Experimental observations and constitutive description of the effect of compaction banding on the hydraulic properties of porous rock

Julia Leuthold[a], Univ.-Prof. Dr.-Ing. habil Theodoros Triantafyllidis[a]

a. Karlsruher institute for technology, Institute for soil and rock mechanics

julia.leuthold@kit.edu, theodoros.triantafyllidis@kit.edu

Keywords: localization, compaction bands, permeability, nonlocal models, pore collapse

ABSTRACT

The aim of the present work is the investigation, both from an experimental and a constitutive point of view, of the effect of localization of deformation on the hydraulic properties of rock, with special focus placed on the formation of compaction bands. The localization of deformation into thin bands of a given orientation is not only a source of instability, but also a source of anisotropy as far as both the mechanical and the hydraulic properties of the rock are concerned. The available evidence, both in situ and in the laboratory, is limited and, to some extent, contradictory. Baxevanis et al. [1] performed laboratory tests on Tuffeau de Maastricht calcarenite and observed permeability reactions that, though not in agreement with the Kozeny - Carman model [2], [3], were smaller than an order of magnitude. Holcomb and Olsson [4] on the other hand registered permeability variations of up to two orders of magnitude as a result of the compaction of Castlegate sandstone with an initial porosity of 28%. Ballas et al. [5] measured the permeability of naturally occurring compactive shear bands in porous sandstone in Provence. Cataclastic shear zones were found to possess a permeability that was three to five orders of magnitude smaller than that of the host rock.

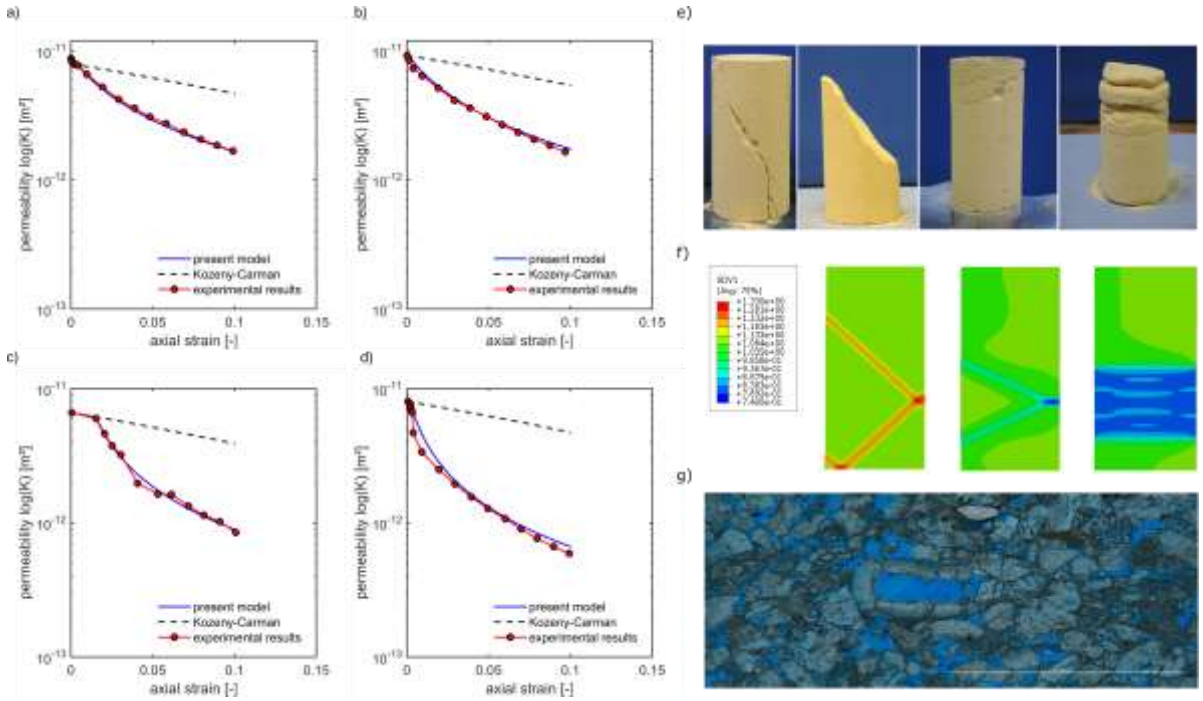

Figure 1 a-d: results of the analytical model based on the Kozeny-Carman equation and experimental results from drained triaxial tests with different confining pressures: permeability in axial direction plotted in logarithmic scale against axial strain. e) samples after triaxial tests under dry conditions at different confining pressures, f) numerical results of biaxial test with different confining pressures, g) thin section of the compacted rock

From a practical point of view, such behavior is of particular interest when considering reservoirs in soft, porous rocks. The reduction in pore pressure, which is linked to the production, leads to the possibility of compaction in the vicinity of the borehole. One obvious effect is the risk of the loss of stability or of increased sand production. Another is the reduction of the permeability locally. The probability of such occurrences and the magnitude of such effects is currently under debate.

Triaxial and oedometric tests on a soft calcareous sandstone were performed for the needs of the present work, both under dry and under saturated conditions. In the second case, the permeability and its variation as a function of the axial strain was also measured. On the basis of these results and results from the literature, it is examined whether the Kozeny - Carman formulation may be applied in this case. Its limits of validity are discussed and an alternative is suggested, taking into account the volumetric collapse and phenomena taking place in the microscopic scale, such as grain crushing.

From a numerical point of view, a nonlocal model is suggested to simulate the formation of compaction bands and validated against the experimental results. The effects on the evaluated permeability are numerically calculated and the resulting anisotropy of the hydraulic properties is assessed.

Finally, conclusions are drawn and implications on reservoir compartmentalization are discussed.

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