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ON MODELING THREE-COMPONENT POROUS MEDIA INCORPORATING HYSTERESIS

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If the voids of a porous medium are filled by two (or more) immiscible fluids, as for example, water and air, then they are called ‘partially saturated’. The pore fluids possess different partial pressures, i.e. there exists a discontinuity in the pressure across the interface separating them. This difference is called capillary pressure p_c. It depends on the geometry of the void space, on the nature of the solids and and on the degree of saturation S, i.e. the ratio of the volume occupied by one of the pore fluids over the entire void volume. The capillary pressure exhibits different values depending on the initial state of saturation. If, initially, a sample is saturated by a wetting fluid (index w) which tends to adhere to the solid walls of the void space (in contrast to the non-wetting fluid which tends to stay away from the solid wall) then drainage takes place. In the case of a non-wetting fluid (index n) filling the void space initially, the wetting fluid which invades the void space will tend to spread on the solid wall by imbibition (wetting), gradually displacing the non-wetting fluid. The hysteresis, i.e. the occurrence of two different branches of the capillary pressure curve as function of the saturation, reflects the dependence of the curve upon the history of draining and wetting (see left panel of Figure 1).

For simplicity, in most approaches of partially saturated porous media – including my own investigations (see: [3]) – only one of the branches is taken into account. But also investigations including hysteresis exist, though at the beginning not the hysteresis in the capillary pressure-saturation relationship was addressed but general thoughts, following from studies of magnetism or ferroelectrics. The outcome are several either empirical or mathematically derived models which are introduced in details in [1].

Both empirical models describing the effect of hysteresis theoretically and mathematical approaches dealing with soil-moisture hysteresis (and other types of hysteresis, e.g. shape memory alloys) aim to fit experimental results as accurately as possible. In the case of the capillary pressure in partially saturated soils these are not only values on the main hysteresis curves (boundary curves) but also on inner hysteresis curves (so-called scanning curves) which occur upon re-wetting and re-drying (see right panel of Figure 1).

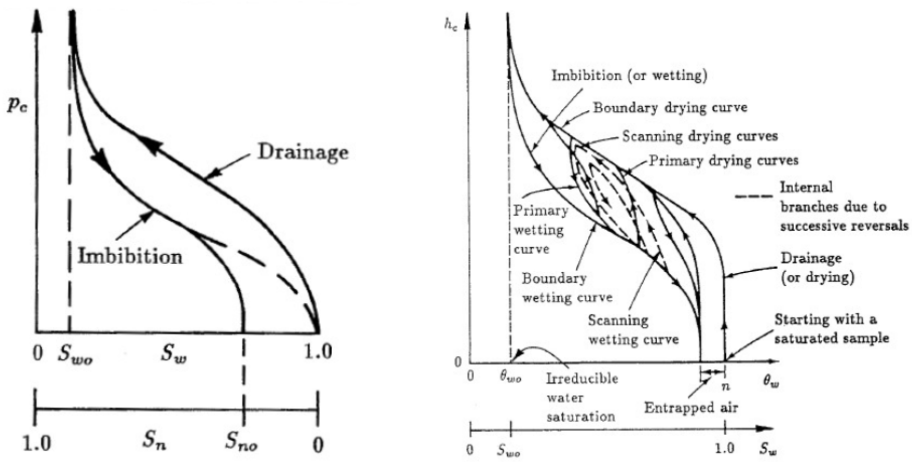

Fig. 1. Hysteresis in capillary pressure curves. Left: one cycle, right: three cycles (taken from Bear & Bachmat [4]).

In this contribution two objectives are pursued: The first is the presentation of nonlinear mathematical hysteresis modeling by use of operators like the Preisach operator. The other is the application of a linear model to wave propagation. Also in the latter case hysteresis is accounted for: the analysis is performed for the two limit cases of main drying and main wetting. In [2] the influence of the application of drying and wetting data on the propagation of sound waves is studied theoretically by means of the continuum model presented in [3] and numerically exploited for the example of Del Monte sand filled by an air-water mixture. Four waves appear: one transversal wave and three longitudinal waves. For the waves driven mainly by the skeleton it could be expected that the influence of the hysteresis in the capillary pressure curve is negligible. This is different from the expectations for the waves driven by the pore fluids. The numerical results exhibit – at least for the present example – a smaller influence than expected.

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