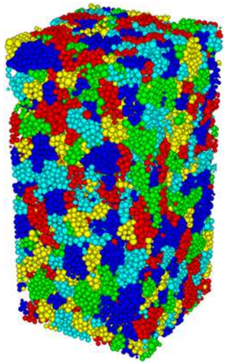


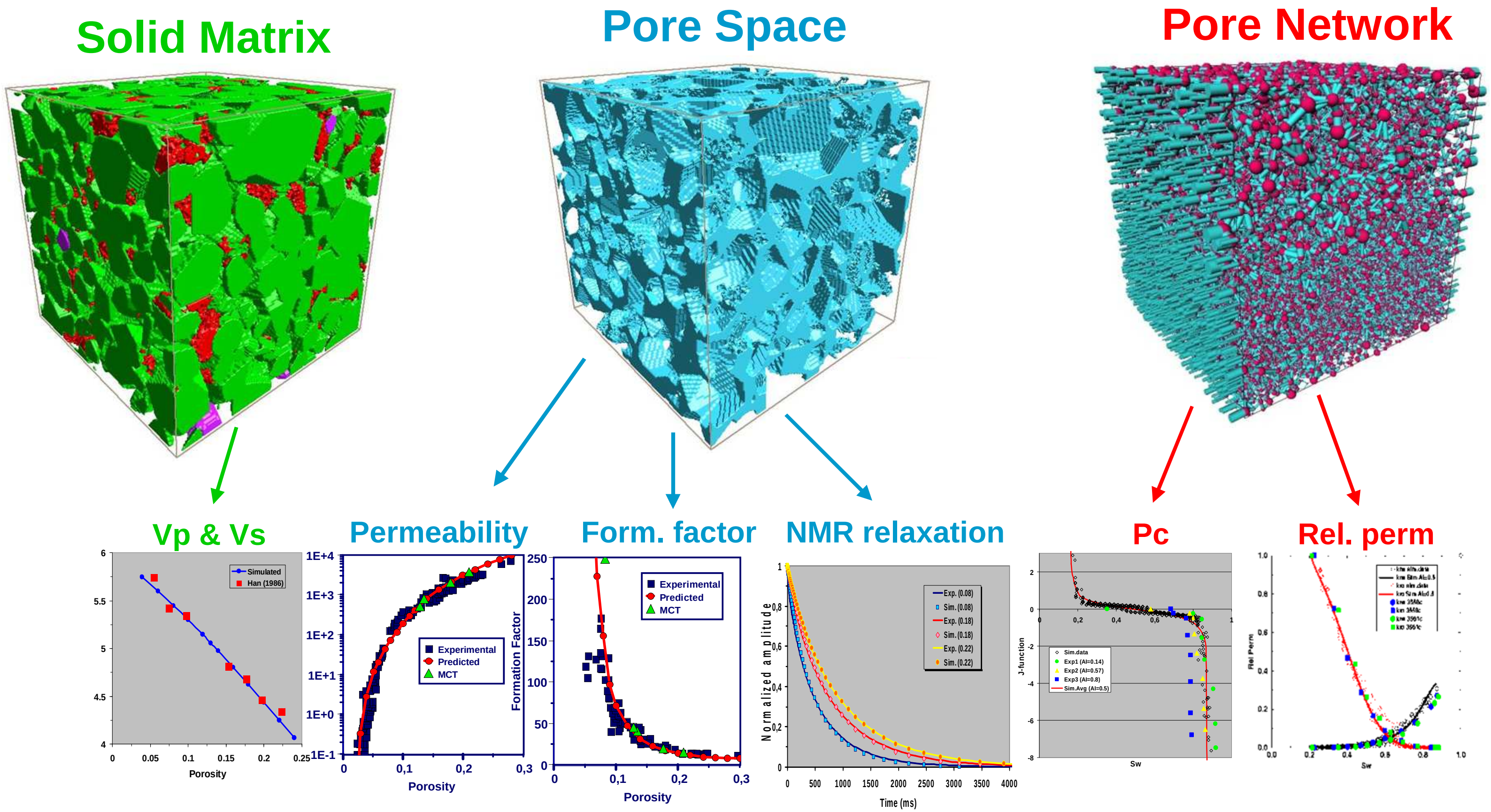
Grain scale modeling of rock mechanical and petrophysical behaviour

Liming Li[1], Idar Larsen[1], Rune M Holt[1,2]

1. SINTEF Petroleum Research, Norway

2. Norwegian University of Science and Technology

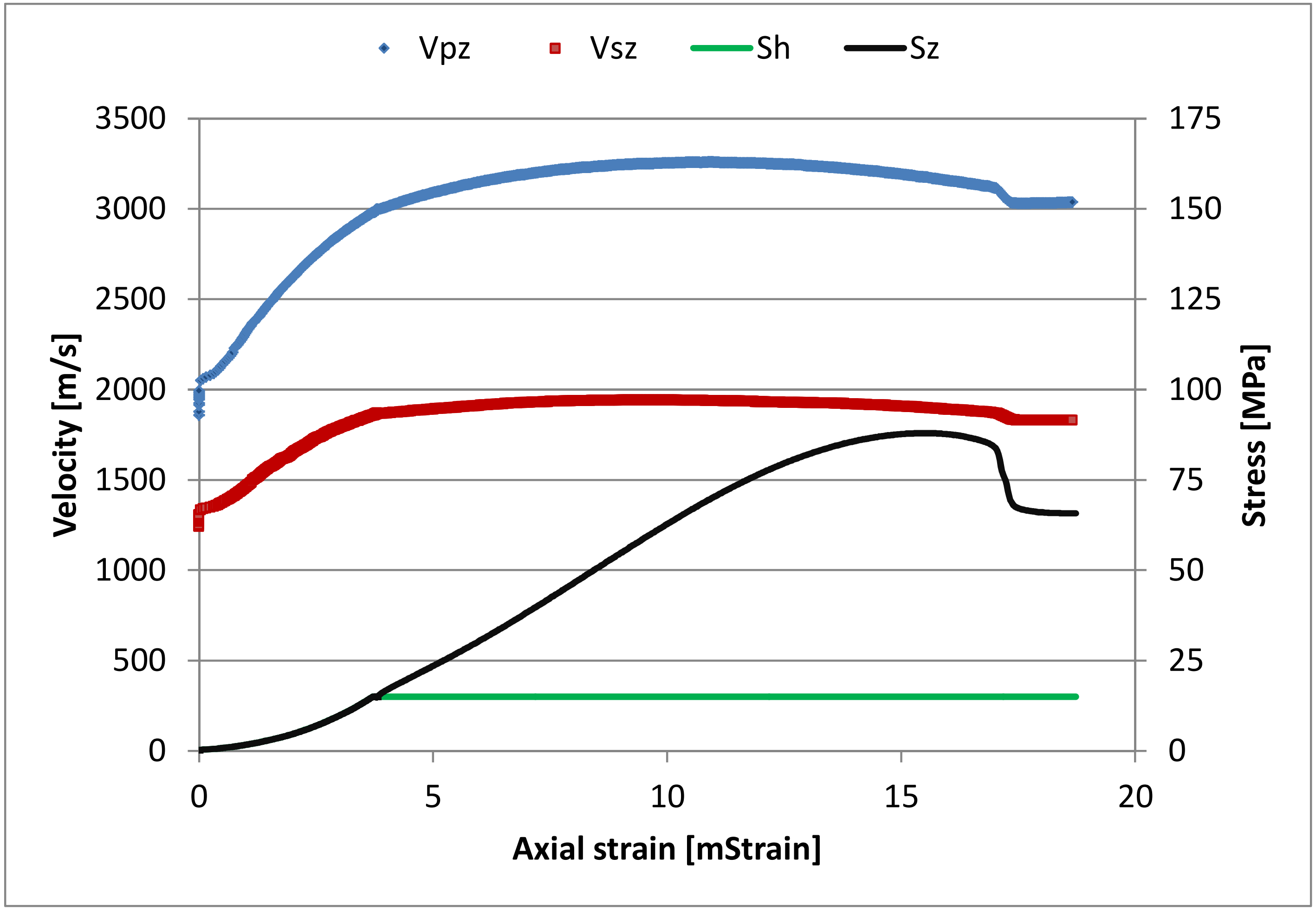
Pore-scale modeling of rock properties, without stress



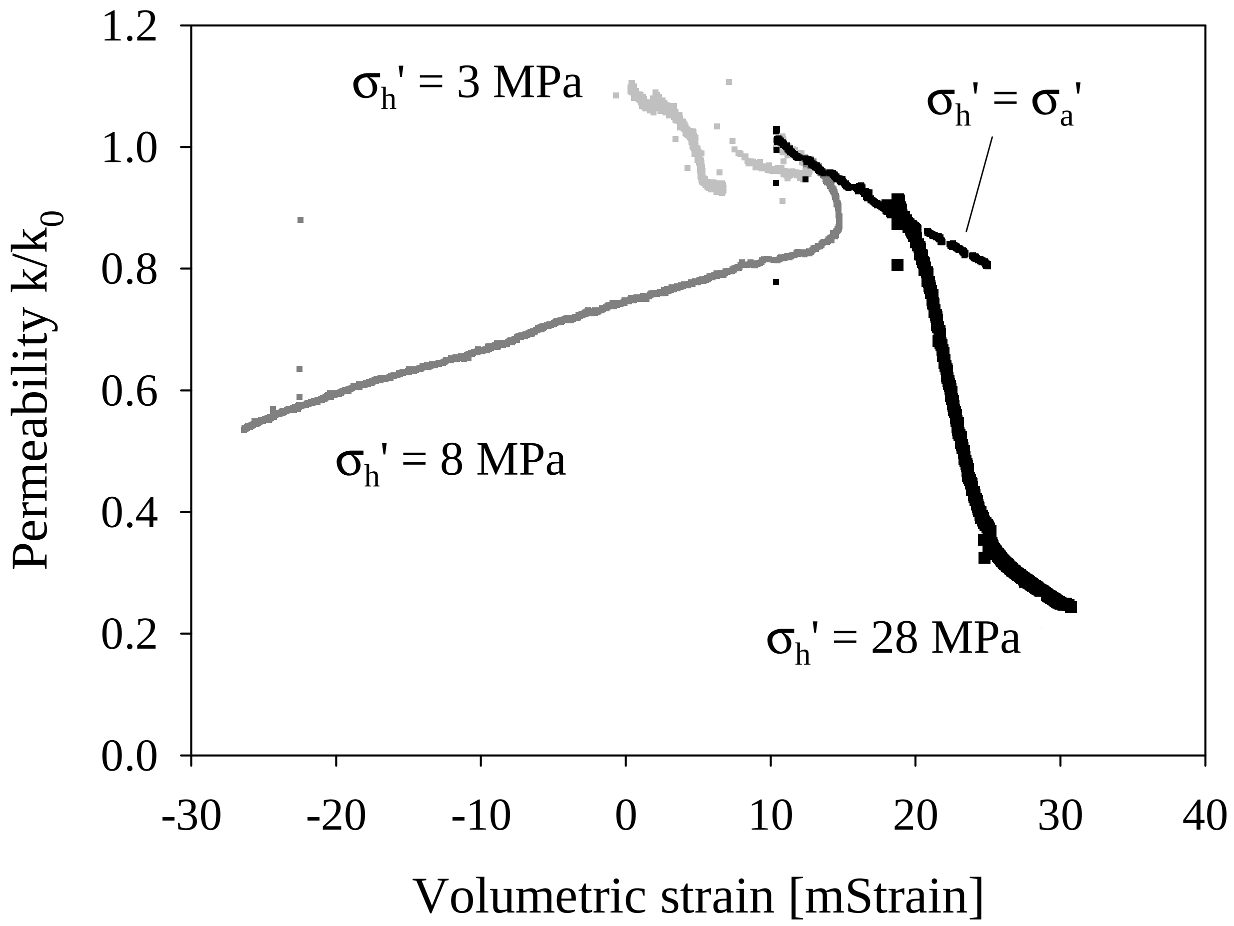
Courtesy of Numerical Rocks, Norway

Stress effects on elastic wave velocities

(Velocities measured in Castlegate sandstone under triaxial compression)

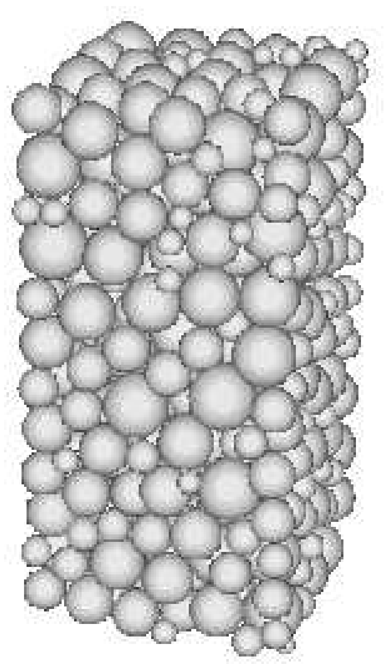


Stress effects on permeability



Permeability measured in Red Wildmoor sandstone under triaxial compression (Flornes, 2005)

Discrete element modeling of rock properties under stress

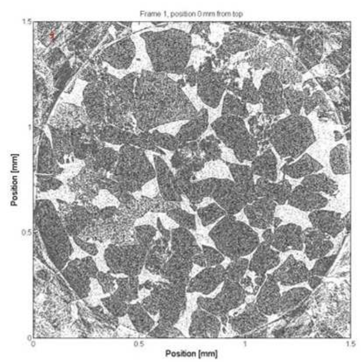


A DEM model (here using PFC from Itasca)

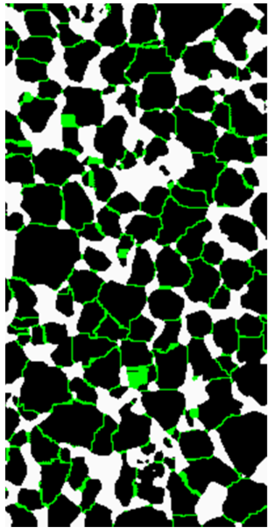
- To simulate the deformation of an assembly of elastic spheres, in the simplest case, a DEM model may be identical to or better than a grain-pack-based effective medium model.
- Simplified bonding logic can be applied in order to simulate rock or rock-like material.
- Wave propagation, complex rock deformation and failure behavior can be directly simulated.
- What about stress-dependent rock mechanical and petrophysical properties which are very much related to the change of the microstructure of the rock (at grain/pore scale)?

Generation of a microstructure-based model for sandstone

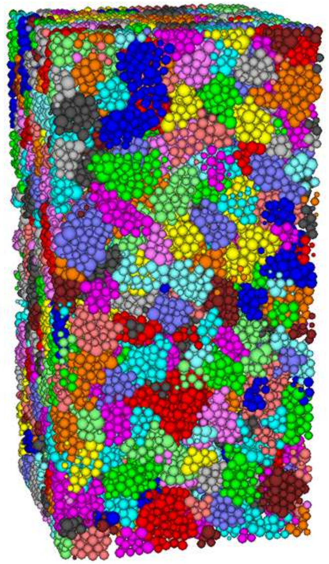
Sandstone specimen (may be from disintegrated core material or drill cuttings)



3D micro-CT image



Segmented 3D micro-CT data



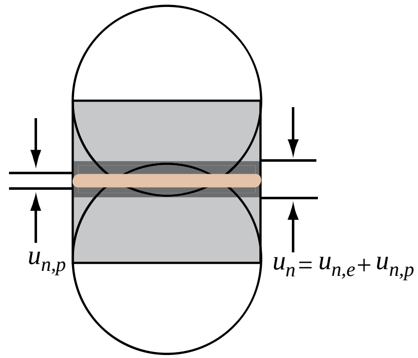
Discrete element model of the sandstone (Each sand grain is represented by a cluster of elements of the same color.)

Contact law: interactions between the elements

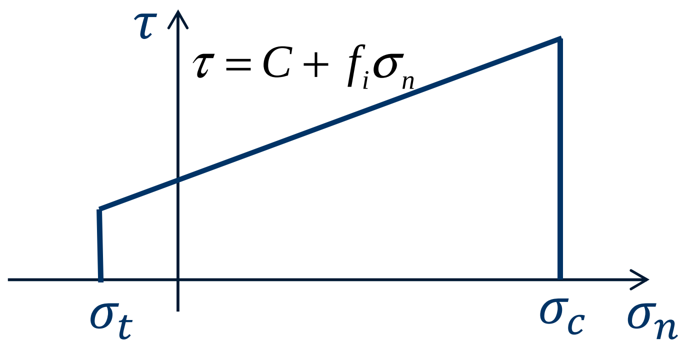
- The constitutive contact law describes how the interactions between a pair of elements are calculated from the relative displacements.

e.g., the normal contact force at a bonded contact

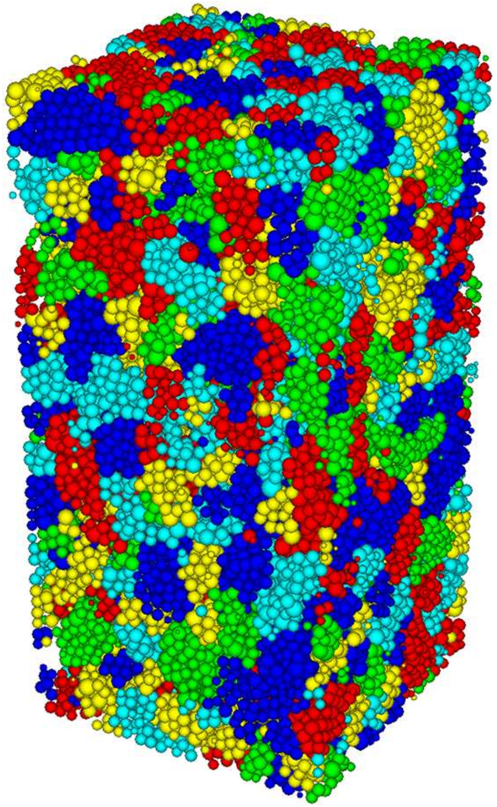
$$F_n = K_{nc}(u_n - u_{n,p})^2 + K_{nb}(u_n - u_{n,p})$$



- For a bonded contact, the failure criterion follows Mohr-Coulomb, but with a tensile stress limit and a compressive stress limit.



Using clusters of elements to represent grains



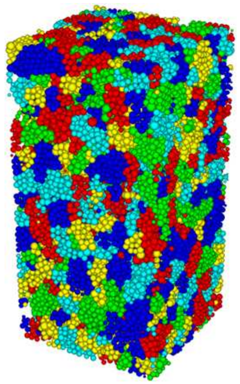
Two sets of bonding parameters:

Intergranular bonds: for a pair of elements which belong to two different grains.

Intragranular bonds: for a pair of elements which belong to the same grain.

Model calibration to determine input parameters

Fit the results of different lab tests with real rock specimens using the same model (same parameters).



Model generation

Load the model hydrostatically to different pressures

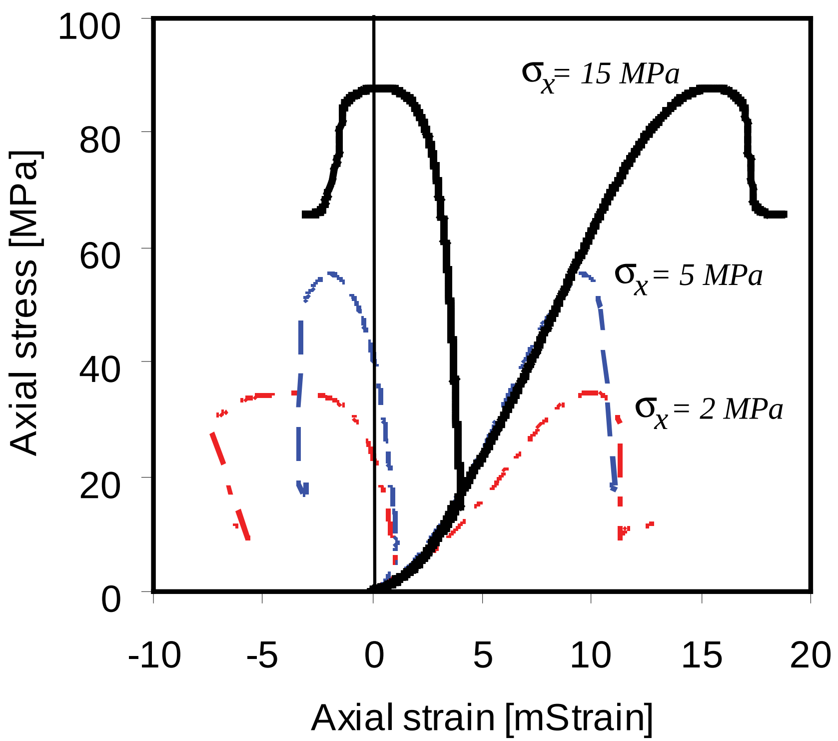
Triaxial test with 15 MPa confining stress

Triaxial test with 5 MPa confining stress

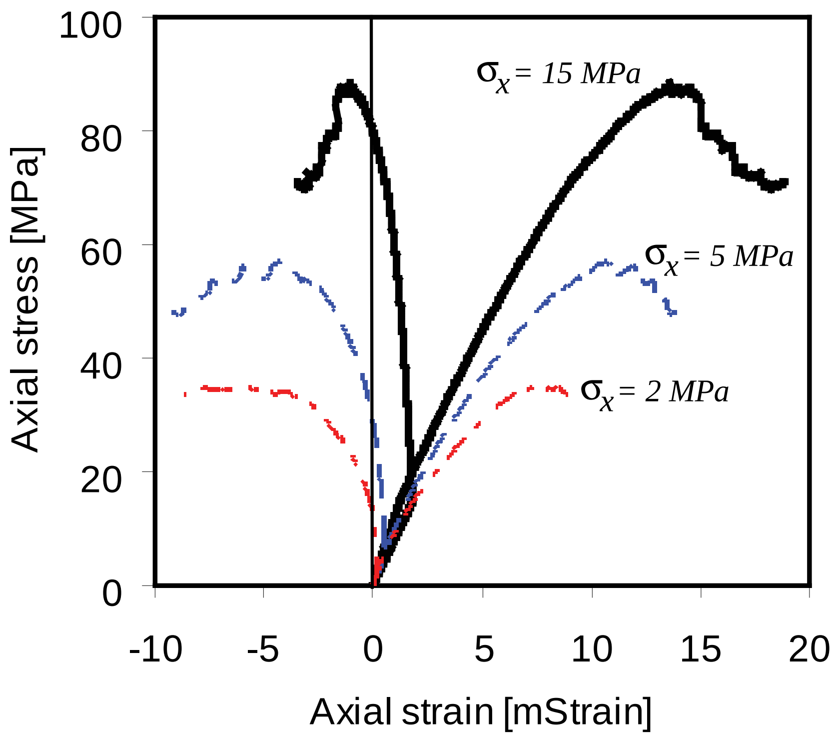
Triaxial test with 2 MPa confining stress

Comparison of simulation results and data measured on Castlegate sst.

Stress vs. strain



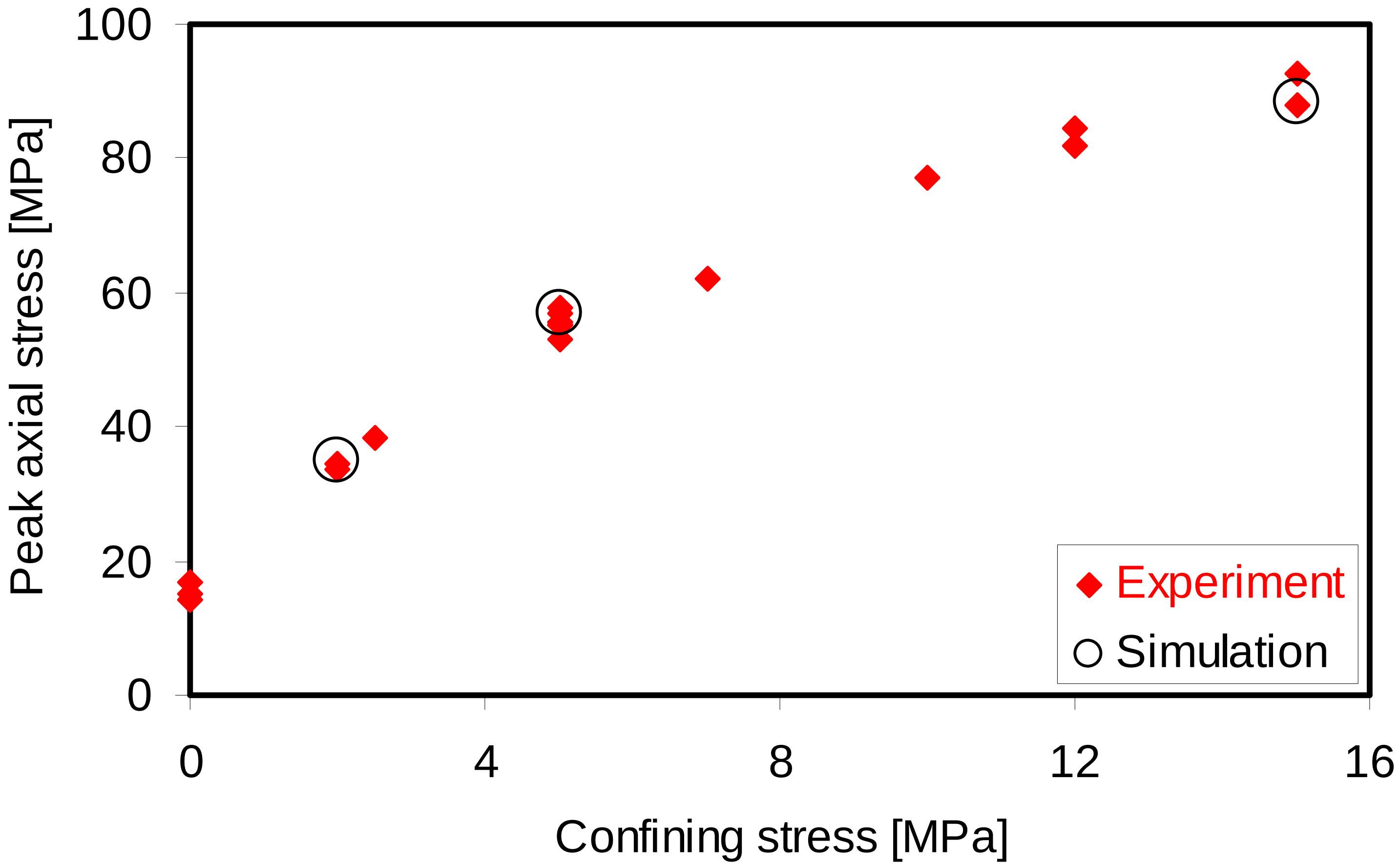
Experiment



Simulation

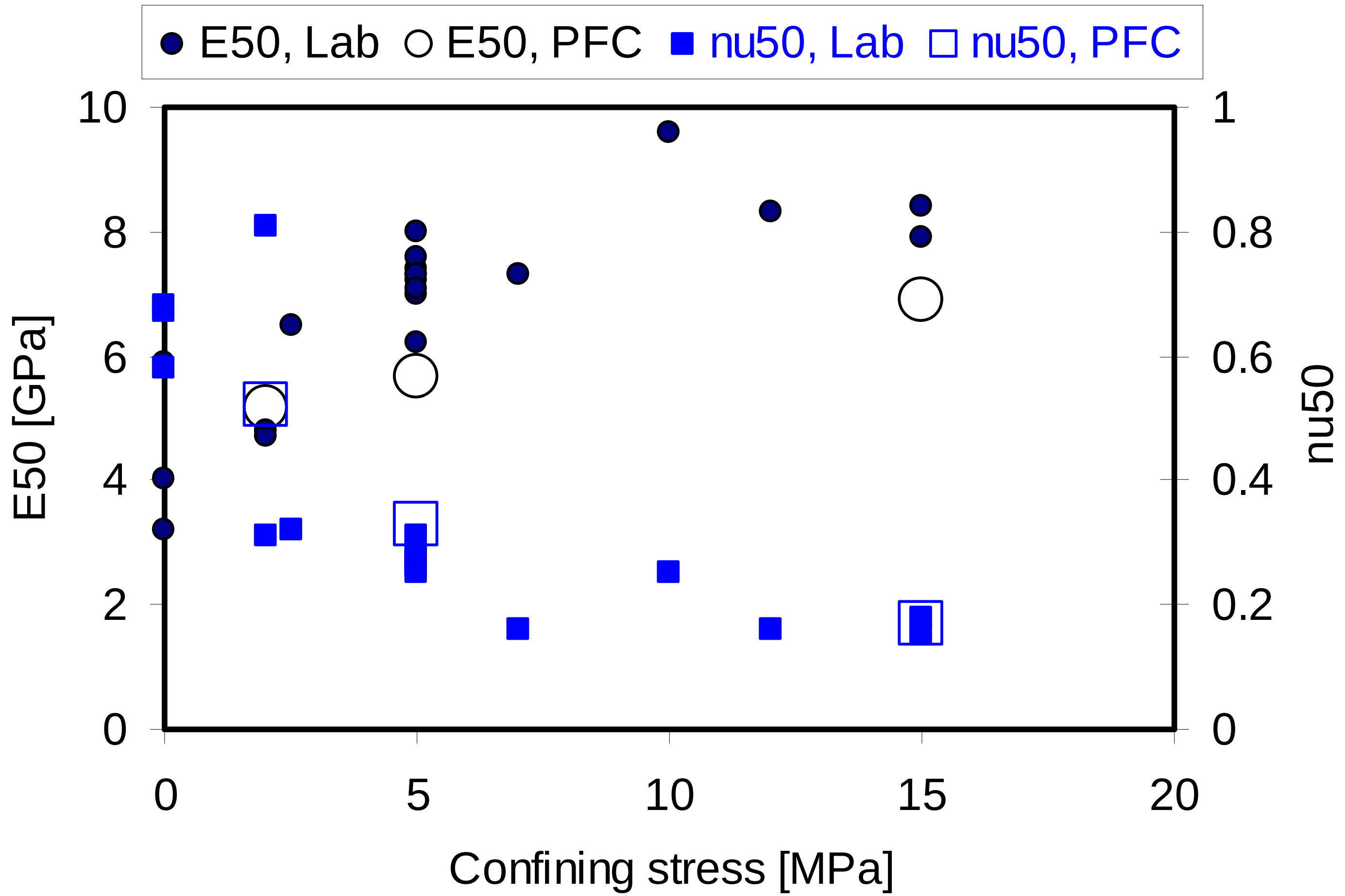
Comparison of simulation results and data measured on Castlegate sst.

Peak axial stress vs. confining stress



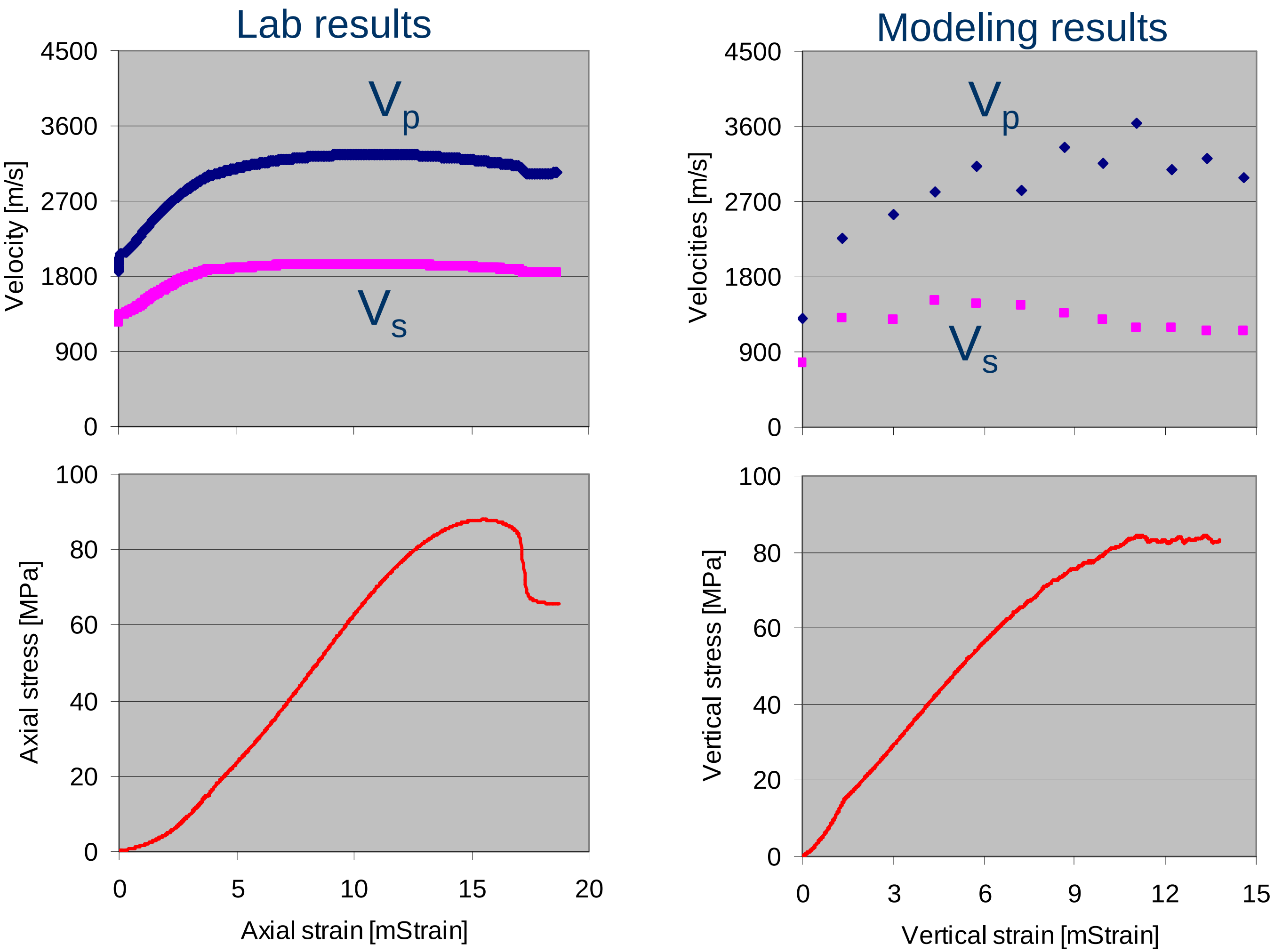
Comparison of simulation results and data measured on Castlegate sst.

E-modulus and Poisson's ratio vs. confining stress

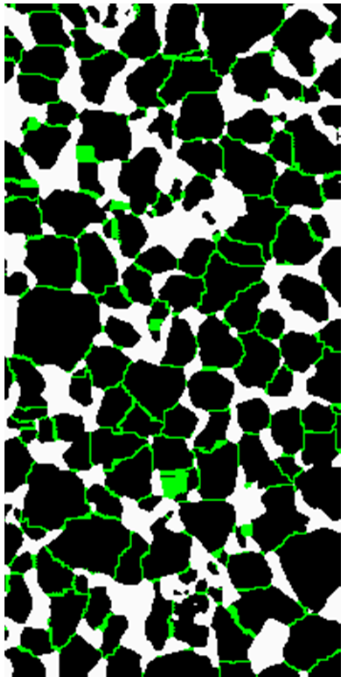


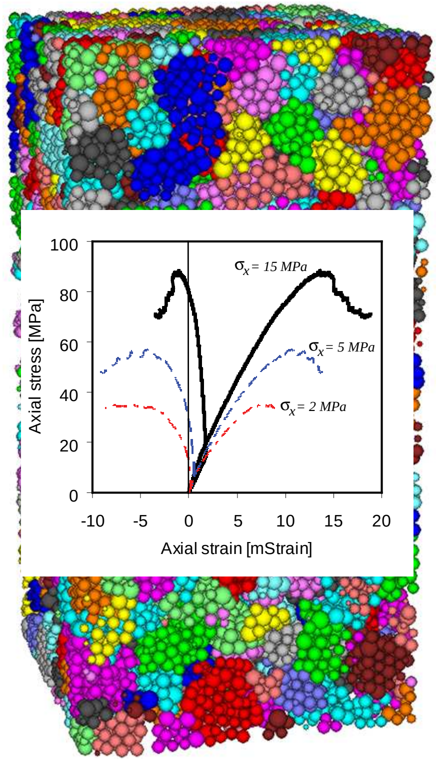
Comparison of simulation results and data measured on Castlegate sst.

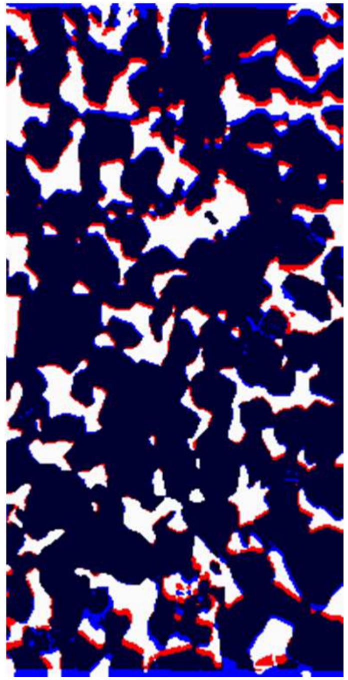
Velocities in a triaxial test (confining pressure 15 MPa)



Grain and pore deformation under any strain condition







Deformed image which can be used to compute petrophysical parameters of the strained rock

Summary

- A method to simulate stress-dependent rock mechanical and petrophysical behavior using grain/pore scale model has been studied.
- Using processed micro-CT data of sandstone as input, the discrete element model mimics the global deformation and failure behavior of a stressed sandstone specimen, and simultaneously the deformation of the grains and the pores.
- The deformed microstructure of the sandstone can be used as input to the pore-scale flow model in order to calculate the petrophysical parameters of the stressed sandstone.
- Such kind of modeling can be applied to improve the understanding of the complex physics of stressed porous media.

- The procedures in the whole workflow need to be refined and improved in order to make more accurate predictions.

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