Stress Dependent P- and S-Wave Velocities in Brine Saturated Sand-Clay Mixtures

Summary of MSc Thesis

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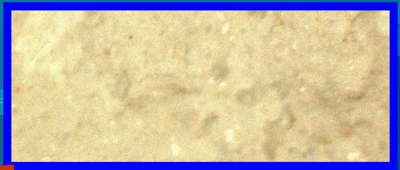
Objectives

1. The effect of external stress and pore pressure on the wave velocities.
2. Stress-strain behavior of unconsolidated sand-clay lithology.
3. The effect of clay contents on wave velocities and porosities.
4. Change of Anisotropy with applied stress and lithology.
5. Reflection coefficient on various lithological Interfaces.
6. Wave velocities guide to lithological identification.
7. The effective stress coefficient, stress sensitivity and strain sensitivity parameter.

Sand: Ottawa sand

3.5 wt% NaCl brine as saturating fluid



Clay: Kaolinite

Samples

Composition (vol%)	
Sand	**Clay**
100	0
75	25
70	30
60	40
50	50
25	75
0	100

Oedometer test system

Dry grains mixed as definite volume concentration, mixed stepwise with brine, treated under vacuum chamber to get rid of air

Precompaction (~2.7MPa) within the system

Sample Dimension
Length: 22-25mm
Diameter: 69mm

Tested under:
Uniaxial strain Condition

Triaxial test system

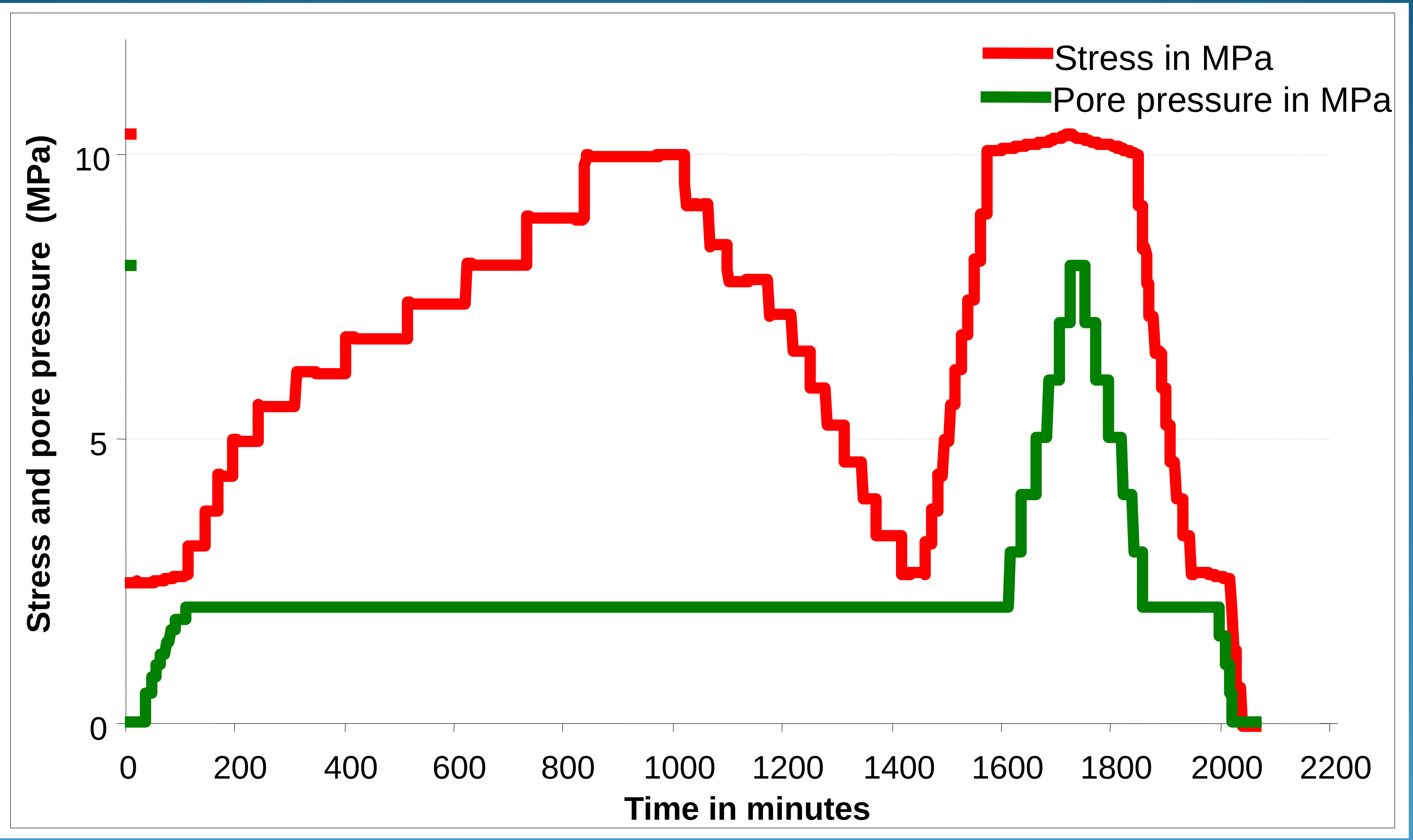
Precompaction (~3.0 MPa) outside the system using Precomp Cell

Sample Dimension
Length: 60-65mm
Diameter: 38mm

Tested under: Uniaxial strain, Hydrostatic and Constant Mean Stress Condition

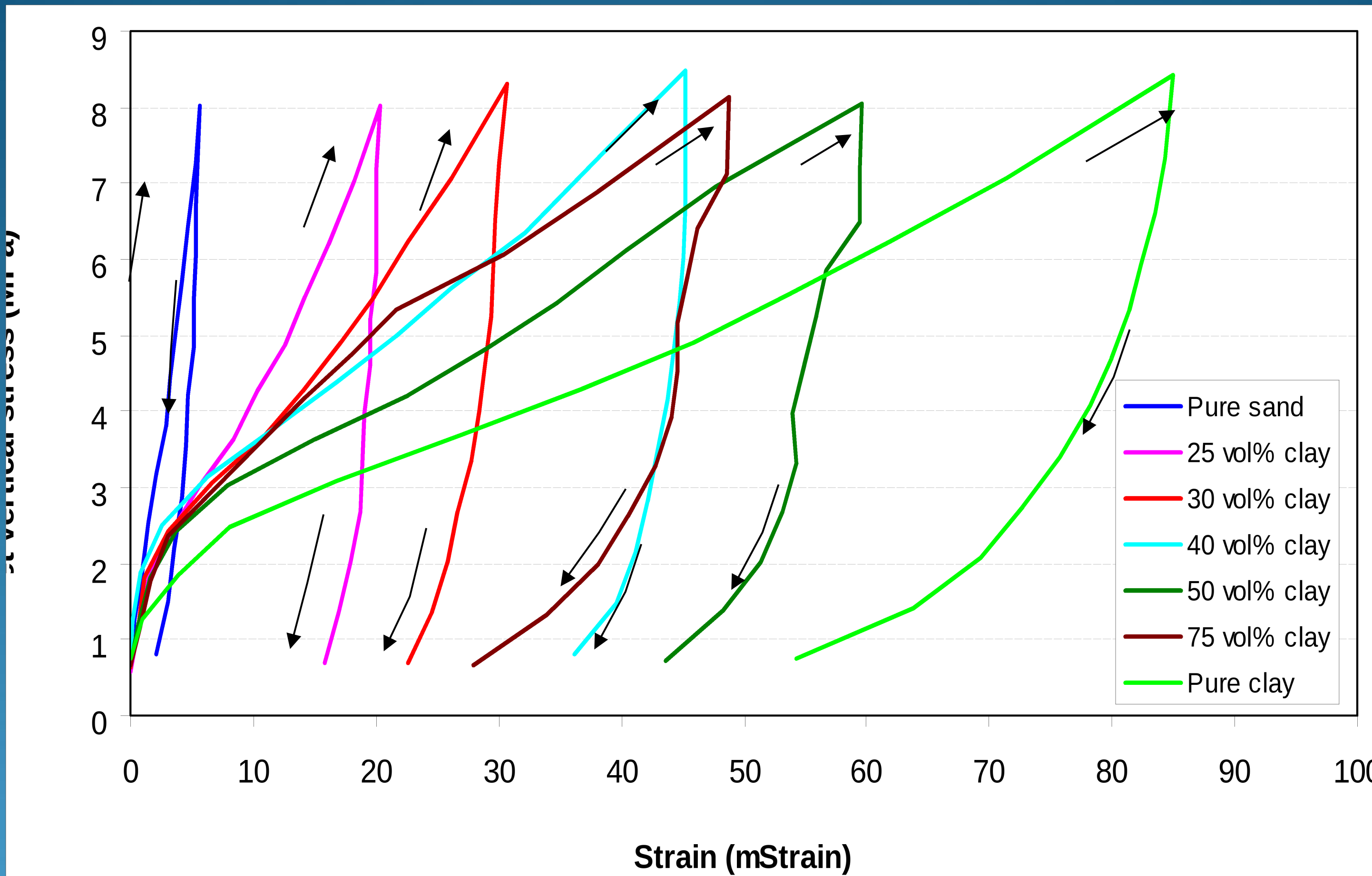
Composition (vol%)	
Sand	**Clay**
100	0
50	50
0	100

Test Plan
(Uniaxial strain setup)



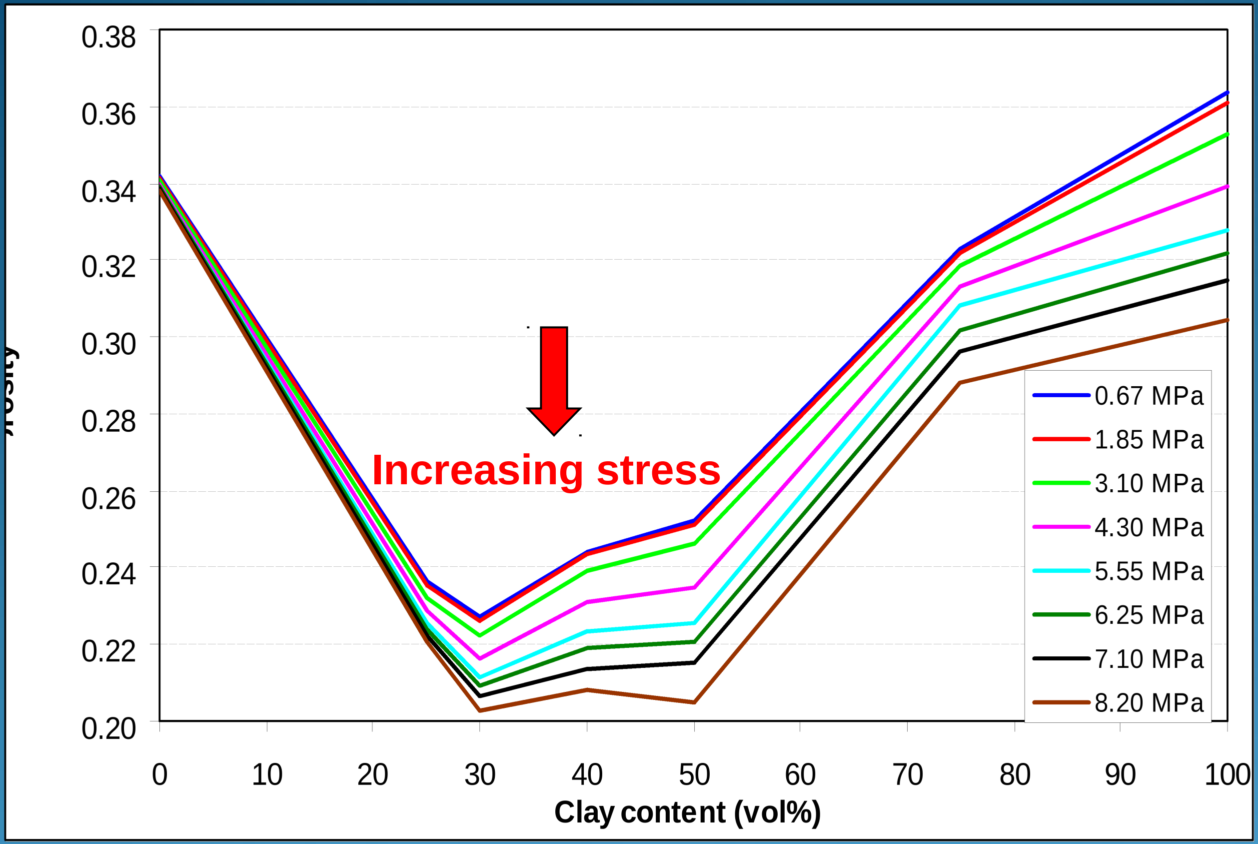
Example taken from test of sample with high clay content

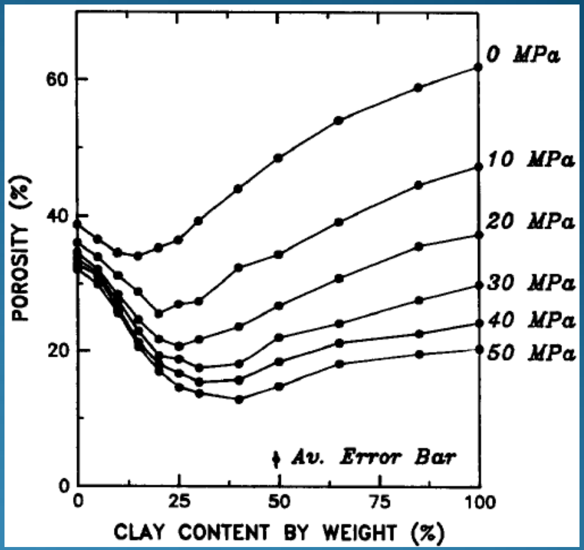
Strain Hysteresis



- Except pure sand, all other lithologies show permanent strain.

Change of porosity with increase in clay content



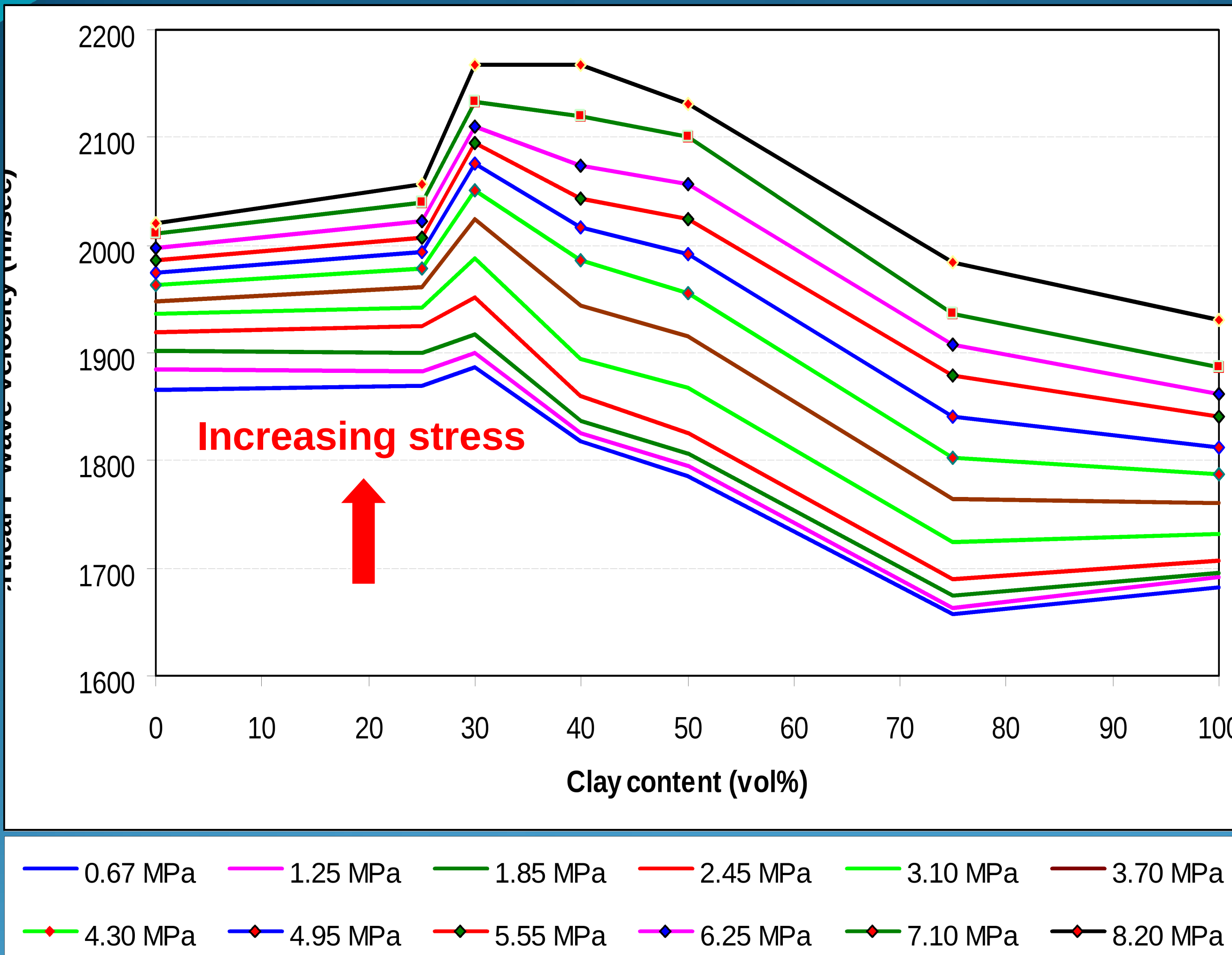


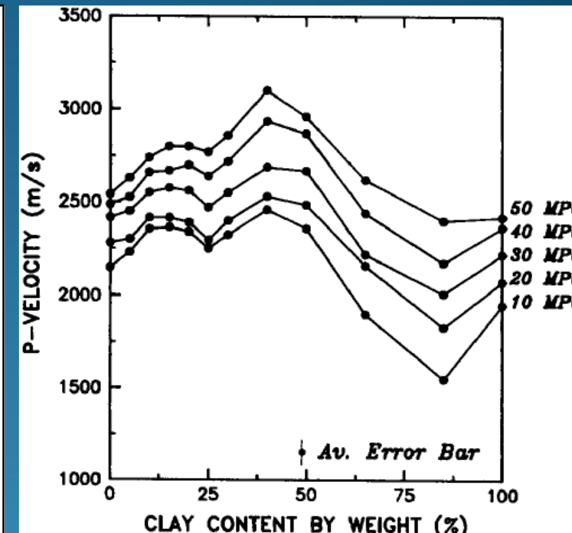
From
Marion, et al., 1992

- Porosity decrease with increasing clay content where sand is load bearing grains.
- In clay load bearing samples, porosity increase with increasing clay content.

Using only Oedometer test data

Vertical P-wave velocities versus clay content



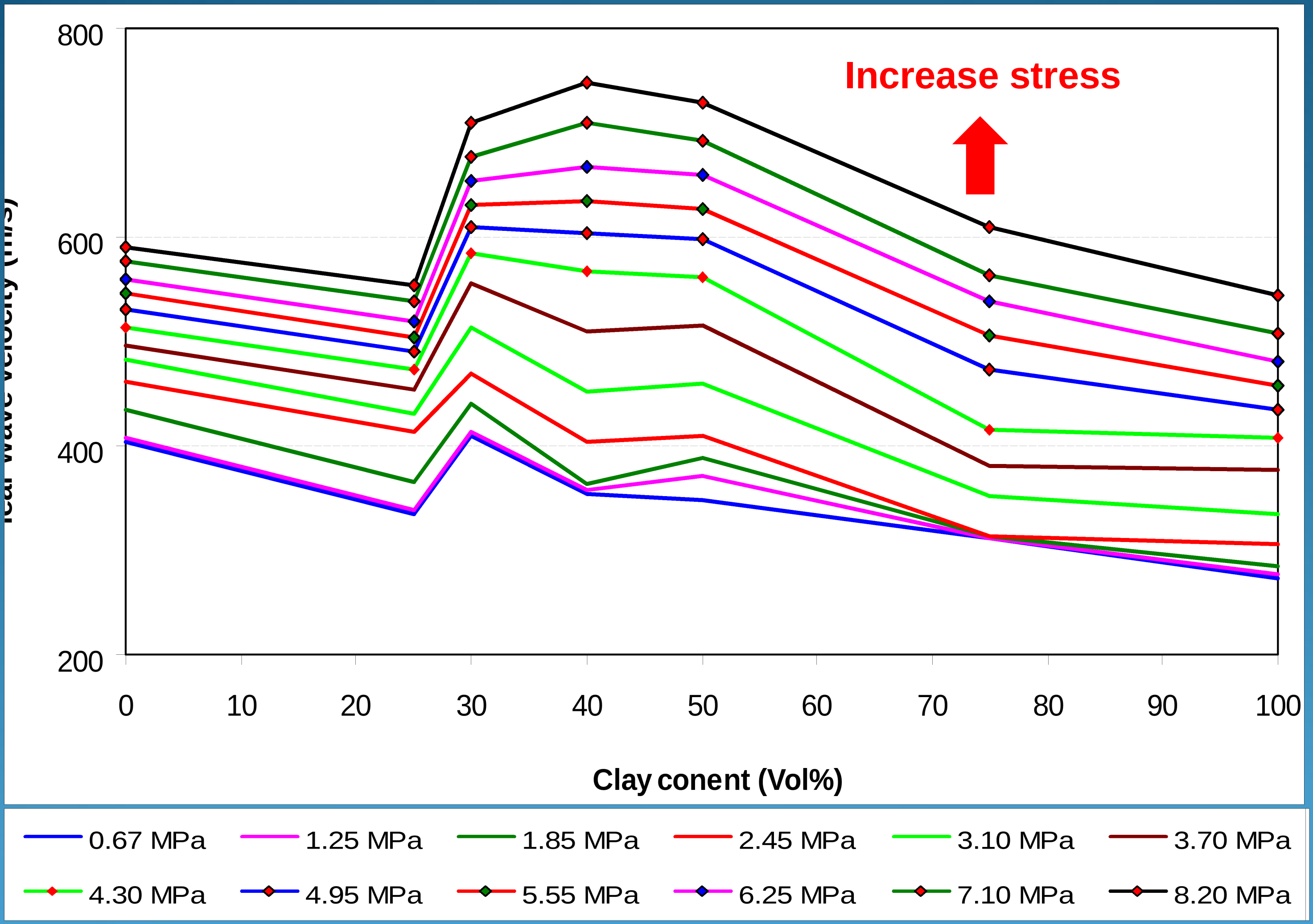


From
Marion, et al., 1992

Using only Oedometer test data

- In sand load bearing (<30-40 vol% clay) samples, P-wave velocity increase with clay content.
- Opposite trend is for higher clay content.

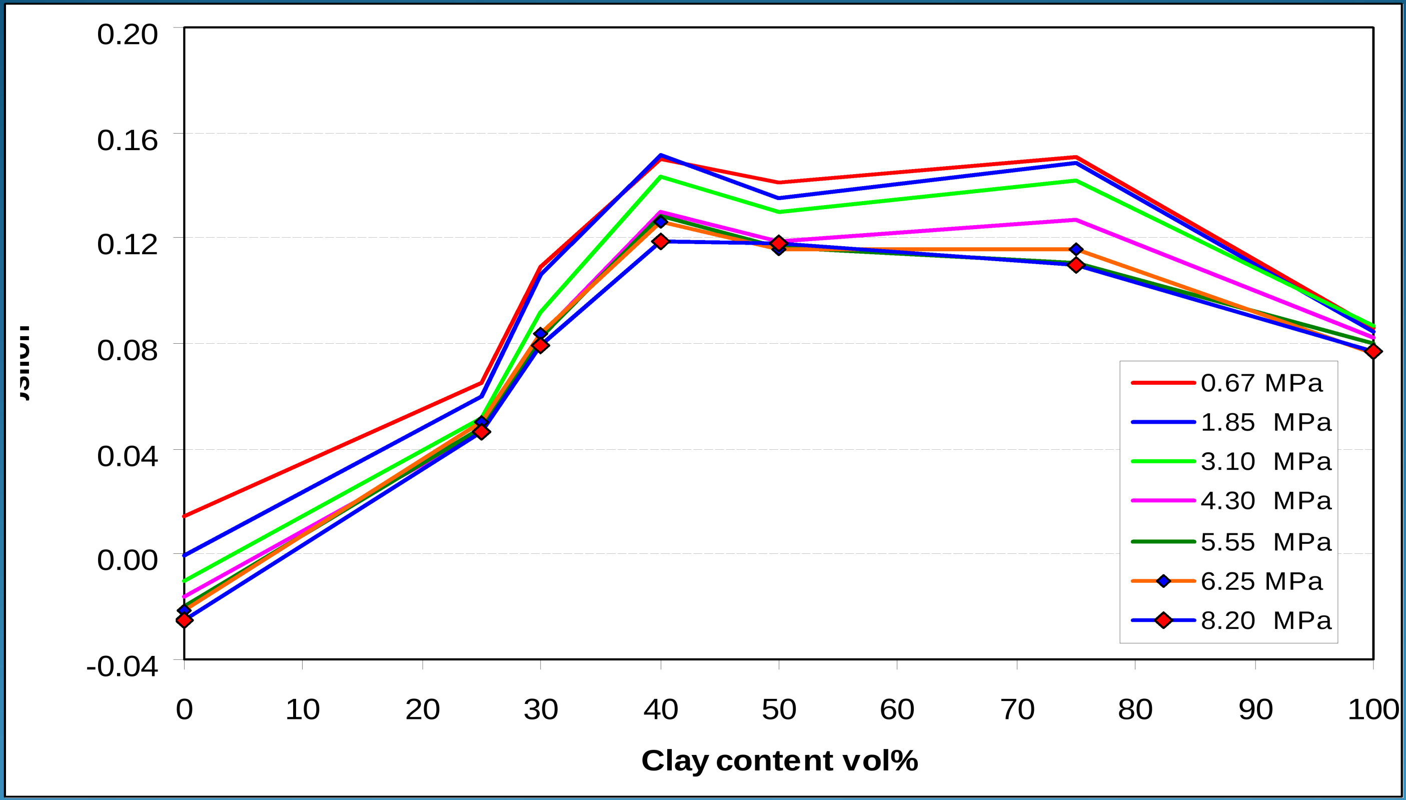
Vertical S-wave velocities versus clay content



Using only Oedometer test data

- Initial decrease of S-wave velocity is due to the increase of density more than shear modulus.

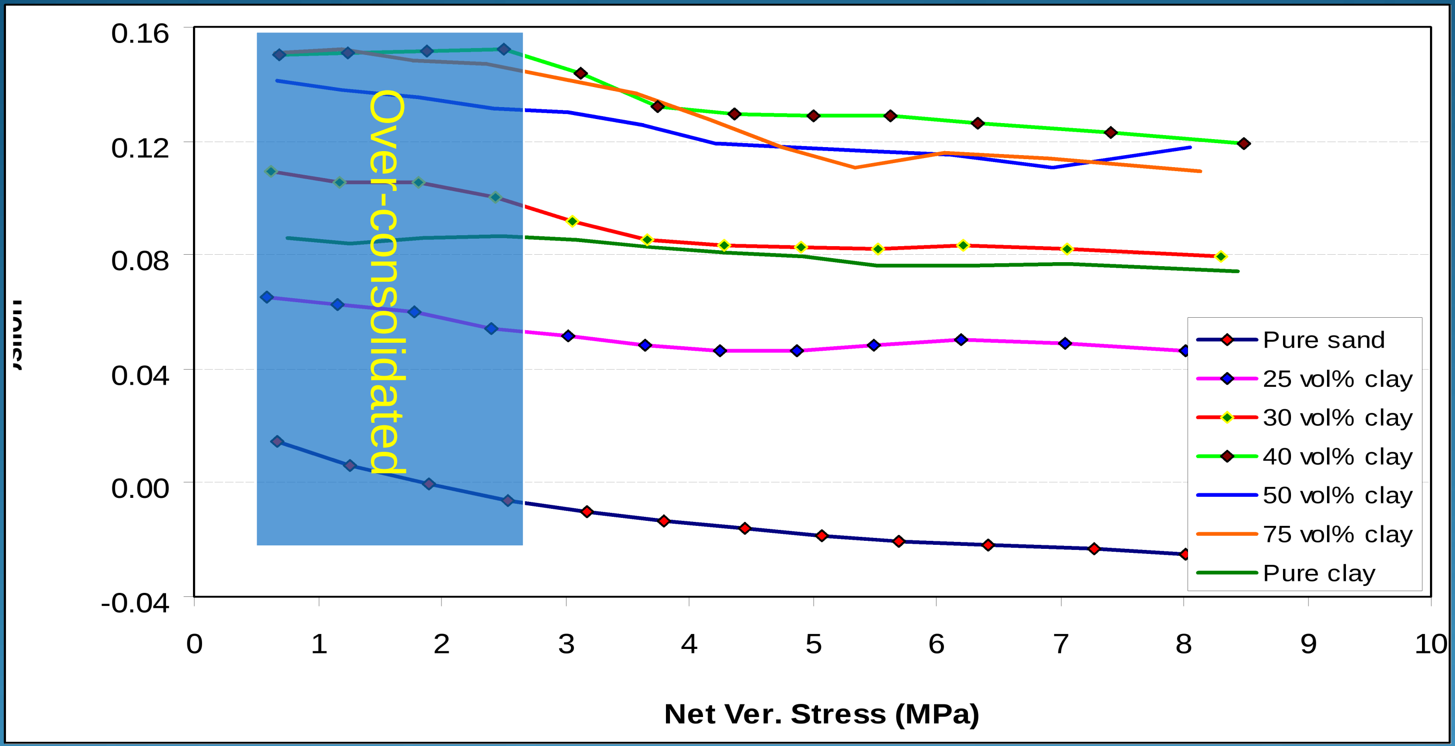
P-wave velocity anisotropy versus clay content



Using only Oedometer test data

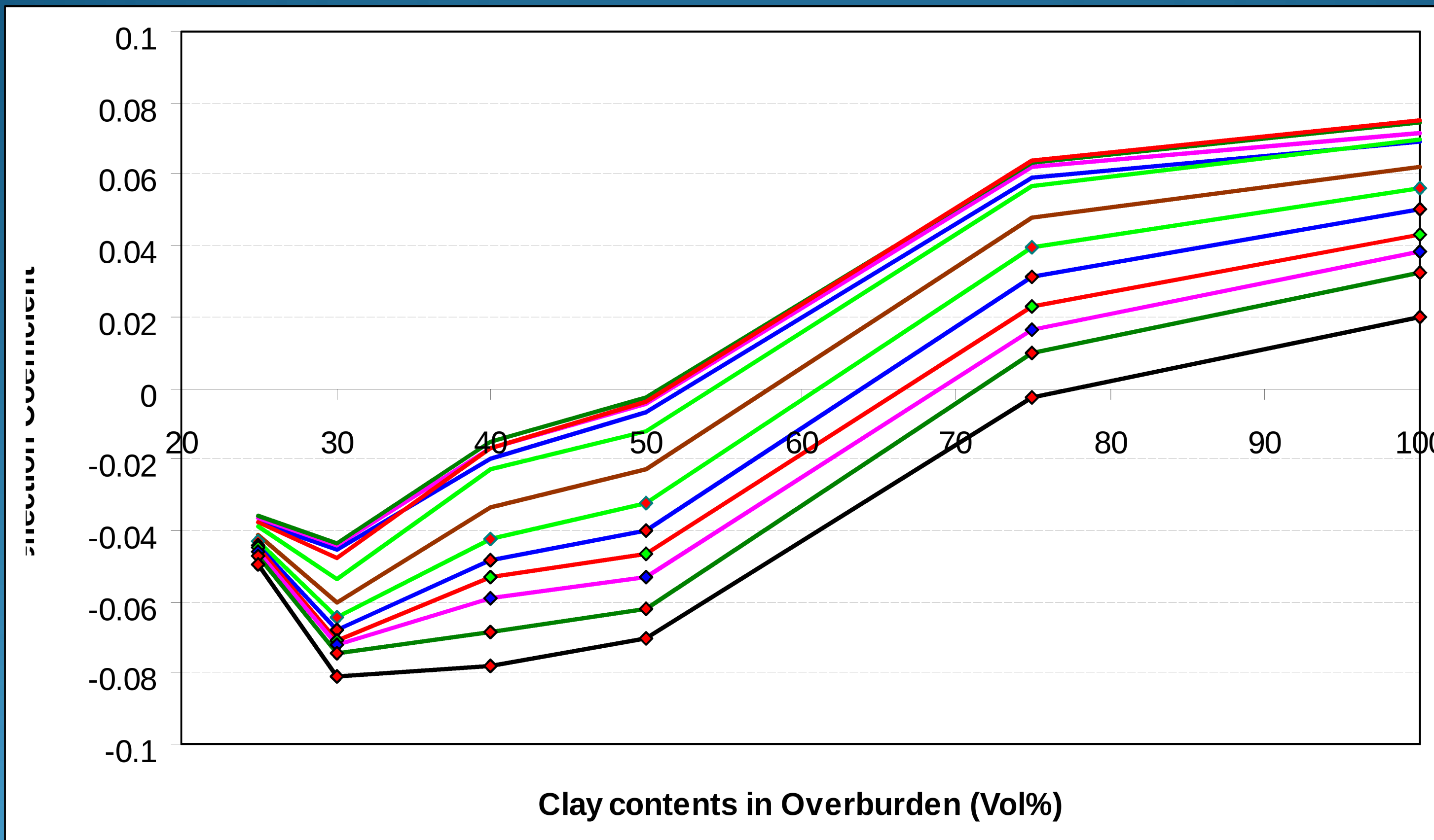
- P-wave anisotropy (epsilon) increase with increasing clay. More or less equal for sample with 40 to 75 volume percent clay.
- The reduction of epsilon in pure clay might be attributed to the textural arrangement of grains.

The P-wave anisotropy with net vertical stress for different lithologies



Using only Oedometer test data

- Pure sand does not show any P-wave anisotropy (epsilon) at any stress level.
- The sample even with few volume percent of clay show P-wave anisotropy at low stress level indicating intrinsic anisotropy.
- However, epsilon is less in pure clay compared to sample with 40-75 volume percent clay.
- The P-wave anisotropy is decrease with increasing stress, indicating stress induced effect on lithologies.

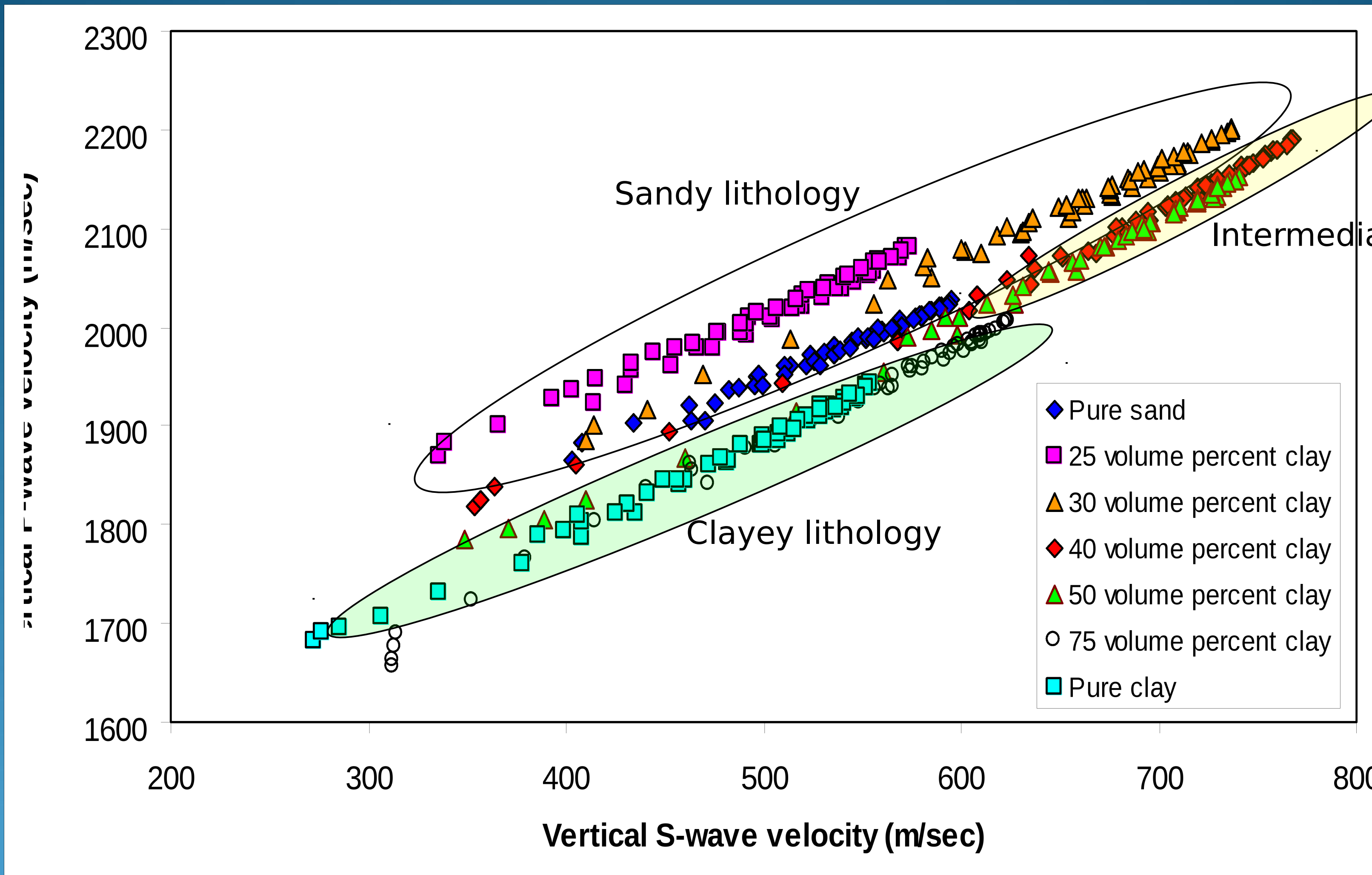


Using only Oedometer test data

'Zero offset' Reflection coefficient

- The zero offset reflection coefficient (RC) varies with clay content of the overburden and reservoir rock.
- In this case, overburden with 40-70 volume percent clay make the interpretation difficult, since RC is close to zero.
- RC increase with stress when the overburden having less than 50 volume percent clay whereas

Vertical P-wave velocity versus vertical S-wave velocity to distinguish different lithologies

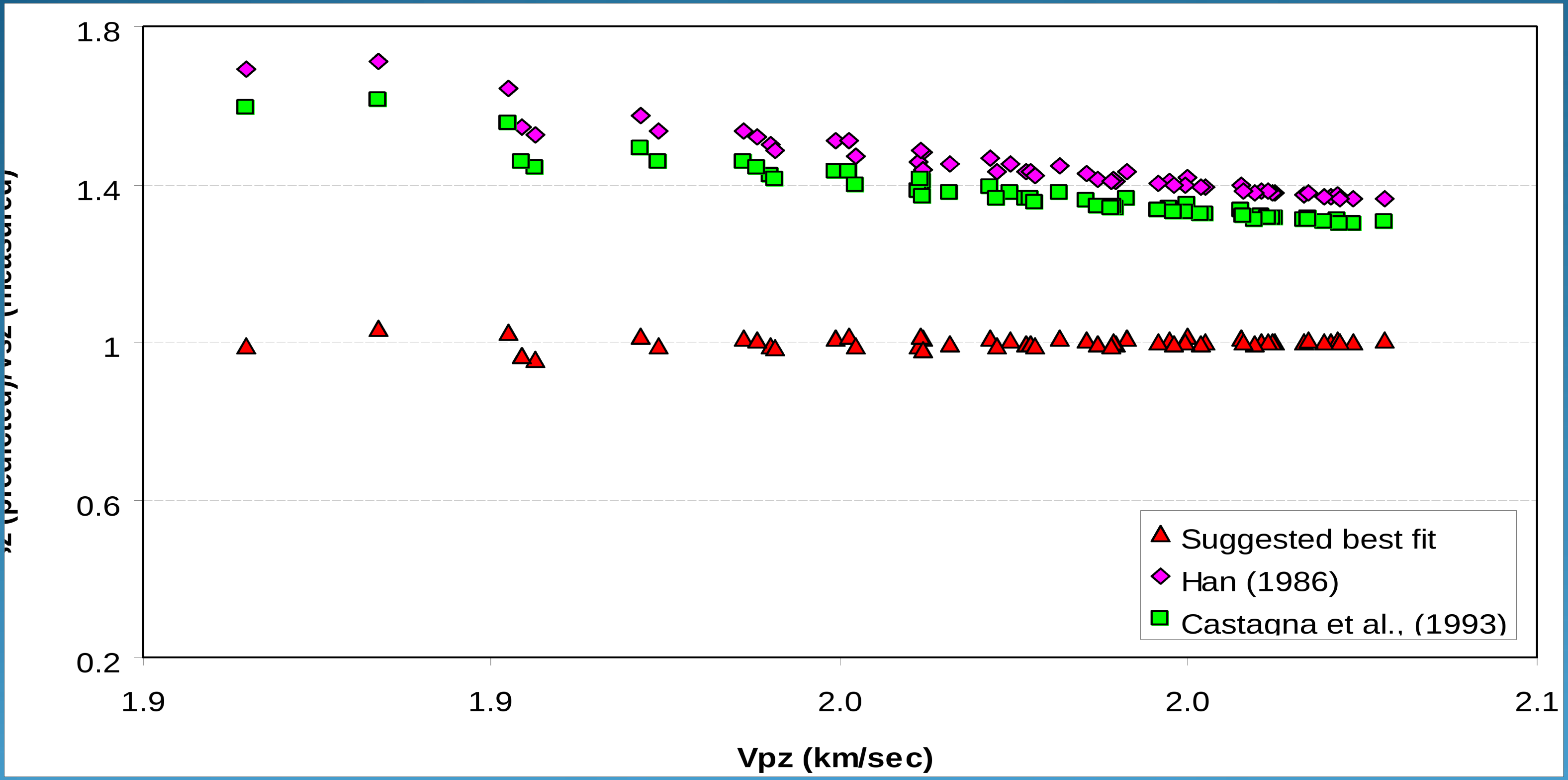


Using only Oedometer test data

Velocity Model for pure unconsolidated sand

Best fit for the brine saturated unconsolidated pure sand at low vertical stress (≈10.0 MPa) where fitting parameter R^2=0.99.

$$V_s = 1.23V_p - 1.895\left(km/\sec\right)$$



Using only Oedometer test data

Han (1986) and Castagna et al., 1993 models prepared based on consolidated sand samples.

Effective stress coefficient

$$V_{p,s} = f\left(\sigma, P_f\right)$$

$V_{p,s}$ is the P-wave and S-wave velocity and σ is the external stress and P_f is the pore pressure.

$$n = -\frac{\left[\dfrac{\delta \mathrm{v}}{\delta P_f}\right]_{\sigma_z}}{\left[\dfrac{\delta \mathrm{v}}{\delta \sigma_z}\right]_{P_f}}$$

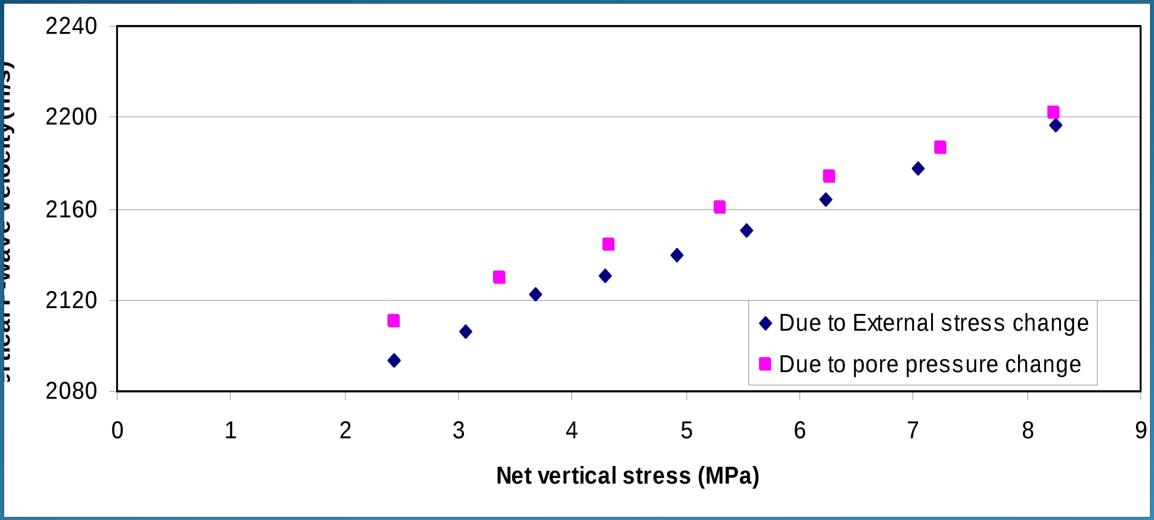
n is the effective stress coefficient, v is the wave velocity of interest,

σ_z is the vertical stress and

P_f is the pore pressure.

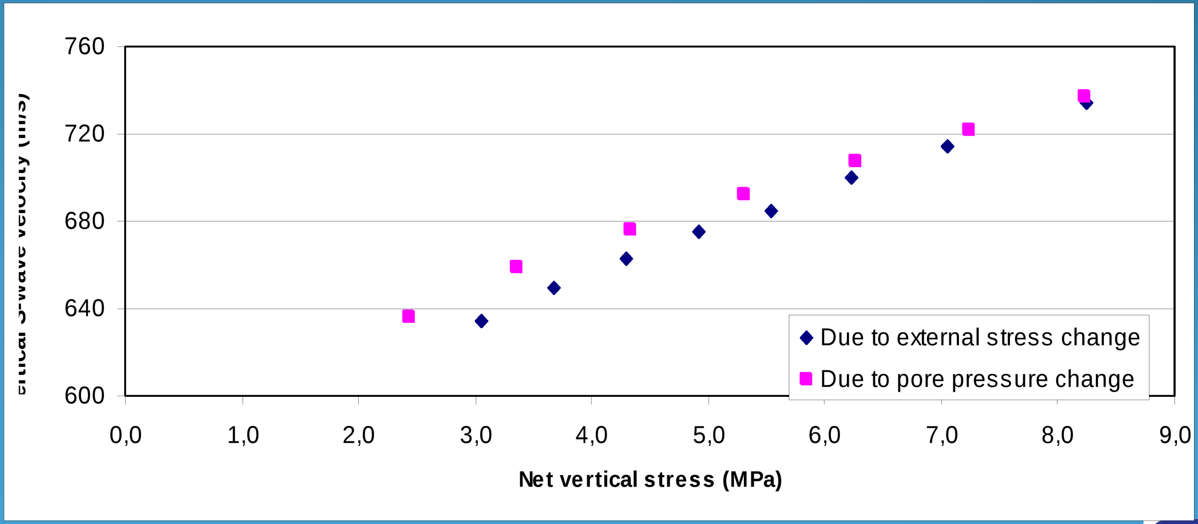
Change of Velocity due to external stress and pore pressure change

(without considering effective stress coefficient)

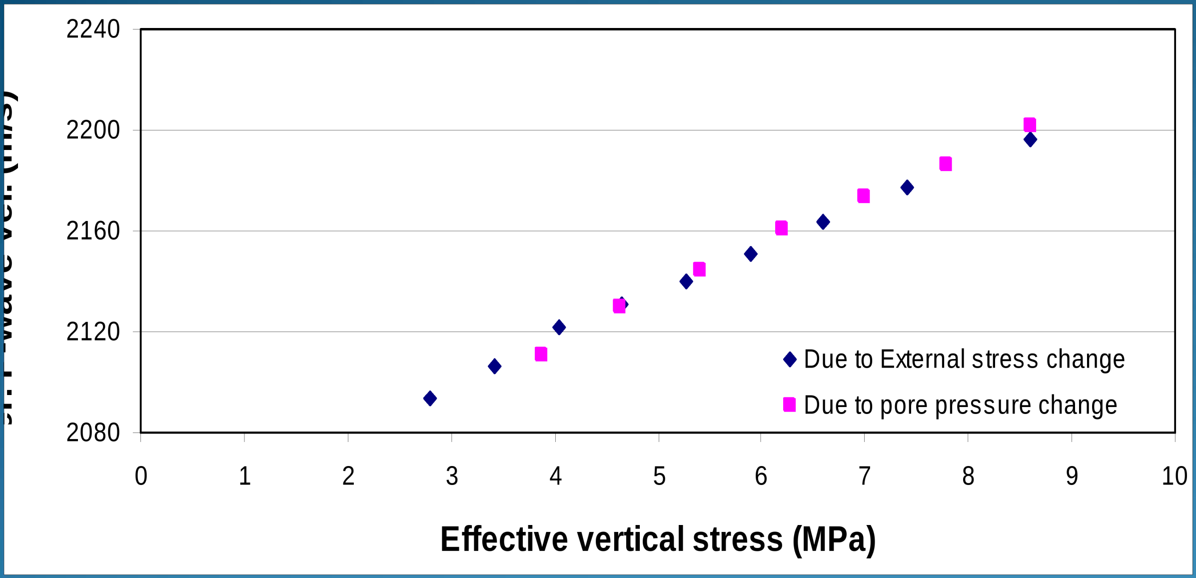


30 volume percent clay sample has used

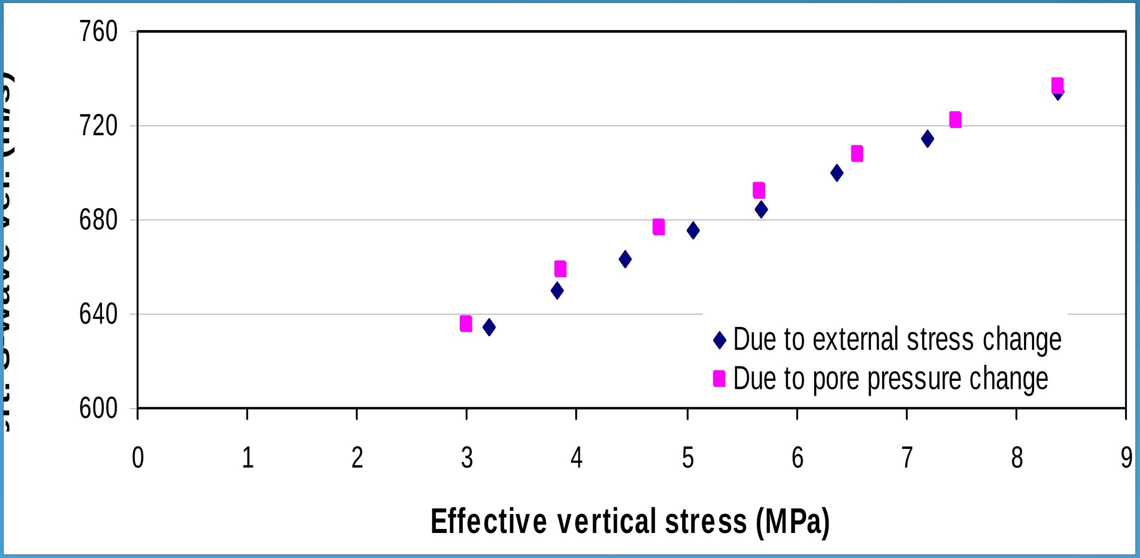
- Stress sensitivity of the velocity show different for change of external stress and pore pressure.
- This study lead to investigate the effective stress coefficient for velocity



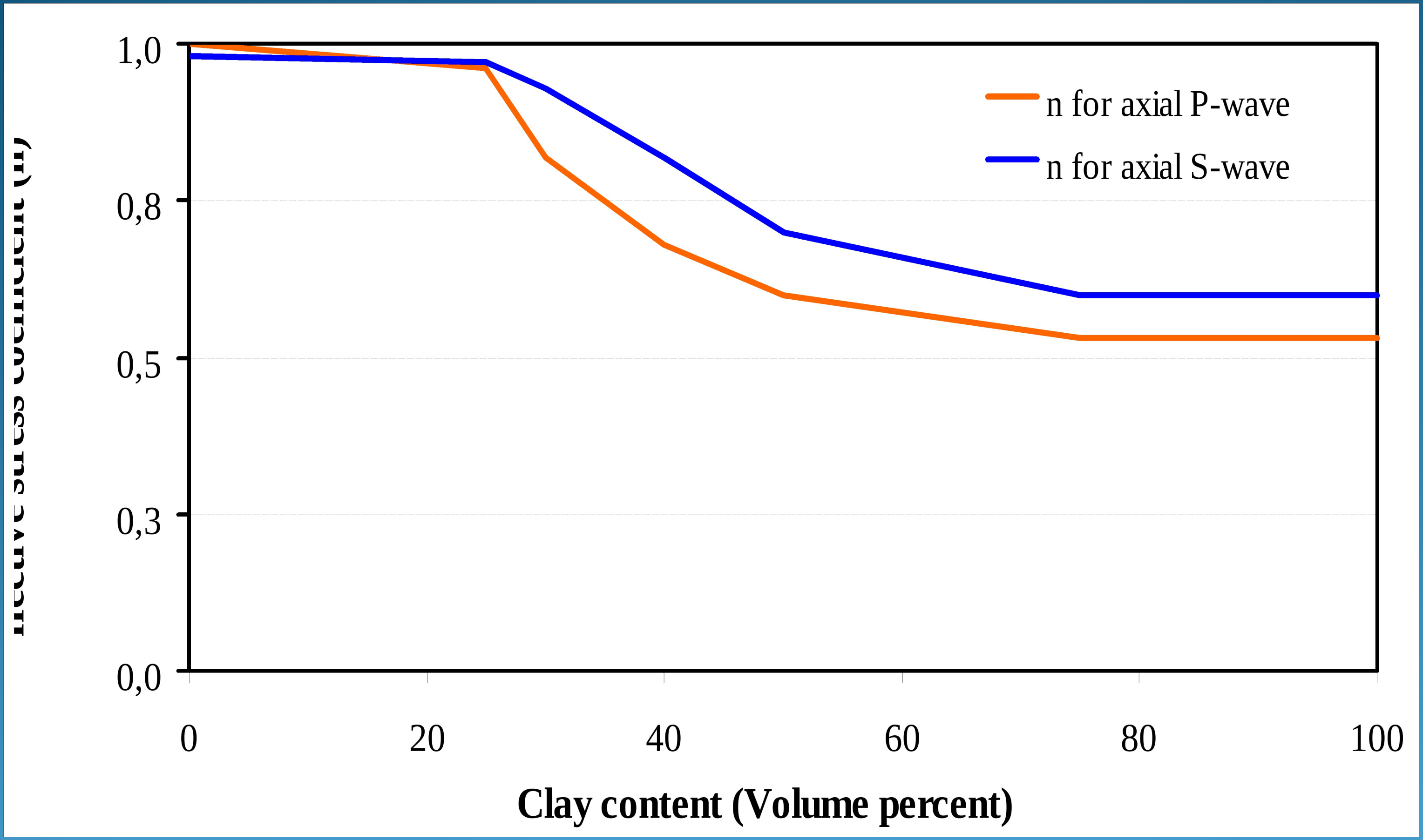
Change of Velocity due to external stress and pore pressure change
(considering effective stress coefficient)



30 volume percent clay sample has used



Effective stress coefficient with clay content



Using only Oedometer test data

S for different waves type and consolidation state as function of clay content

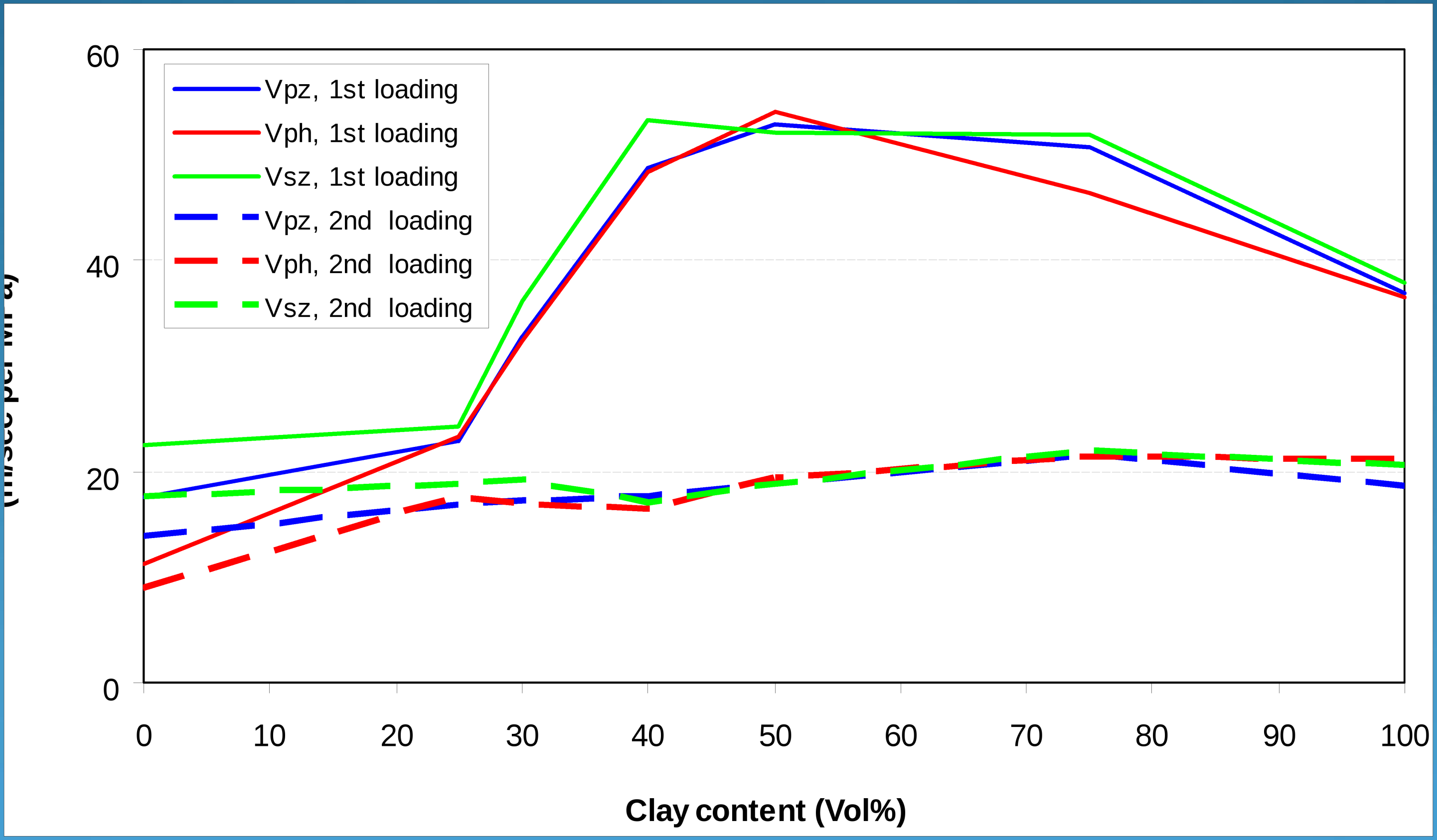
(only Oedometer test data)

$$S = \frac{\Delta V}{V \Delta \sigma'}$$

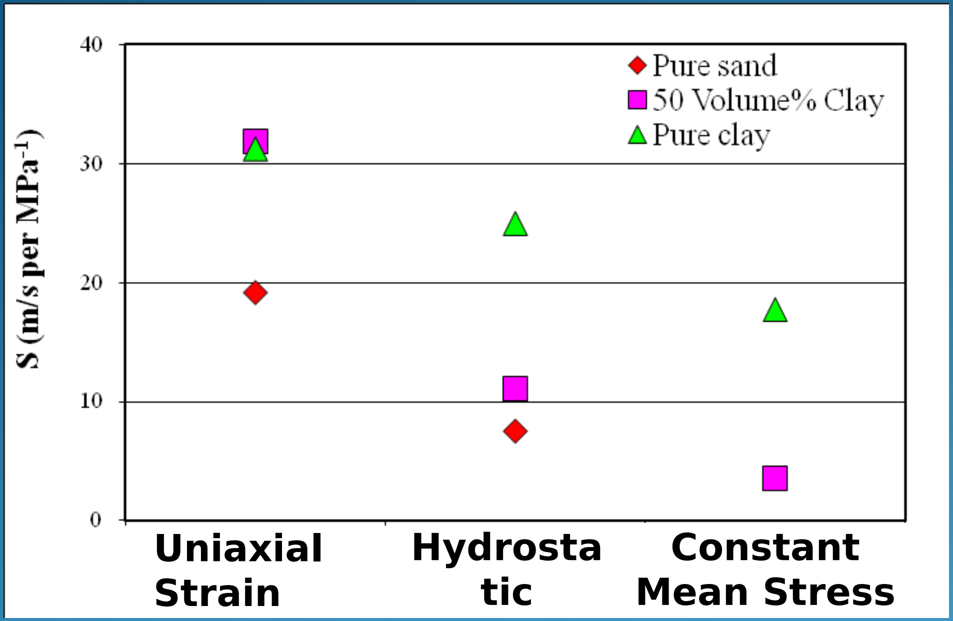
S is the stress sensitivity of the velocity,

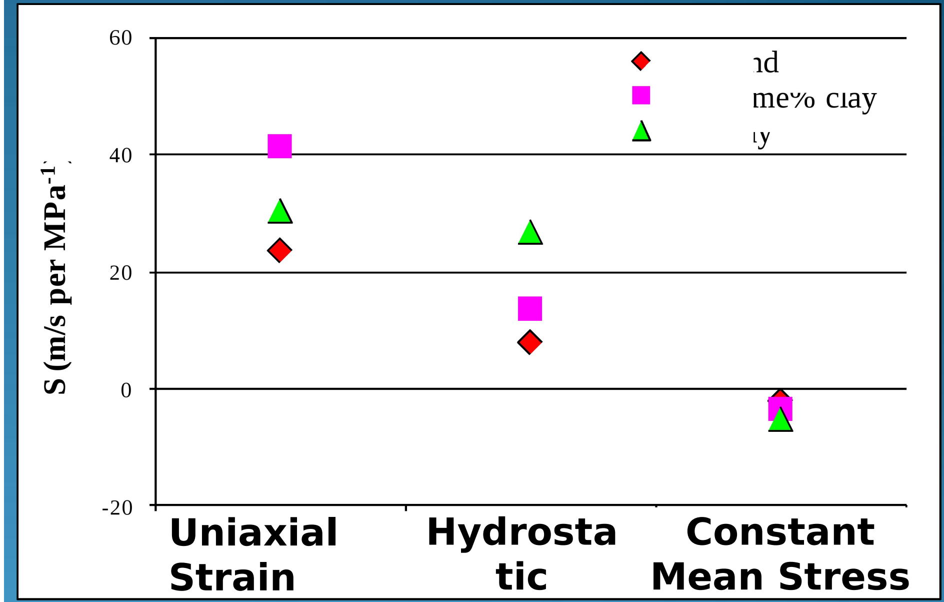
$\Delta \sigma'$ is the change of net applied stress

V is the change of velocity



The stress sensitivity in pure sand and sample with 50 vol% clay contents as a function of stress path (only Triaxial data used)





Stress sensitivity of axial P-wave velocity for 3 different stress paths

Stress sensitivity of axial S-wave velocity for 3 different stress paths

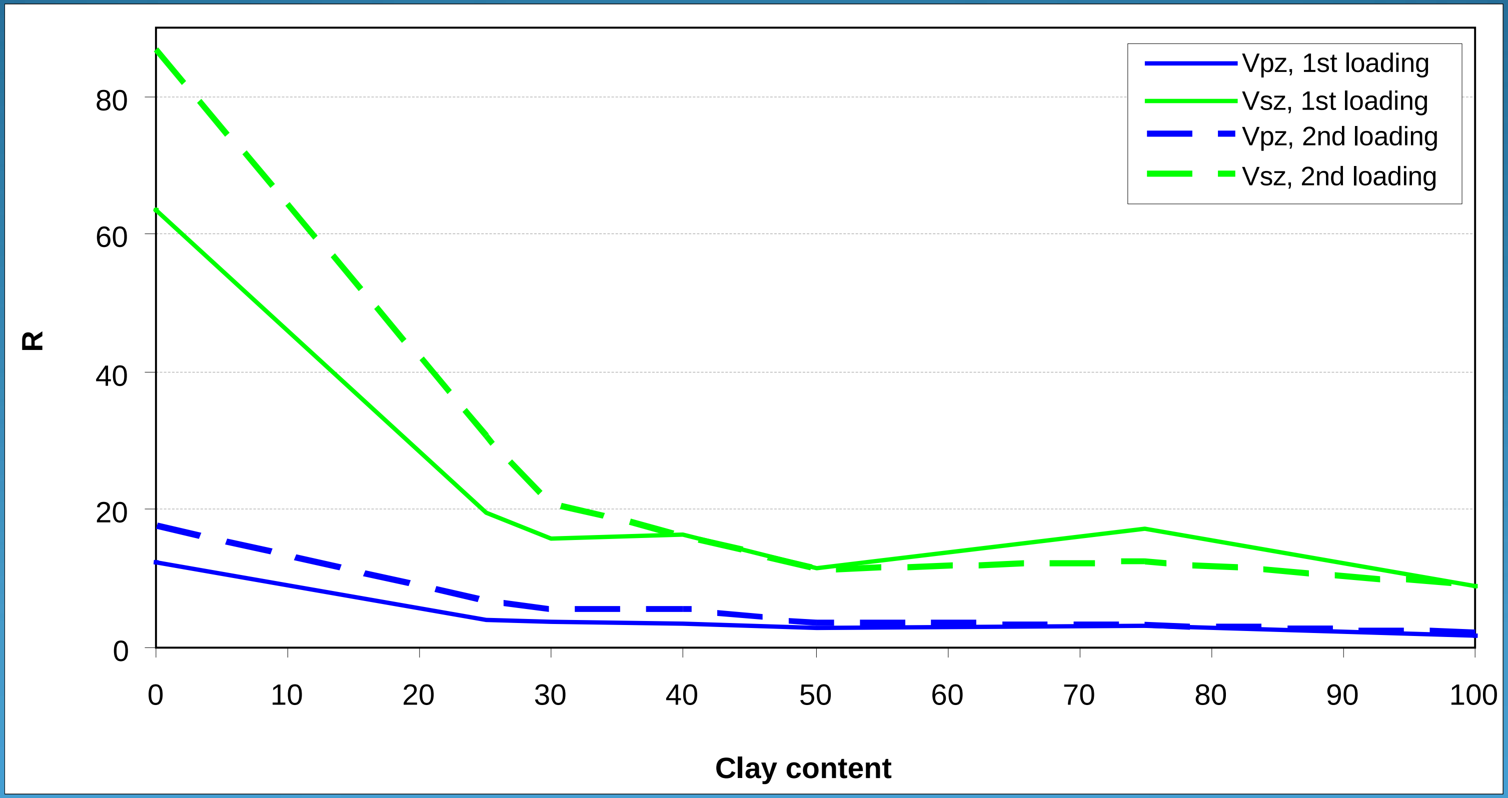
R for different waves type and consolidation state as function of clay content

(only Oedometer test samples)

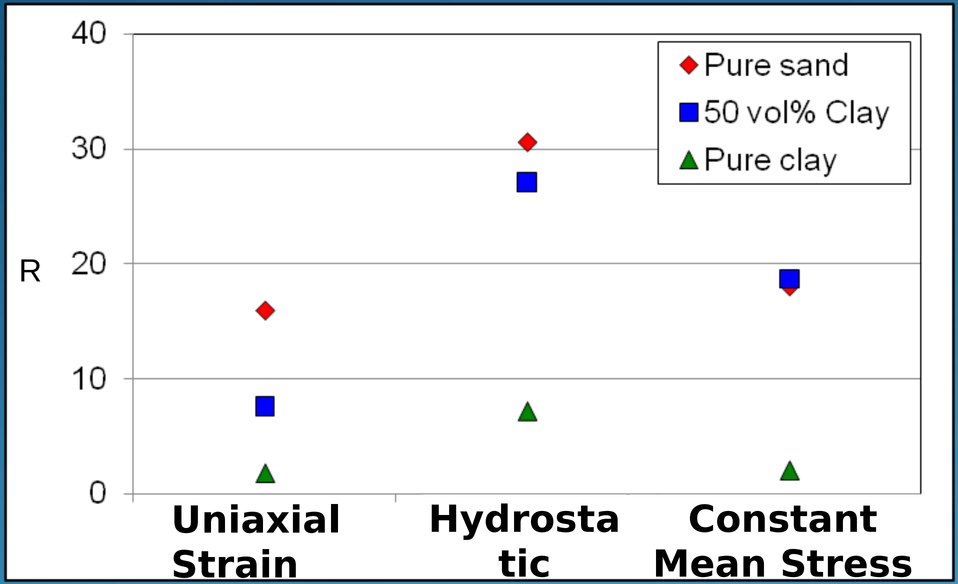
$$R = \frac{\Delta V_{pz/sz}}{V_{pz/sz} . \Delta \varepsilon_z}$$

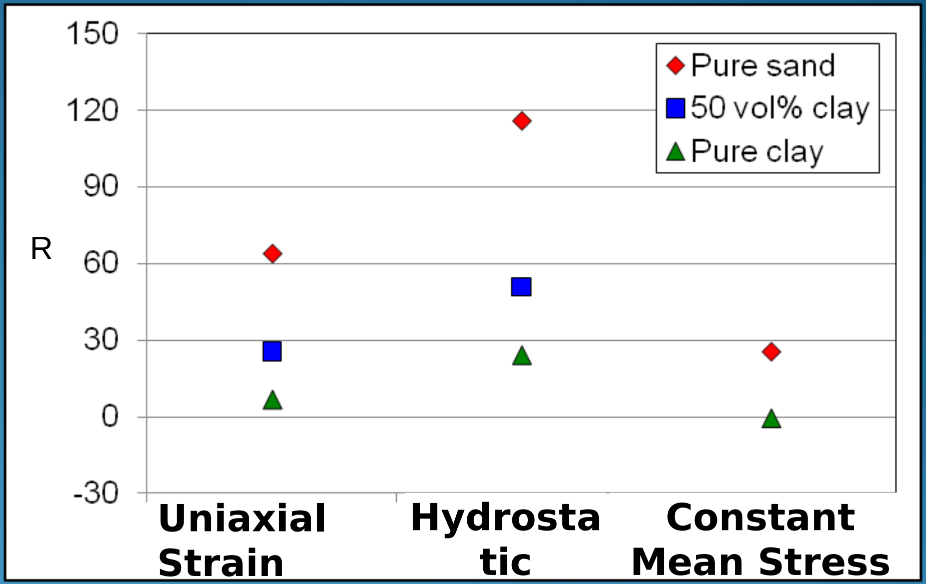
ε_z vertical strain and defined as positive for compaction

$V_{pz/sz}$ vertical P-/S-wave velocity



R as a function of stress path (only Triaxial data used)





The value of *R* obtained in this study shows conformability with Holt et al. (2008).

Conclusions

- A transition between clay and sand bearing lithologies occur around 30 – 40 % clay content, resulting in a minimum porosity and a maximum in P- and S-wave velocities.

- With presence of clay, intrinsic velocity anisotropy occurs at low stress, indicating textural ordering of clay minerals.

- In all samples, velocity anisotropy decreases with increasing stress.

  - In pure sand, the anisotropy is negative and purely stress induced.

  - P-wave anisotropy in pure clay is lower than in samples with 40-75 volume percent clay!

- Stress and Strain sensitivities depend on loading history, clay content and stress path.

  - The effective stress coefficient controlling velocities decrease with increase in clay content.

Thank You