Swelling and swelling pressure of clay soils: experimental data and model simulations

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Abstract. The behavior of soils and rocks containing clay minerals is the effect of complex chemo-mechanical processes of interparticle interaction (Di Maio, 1996; Di Maio et al., 2015; Gajo et al., 2002). Such processes must be taken into account in a number of engineering problems ranging from those related to slope stability to the design of tunnels, supports of excavation surfaces, foundations, "impermeable" barriers.

This paper presents experimental results and model simulations showing the influence of mineral composition and pore fluid composition on the processes of swelling and swelling pressure onset.

The considered soils are a bentonite mainly composed of Na-montmorillonite and a natural clayey soil with a composite mineral composition. The two materials were reconstituted with distilled water or salt solutions at different concentrations, and compressed in oedometric conditions to different stress levels. The tendency to swell was induced by unloading or by exposure to a fluid different from the pore fluid. Swelling was permitted to a set of specimens, whereas it was prevented to another set of specimens by applying increasing pressures. The temporal evolution of swelling and swelling pressure, ion concentration in the pore fluid, and pore water pressures was monitored. The influence of stress state and of stress history was evaluated.

The observed chemo-mechanical processes were modelled with the FEM method. The solution of the coupled phenomena was obtained with a user-defined UEL subroutine that was implemented in the commercial code ABAQUS. The subroutine takes account of the chemo-mechanical interactions in the solid skeleton, through a suitable constitutive model, and the coupled fluxes in the porous space. In the proposed constitutive model, chemical interactions are assumed to affect both the plastic and the elastic response, as observed experimentally, thus an extended elasticity law is needed. The constitutive model is an evolution of the original chemo-mechanical model proposed by Gajo et al. (2002) and Loret et al. (2002), which was based on *q-p* formulation and on Cam-Clay-like elastic response. In contrast, in this work, a multiaxial formulation is considered and a new hyperelastic law is presented, in which both the tangent shear stiffness and bulk stiffness depend on the applied stress state and salt concentration in pore water. Model simulations is extendedly compared with the results of oedometer tests in terms of both chemical and mechanical processes, thus leading to a deeper insight into the macro-scale, chemo-mechanical interactions affecting slope stability.

Keywords: clays, swelling, swelling pressure, chemo-mechanical coupling, model simulations

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