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Anisotropy in porous sedimentary rocks

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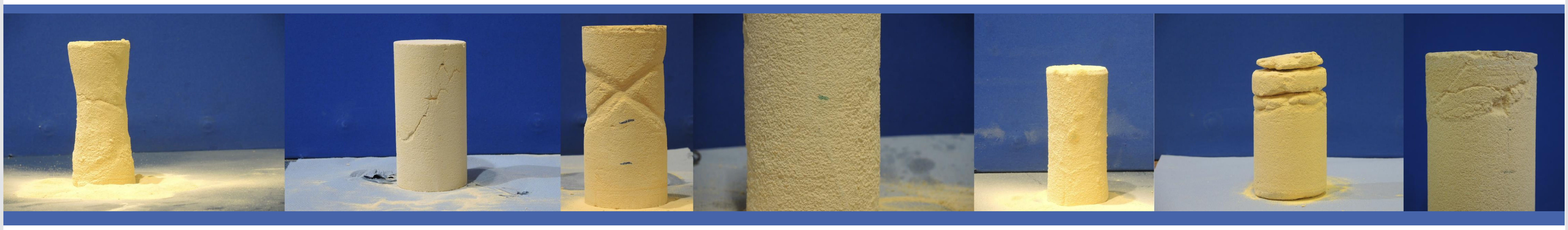


Strain localization in porous rocks

[5]

- Strain localization in porous rocks occurs in the formation of shear and compaction bands
- Compaction bands are thin narrow bands that have a smaller porosity than the surrounded rock. They were documented in the field and in the laboratory in triaxial tests with high confining stresses
- Due to the smaller porosity in compaction bands the permeability is locally reduced and hence, the formation of compaction bands is of high interest for reservoir engineering and CO_2 sequestration

Inherent Anisotropy

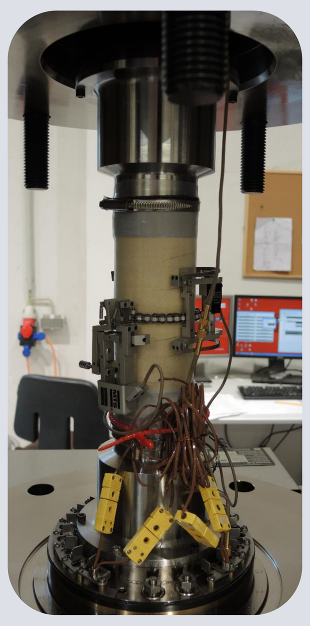
- Due to the formation process, sedimentary rocks are naturally anisotropic
- In a clastic sedimentary rock like shale it has been observed that the brittle strength has a minimum at a foliation angle of about 30-45°, but in high porosity rocks it has been documented that the strength minimum is parallel to the bedding. [1]
- Therefore it is important to consider the effects of bedding and foliation on mechanical anisotropy, damage evolution and the failure mode in the investigation of the mechanical properties of porous rocks

Experimental investigation

Material

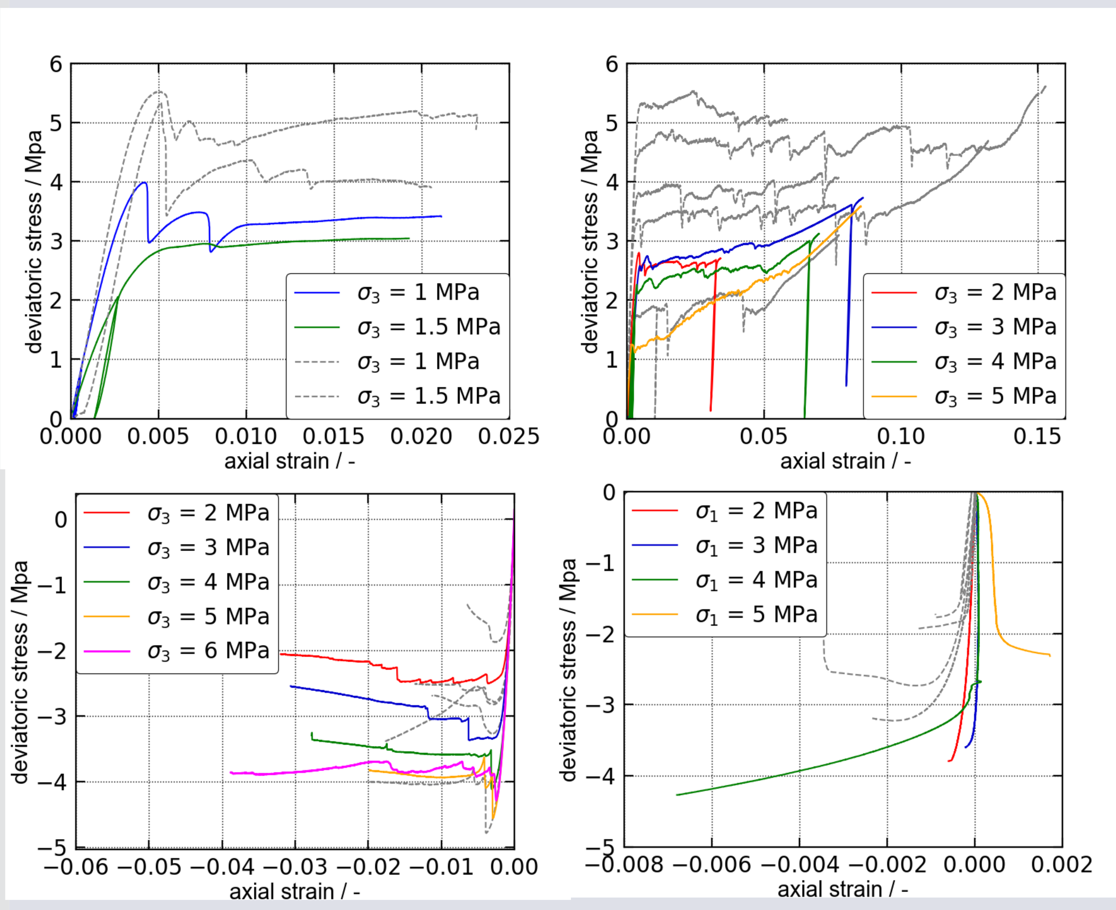
Maastricht Calcarenite:
- Porosity: 52 %
- Mineralogical composition: 98 % calcite
- Weak cementation
- Intergranular porosity

Test device



Servo cotrolled triaxial test device:
- Axial load cell: 250 kN
- Max confining stress: 140 MPa
- Local strain measurements

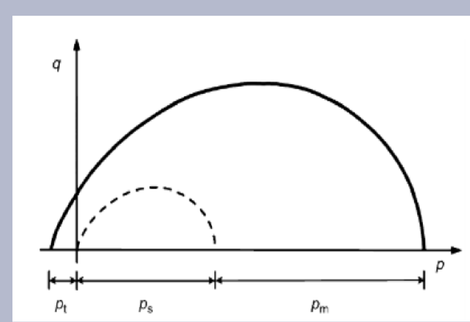
Test results



- Coloured: Triaxial tests with samples cored parallel to the bedding; gray: samples cored perpendicular to the bedding
- First row: compression tests; second row: extension tests
- The yield strength is smaller parallel to the bedding than perpendicular to the bedding under compression and higher under extension; the failure behavior is also affected by the bedding orientation

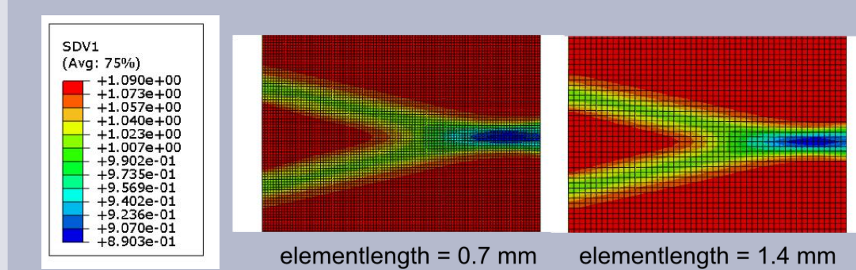
Constitutive models

Internal variables & Yield surface



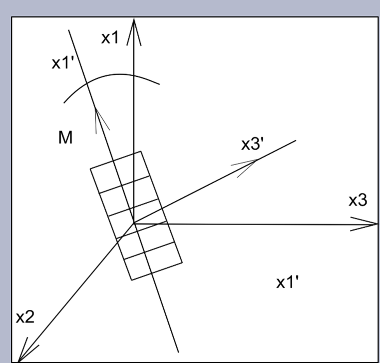
- Model by Nova and Castellanza[4] for the description of the softening and hardening behavior in the plastic deformation regime
- The isotropic strength p_c is devided in a strength for the grains p_s and a strength for the cementation p_m
- Model for yield surface/ plastic potential: model by Gerolymatou and Grandas[2]

Non-local model



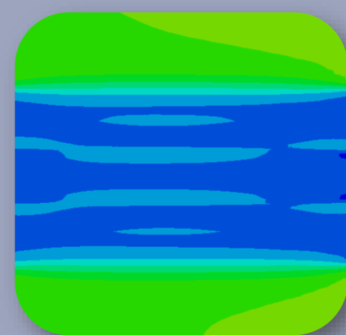
- Model by Gerolymatou[3] where the isotropic strength p_c is averaged over a length l_c to inhibit mesh dependence in the numerical calculations

Transverse isotropic strength



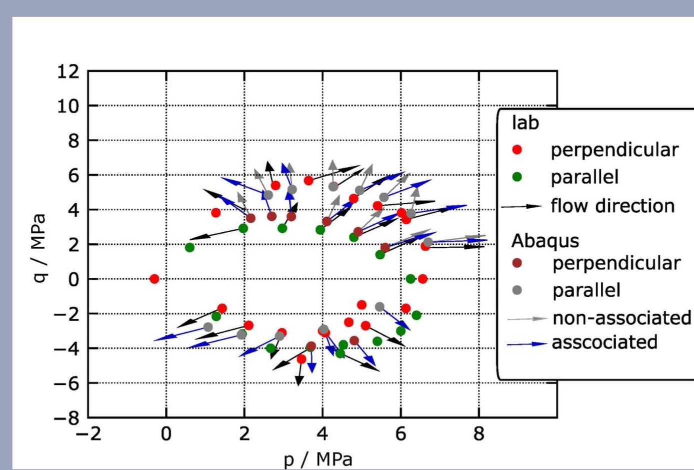
- Model for transverse isotropic solids by Boehler and Sawczuk[6]

Numerical simulations

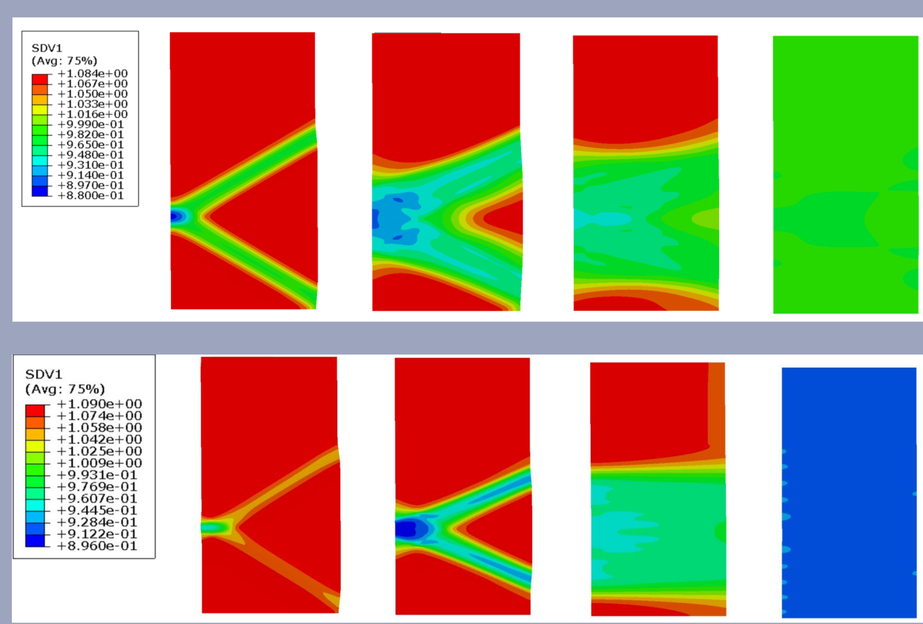


Numerical simulations with the FEM software Abaqus

- User defined material for the implementation of the constitutive models



- Yield surface and flow directions in the p-q-diagramm that result from the investigations in the laboratory and the numerical caluctaions



- Biaxial tests with different confining stresses, distribution of void ratio
- First row: perpendicular to the bedding: 2.5 MPa, 3.25 MPa, 4 Mpa, 5 MPa confining stress
- Second row: parallel to the bedding plane: 2.0 MPa, 3.0 MPa, 4.0 MPa, 5.0 Mpa confining stress
- Brittle-ductile transition: formation of shear bands at small confining stresses and formation of compaction bands at high confining stresses

Outlook

- Investigation of the effect of inherent and induced anisotropy on the hydro-mechanical properties of the rock
- Considering the wethering effect due to hydraulic loading and the effect of compaction bands on the permeability
- Considering hydro-mechanical coupling in the numerical calculations

Literature: [1] Baud, P.; Louis, L.; David, C.; Rawling, G. C. & Wong, T.-F., Effects of bedding and foliation on mechanical anisotropy, damage evolution and failure mode *Geological Society, London, Special Publications, Geological Society of London,* **2005**, *245*, 223-249, [2] Gerolymatou, E.; Grandas-Tavera, C. & Triantafyllidis, T., A simple yield surface with a flexible shape, *Computers and Geotechnics,* **2017,** [3] E. Gerolymatou, "Induced and inherent anisotropy in rock mass [Habilitation Thesis]", *Publications of the Institute for Soil Mechanics and Rock Mechanics, Karlsruhe Institute of Technology [Issue no. 183]*, 2017., [4] Nova, R.; Castellanza, R. & Tamagnini, C., 'A constitutive model for bonded geomaterials subject to mechanical and/or chemical degradation', *International Journal for Numerical and Analytical Methods in Geomechanics,* **2003**, *27*, 705-732 , [5] Zach Schierl, Website: https://zschierlphotography.com/tag/compaction-bands/ **,** 24.09.2019, [6] Boehler JP, Sawczuk A. Equilibre limite des sols anisotropes. Journ de Macanique 1970;3:5–33