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# Pore-pressure induced transition of compaction bands to shear bands in saturated high-porosity sandstone: a multiscale study

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## Introduction

High-porosity sandstones are important host rocks for hydrocarbon or water reservoirs, $CO_2$ sequestration and hazardous waste disposal. The occurrence of compaction bands may reduce the permeability of sandstone up to several orders of magnitude and act as fluid-flow barriers or alter the flow patterns. In pertinent engineering settings sandstones are usually saturated or partially saturated where the pore fluid may play an important role. However, how pore fluids interplay with the occurrence and evolution of compaction bands remains largely unclear. In this study, we extend our previous multiscale modeling of compaction bands in high-porosity sandstones under dry conditions (Wu et al., 2018) with a recently developed fully coupled hydro-mechanical scheme (Guo & Zhao, 2016) to investigate the role of pore fluid in the evolution of compaction bands in saturated high-porosity sandstones.

## Methodology

The coupled FEM/DEM hierarchical multiscale approach adopts finite element method (FEM) to solve a typical boundary value problem (BVP) of sandstone. The constitutive relationship required in a traditional FEM is replaced by direct discrete element method (DEM) computations of the representative volume element (RVE) attached at each Gauss point of the FE mesh, so that we could avoid making assumptions on any phenomenological continuum models. The hydro-mechanical coupling is accomplished by adopting a standard $\mathbf{u} - p$ formulation. The total stress ($\sigma_{ij}$) in the equilibrium equation of the fluid-solid mixture is the superimposition of the pore pressure ($p$) and the effective stress ($\sigma'_{ij}$, derived from the DEM solution) according to Terzaghi's effective stress principle. The pore pressure is solved according to the mass conservation of the fluid phase. Detail of the hydro-mechanical coupling scheme can be found in (Guo & Zhao, 2016).

## Simulations and Results

A RVE with bimodal porosity structure is prepared to represent the typical microstructure of high-porosity sandstones. Multiscale simulations of drained and undrained biaxial compression tests are conducted to examine the effects of pore fluid during the evolution of compaction bands. The compaction bands in a drained test may evolve with increasing width during axial loading. However, under undrained conditions, the build-up of induced pore pressure is significant (see *Figure 1(a)*), which may considerably reduce the effective confinement and alter the initially formed compaction band to a compactive shear band later through a transition stage (see the evolution of compaction bands in *Figures 1(b-e)*). The local difference in pore pressure and the Darcy flux are also captured in the simulations. Localized volumetric contraction induces relatively higher excess pore pressure within the band and causes an out-of-band flow.

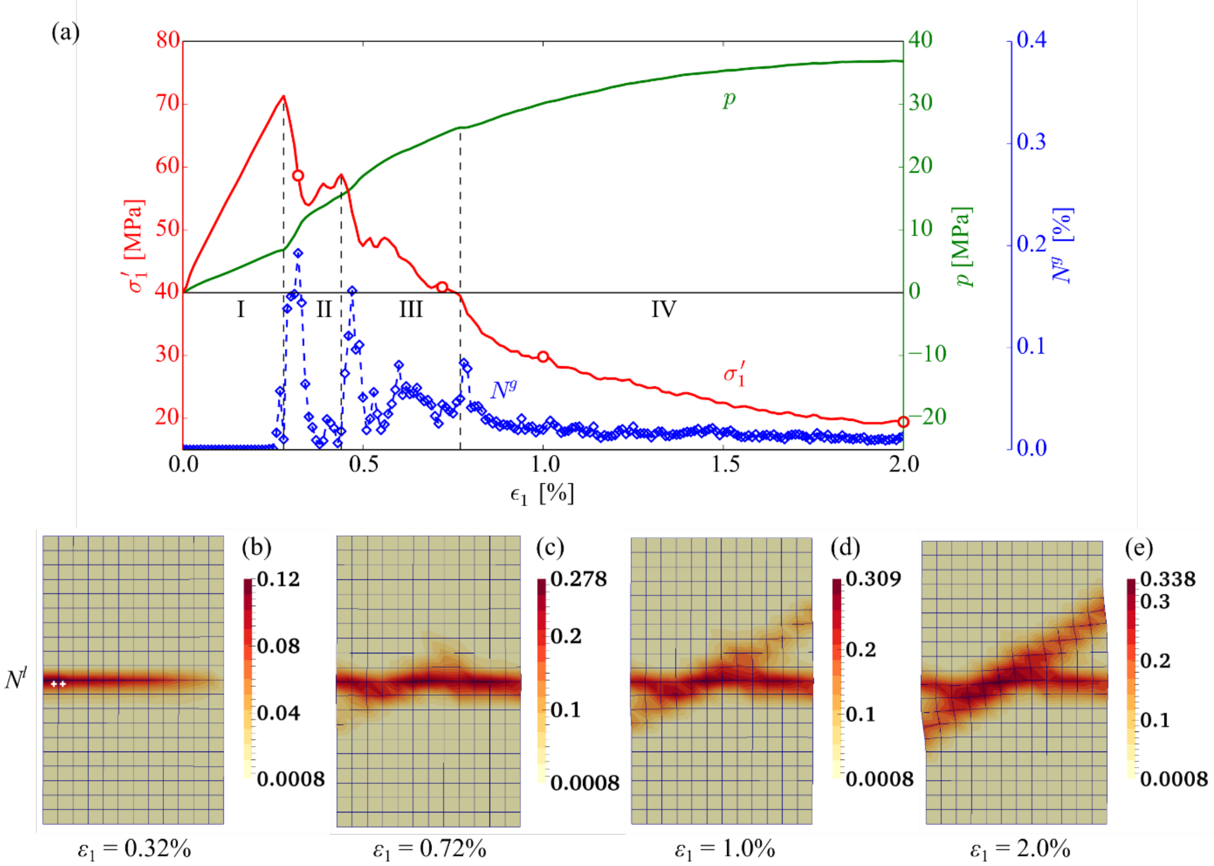


*Figure 1: (a) The global responses of the undrained test under total confinement of 40 MPa in terms of effective axial stress ($\sigma_1'$), induced pore pressure (p) and global normalized debonding number ($N^g$) with increased axial strain ($\epsilon_1$) and (b-e) the evolution of compaction bands in terms of local normalized debonding number ($N^l$).*

## Conclusions

A coupled hydro-mechanical multiscale modeling of high-porosity sandstones has been conducted to investigate the coupling effects between compaction bands and the pore fluid. In contrast to the continuous thickening under dry conditions, compaction bands occurring first in a saturated sample under undrained shear may gradually evolve to a compactive shear band. The increased pore pressure causing decreased effective stress plays a major role accounting for the transitional behaviour.

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### References

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