Thermo-hydro-mechanical modelling of unsaturated porous media coupling damage and plasticity

Solenn Le Pense, Behrouz Gatmiri, Ahmad Pouya

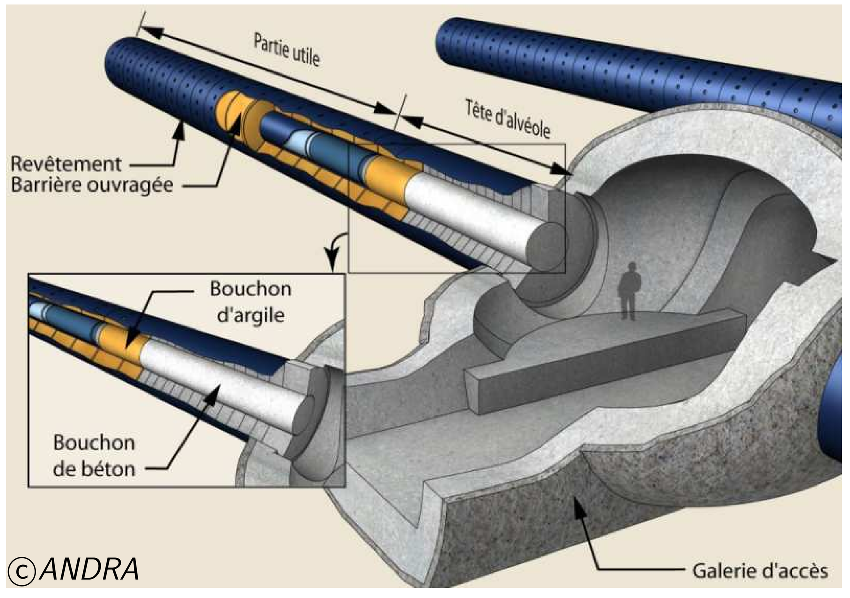
Thermo-hydro-mechanical modelling of unsaturated porous media coupling damage and plasticity

Le Pense S., Gatmiri B., Pouya A.

Université Paris-Est, Laboratoire Navier (ENPC/IFSTTAR/CNRS),
Ecole des Ponts ParisTech, 6 & 8 av Blaise Pascal, 77455 Marne-la-Vallée, France.
e-mail : solenn.le-pense@cermes.enpc.fr

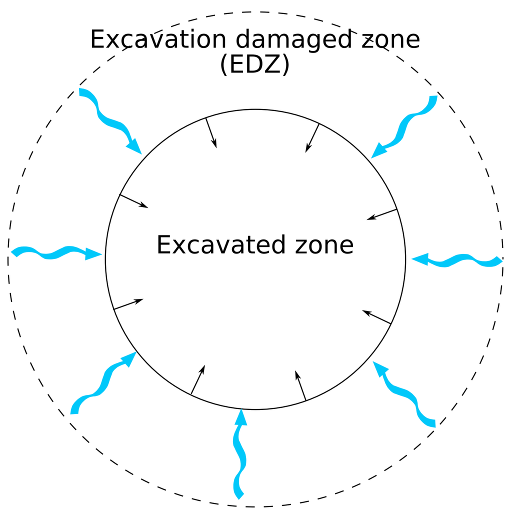
UNIVERSITÉ PARIS-EST

Context



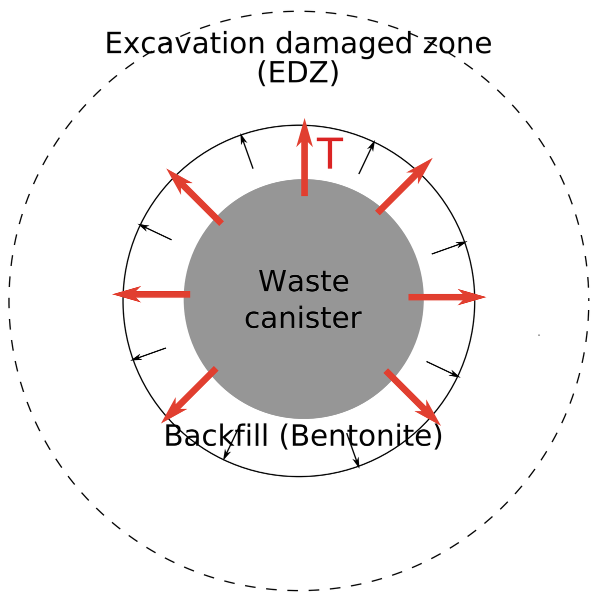
©ANDRA

Excavation and open-drift stages



- Excavation $\Longrightarrow$ decompression
- Stress redistribution around the opening
- Creation of an excavation damaged zone (EDZ)
- Increase of permeability
- Desaturation due to ventilation

Storage stage



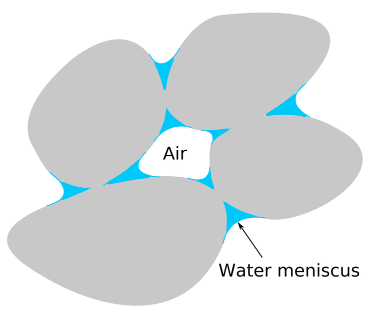
Early closure stage

- Resaturation due to closure
- Heat release from waste
- Back pressure due to backfill swelling

Late closure stage

- Self-sealing
- Chemical and biological effects
- Degradation of materials

Elasto-plasticity of unsaturated geomaterials



Three phases

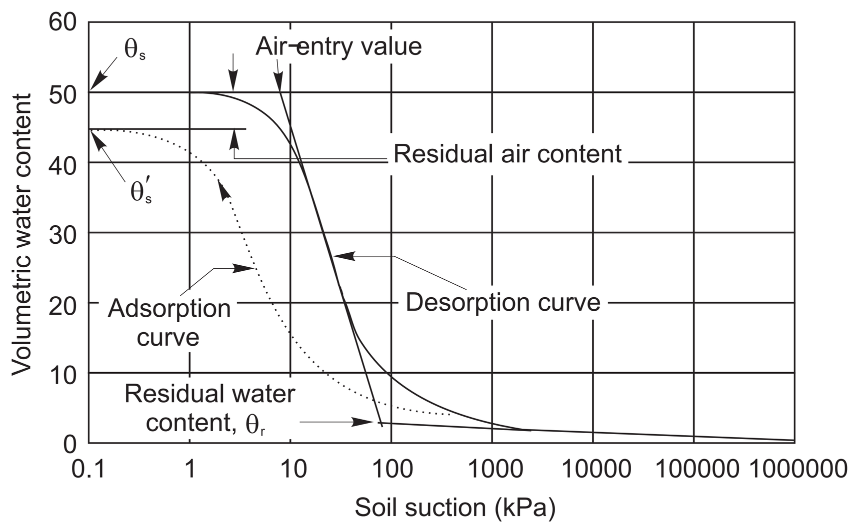
- **Solid:** soil skeleton
- **Liquid:** water, dissolved air
- **Gas:** air and water vapour

Important parameters

- Stress
- Suction
- Temperature

Hydraulic behaviour

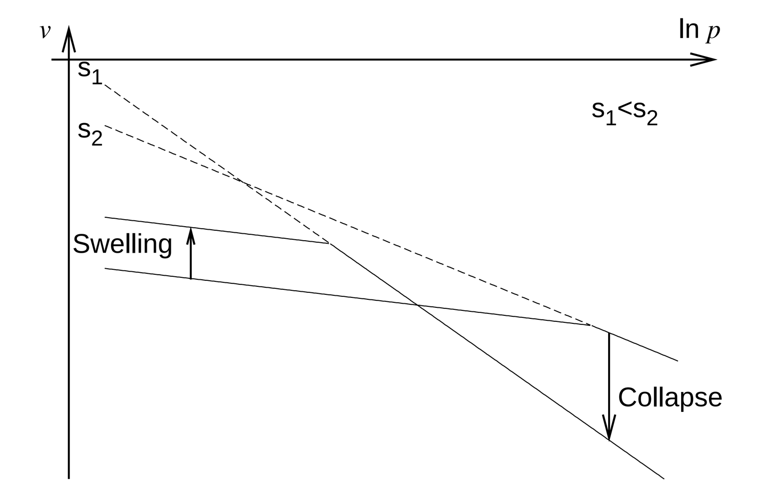
- Hysteresis of water retention curves



Typical Desorption and absorption curves for a silty soil (Fredlund, Xing & Huang, 1994)

Mechanical behaviour

- Suction $\nearrow$ $\Longrightarrow$ soil stiffening
- Collapse phenomenon



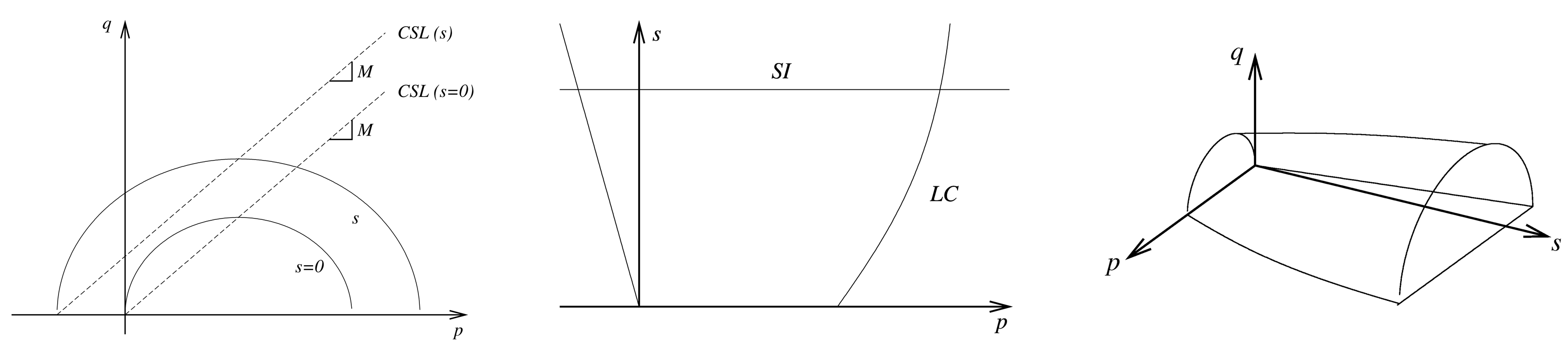
Compression curves. (Alonso, Gens & Josa, 1990)

Elasto-plastic models

Framework

- Choice of the stress variables
- Elastic behaviour
- Isotropic compression virgin line
- Yielding surface + hardening laws
- Plastic flow rule (associated or non-associated)
- Critical state

Most of the current models are derived from the Barcelona Basic Model (BBM)



Yield surfaces in (p, q, s) stress space (Alonso, Gens & Josa, 1990)

Choice of stress variables

Classic models: use of stress and suction as variables

Generalized effective stress: work-conjugate stress and strain variables.

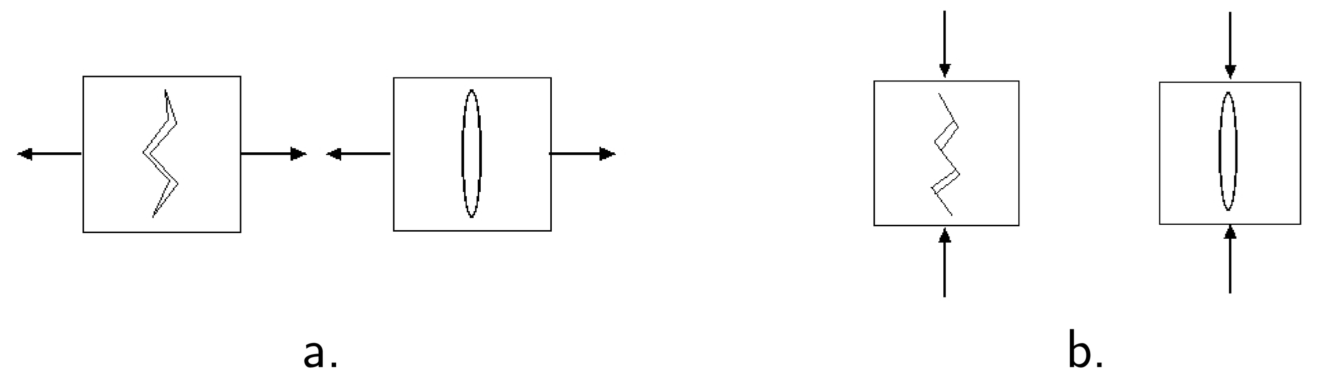
$$\begin{cases} \sigma - (u_a - S_r(u_a - u_w)) & \longleftrightarrow \epsilon \\ \phi(u_a - u_w) & \longleftrightarrow S_r \end{cases}$$

(Houlsby, 1997)

Damage

Micromechanical approach

Creation of microcracks and microvoids



Cracking Modes: a. Traction, "splitting effects". b. Compression, "crossing effects". (Ortiz, 1985)

If we consider three orthogonal sets of parallel non-interacting microcracks :

Second order damage tensor: $\mathbf{\Omega} = \sum_{j=1}^{3} \mathbf{d_i} \cdot \vec{\mathbf{n}}_\mathbf{i} \otimes \vec{\mathbf{n}}_\mathbf{i}$ *(Kachanov, 1992)*

Objective: to determine relevant nucleation and propagation criteria of microcracks and kinetic laws in microscopic level (REV)

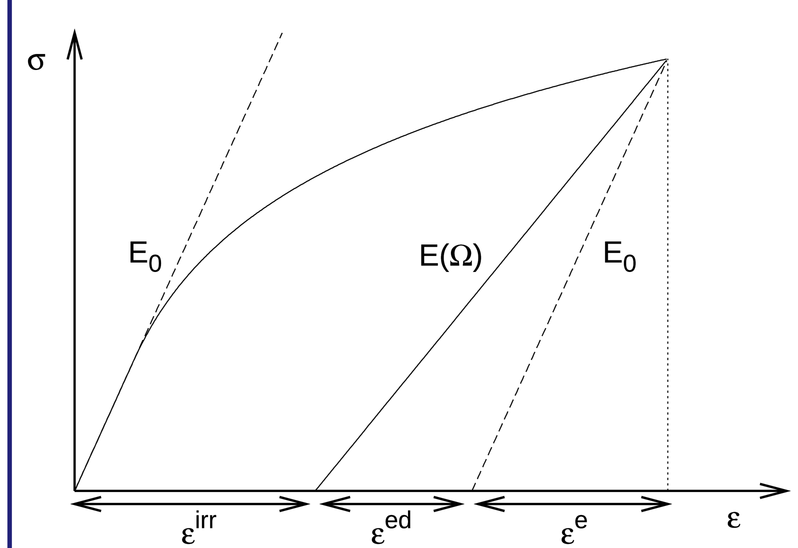
Advantages

- Ability to account for physical mechanisms involved in nucleation and growth of microcracks

Weaknesses

- Homogenisation procedure $\Longrightarrow$ difficulties of use in practical applications

Phenomenological approach



- Non-linearity of stress-strain relationship
- Deterioration of elastic properties
- Induced material anisotropy
- Irreversible damage strains due to residual crack opening
- Unilateral response due to crack closure effect

Objective: to use internal variables to represent material damage state; formulated in the irreversible thermodynamics framework

Advantages

- Provides macroscopic constitutive equations

Weaknesses

- Difficulty to determine the corresponding parameters

Coupling of damage and plasticity in unsaturated geomaterials

Future work: To develop a thermodynamically consistent thermo-hydro-mechanical model for unsaturated geomaterials coupling elasto-plasticity and damage

Main issues:

- What is the relative importance of plasticity and damage phenomena? Which one appears first?
- How does plasticity influence damage apparition and evolution?
- How does damage influence plasticity yield surface and plastic flow rules?