Multi-physics modelling of the coupled behaviour of thermo-elasto-plastic porous media with fluid phase change

Giovanni Bonifetto [1], Alberto Bonetto[2], Lorenzo Sanavia [3] and Lyesse Laloui [4]

1-3) University of Padua: Department of Civil, Environmental and Architectural Engineering

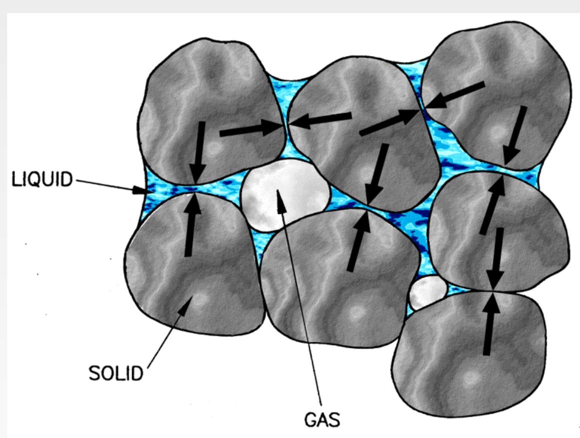
4) École Polytechnique Fédérale De Lausanne, Laboratory of Soil Mechanics

Contact: lorenzo.sanavia@unipd.it

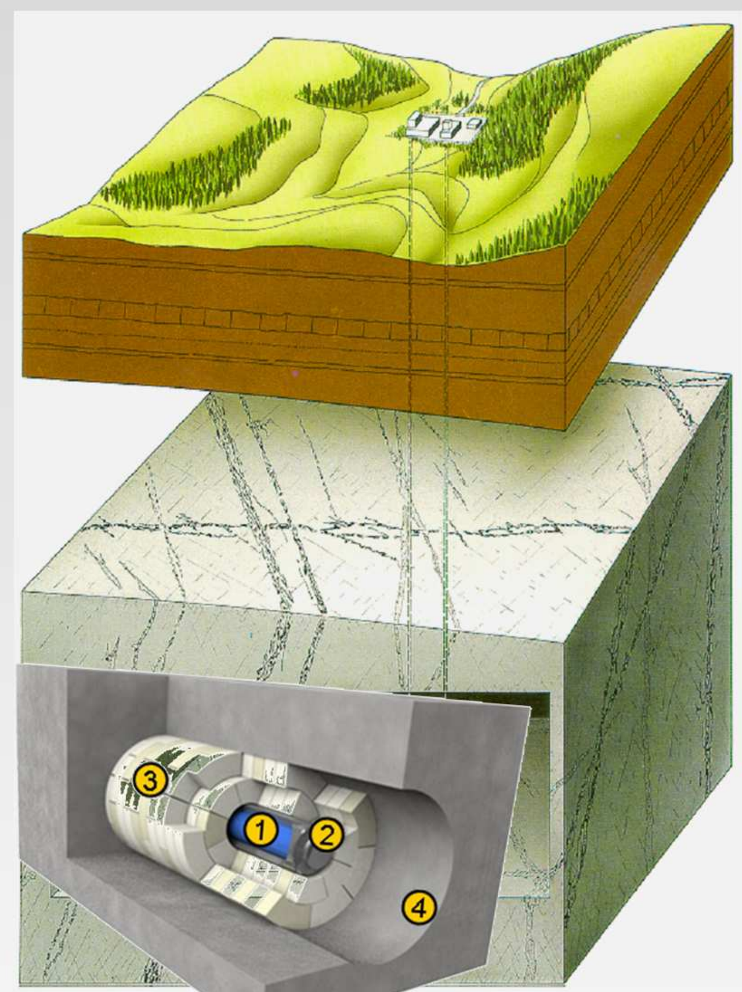
CONTEXT

Coupled Hydro-Thermo-Mechanical (HTM) behaviour of elasto-plastic porous media is of particular interest in geo-environmental engineering as, for example, issues related to the safety of deep nuclear waste disposal, the onset of catastrophic landslides, desiccation of soils or the performance of geothermal structures.

In all of the above mentioned problems, porous media have to be studied as non-isothermal multi-phase materials in multi-physics conditions.



Microscopic view: partially saturated soil



Depth: 400 m ÷ 700 m
1) vitrified waste 2) steel canister
3) buffer material 4) host material

Scheme of a deep repository for nuclear waste

(Gens, Olivella, CISM lecture notes 2001)

AIMS OF THE STUDY

In case of deep nuclear waste disposal, the effect on the integrity of host material, due to a possible phase-change caused by failure of the canisters, can be studied through a fully coupled hydro-thermo-mechanical finite element model.

In this context, as a preliminary study, consolidation of a Boom clay column is analyzed in detail, aiming to understand the coupled effects of hydro-thermo-mechanical loads on this material, which is a candidate for an underground nuclear waste storage facility in Belgium.

A particular case of rapid heating inducing evaporation of the liquid water is presented in this work.

TOOLS

COMES – GEO *http://www.dicea.unipd.it*

A Finite Element code for multi-phase geomaterials developed at the University of Padua

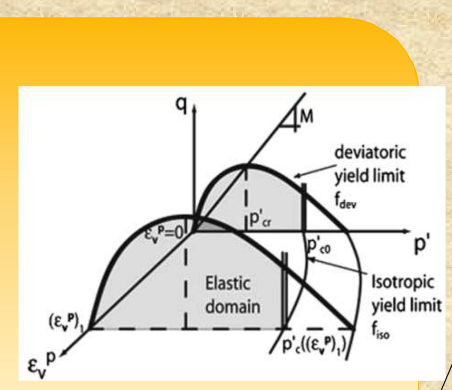
Mathematical and physical model

Finite Element procedure

+

ACMEG-TS:

*A*dvanced *C*onstitutive *M*odel for *E*nvironmental *G*eomechanics with *T*hermal and *S*uction effects, for clayey soils



(Laloui, François NAG08; Laloui, François JEM09)

SIMULATION

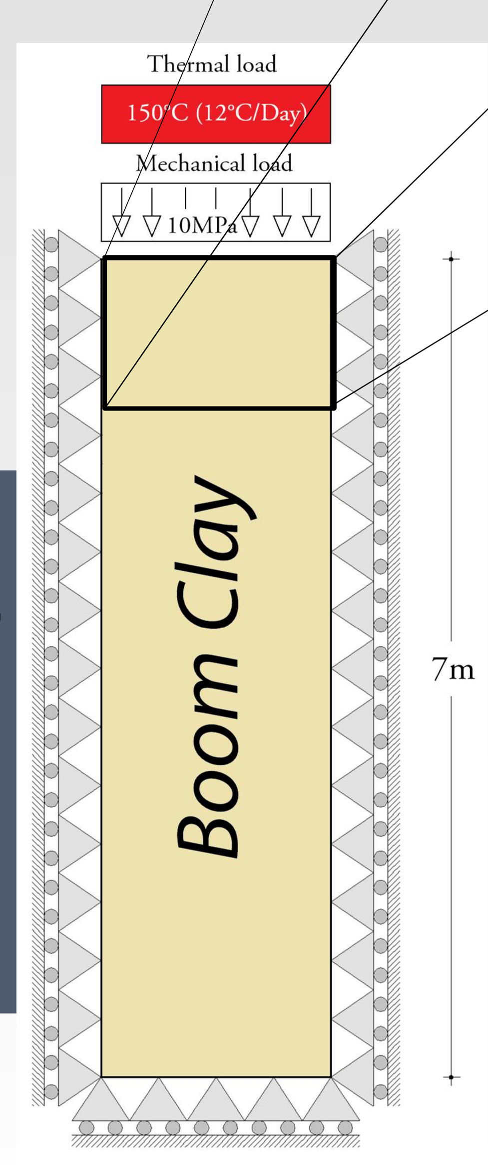
A soil column of Boom clay, 7,00 m high and 2,00 m wide, loaded by thermal and mechanical loads, is simulated.

2D plane-strain problem

B.C.s. For the Mechanical problem	B.C.s. For the Thermal problem	B.C.s. For the Hydraulic problem (2fluids)
Lateral surfaces: Ux = 0 Bottom surface: Uy = 0 Top surface: 10.0MPa	Isolation in all the surfaces except for the top 30°C →150°C (+Δ120°C) thermal load applied to the top surface with a ramp of 12°C/day	Lateral and bottom surfaces: sealed Top surface: Pgas = atmospheric RH = 95%

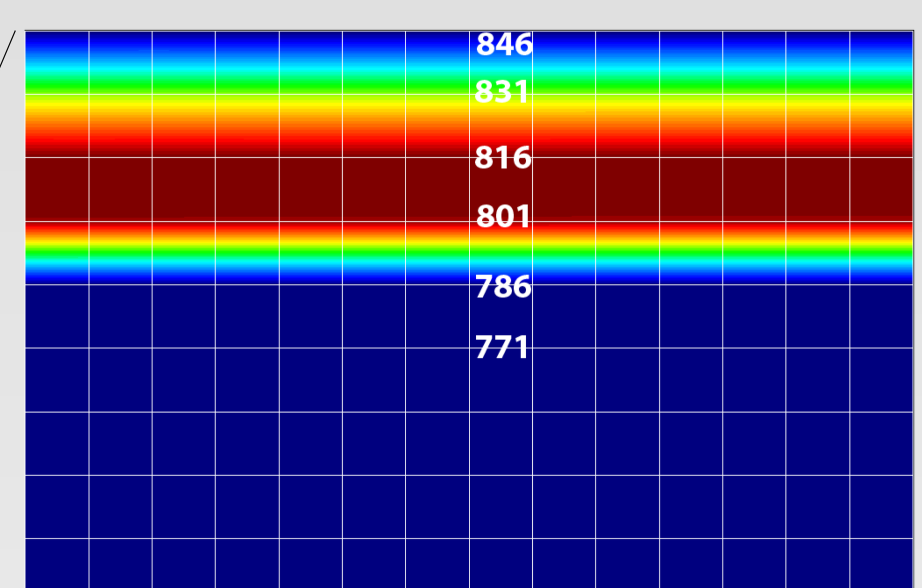
Fluxes = 0

Initial conditions: the steady state consolidation state under a compressive load of 10MPa.



RESULTS

➢ A temperature load from 30°C to 150°C is applied on the top surface of the column in 10 days.

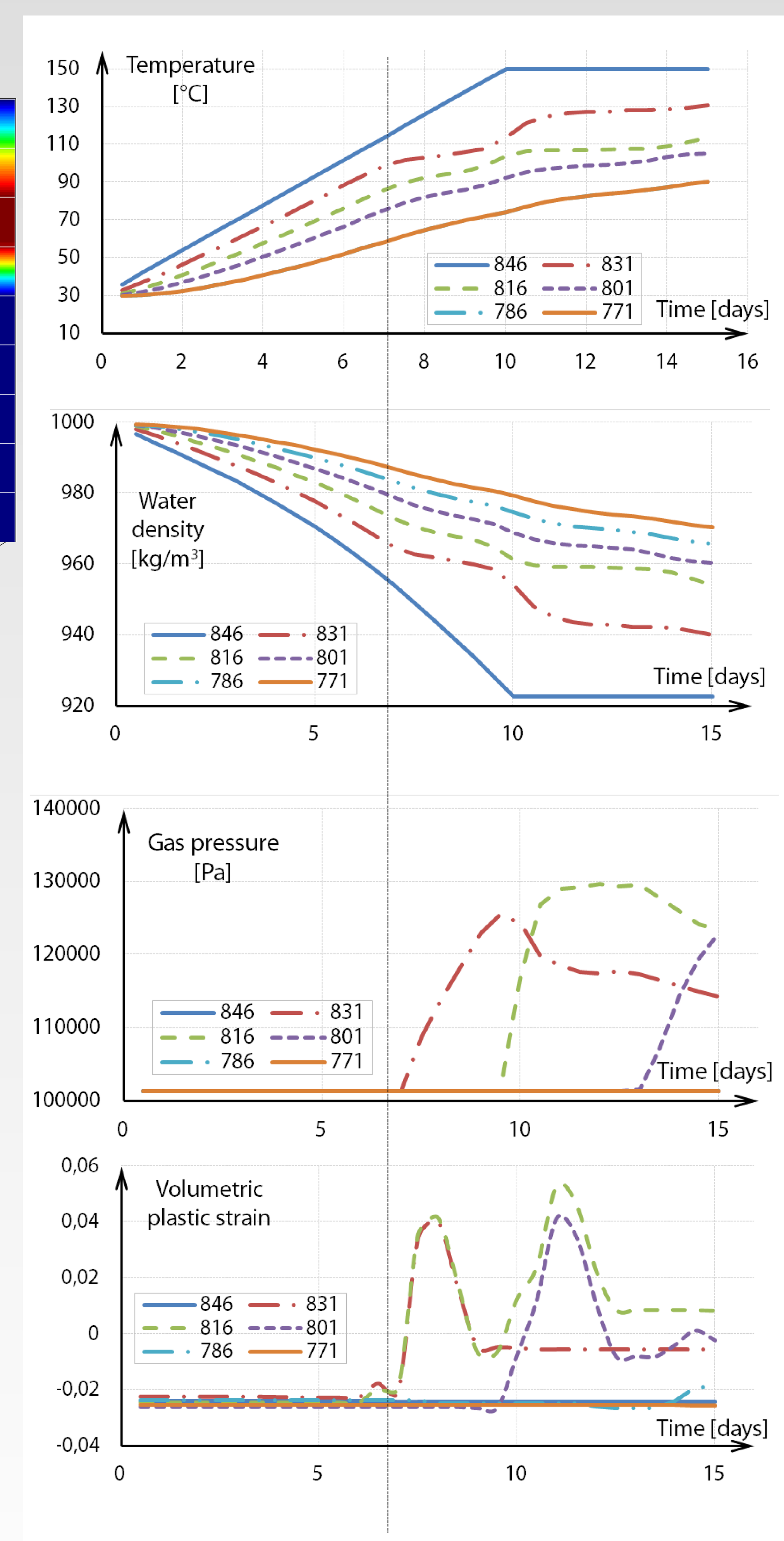


Vapor pressure contour at 15 days and position.

The results show that:

➢ Water density decreases with the increase of temperature, causing increment of water pressure

➢In the upper part of the column, when the temperature reaches the boiling value, phase change of liquid water is described and a vapor phase appears, inducing a sudden increment of the gas pressure (see node 831) and releasing the compressive volumetric plastic strain up to the development of dilatant plastic strain, partly recovered in time, showing deterioration of the integrity and the properties of the Boom clay.



Time history of respectively temperature, water density, gas pressure and volumetric plastic strain at different depth

References

R.W. Lewis and B.A. Schrefler: The Finite Element Method in the Static and Dynamic Deformation and Consolidation of Porous Media. J. Wiley, 1998.

L.Sanavia, F. Pesavento and B.A. Schrefler: Finite element analysis of non-isothermal multiphase geomaterials with application to strain localization simulation. *Computational Mechanics*, 37 (2006), 331-348.

L. Sanavia, B. François, R. Bortolotto, L. Luison and L. Laloui: Finite element modelling of thermo-elasto-plastic water saturated porous materials. *Journal of Theoretical and Applied Mechanics*, 38 (2008), 7-24.

B. François and L. Laloui, Acmeg-Ts: A constitutive model for unsaturated soils under non-isothermal conditions. *Int. J. Numer. Anal. Meth. Geomech.* 32 (2008), 1955-1988.

Acknowledgement

The authors would like to thank the University of Padua (project: CPDA097373) and Regione Veneto (grant: 2105/201/7/1686/2012) for the financial support.