Stress sensitivity of non-elastic processes in a weak sandstone

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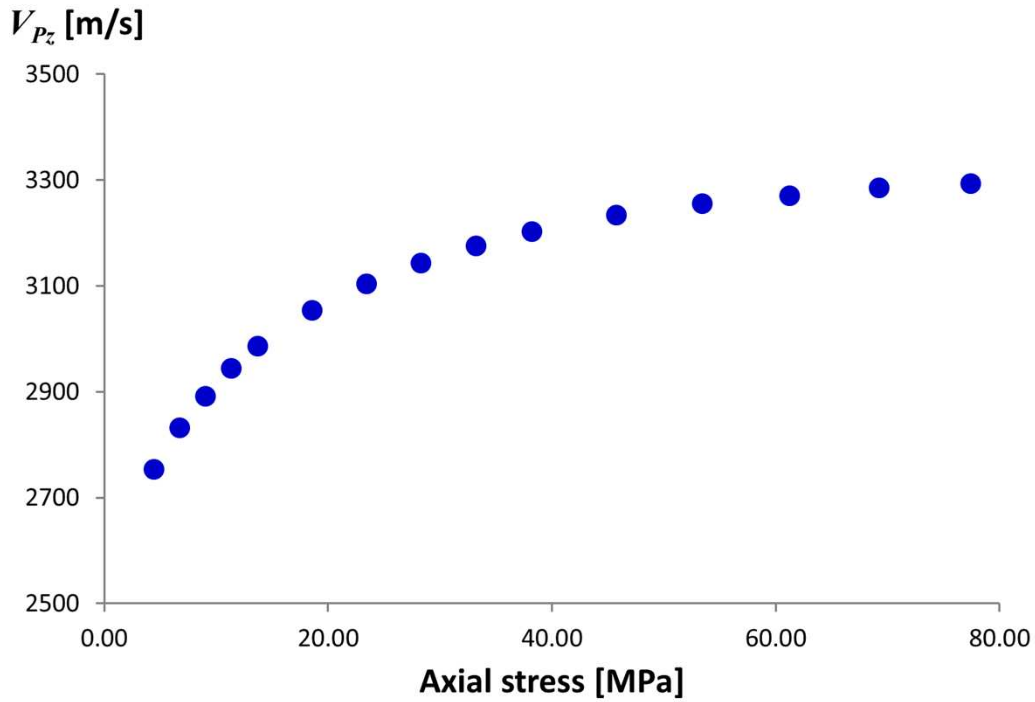
Wave velocities of soft rocks depend on stress.

Why?



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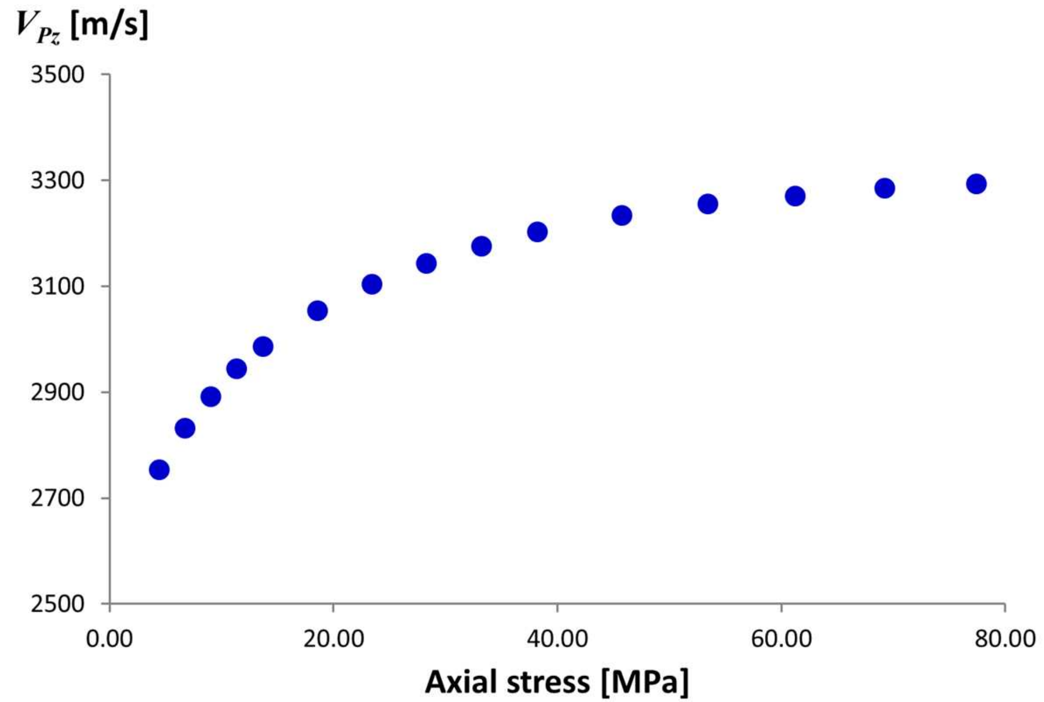
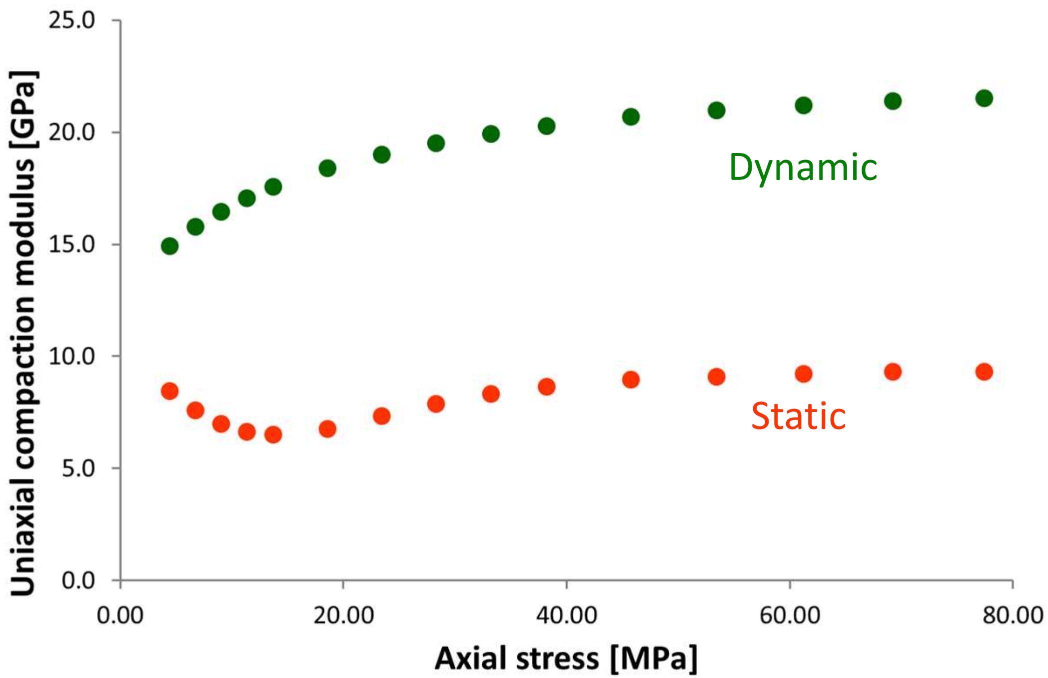


Static and dynamic moduli of soft rocks are different - also for dry rocks.

The difference changes along the stress path.

Why?

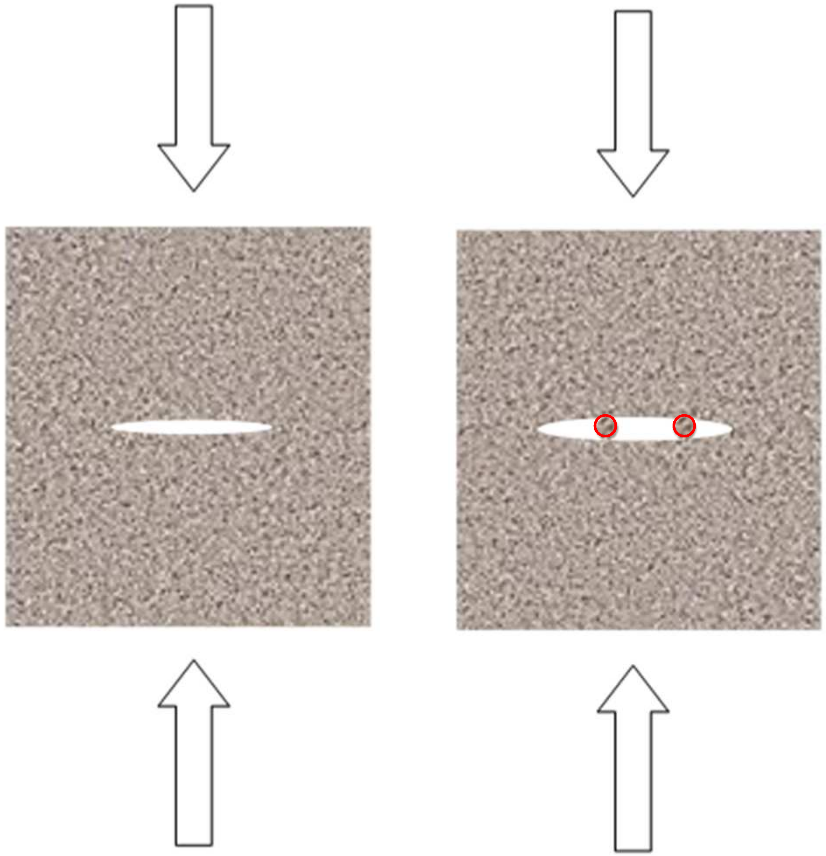


Potential processes causing non-linear elastic and non-elastic behavior

Closing/opening
of cracks

Elastic process

Potential processes causing non-linear elastic and non-elastic behavior



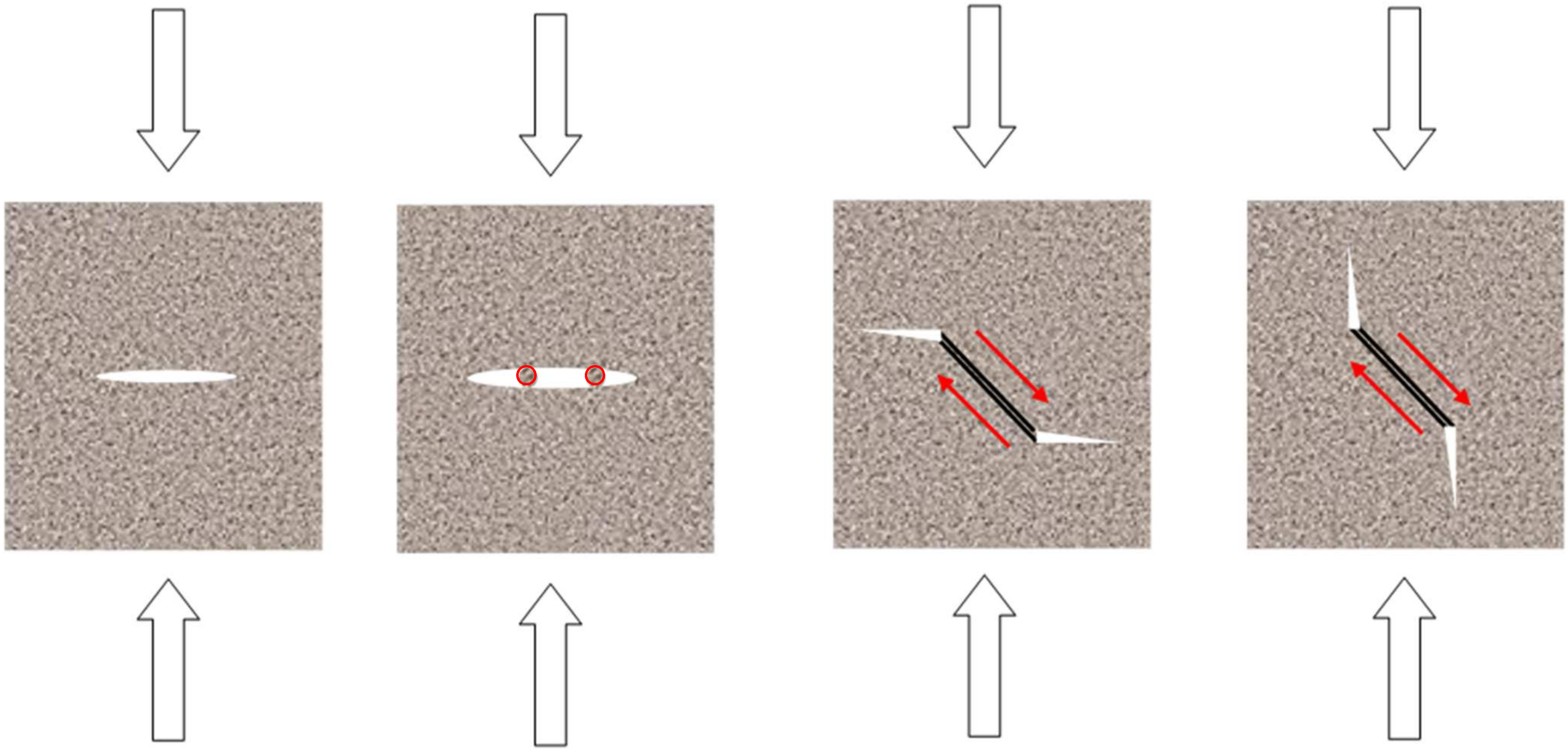
Closing/opening of cracks

Elastic process

Crushing of small particles or grain contacts

Only during loading

Potential processes causing non-linear elastic and non-elastic behavior



Closing/opening of cracks

Crushing of small particles or grain contacts

Shear sliding of closed cracks. May involve opening as well as closure of “wing cracks”

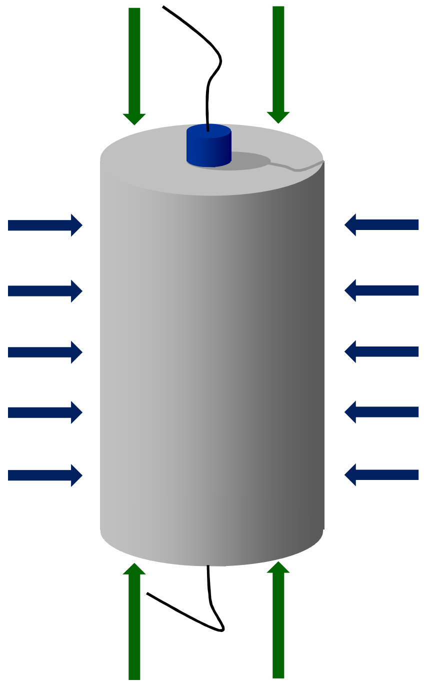
Elastic process

Only during loading

May occur both during loading and unloading

Laboratory tests:

Standard triaxial set-up + acoustics



Axial stress

Confining stress

Axial wave propagation

- P-waves
- S-waves

Here:

- Dry outcrop sandstone → No fluid effects

- Castlegate sandstone → No clay effects

- K0 path → Both static and dynamic C_{33}

- Unloading → Exclude crushing of contacts

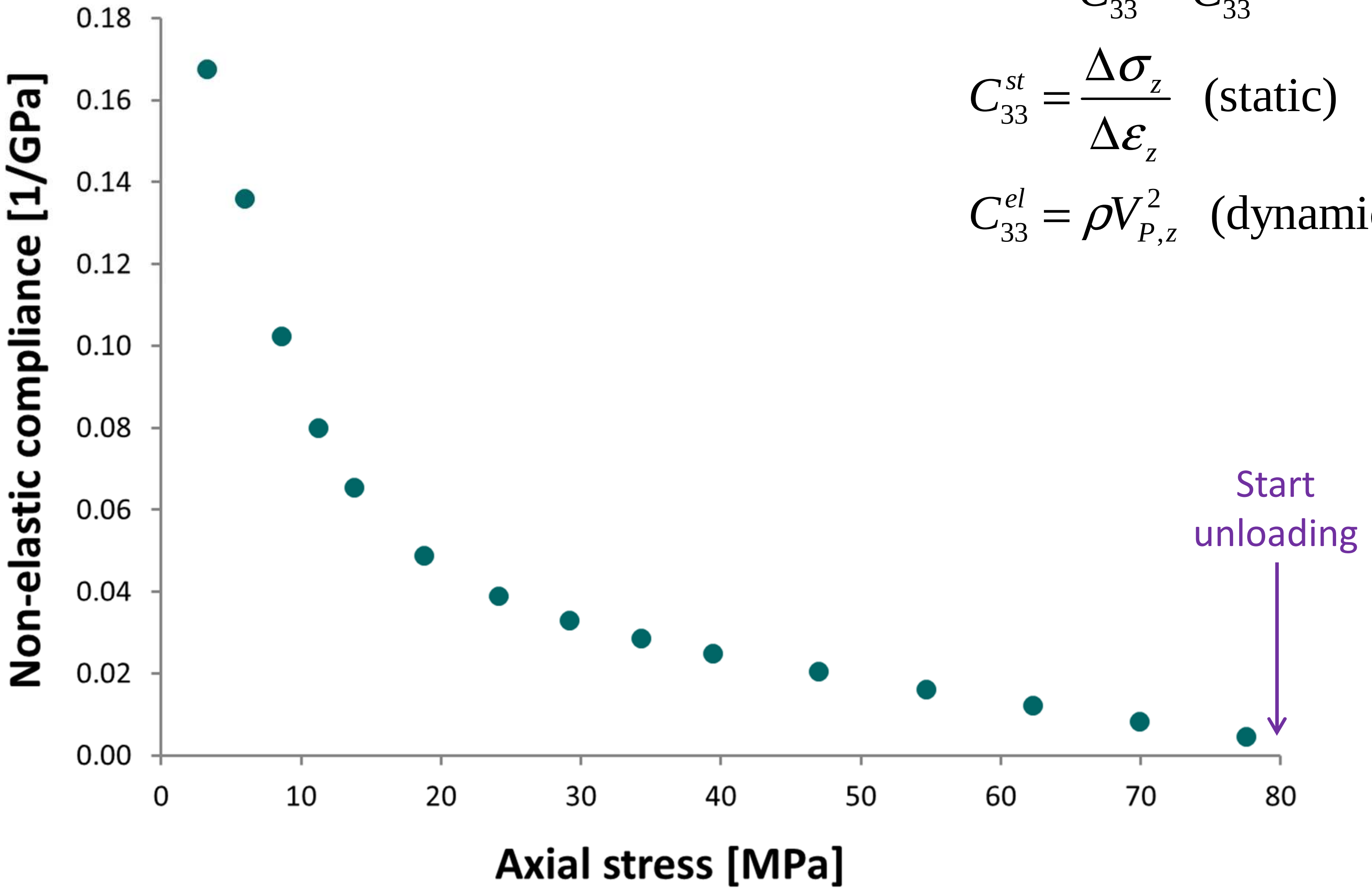
Static vs dynamic:

Non-elastic compliance:

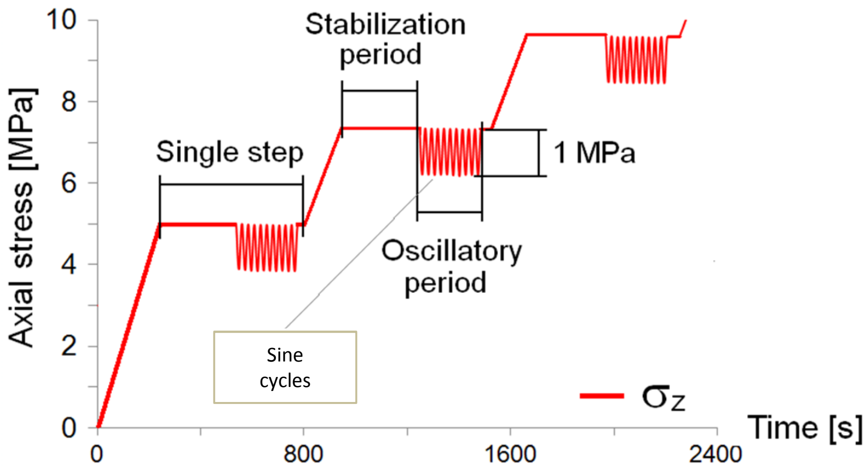
$$S_H = \frac{1}{C_{33}^{st}} - \frac{1}{C_{33}^{el}}$$

$$C_{33}^{st} = \frac{\Delta\sigma_z}{\Delta\varepsilon_z} \quad \text{(static)}$$

$$C_{33}^{el} = \rho V_{P,z}^2 \quad \text{(dynamic)}$$



Non-linear acoustic tests
(Stroisz and Fjær, 2011):



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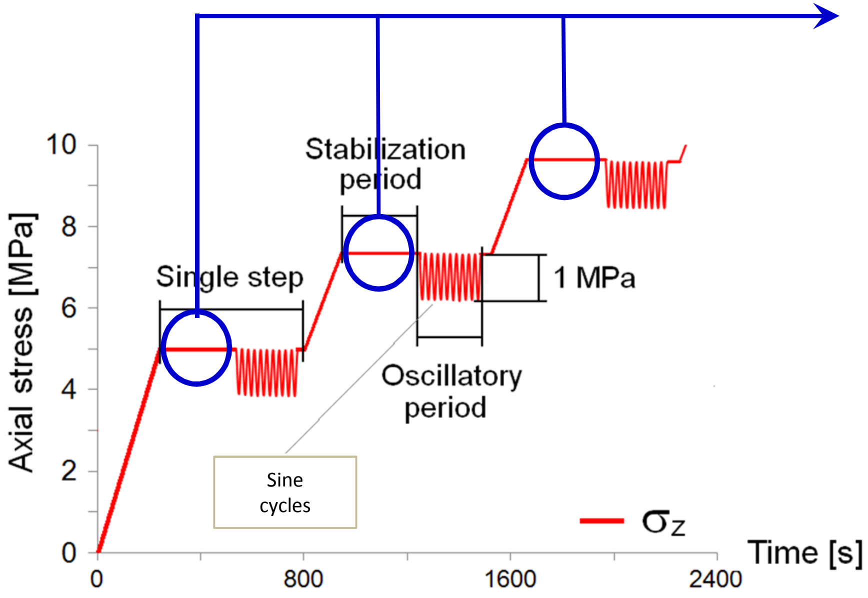

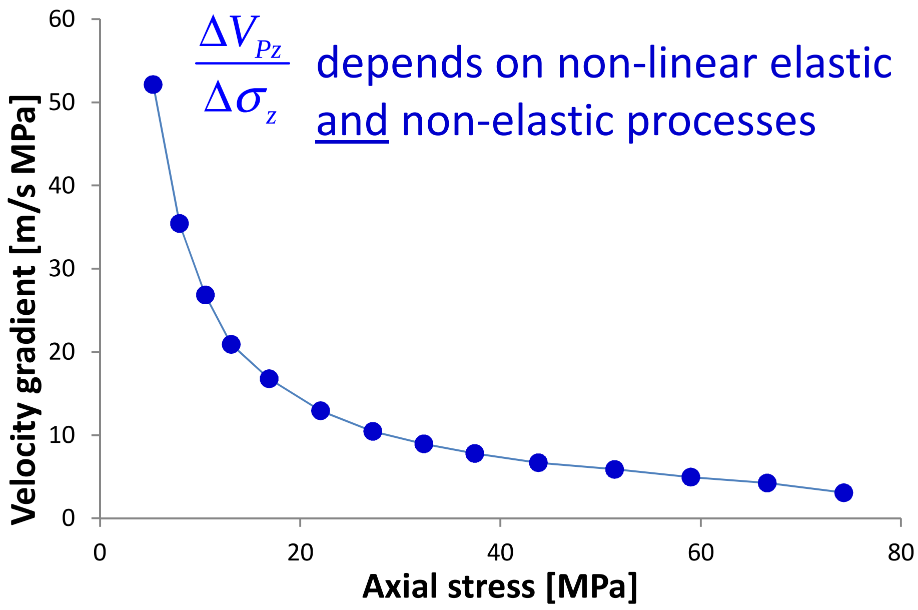

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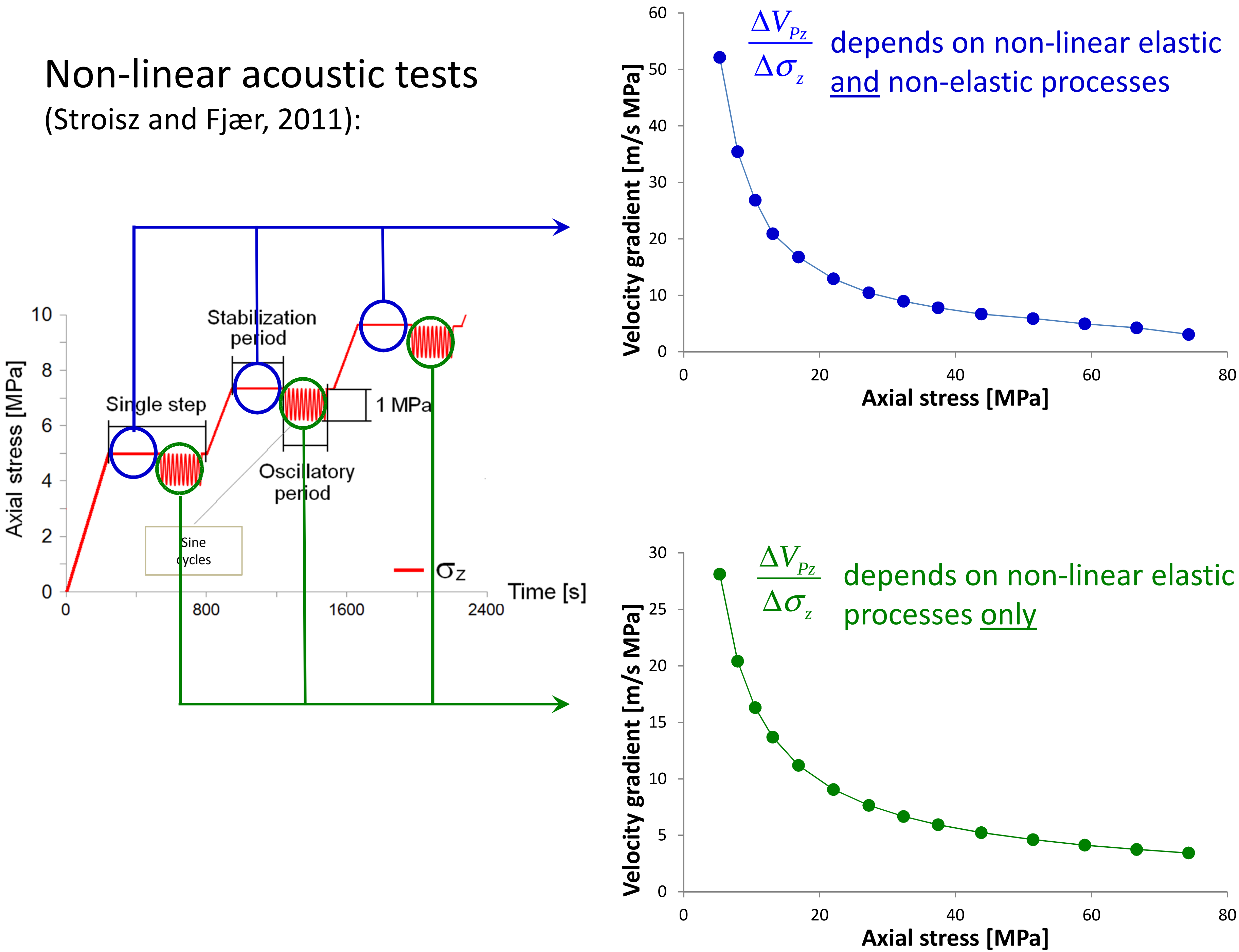


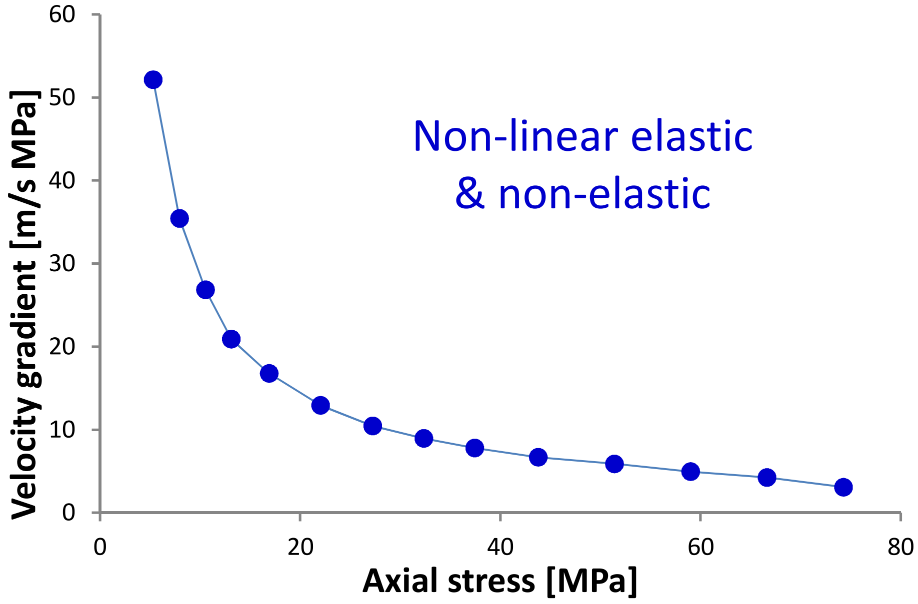
Non-linear elastic
& non-elastic

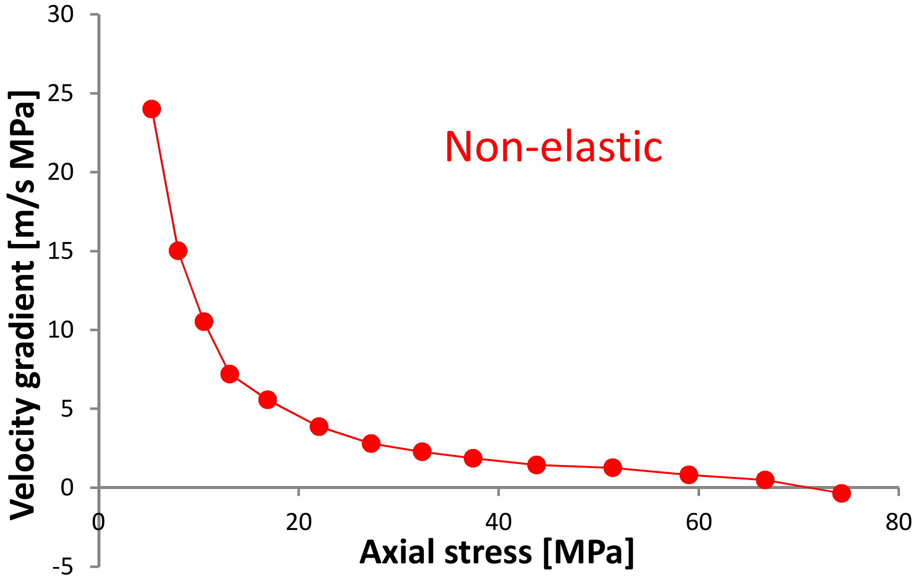
÷

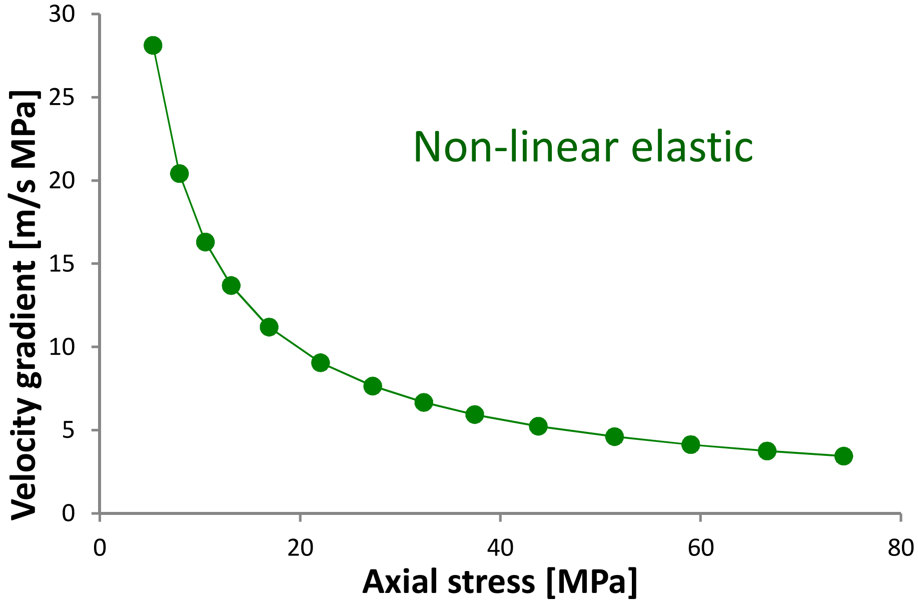
Non-linear elastic

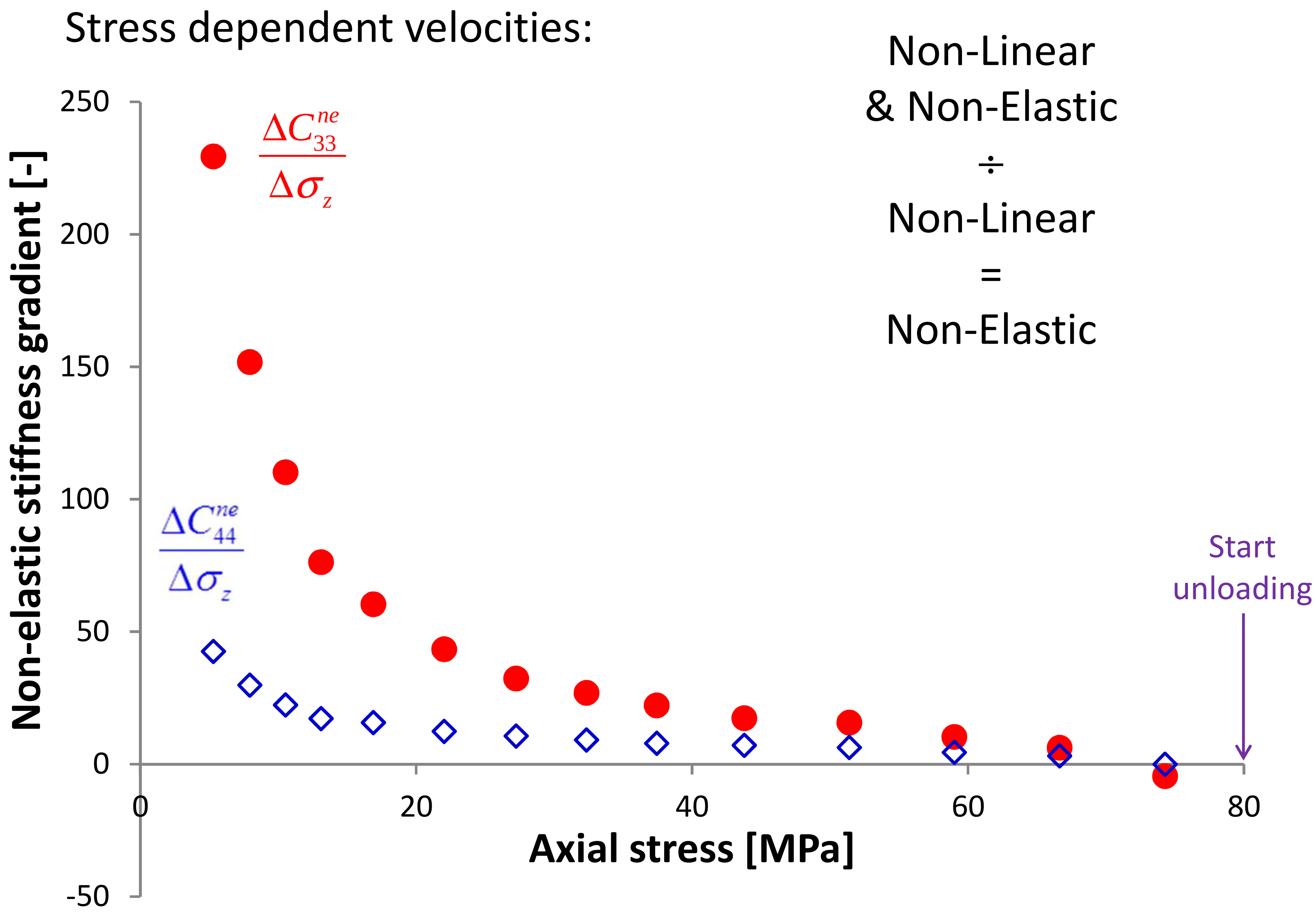
=

Non-elastic



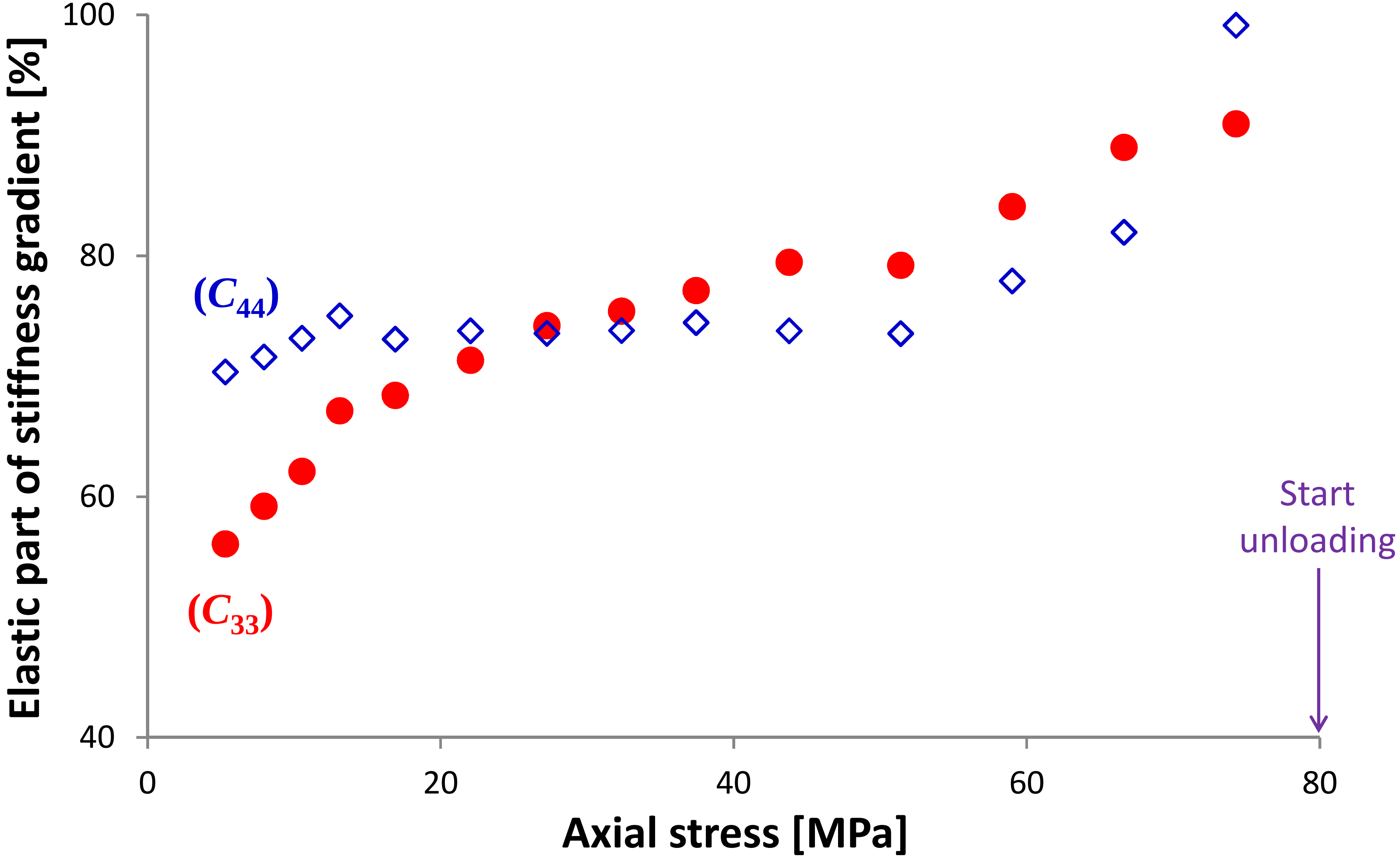






Stress dependent velocities:
Non-Linear
& Non-Elastic
÷
Non-Linear
=
Non-Elastic
$\frac{\Delta C_{33}^{ne}}{\Delta \sigma_z}$
$\frac{\Delta C_{44}^{ne}}{\Delta \sigma_z}$
Start
unloading
Non-elastic stiffness gradient [-]
250
200
150
100
50
0
-50
0
20
40
60
80
Axial stress [MPa]

The stress dependence of wave velocities is mostly due an elastic process



Non-elastic contributions

Stress dependent velocities:
Non-elastic part of stiffness gradient

$$\frac{\Delta C_{33}^{ne}}{\Delta \sigma_z}$$

Static vs dynamic:
Non-elastic compliance

$$S_H = \frac{1}{C_{33}^{st}} - \frac{1}{C_{33}^{el}}$$

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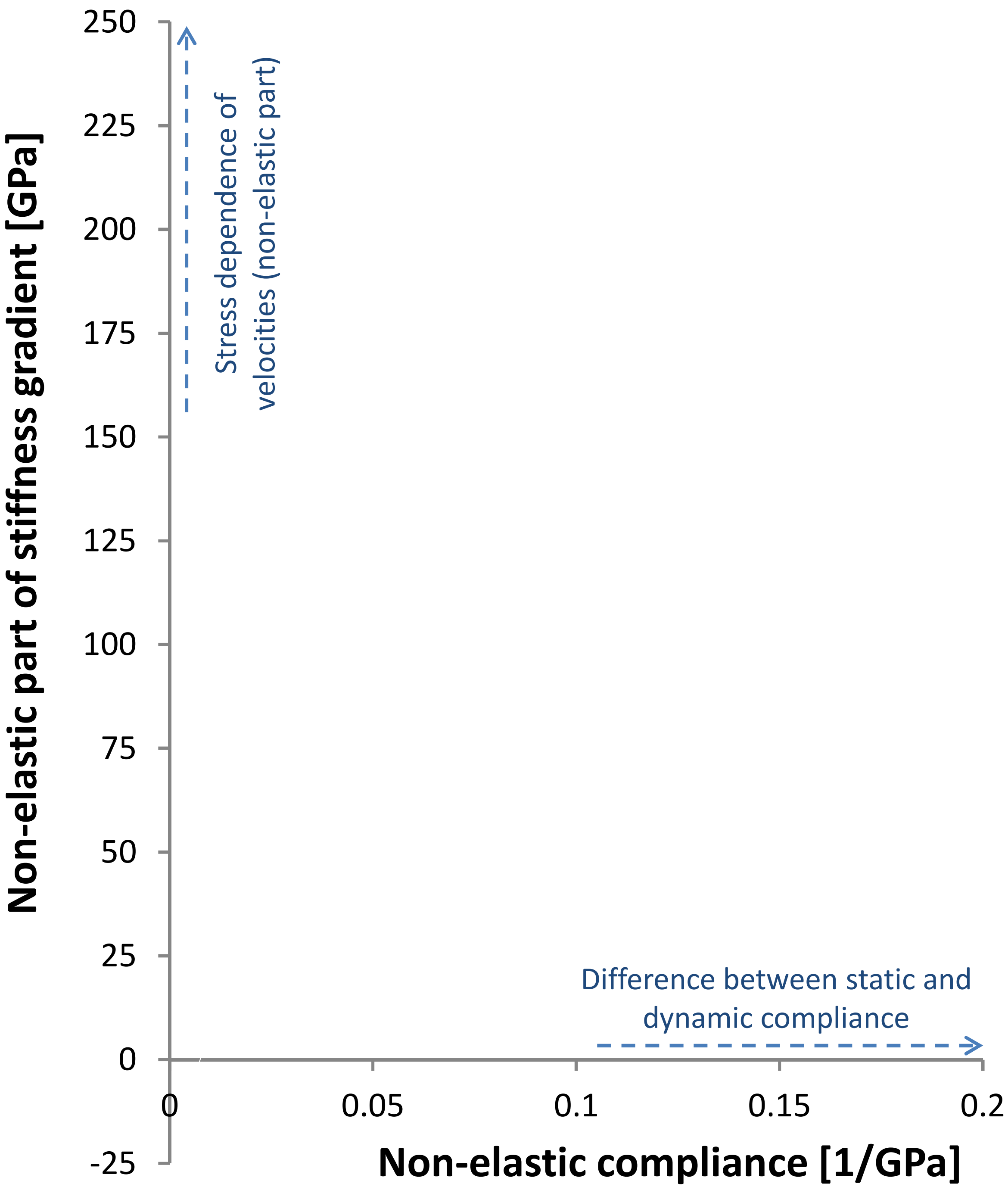

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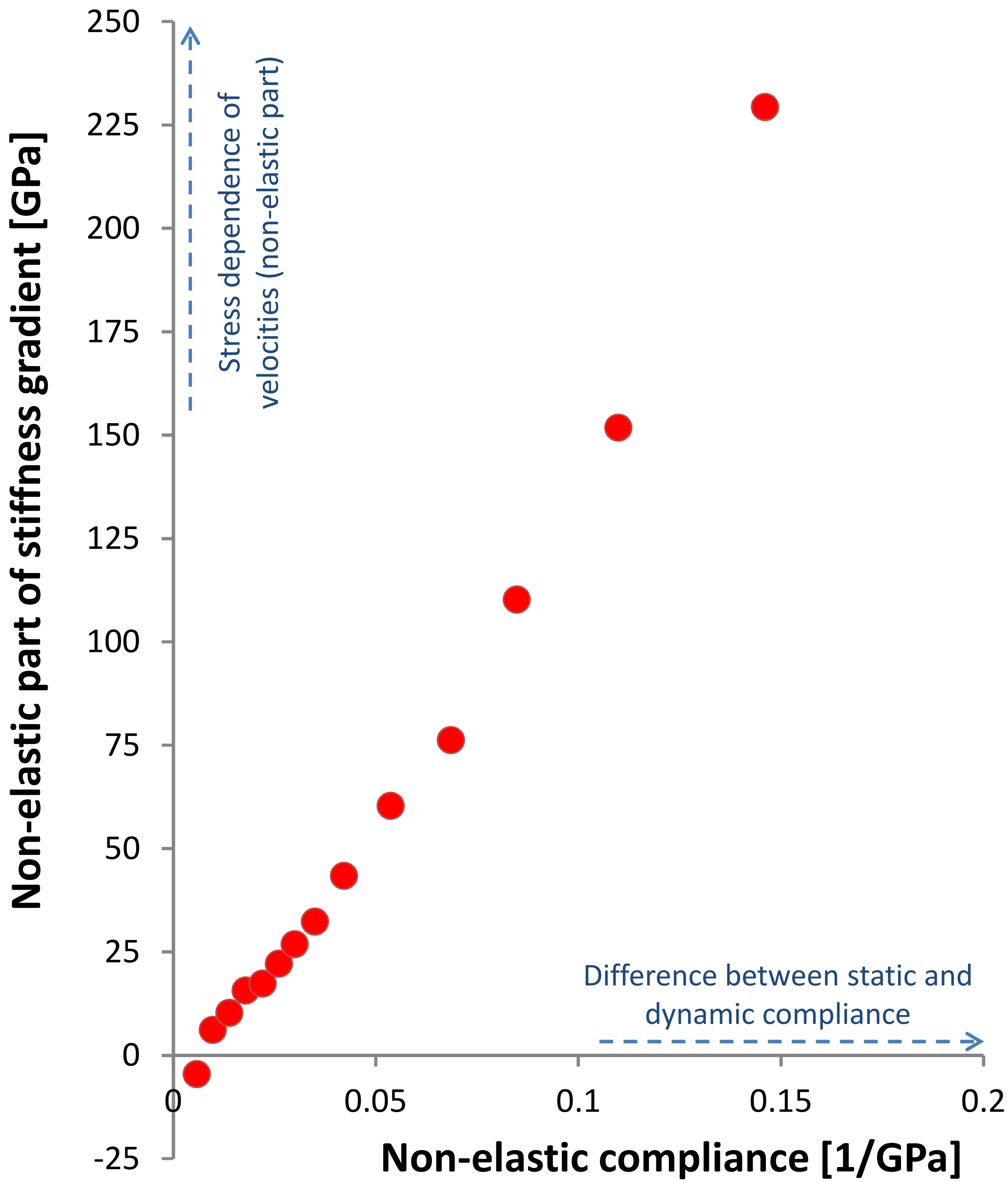

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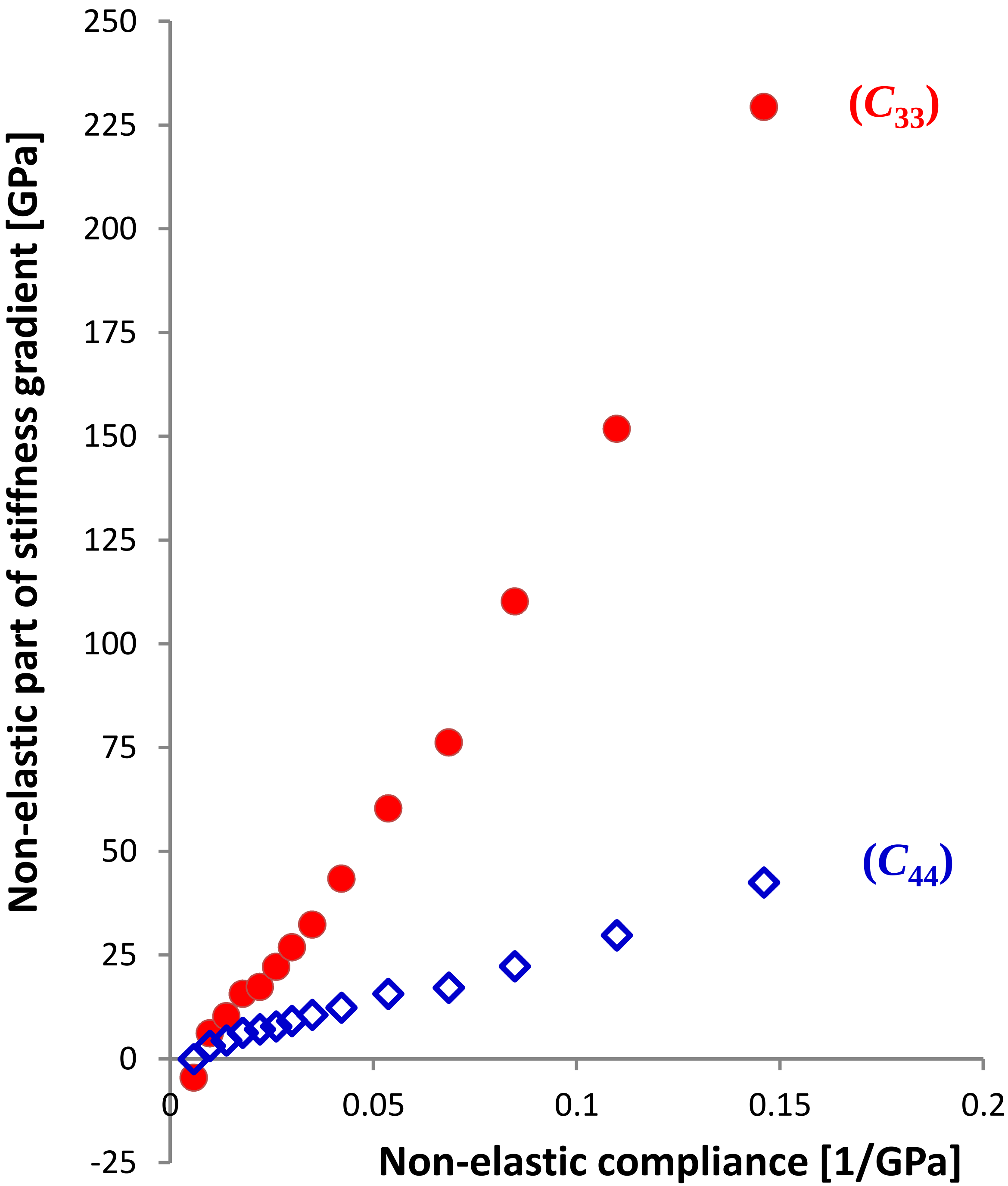
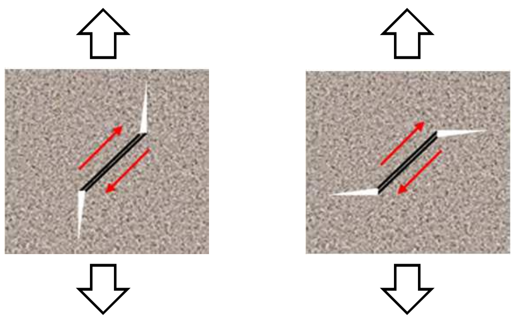
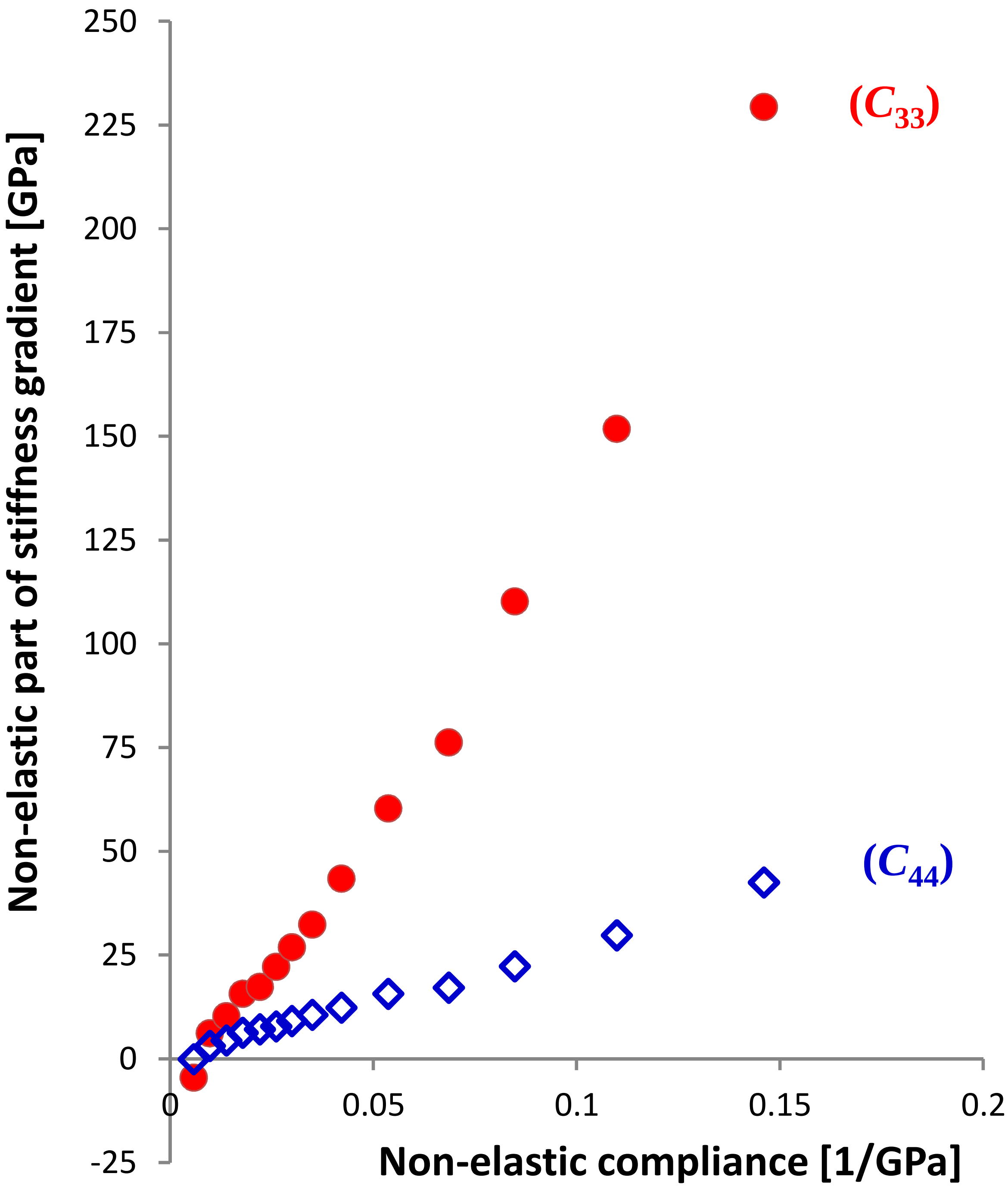


Very clear correlation
between
the non-elastic part of the
stiffness gradient
and
the non-elastic compliance

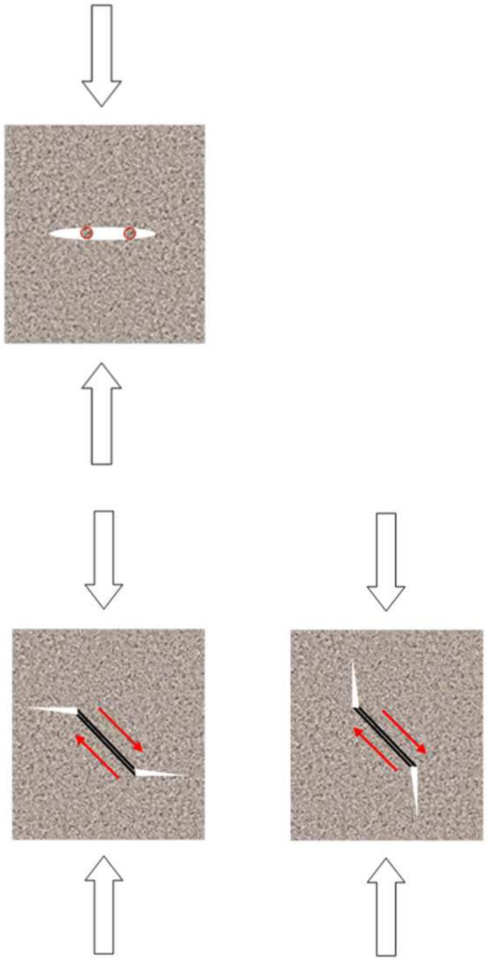
Suggests that the same process controls both parameters during unloading

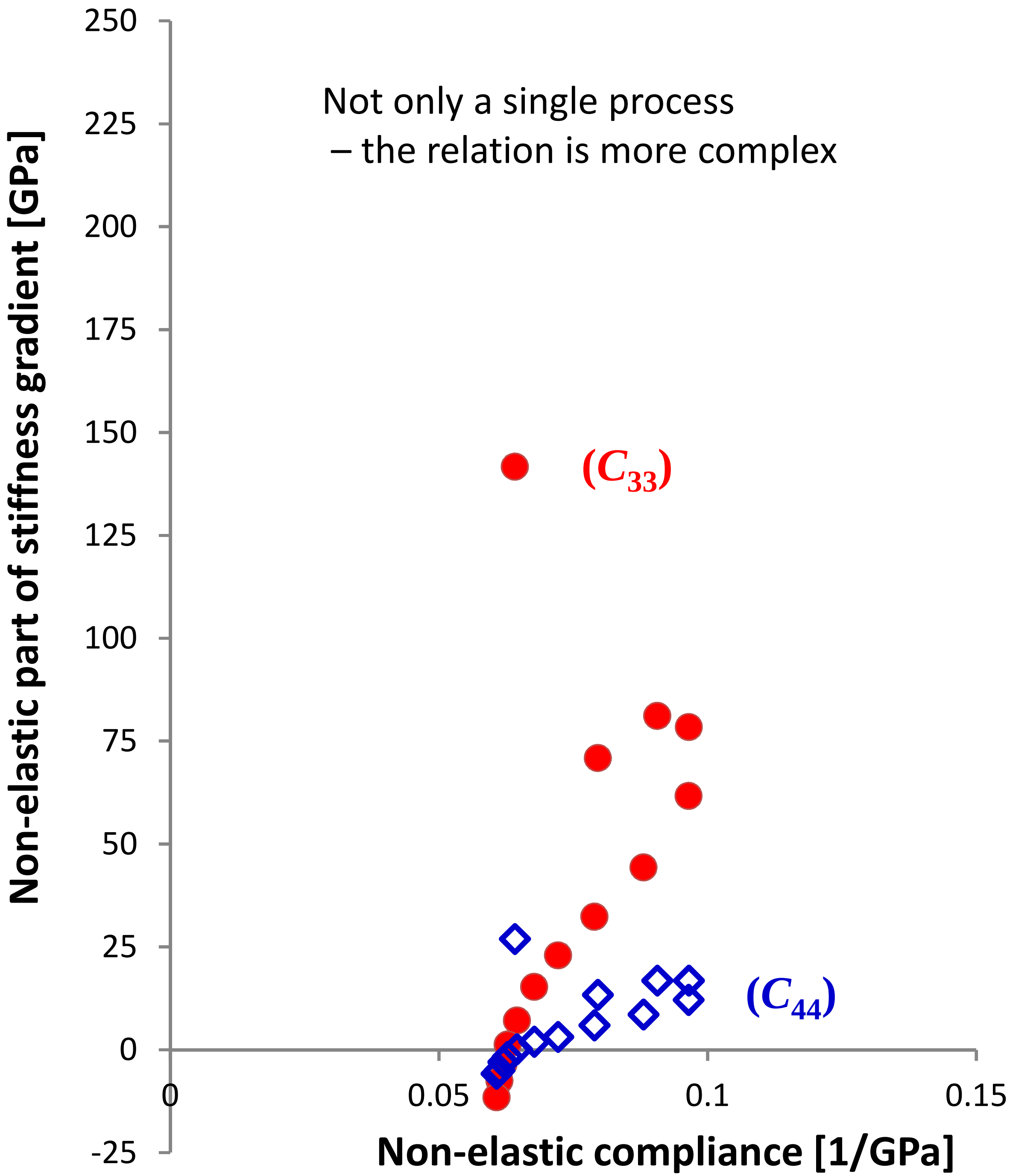


Shear sliding of closed cracks



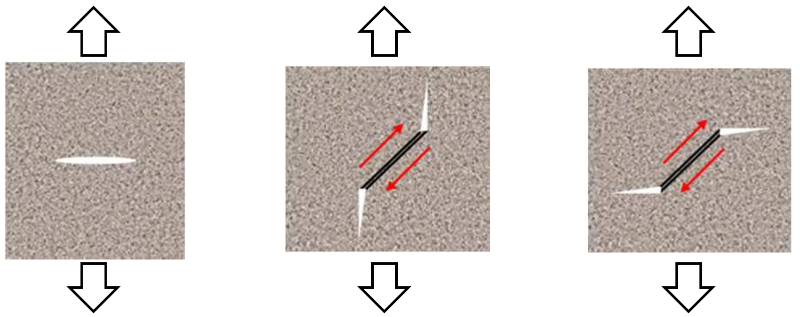
During **loading**,
also crushing of small
particles or grain contacts
will occur





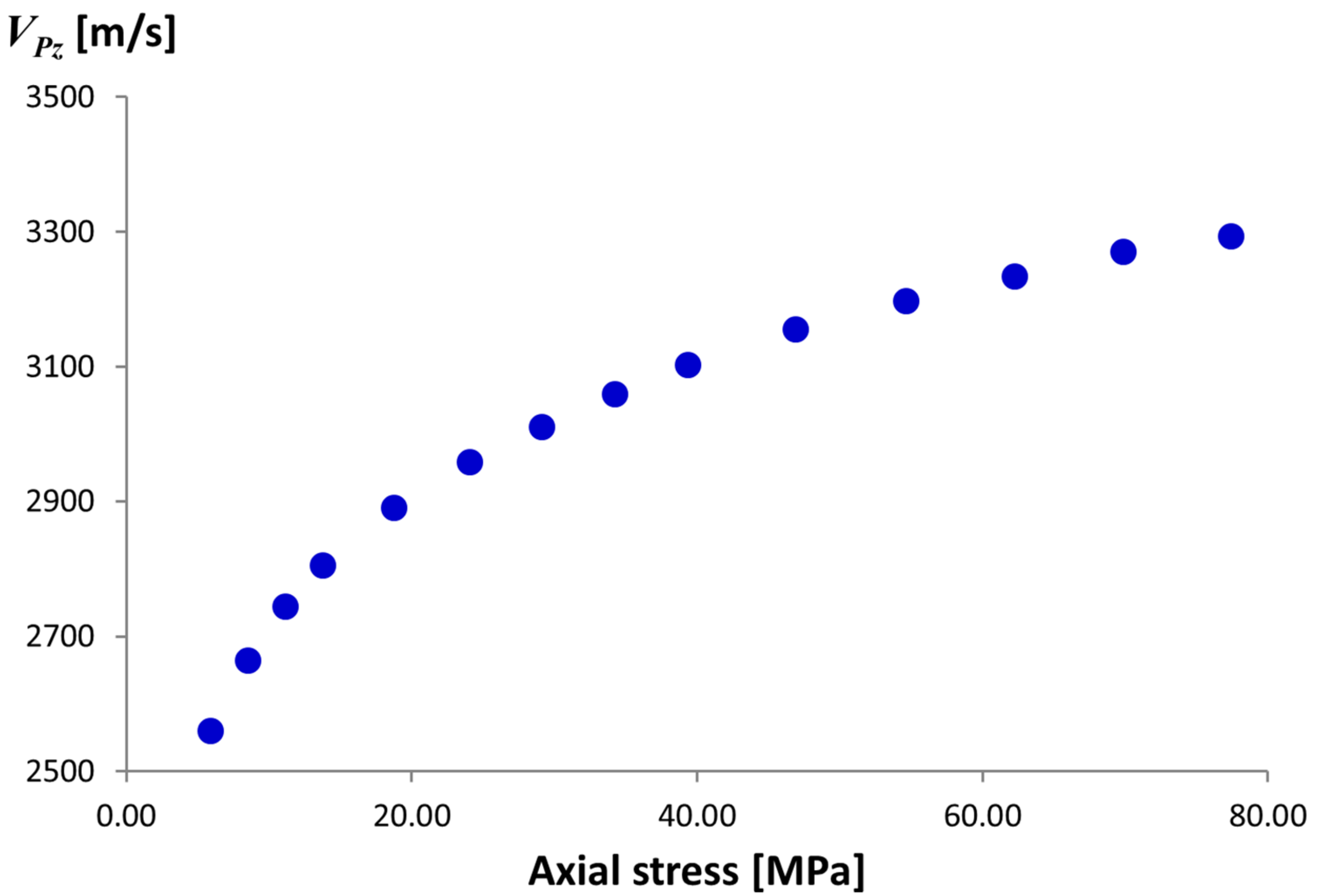
K0 unloading of a dry, clay-free sandstone:

Wave velocities of soft rocks depend on stress - because:



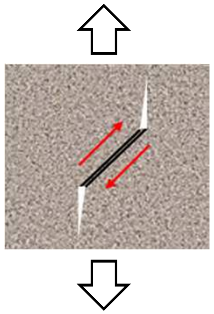
Mostly

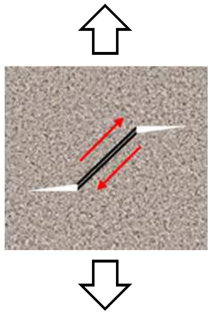
More and more



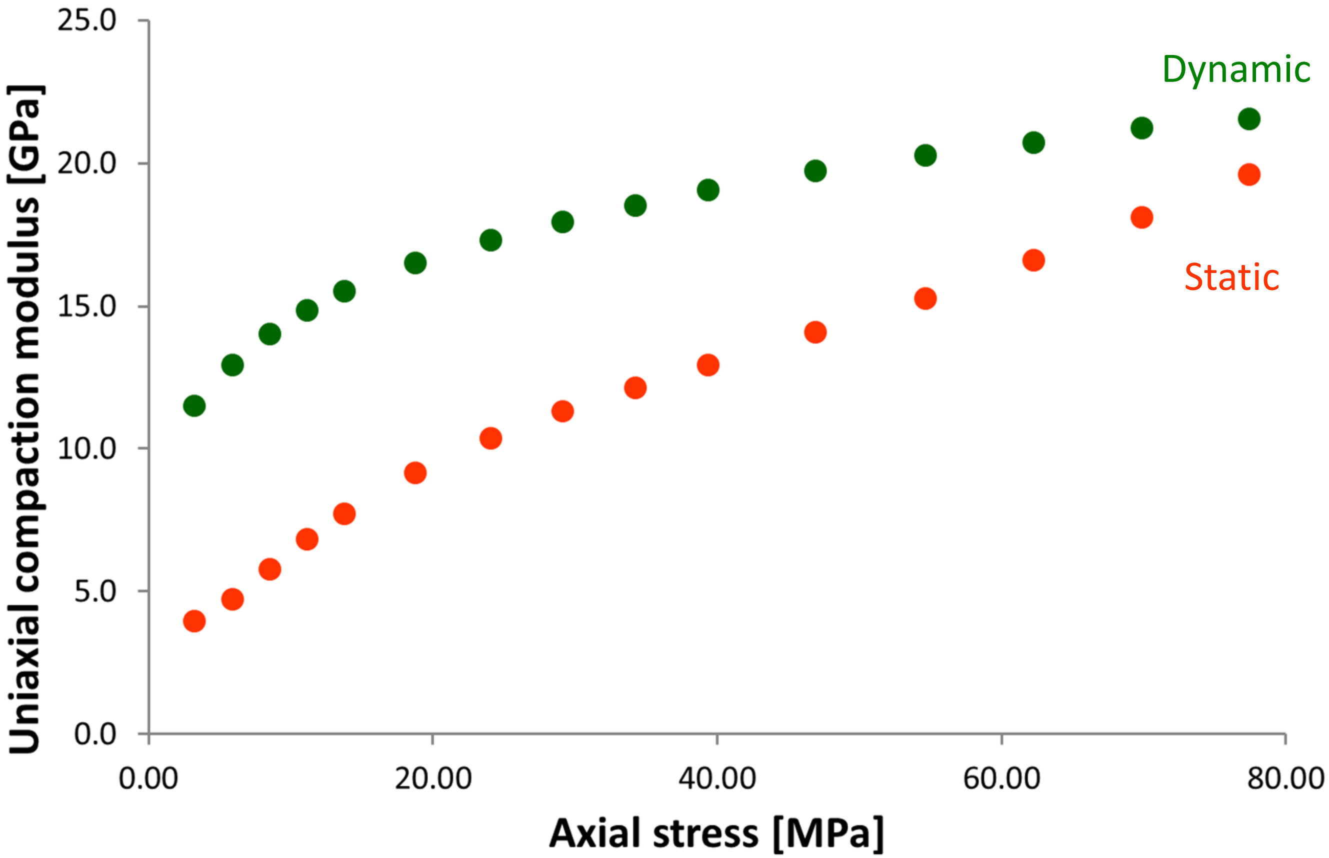
K0 unloading of a dry, clay-free sandstone:

Static and dynamic moduli
of soft rocks are different - because:





Only



Summary:

- During K0 unloading of a dry, clay-free sandstone, the stress dependence of elastic waves is mainly caused by an elastic process, but a non-elastic process causing opening/closure of cracks become increasingly important

- The same non-elastic process appears to be the cause for the difference between static and dynamic moduli under these conditions

- This non-elastic process may be associated with shear sliding of closed cracks

Acknowledgements

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