LOCALIZATION AND STABILITY OF UNSATURATED SOIL

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Summary Unsaturated soil plays a dominant role in geotechnical engineering, e. g., when the draining of embankments or embankment deformation and stability problems are concerned. Based on the well-founded Theory of Porous Media, the contribution describes unsaturated soil as a triphasic continuum of solid, fluid and gas and exhibits the numerical implementation together with the demonstration of various initial boundary-value problems including the localization and stability behaviour of embankment problems.

INTRODUCTION

In the framework of continuum mechanics, the Theory of Porous Media (TPM) provides an excellent basis for the description of a variety of volumetrically coupled solid-fluid problems. In the present contribution, the focus lies on the investigation of unsaturated soil modelled as a triphasic continuum consisting of a porous solid skeleton (the soil), a pore-liquid (water) and a pore-gas (air), thus including saturated soil (solid matrix and pore-water) and empty soil (solid matrix and pore-gas) as special cases. Proceeding from a triphasic material, realistic problems in soil mechanics can be computed, as there are, on the one hand, the general problem of draining and, on the other hand, those phenomena combining the effects of draining with the deformation and localization behaviour of the soil skeleton. All these issues are of great importance in geotechnical engineering and occur, for example, when localization and stability problems of embankment structures have to be investigated.

UNSATURATED SOIL AS A TRIPHASIC CONTINUUM

Based on a triphasic continuum embedded in the TPM, the model is assumed to consist of a materially incompressible, elasto-viscoplastic soil skeleton saturated by an immiscible mixture of two viscous fluid components, a materially incompressible liquid and a materially compressible gas. In particular, the viscoplastic formulation of the soil is based on the single-surface yield criterion by Ehlers [1] together with the overstress concept of Perzyna type [2, 3], where an elasto-plastic model is included as a special case. In addition, the liquid and the gas phases are governed by Darcy-like relations together with an extended van Genuchten model for the description of the capillary pressure and the relative permeability functions [4].

NUMERICAL TOOLS

Based on a weak formulation of the overall continuum problem, a volumetrically coupled set of equations has to be solved. Proceeding from quasi-static situations, the computations are governed by the overall momentum balance tested by the solid displacement function together with the liquid volume and the gas mass balances tested by the effective liquid and gas pressures. As a result of the liquid incompressibility, the liquid pressure acts as a Lagrangean, while the gas pressure is obtained as a function of the effective gas density. The governing set of equations is incorporated into the FE tool PANDAS [5, 6], which has been particularly designed for the solution of volumetrically coupled solid-fluid problems. Apart from standard displacement-pressure formulations, PANDAS has been extended towards time- and space-adaptive methods, thus offering the possibility to produce proper and reliable numerical results. In case that localization phenomena occur, which, usually, lead to mathematically ill-posed problems, several regularization procedures can be used to overcome this problem, where, in the present contribution, use is made of the solid viscoplasticity concept.

NUMERICAL RESULTS

Proceeding from a two-pressures-displacement formulation for the numerical description of unsaturated soil, embankment localization and stability problems can be solved for arbitrary embankment geometries and structures. Apart from the general draining problem following, e. g., the Liakopoulos test [7], the present contribution concentrates on embankment problems, cf. Figures 1 and 2, where the coupled draining-deformation behaviour has been investigated. Considering a standard embankment structure with a filter unit at the air side, Figure 1 exhibits the stationary state, where the pore-water is draining through the embankment towards the filter. As a result of the embankment design governed by the filter unit together with the moderate angle of both embankment slopes, there is no water leaking through the air side of the structure. As a consequence, no localization of plastic strains can be observed, and the structure can be concluded to be save with respect to the given height of the water table at the left slope. On the other hand, if an embankment with the same water table would have been designed, however, without a filter unit at the air side, where, furthermore, a steeper slope had been chosen, cf. Figure 2, it is immediately seen that the construction runs into problems. In particular, water is leaking from the embankment through the slope at the air side, thus leading to a typical situation that can be observed after natural hazards, such as heavy rainfall, etc. Furthermore, as a result of the leakage, the soil body is under buoyancy, thus losing strength obtained from gravitational forces. As a consequence, plastic strains are localizing forming a shear band with the onset at the kink between the slope and the ground level. If the water table does not rapidly decrease, this shear band is running up to the top of the embankment and will lead to a destruction of the complete structure. Following this, steps have to be taken to prevent the embankment from destruction, e. g., by loading the air side of the structure by additional weights as is usually done by sandbags.

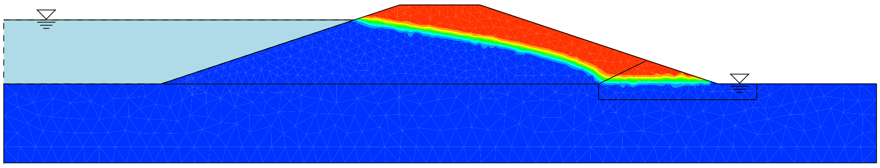

Figure 1: Pore-liquid distribution in an embankment.

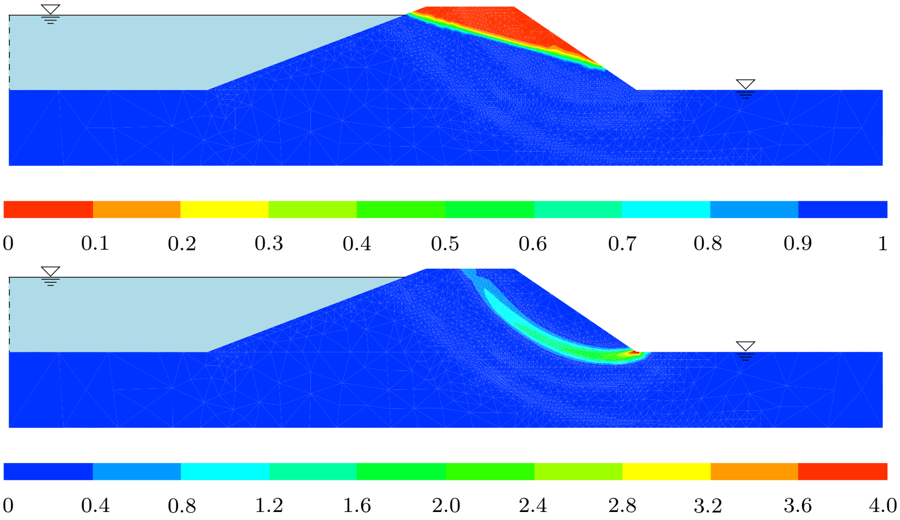

Figure 2: Pore-liquid distribution (top) and localization of the accumulated plastic strains $[10^{-1}]$ (bottom).

CONCLUSION

Based on a triphasic material, unsaturated soil has been investigated within the framework of the well-founded TPM [3]. Proceeding from an elasto-viscoplastic soil skeleton saturated by an immiscible mixture of two viscous and mobile pore-fluids, water and air, the numerical examples reveal the volumetrically coupled solid-fluid behaviour from draining to the onset and the development of shear bands. Apart from the 2-dimensional examples presented above, the oral presentation will furthermore include 3-dimensional examples computed by both single-processor and multi-processor (parallel) techniques.

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