MULTIPHYSICS MODELLING OF FLOWSLIDES INITIATION

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Summary Aim of this work is the multiphysics modelling of the initiation of flowslides in pyroclastic soils due to the increase of water pressure induced by rainfall. Soils are modelled as a multiphase elastoplastic porous continuum where heat, water and air flow are taken into account. The finite element method is adopted to discretize in space and time the balance equations. A real case occurred in May 1998 in the south part of Italy is simulated. It is shown that the first failure of the lower part of the slope is captured, as observed in situ.

INTRODUCTION

In this work we show a finite element analysis of the initiation of a flowslide in pyroclastic soils which took place in May 1998 in the southern part of Italy and was due to the increase of water pressure induced by heavy and sustained rainfall. Significant examples of flowslides occur periodically in the Campania Region (South Italy) triggered by critical rainfall events. They involve shallow slips on slopes of unsatured pyroclastic soils. These soils were originated by the explosive phases of the Somma-Vesuvio volcano which covered the limestone and tuffaceous slopes over an area of about 3000 km2. In this area, one of the most calamitous events occurred on May 5-6, 1998, when 160 casualties and serious damages were recorded in four small towns (Braccigliano, Quindici, Sarno and Siano) located at the toe of the Pizzo d'Alvano relief. Raingauges located at the toe of Pizzo d'Alvano massif recorded, for the period April 28-May 5, 1998, a cumulative rainfall value of 183 mm, of which 120 mm fell in the last two days. During and soon after these events, within an interval of about ten hours, more than 100 flowslides occurred in almost all the basins of the massif. Survey conducted following their occurrence revealed that triggering zones where characterized by an average slope angle varying from 30 to 41 degrees and a soil thickness ranging from 0.5 m to 5.0 m (Figure 1). As pointed out in [1] in case of heavy rainfall events a flow regime parallel to the surface installs itself in the upper partially saturated layers and carries water to the toe region. This induces an increase of the degree of saturation and a reduction of the capillary pressure between soil grains even up to water saturated condition e.g. in the toe zone. A weakening of the slope ensues. Further due to the flow inside the soil layers a destabilizing downhill frictional drag may develop. Hence the key factors involved in the onset of shallow landslides are water flow through the solid matrix, soil water retention behaviour and the effect of matric suction on the mechanical behaviour of the skeleton.

MULTIPHASE POROUS MEDIA MODEL

The full mathematical model necessary to simulate HTM transient behaviour of variably saturated porous media was developed within the Hybrid Mixture Theory in [2] using averaging theories. In this model the porous materials are treated as multiphase system composed of the solid skeleton with open pores filled with liquid water and gas. The latter is assumed to behave as an ideal mixture of dry air and water vapour.

At microscopic level, the solid constituents and the liquid water are considered incompressible, while gas is compressible. At macroscopic level the porous material is modelled by a substitute continuum that simultaneously fills the entire domain, in which each constituent has a reduced density which is obtained through the volume fraction.

The solid is deformable and non-polar, and the fluids, solid and thermal fields are coupled. All fluids are in contact with the solid phase. The constituents are assumed to be isotropic, homogeneous, immiscible except for dry air and water vapour, and chemically non-reacting. Local thermal equilibrium between solid matrix, gas and liquid phases is assumed. Heat conduction, heat convection, vapour diffusion, liquid water flow due to pressure gradients or capillary effects and water phase change (evaporation and condensation) inside the pores are taken into account.

Small strains and quasi-static loading conditions are assumed. The macroscopic balance equations (fully coupled) of the model are: the equilibrium equation of the mixture, the mass balance equation for the liquid water and its vapour, the mass balance equation for the dry air and the enthalpy balance equation of the mixture, [1], [3].

As constitutive equations, for the gaseous mixture of dry air and water vapour, the ideal gas law is introduced and the equation of state of perfect gas (Clapeyron's equation) and Dalton's law are applied. In the unsaturated zones, the equilibrium water vapour pressure is obtained from the Kelvin-Laplace equation, where the water vapour saturation pressure is calculated from the Clausius-Clapeyron equation. The fluid saturation and the relative permeability are experimentally determined functions.

The effective stress state of the solid skeleton is limited by the Drucker-Prager yield surface with linear isotropic hardening, non associated plastic flow and capillary pressure dependent cohesion.

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The governing equations of the model have been discretized within the finite element method; the standard Galerkin procedure and the Generalised Trapezoidal Method have been adopted for the space discretization and for the time integration, respectively. The state of the medium is described by capillary pressure, gas pressure, absolute temperature and displacements of the solid matrix. For a detailed discussion about the chosen primary variables see [3].

FINITE ELEMENT RESULTS

The modelled slope section is shown in Figure 1 together with the stratigraphic details sketched for some verticals. The hydro-mechanical properties of the three types of layers mentioned above have been determined by laboratory tests [4]. We have analysed the period of time from April 28 until May 6, loading the upper surface of the slope with a water flux corresponding to a double rainfall compared to that measured at the toe of Pizzo D'Alvano massif, because the analyzed slope is sited in the upper part of the massif, where regularly higher rainfall occurs [4].
As expected the results of the simulation when landslides occurred (May 6) show that the displacements are concentrated in the lower part of the slope, with a maximum value of 1.73 m. From the time history of the displacements norm of some nodes in the final part of the slope in Figure 2 can be observed that the onset of the landslides has been captured by the multiphase model because a very high displacement rate is obtained in the last two days of the period analysed (May 5 and 6), in agreement with what observed in situ.
The numerical results reveal that collapse is due to the accumulation of the equivalent plastic strain in the lower part of the slope, Figure 3, because the materials becomes fully saturated, Figure 4. In particular, plastic strain reaches higher values within the pumice layers, which are the less resistant and more permeable ones, Figure 3, and saturate even if dilatant.

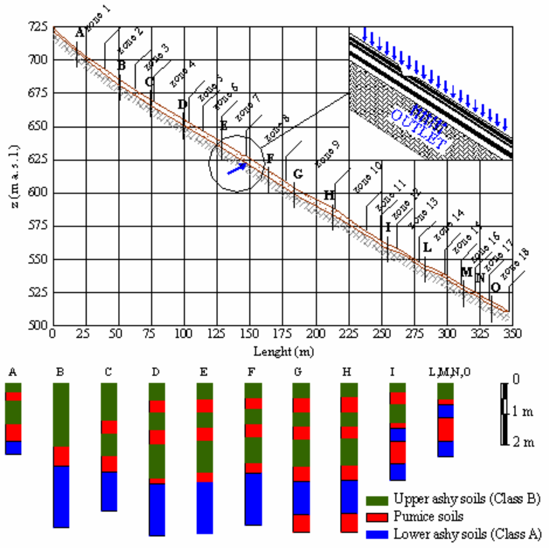

Figure 1. Geometric and stratigraphic section [4].

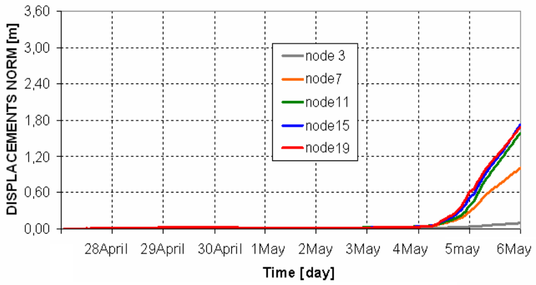

Figure 2. Displacements norm time history (lower part of the slope).

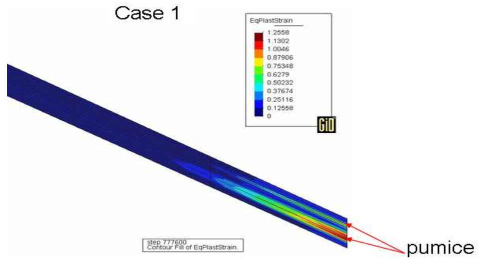

Figure 3. Equivalent plastic strain at the end of May 6 (lower part of the slope).

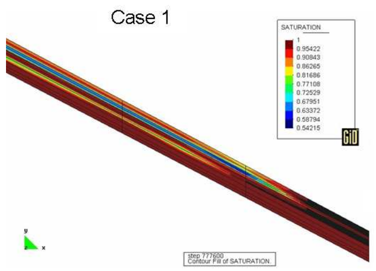

Figure 4. Saturation at the end of May 6 (lower part of the slope).

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