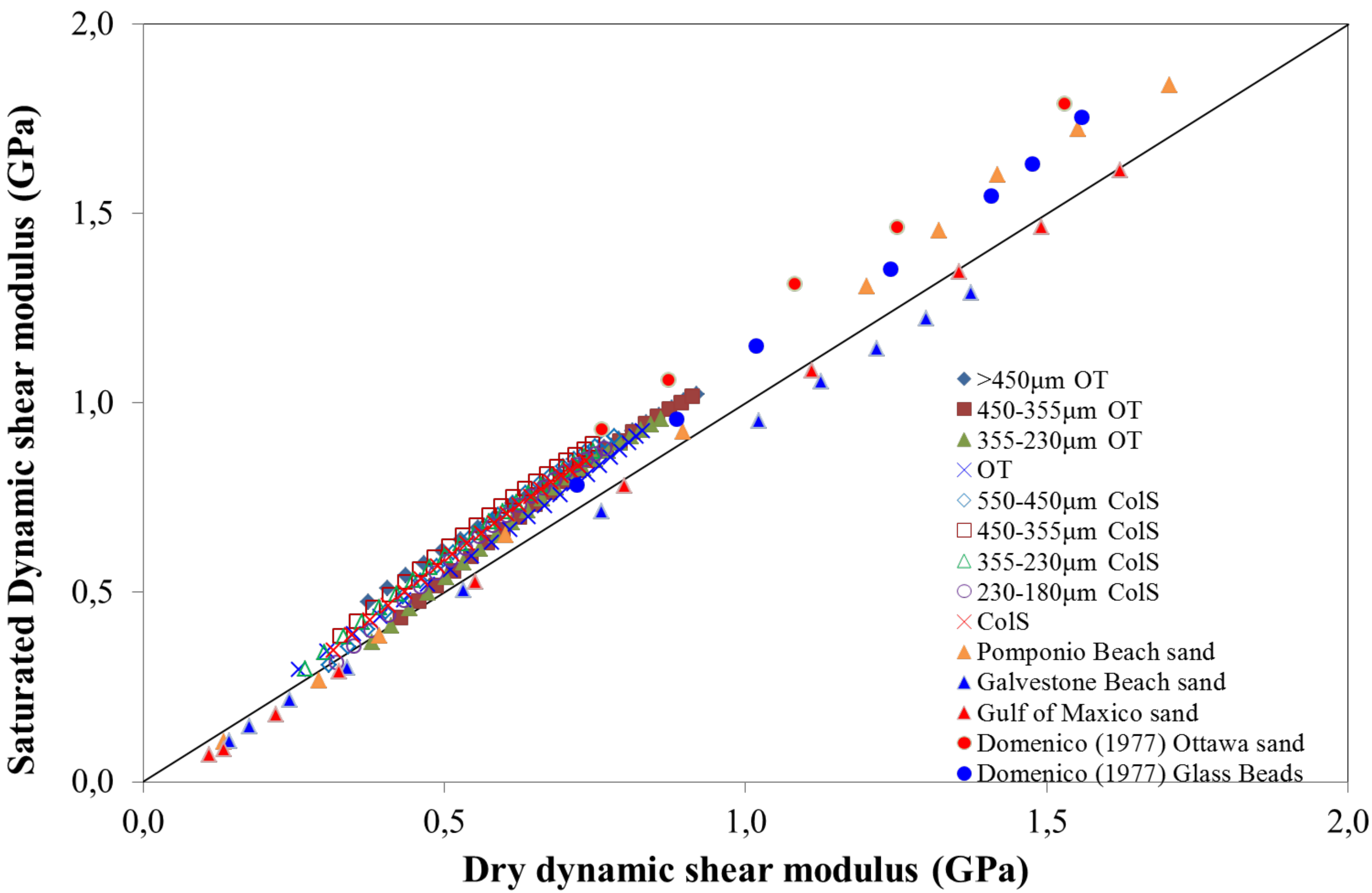
- Velocity decrease upon saturation

G(C_{44}) of Dry and Saturated sands



- But, Shear modulus increase upon saturation

Comparison between G of experimental and dry sand



- Shear modulus hardening upon saturation is evident.
- Q: Why?

Possible Mechanisms for hardening/softening effect

1. Fluid saturation
2. Presence of clay
3. Fluid viscosity
4. Effect of pore surface area
5. Effect of pressure
6. Dispersion

Possible Mechanisms for hardening/softening effect

Fluid saturation

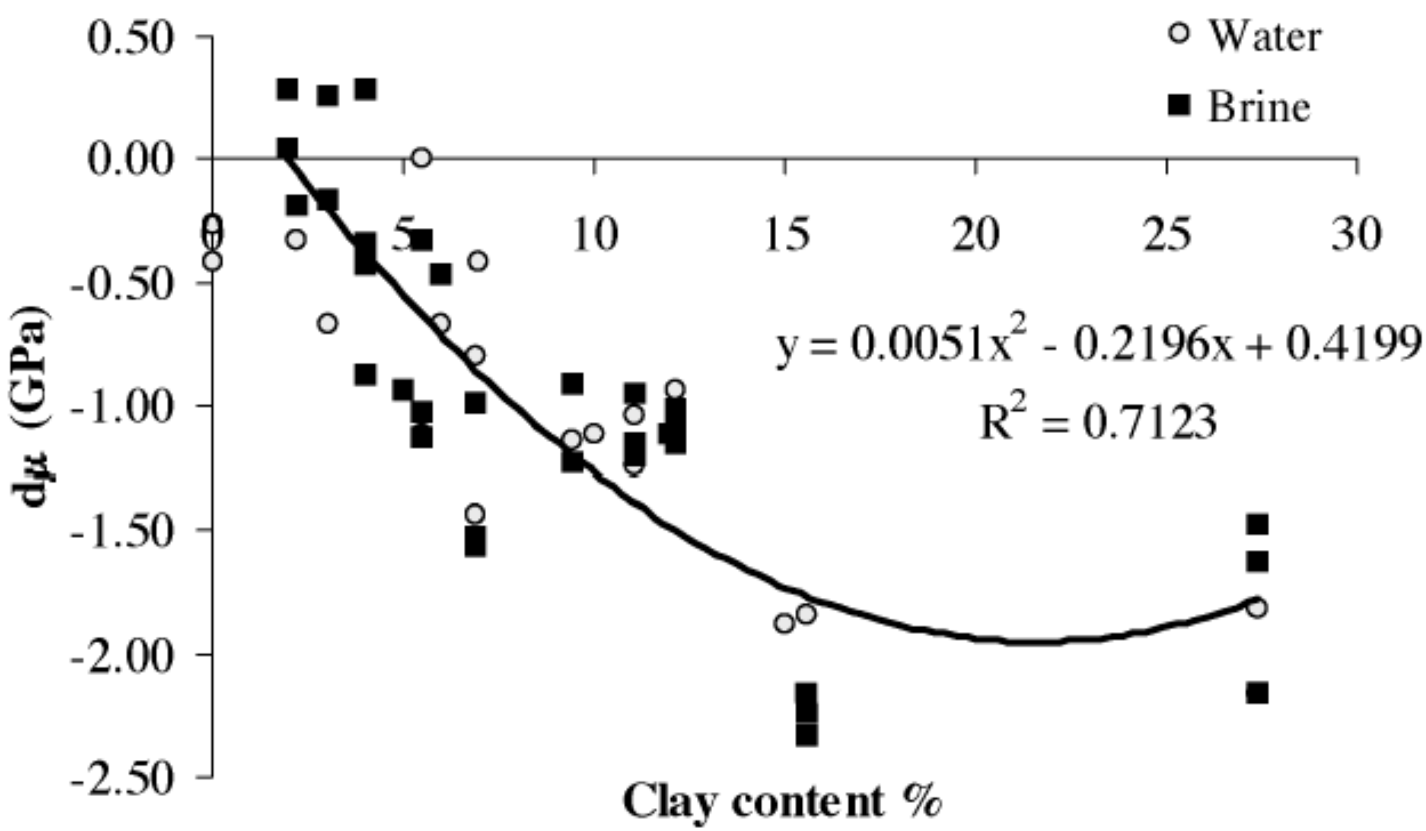
Fluid saturation (Polar fluid) may cause softening the shear modulus by two possible mechanism:

A. Chemical influence of pore fluid

B. Mechanical role of pressurized pore fluid

Possible Mechanisms for hardening/softening effect

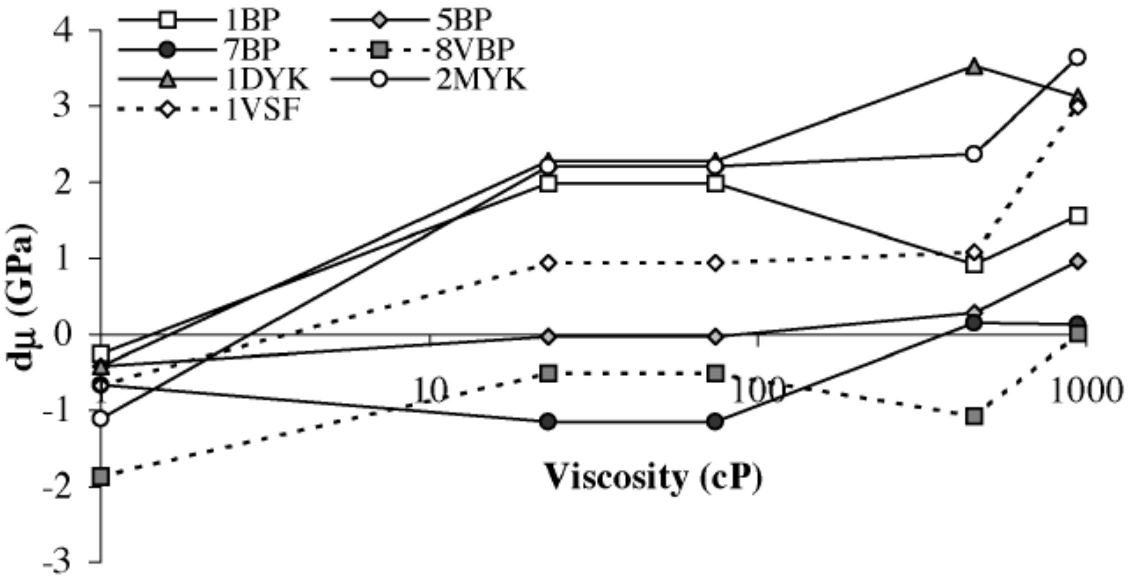
Presence of clay



Jalal Khazanehdari and Jeremy Sothcott 2003

Possible Mechanisms for hardening/softening effect

Fluid viscosity



(after Best and McCann, 1994)

Possible Mechanisms for hardening

Dispersion

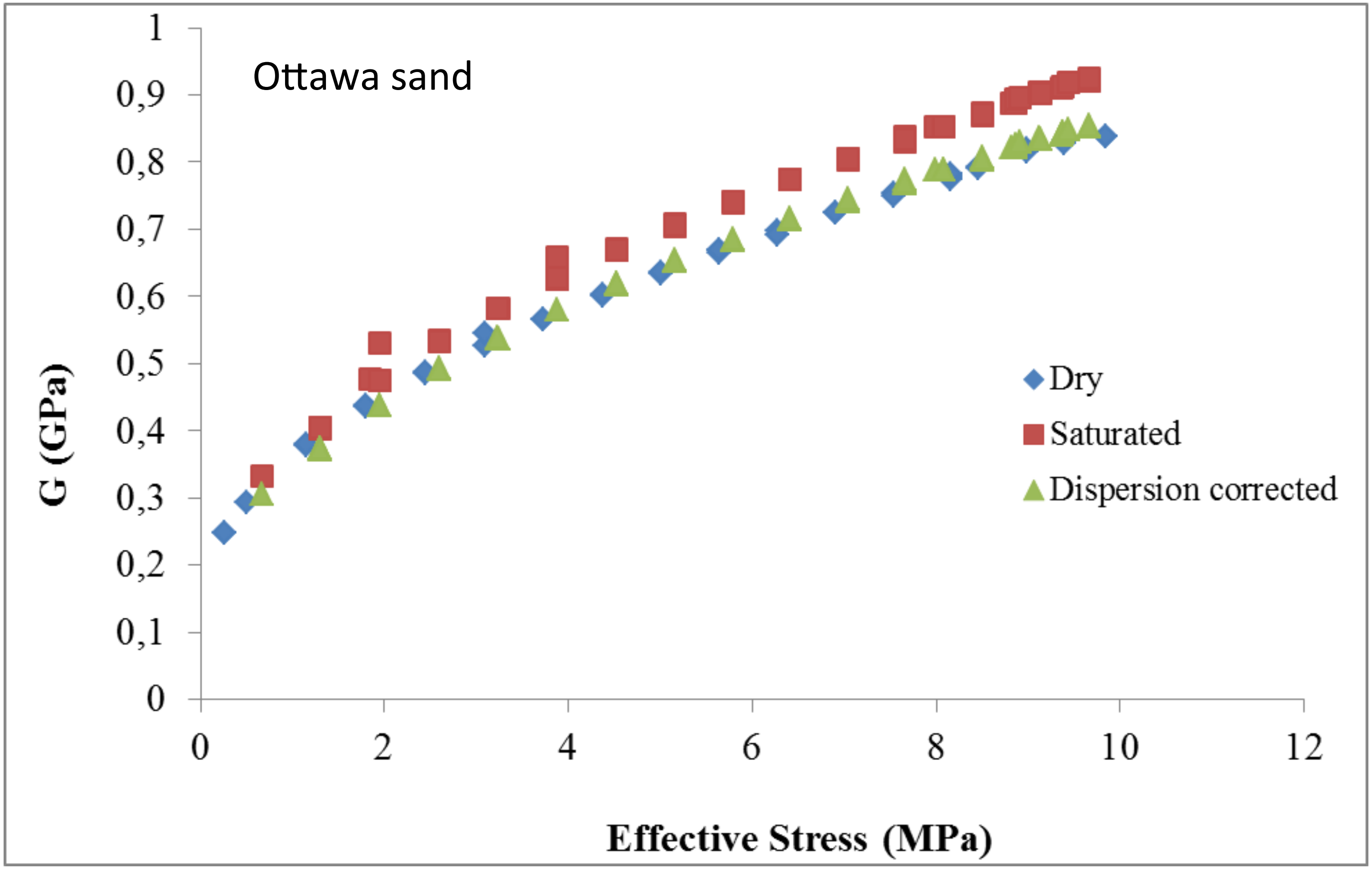
Shear stiffness increase by the unrelaxed fluid in the pore space during ultrasonic acoustic measurement (e.g. Mavko and Nolen-Hoeksema, 1994)

The relaxation time depend on rock permeability, fluid properties and pore compressibility

$$\boldsymbol{V_{s_{\text{sat}}}} = \sqrt{\frac{\boldsymbol{G_{dry}}}{\boldsymbol{\rho_{sat}}}} \frac{\mathbf{1}}{\sqrt{\mathbf{1} - \frac{\boldsymbol{\Phi\rho_{fl}}}{\boldsymbol{T\rho_{sat}}}}}$$

$$V_p^2 = \frac{H}{\rho} \frac{\left(\frac{T}{\Phi}\rho_{fl} + (\rho - 2\alpha\rho_{fl})\frac{M}{H}\right)\left[1 + \sqrt{\frac{4\rho_{fl}\left(\frac{T}{\Phi}\rho - \rho_{fl}\right)\left(1 - \alpha^2\frac{M}{H}\right)\frac{M}{H}}{\left[\frac{T}{\Phi}\rho_{fl} + (\rho - 2\alpha\rho_{fl})\frac{M}{H}\right]^2}}\right]}{2\rho_{fl}\left(\frac{T}{\Phi} - \frac{\rho_{fl}}{\rho}\right)}$$

G: Saturated, Dry and Dispersion corrected



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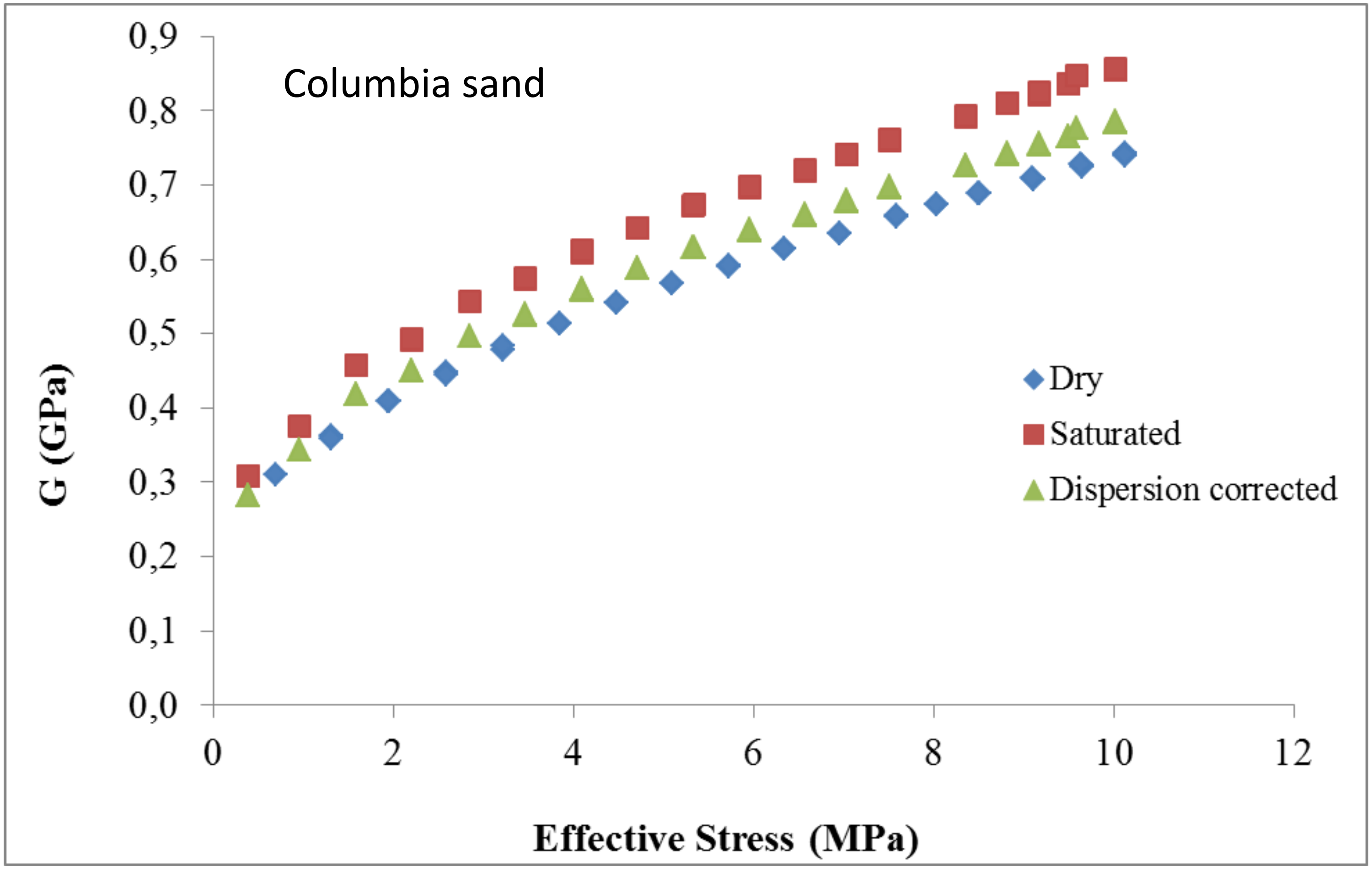

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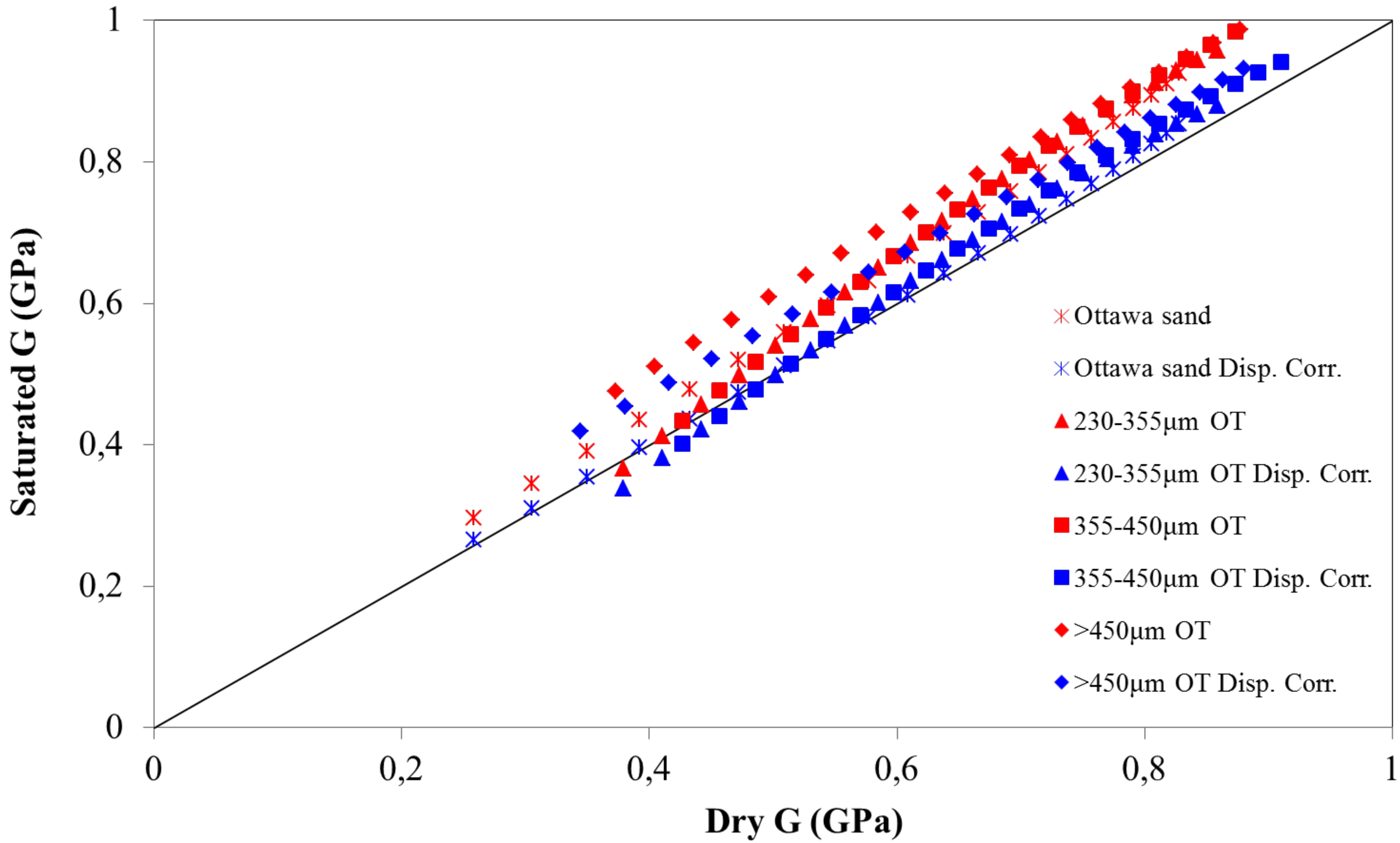

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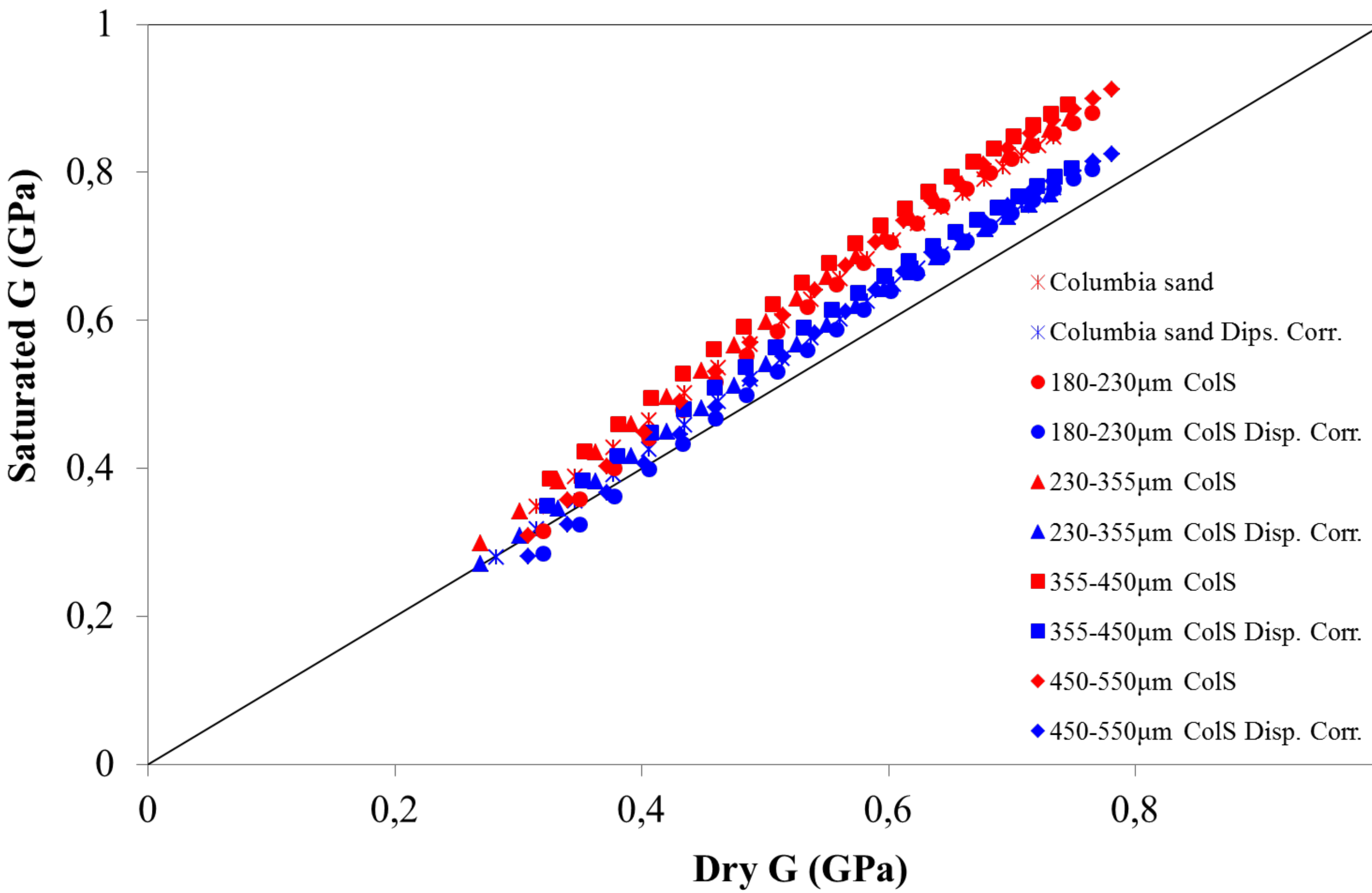
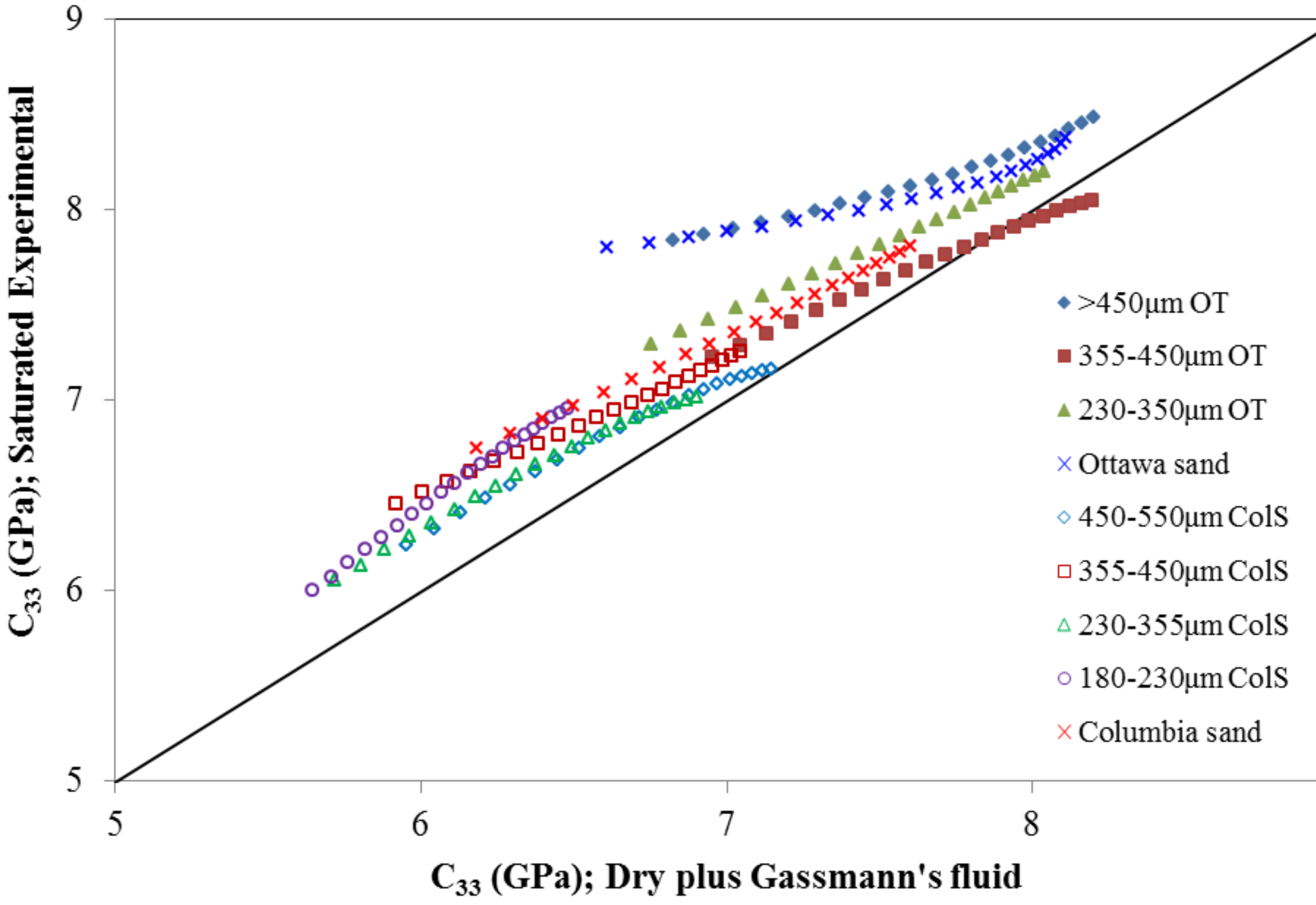
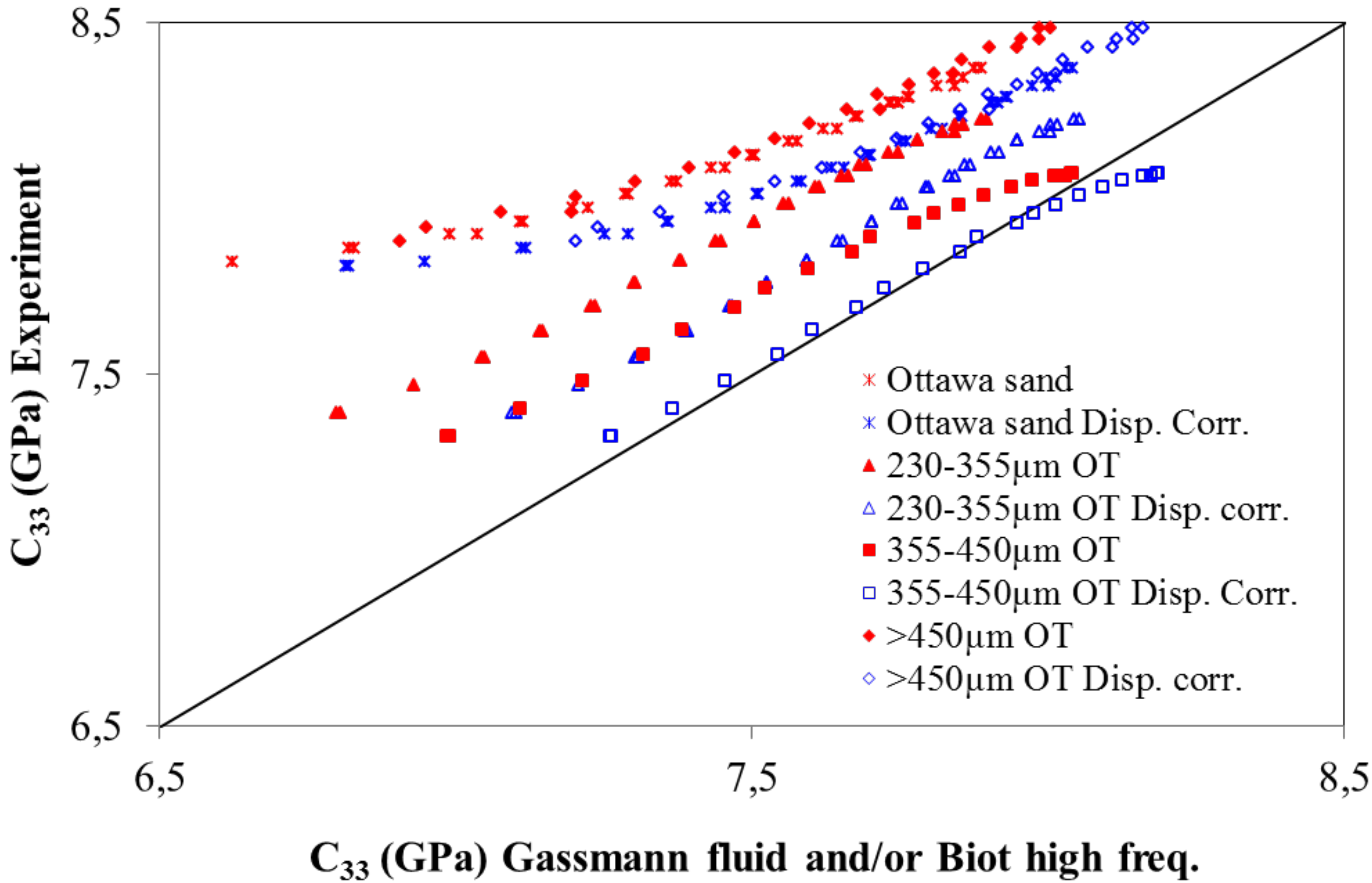


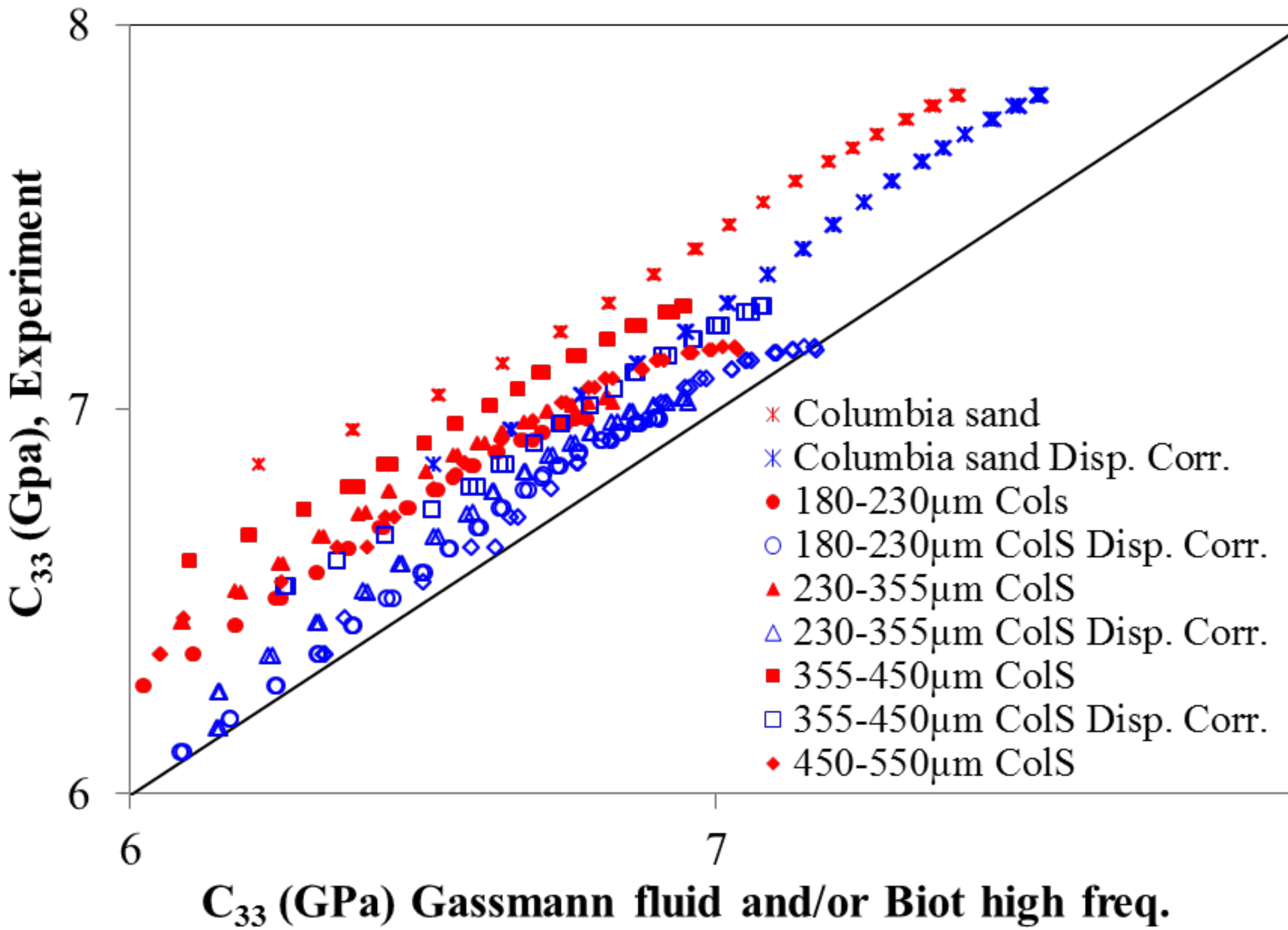
C_{33} Saturated, fluid added with dry sand, literature data



C_{33} Saturated, fluid added dry sand and Dispersion corrected



C_{33} Saturated, fluid added dry sand and Dispersion corrected



Conclusions

1. Shear modulus found sensitive to saturation (polar fluid) for clay free pre-compacted sands

2. Dispersion found to be the prime factor for the shear modulus hardening.

3. Increase of compressional modulus with saturation is underestimated by Biot-Gassmann's fluid substitution.

4. Dispersion (Biot's) can improve the prediction for fluid saturated velocity/moduli specially for highly porous sands.

Recommendations

1. Considering only clay free sand, geophysicist may ignore this hardening effect since dispersion is the prime factor for hardening but…..if there are clay in the rocks: it become important (softening).

2. For modeling, where laboratory data used for calibration: this hardening effect should be consider.

Isotropic, Anisotropic fluid substitution and Dispersion corr.