ECCM 2010
IV European Conference on Computational Mechanics
Palais des Congrès, Paris, France, May 16-21, 2010

Numerical Modelling and Finite Element Analysis of Geotechnical Problems Involving Partially Saturated Soils

G. Hofstetter[1], M. Hofmann[1], M. Pertl[1], R. Kohler[2]

[1] *University of Innsbruck, Austria, {Guenter.Hofstetter,Matthias.H.Hofmann,Michael.Pertl}@uibk.ac.at*
[2] *Pöyry Energy, Salzburg, Austria, Roman.Kohler@poyry.com*

Numerical models for geotechnical problems involving partially saturated soils are based on a finite element formulation for three-phase media and a constitutive model for partially saturated soils. The three phases consist of the deformable soil skeleton and the interstitial fluid phases water and air. The three-phase model, employed in the present context, is based on averaging theory [1]. The primary variables of the finite element formulation comprise the nodal displacements of the soil skeleton, the capillary pressure and the air pressure. A Newton-type solution procedure is employed for solving the set of nonlinear equations of the three-phase model.

A constitutive model, which allows describing the essential features of partially saturated soil behaviour, is based on two stress state variables. Popular choices for the stress state variables are net stress and capillary pressure or generalized effective stress and capillary pressure [2,3]. In this contribution both the well known Barcelona Basic Model, proposed in its original version in [4], and a cap model for partially saturated sands and silts [5] are addressed. The former is formulated in terms of net stress and capillary pressure and the latter is based on the generalized effective stress and capillary pressure.

Within the framework of a FE-analysis the stress update algorithm for the partially saturated soil model plays an important role. To this end, (i) an explicit stress update algorithm, (ii) a general return mapping algorithm, (iii) an optimized return mapping algorithm and (iv) a semi-explicit stress update algorithm are investigated. They are combined with sub-stepping and error control and are compared with respect to robustness, accuracy and efficiency. In addition, an implicit 5th order Runge-Kutta stress update algorithm is included in this comparison. The performance of the stress update algorithms is investigated for different sets of material parameters and for a large range of prescribed combinations of volumetric and deviatoric strain increments.

The capabilities of the two soil models are demonstrated by comparisons of the results of numerical predictions of partially saturated soil behaviour with extensive experimental data on a sandy silt, documented in [6], and on a silty sand, documented in [7,8]. These tests include, e.g., hydrostatic stress paths at saturated conditions, suction controlled hydrostatic tests and different triaxial tests for normal and over consolidated conditions combined with wetting and dewetting as well as unloading and reloading. Finally, the application of the developed coupled FE-model is demonstrated by a simplified 2D numerical simulation of the impoundment of an embankment dam and by the 3D numerical simulation of the injection of compressed air into water saturated soil.

References

[1] R.W. Lewis, B.A. Schrefler, The finite element method in the static and dynamic deformation and consolidation of porous media, 2nd ed., John Wiley & Sons, 1998.

[2] G. Houlsby, The work input to an unsaturated granular material, Geotechnique, 47 (1997), 193-196.

[3] M. Nuth, L. Laloui, Effective stress concept in unsaturated soils: Clarification and validation of a unified framework, International Journal for Numerical and Analytical Methods in Geomechanics, 32 (2008), 771-801.

[4] E. E. Alonso, A. Gens, A. Josa, A constitutive model for partially saturated soils, Géotechnique, 40 (1990), 405–430.

[5] R. Kohler, G. Hofstetter, A cap model for partially saturated soils, International Journal for Numerical and Analytical Methods in Geomechanics, 32 (2008), 981-1004.

[6] M. B. Bucio, Estudio experimental del comportamiento hidro-mecánico de suelos colapsables, Universitat Politècnica de Catalunya, Ph.D.-thesis, 2002.

[7] E.J. Macari, L.R. Hoyos, P. Arduino, Constitutive modeling of unsaturated soil behaviour under axisymmetric stress states using a stress/suction-controlled cubical test cell, International Journal of Plasticity, 19 (2003), 1481–1515.

[8] E.J. Macari, L.R. Hoyos, Mechanical behavior of an unsaturated soil under multi-axial stress states, Geotechnical Testing Journal, 24 (2001), 14–22.