Strain localization in the presence of excess pore water pressure under quasi-static conditions

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Outline

- Pore pressure driven strain softening
  - Quick clay
  - Strain localization
- Local drainage
  - Mechanics
  - Effects on global response
- Shear band thickness
  - Consolidation as a regularization technique?
  - Analysis
- Present and future work

The landslide at Kattmarkveien 2009

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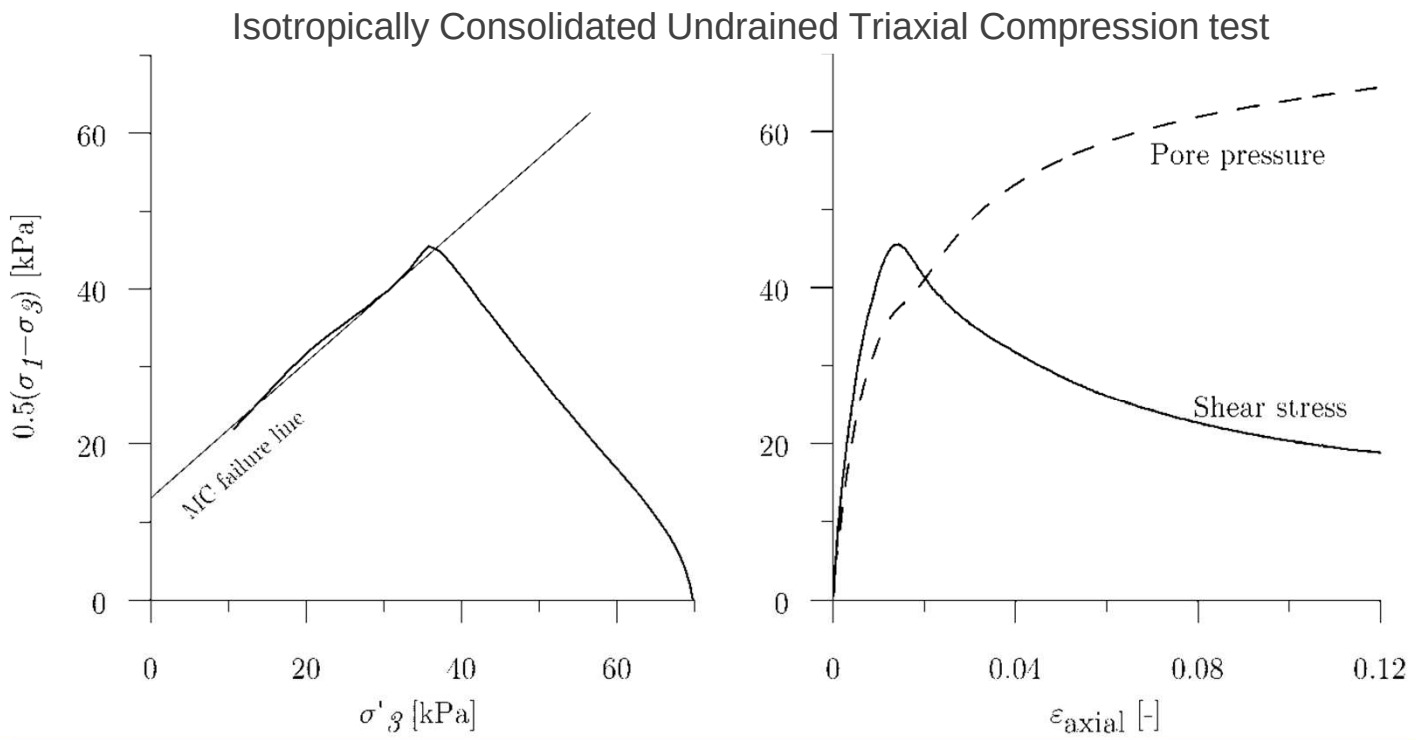
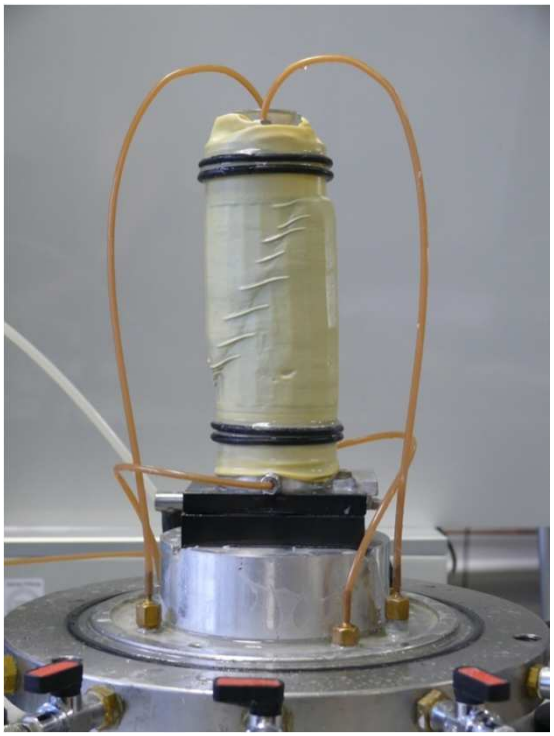
Strain softening by excess pore pressure

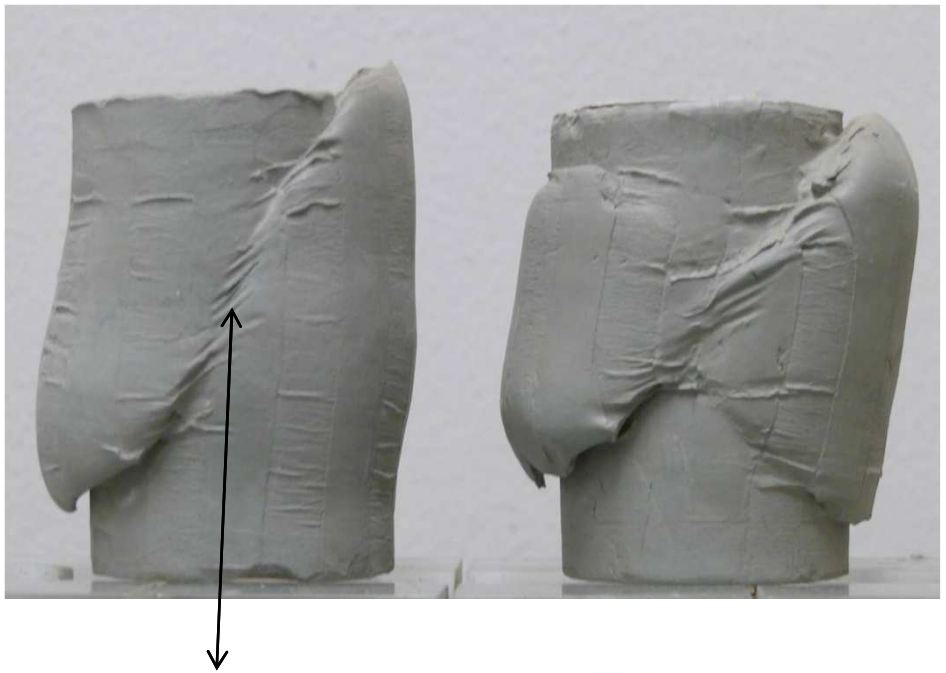
- Undrained shear of saturated loose soil generates excess pore pressure
  - Loose sand (liquefaction)
  - Quick clay



Strain localization

Strain softening ⇨ material instability ⇨ strain localization





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Local drainage

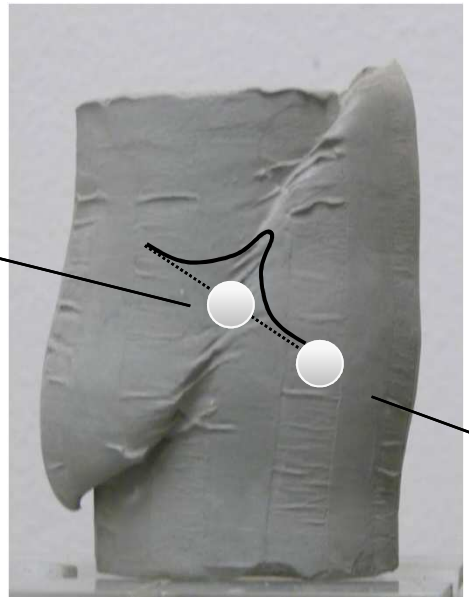
Viggiani et al. (1994) *"The analysis of the onset and propagation of shear bands in porous media such as saturated clays pose a formidable problem, because of coupled effects relating to fluid flow in the soil mass and in the localized zone which have to be taken into account"*

- Characteristic consolidation time ≈ physical event time
- Internal pore pressure gradients

Inside

Plastic shearing

Generation of excess pore pressure



Outside

Elastic unloading

Reciever of excess pore pressure

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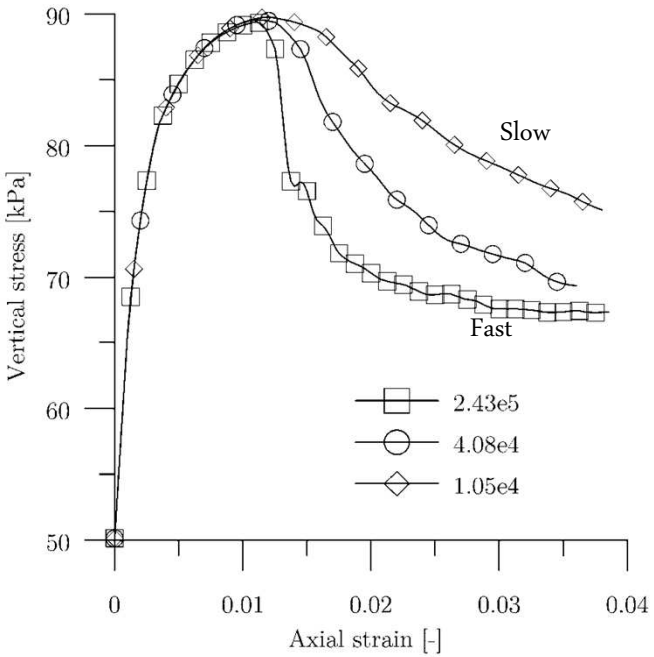
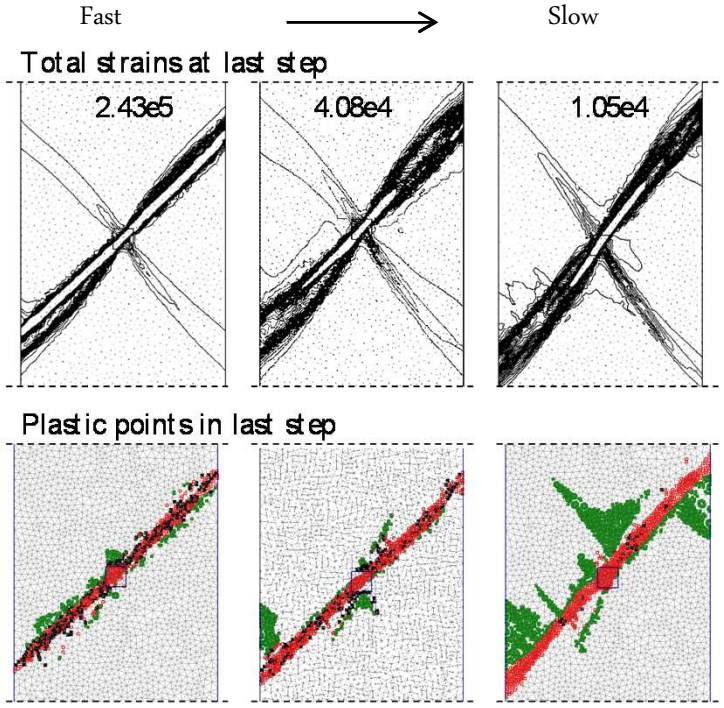
Effects of local drainage

- Global brittleness
- Shear band inclination





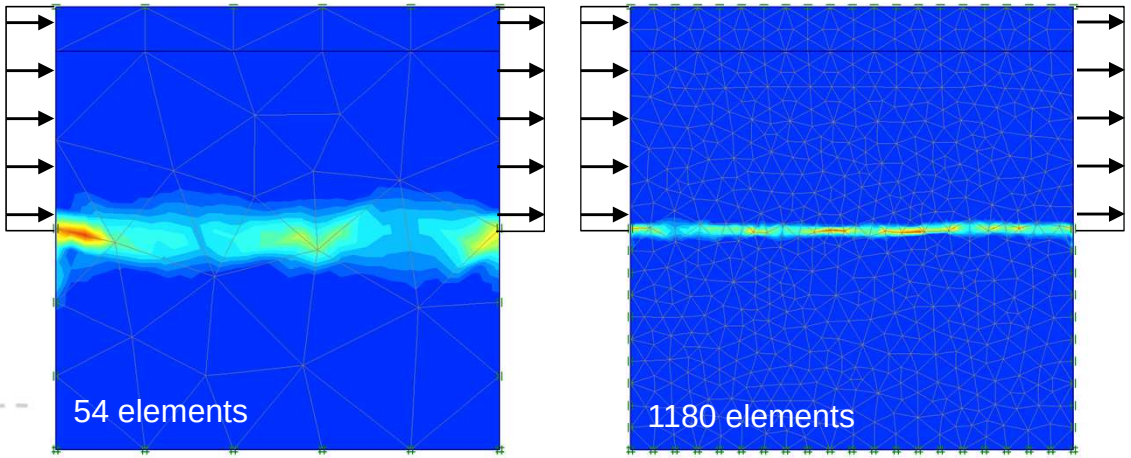
Thakur, V. (2011) *'Numerically observed shear bands in soft sensitive clays*', Geomechanics and Geoengineering

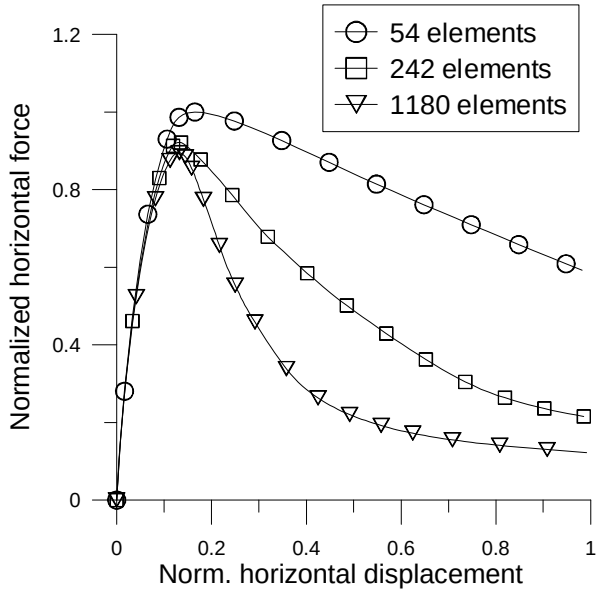
Thakur, V. (2007) *'Strain localization in soft sensitive clay'*, PhD-thesis, NTNU

Effects of local drainage

- Shear band thickness
  - Is an internal length scale introduced through the permeability in consolidation coupled analysis?
  - Inherent regularization?

Mesh dependent one phase strain softening FEM simulation





Consolidation coupled analysis

- Regularization in the litterature

Study	Method	Regularization?
Vardoulakis (1986)	Analysis of the governing equations	Inertia is important
Oka et al. (1995)	Quasistatic	No
Ehlers & Volk (1998)	Quasistatic (theory of porous media)	Yes
Zhang et al. (1999)	Dynamic	Only for a limited range of permeabilities
Lu et al. (2004)	Dynamic	Conseptually, yes
Jostad et al. (2006)	Quasistatic	Yes, at onset
Thakur (2006)	Quasistatic	Yes, at residual
de Borst & Abellan (2007)	Dynamic	No

- Conclusion… Need further investigations

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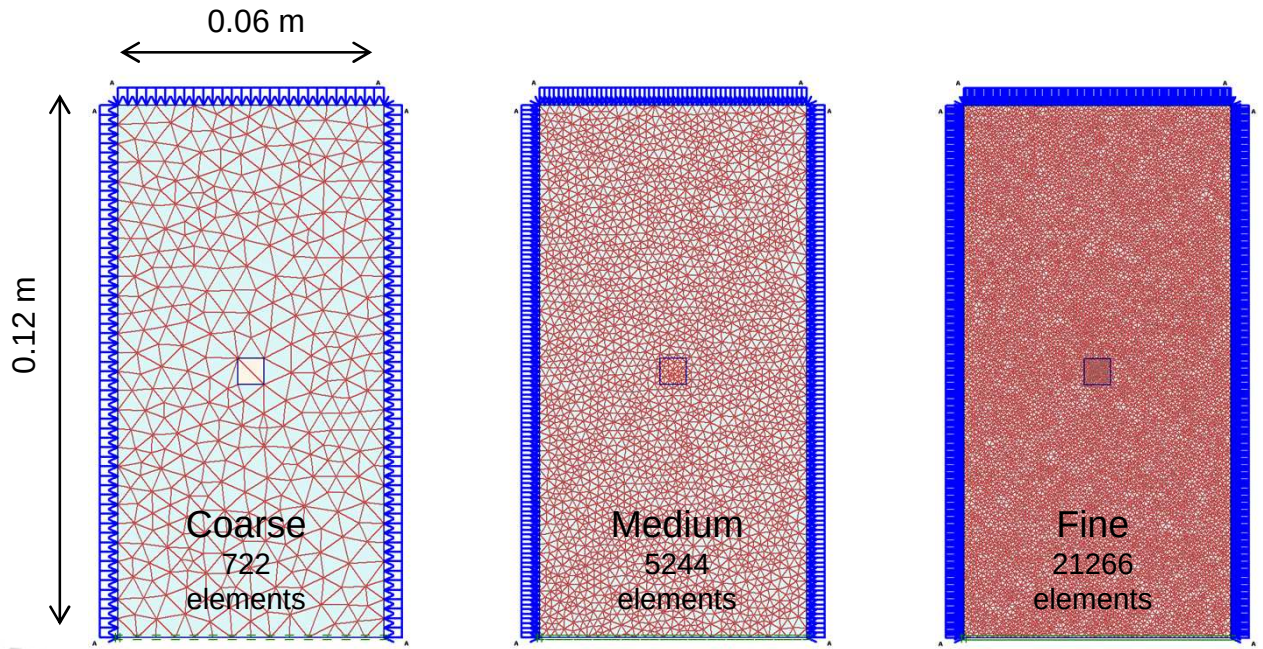
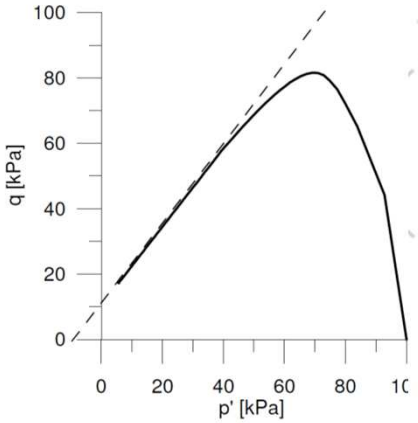
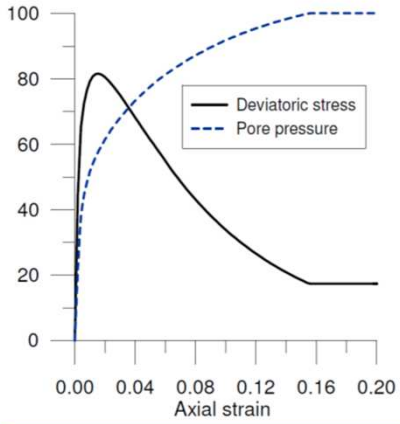
Consolidation coupled analysis

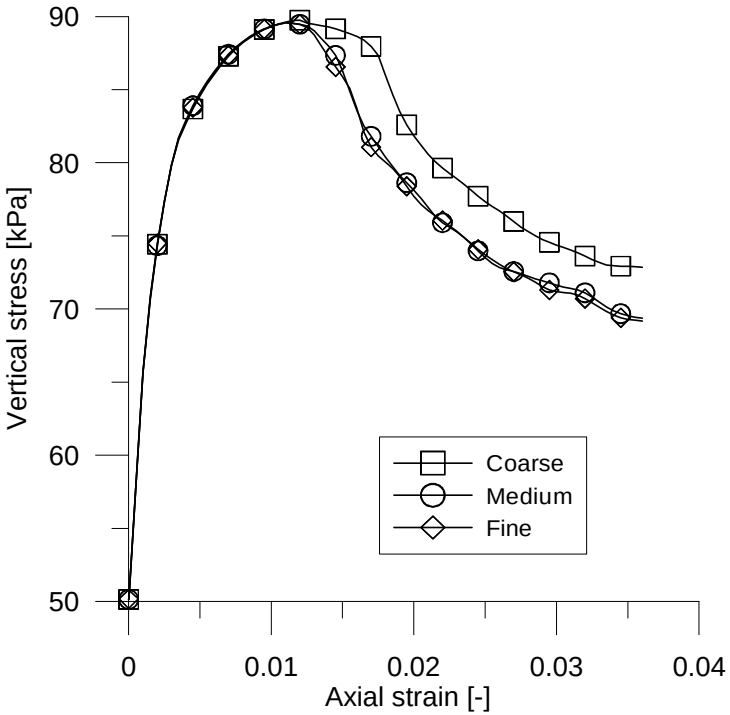
- FEM modeling
  - Plaxis v 9, 6-noded triangular elements, three mesh densities
  - Quasistatic consolidation coupled plane strain test
  - Globally undrained conditions

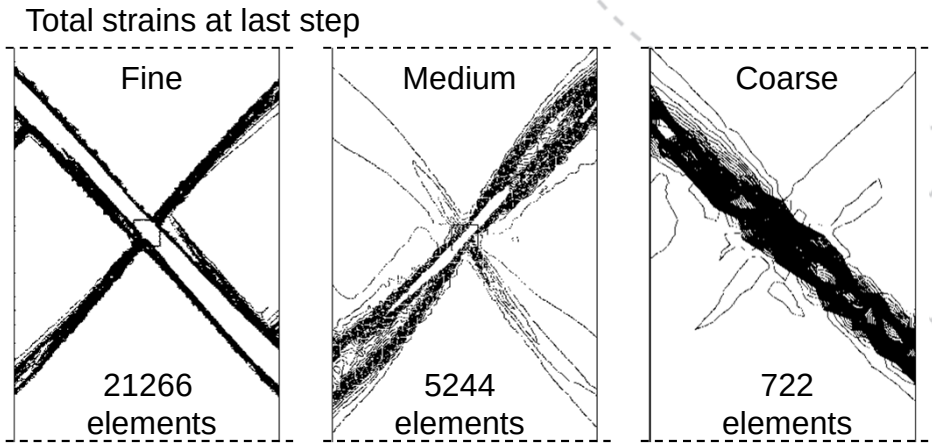






Consolidation coupled analysis





- Convergent solution obtained in quasistatic condition
- Why?
- How does it work?

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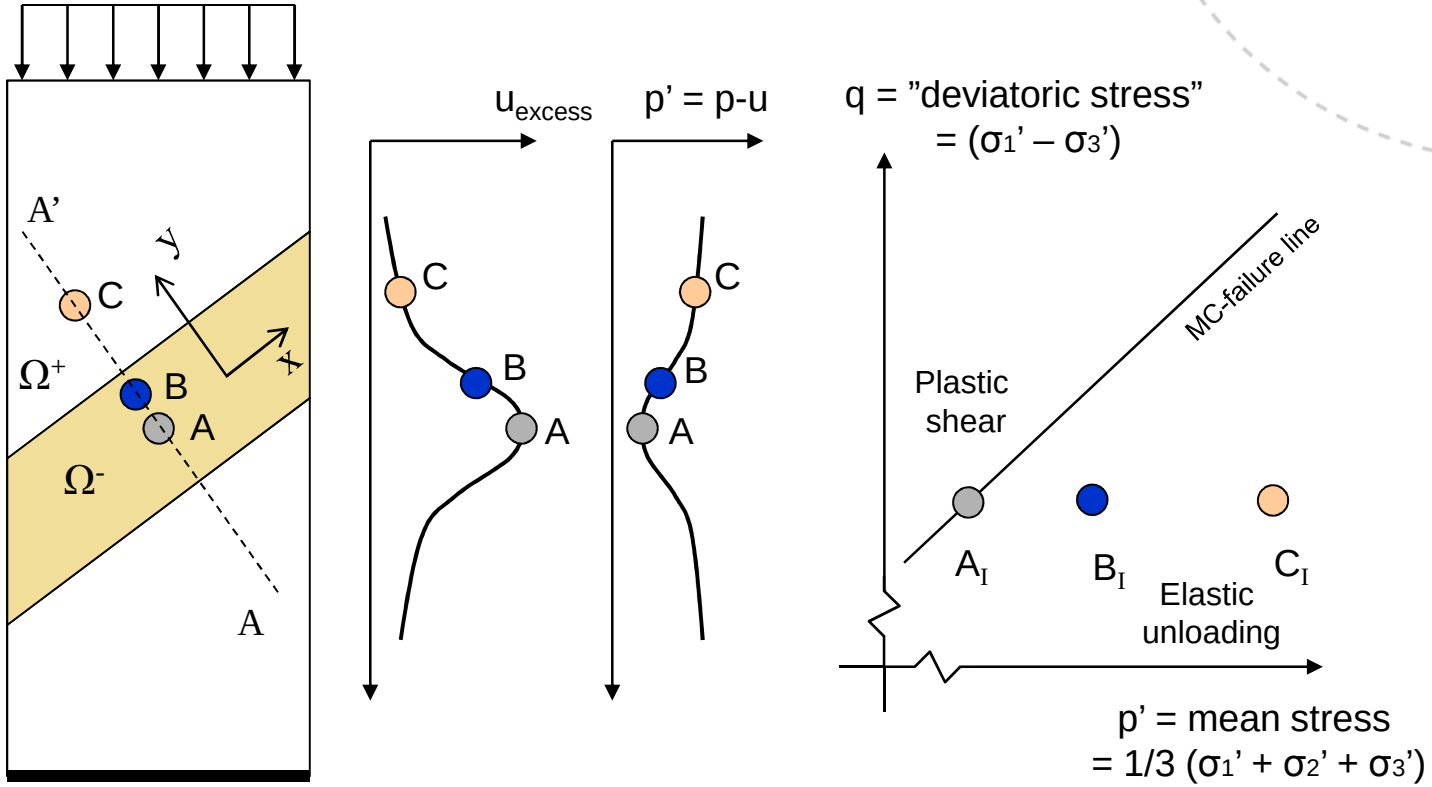
Stress and failure analysis

Active shear band: zone of plastic shearing



I: Uniform stress conditions ⇒ t_{sb} = element size

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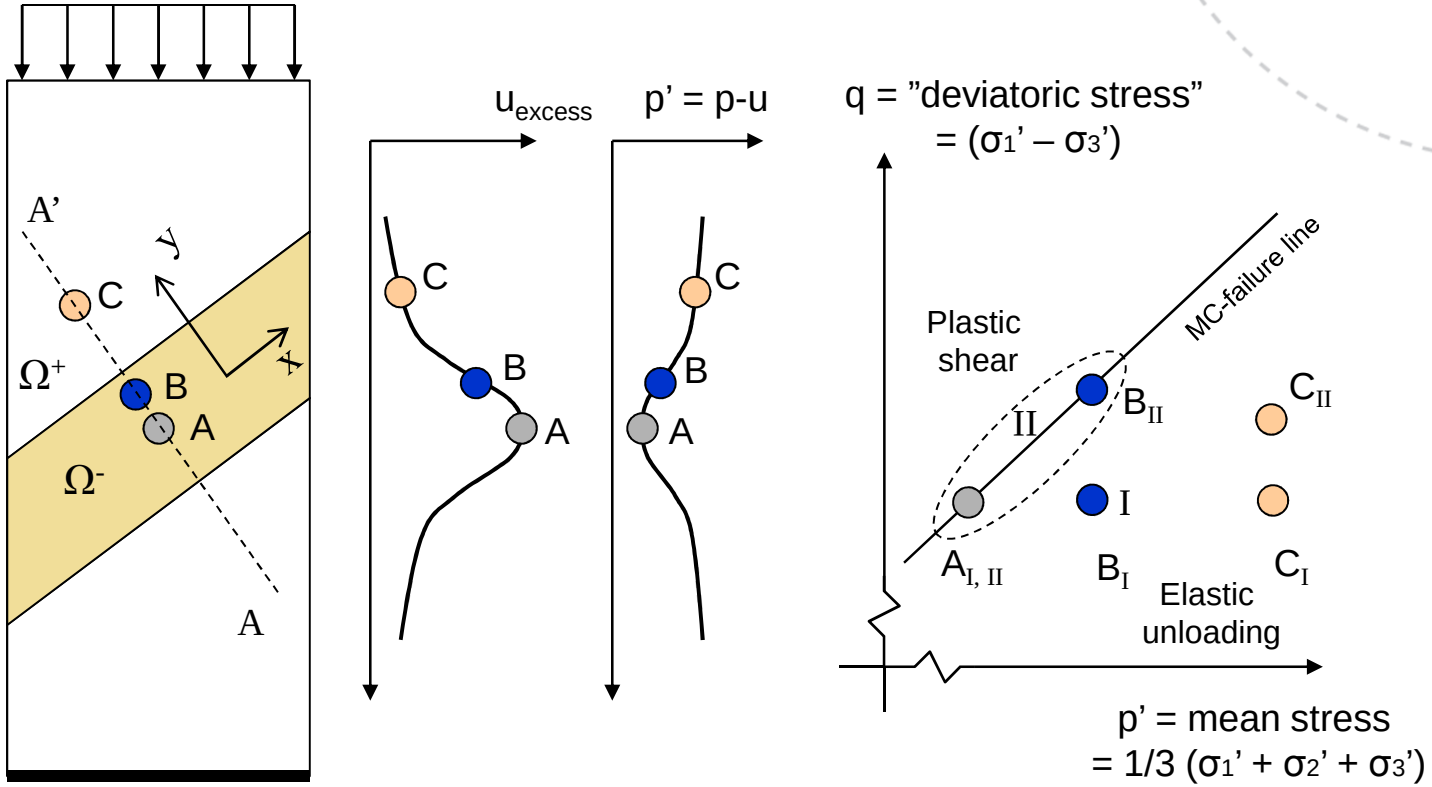
Stress and failure analysis

Active shear band: zone of plastic shearing



I: Uniform stress conditions ⇒ t_{sb} = element size

II: Non-uniform stress conditions ⇒ t_{sb} >= element size

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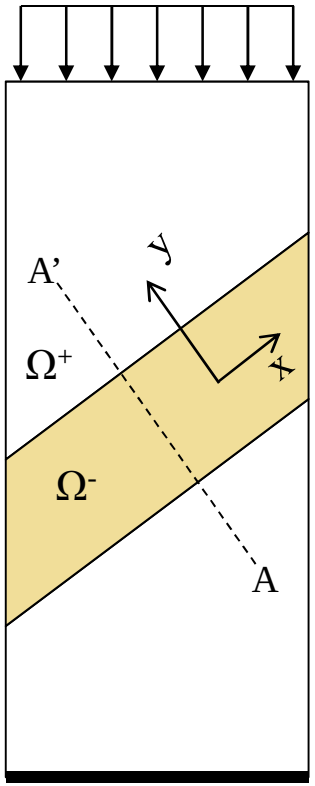
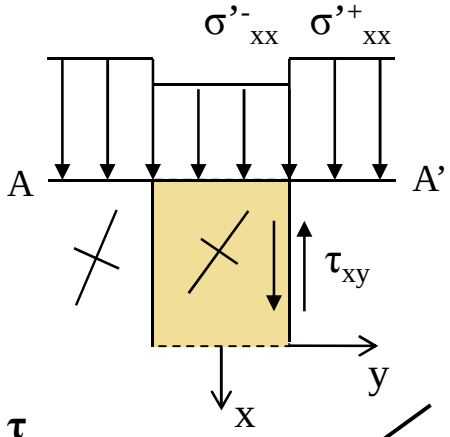
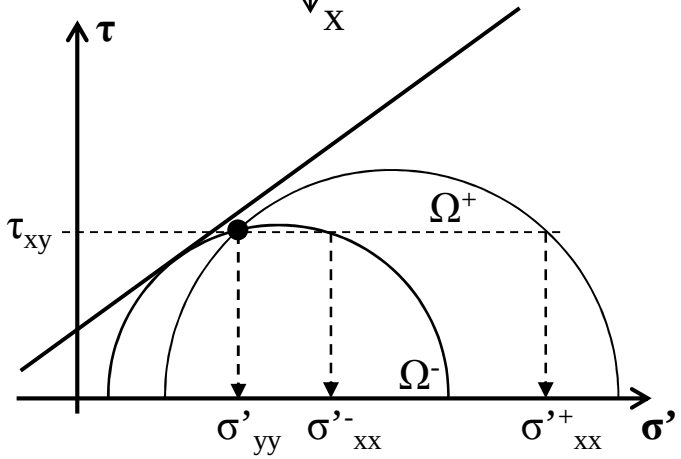
Stress conditions in shear band

- Traction continuity condition
- Can have a discontinuity in the parallell stresses







$$\tau_{xy}^{+} = \tau_{xy}^{-}$$

$$\sigma_{yy}^{\prime +} = \sigma_{yy}^{\prime -}$$

$\sigma_{xx}^{\prime -}$ No constraint

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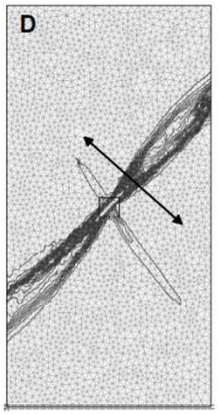
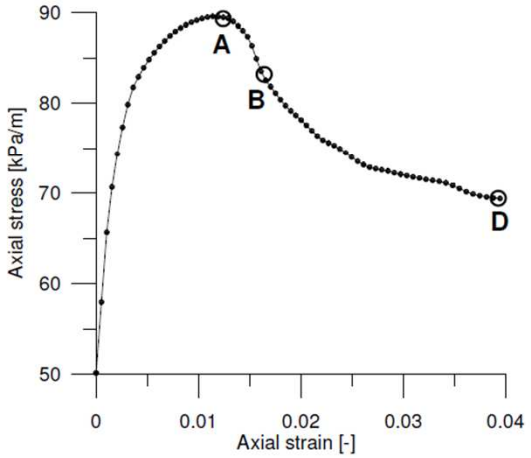
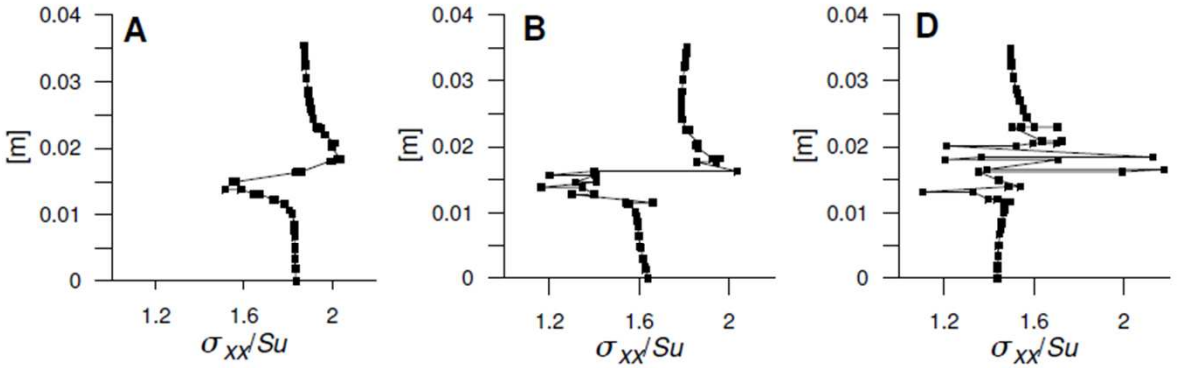
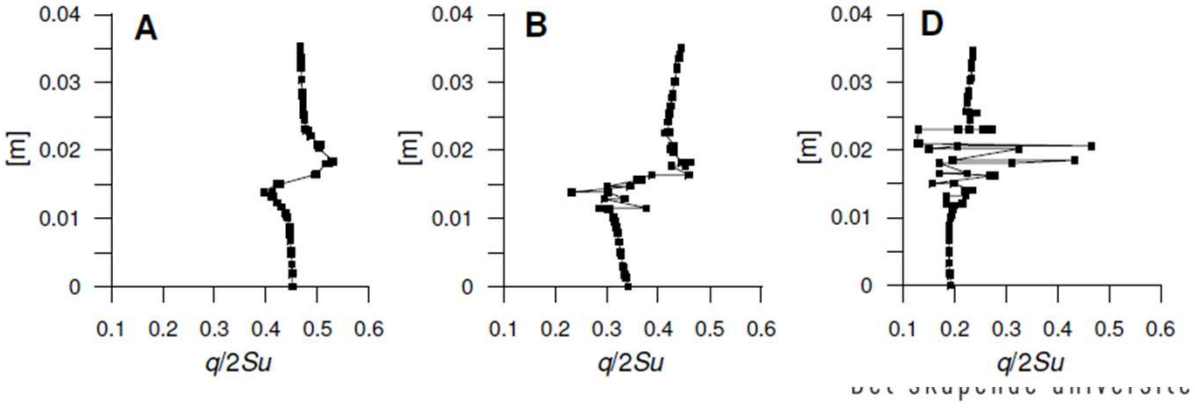
Stress conditions in shear band

- FEM model



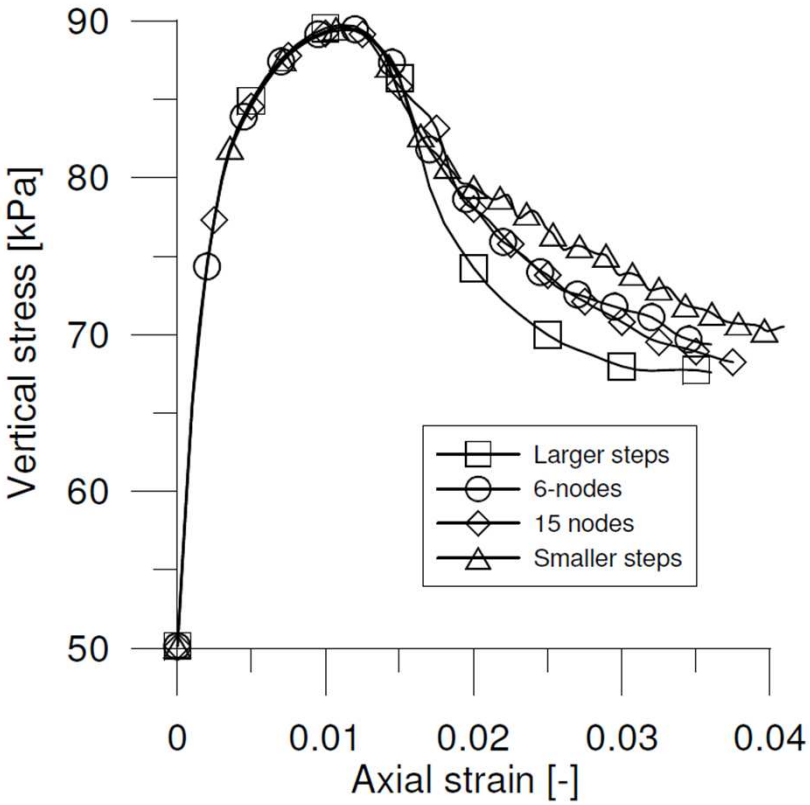






Stress conditions in shear band

- Stress discontinuities depends on
  - Boundary conditions
  - The ability of the FEM solver to distribute stresses in an undetermined solution space
- Algorithm dependency is expected



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Conclusion

- Quasistatic cons. coupled analysis as regularization?
  - Global convergence upon mesh refinement
  - Hypopthesis: Related to stress discontinuities in the shear band
- It is suggested that
  - Quasistatic consolidation coupled analysis does not act as a complete regularizaton technique
  - Shear band analysis from such simulations might incorporate a algorithm dependency

- Ralph B. Peck
  - *”No theory can be considered satisfactory until it has been checked by actual observations”*

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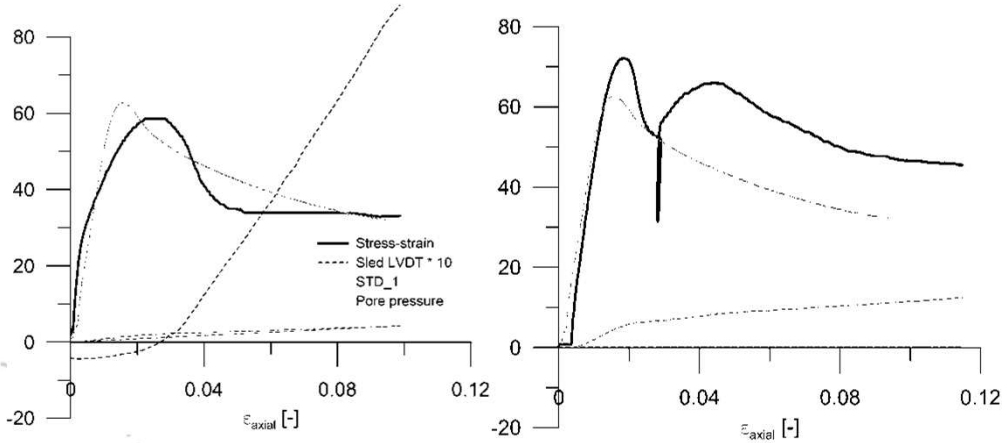
Extensive lab and field program



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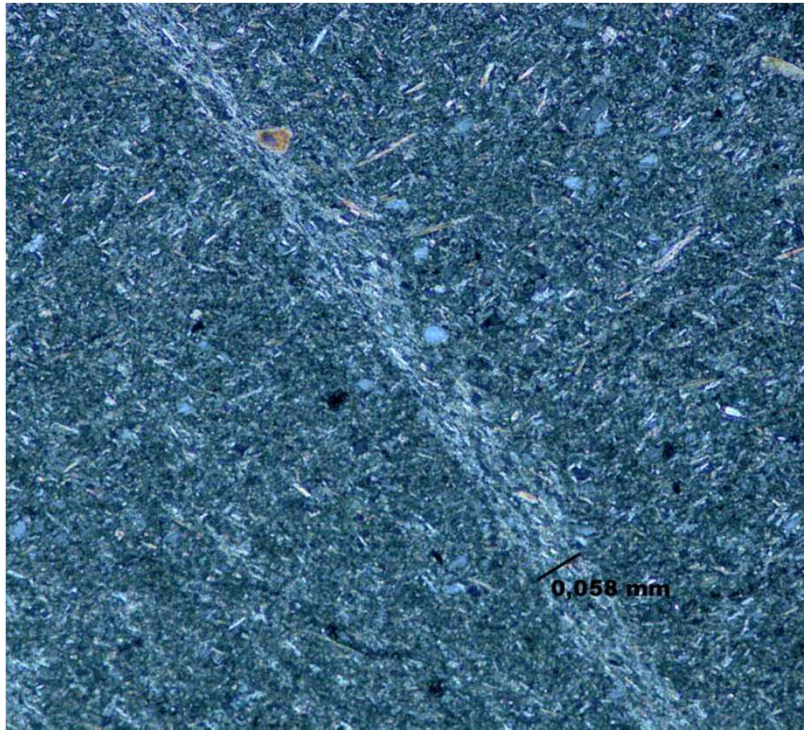
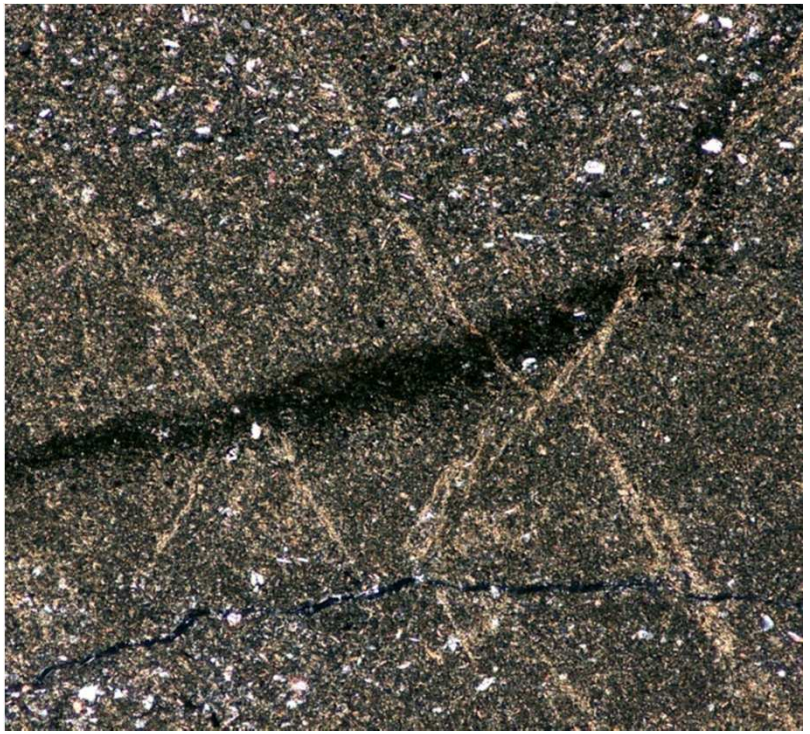
Thin sections





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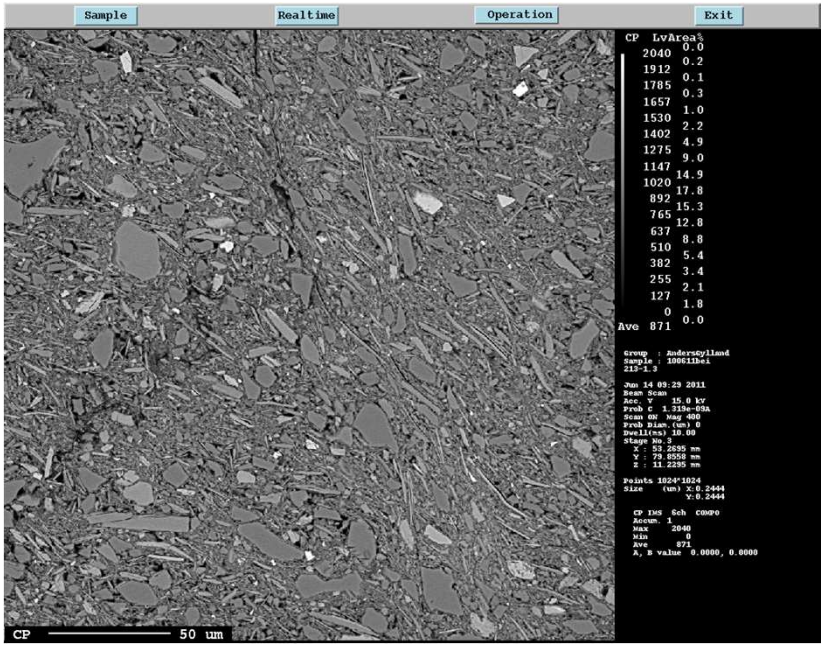
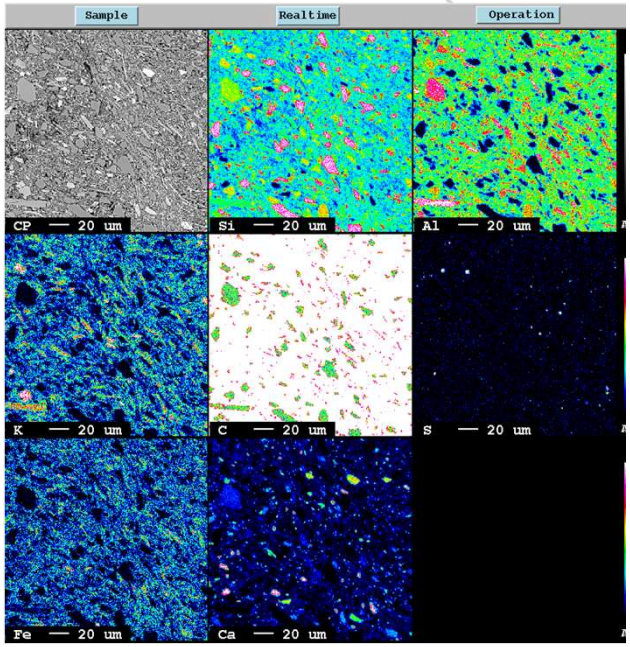
Micro-probe SEM





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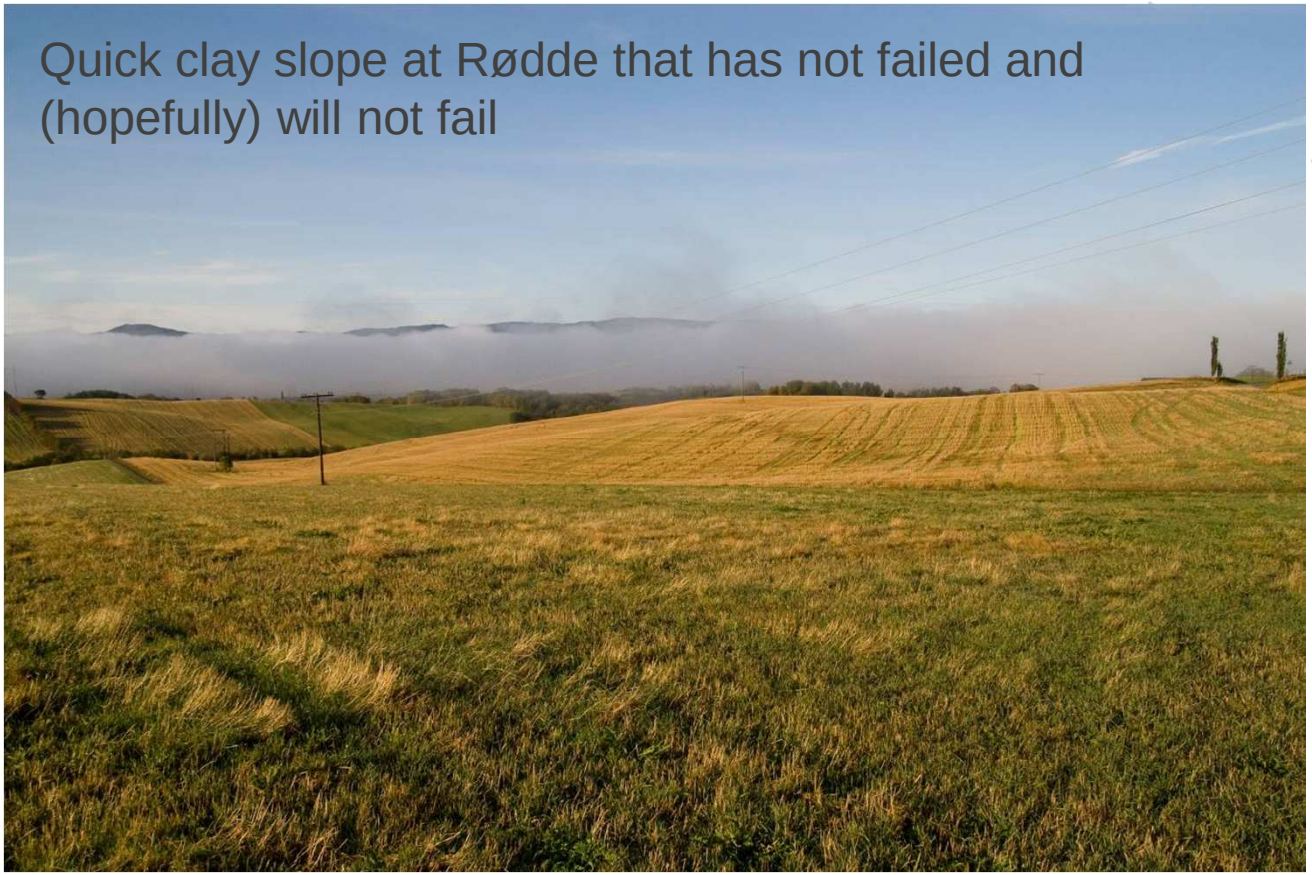

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