1 Introduction

The Richards equation is often used to mathematically describe water movement in the unsaturated zone. It has been introduced by Richards (1931) who suggested that Darcy's law under consideration of the mass conservation principle, is also appropriate for unsaturated flow conditions in porous media. The pressure based formulation of this governing equation (Eq. 1), which selects the unknown primary variable as p, can be written as:

$$\phi \rho_w \frac{\partial S}{\partial p_c} \frac{\partial p_c}{\partial t} + \bigtriangledown \cdot \left(\rho_w \frac{k_{rel}\mathbf{k}}{\mu_w} (\bigtriangledown p_w - \rho_w \mathbf{g}) \right) = Q_w \tag{1}$$

where ϕ is porosity, t is time, ρ_w is the liquid density, μ_w is the liquid viscosity, p_c is the capillary pressure with p_c = -p_w, p_w is the water pressure, S is the water saturation, $\mathbf{g}$ is gravity acceleration vector, Q_w is the source term, k_{rel} is the relative permeability and $\mathbf{k}$ is the intrinsic permeability which is related to the hydraulic conductivity $\mathbf{K}$ with

$$\mathbf{k} = \frac{\mu_w}{\rho_w \mathrm{g}} \mathbf{K} \tag{2}$$

In an unsaturated porous media, the capillary pressure is fundamentally related to the saturation of the gas and liquid phase. If e.g. the water saturation decreases and hence the saturation of air increases, then the water retreats to smaller pores and the capillary pressure increases. The capillary pressure can be seen as a function of the effective saturation S_{eff}. This relationship is primarily determined by the nature of the pore space geometry and interconnectivity and is highly non-linear. Brooks and Corey (1964) and Van Genuchten (1980), among many other scientists, derived functional correlations which contain empiric shape parameters that characterize pore-specific properties. With the Van Genuchten parameterization the capillary pressure can be described as

$$p_c = \frac{\rho_w \mathrm{g}}{\alpha} \left[S_{\mathrm{eff}}^{-1/m} - 1 \right]^{1/n} \tag{3}$$

where α $[1/m]$ is a conceptualized parameter related to the air entry pressure, n is a dimensionless pore size distribution index and m = 1-(1/n). These parameters are usually used to fit the saturation dependent curves of capillary pressure and hydraulic conductivity to experimental data. The relative permeability can be given as

$$k_{rel} = S_{\mathrm{eff}}^{1/2} \left[1 - (1 - S_{\mathrm{eff}}^{1/m})^m \right]^2 \tag{4}$$

The effective saturation is

$$S_{\mathrm{eff}} = \frac{S - S_r}{S_{\max} - S_r} \tag{5}$$

with $S_{\max}$ and S_r as the maximum and residual saturation.

2 Infiltration in homogeneous soil

Definition

This infiltration problem refers to a classical field experiment described by Warrick et al. (1971), who examined simultaneous solute and water transfer in unsaturated soil within the Panoche clay loam, an alluvial soil of the Central Valley of California. A quadratic 6.10 m plot, which had an average initial saturation of 0.455, was wetted for 2.8 h with 0.076 m of 0.2 N $CaCl_2$, followed by 14.7 h infiltration of 0.229 m solute-free water. The soil-water pressure was monitored by duplicate tensiometer installations at 0.3, 0.6, 0.9, 1.2, 1.5 and 1.8 m below surface. Two fixed pressure boundary conditions are used in the flow equation with a uniform initial saturation in the whole domain of 45.5%. At the top, the 2 m high soil column is open to the atmosphere, i.e. the capillary pressure is 0 Pa. The bottom of the column has a capillary pressure of 21,500 Pa. Homogeneous material properties are assumed within the whole domain. The average saturated moisture content, which is equal to the porosity of the soil, is 0.38. The saturated permeability is 9.35e-12 m^2. The relative permeability and capillary pressure vs. saturation data are fitted by the soil characteristic functions respectively.

Results

The simulated and experimental saturation data at various time steps are plotted in Fig.1. The OGS6 simulated infiltration front propagates through the soil column and resembles well the saturation results of OGS5.

To ensure the consistency of different interpolation functions, the soil column has been discretized by two dimensional geometrical models, which contain accordingly consistent finite element types such as triangles or quadrilaterals. Fig. 1 shows the saturation contours after 2, 9 and 17 hours for structured meshes.

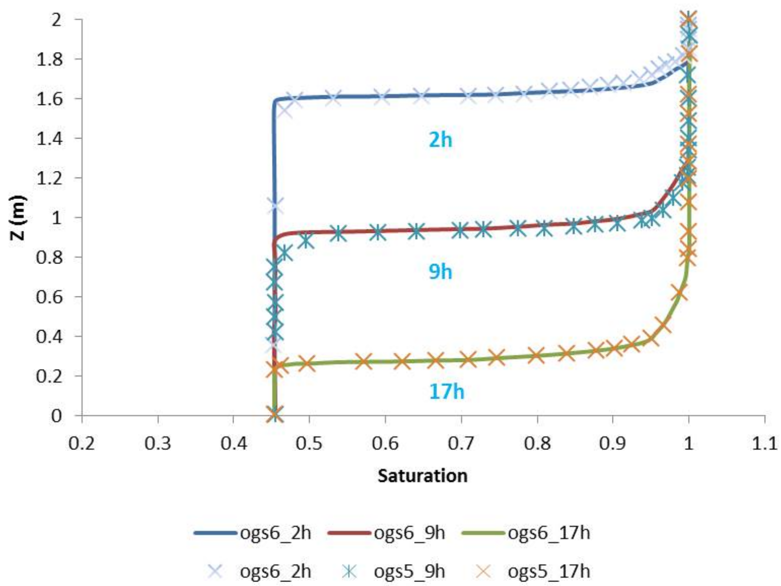

Figure 1: Comparison of OGS6(line) and OGS5(scatter) infiltration.