



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

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

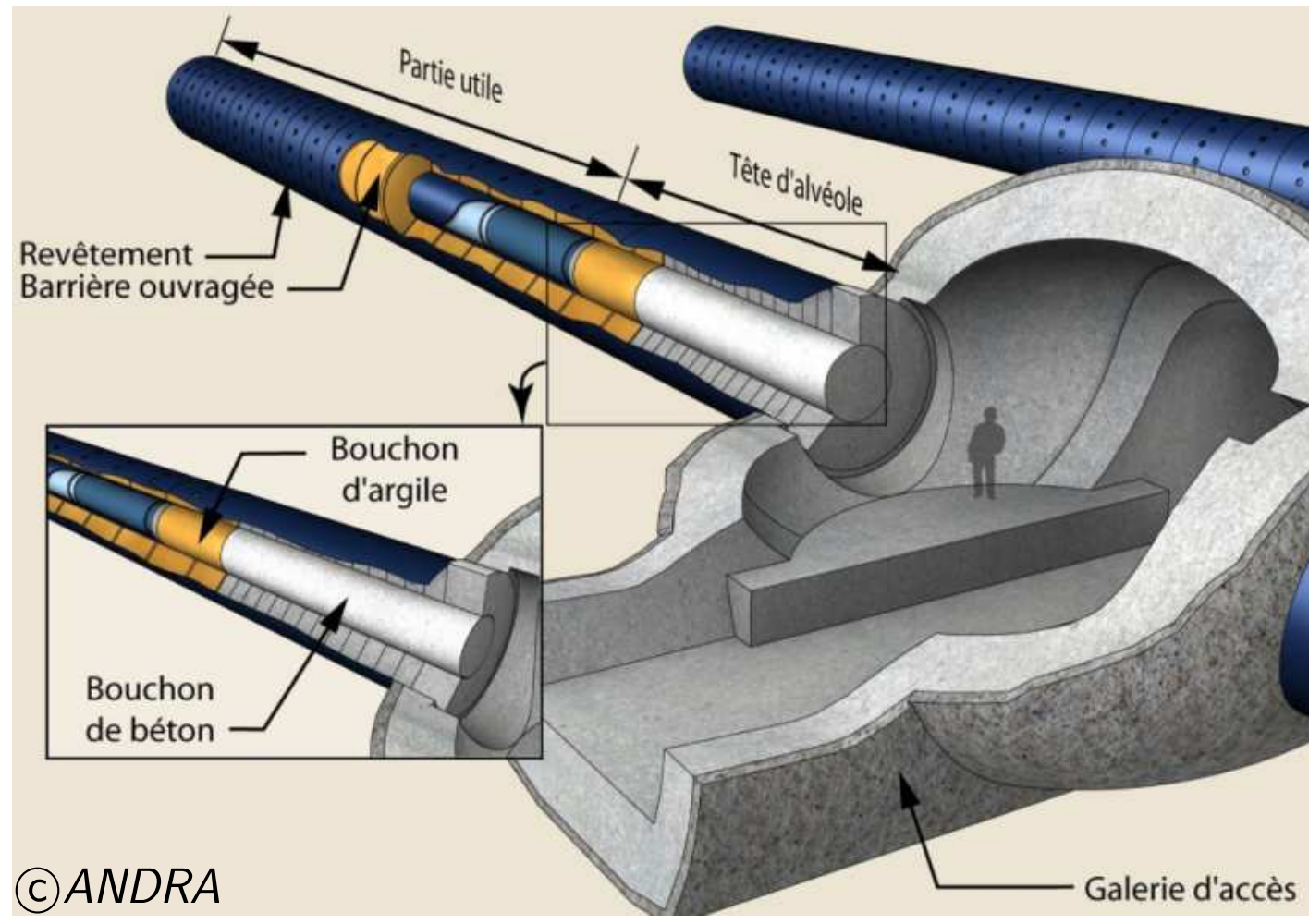
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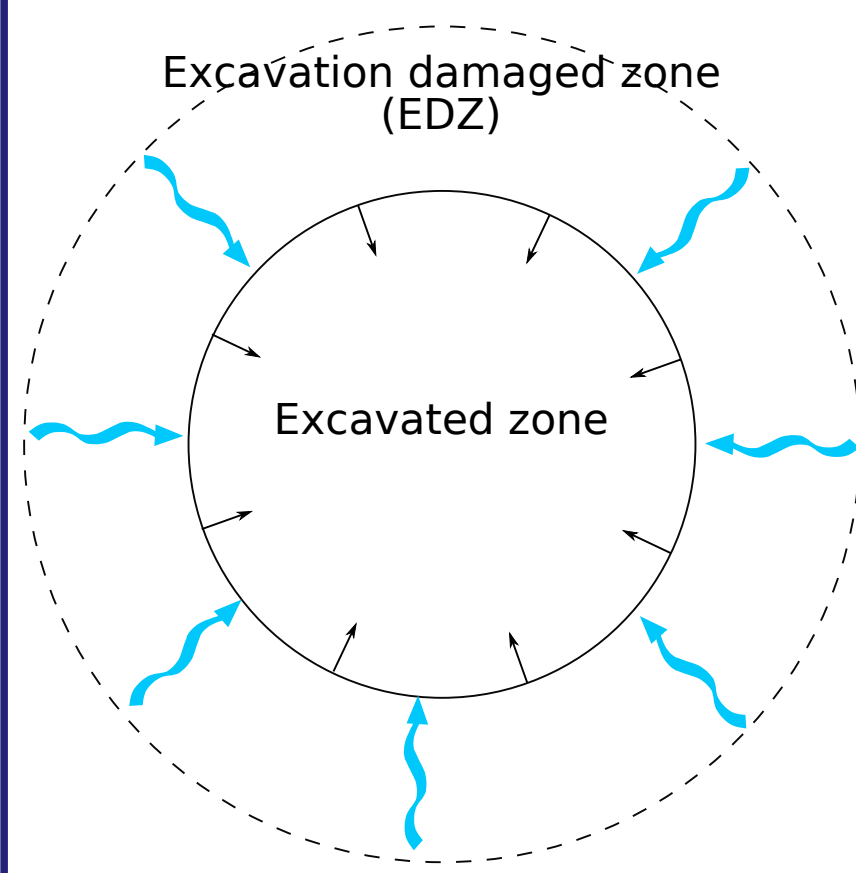


## Context



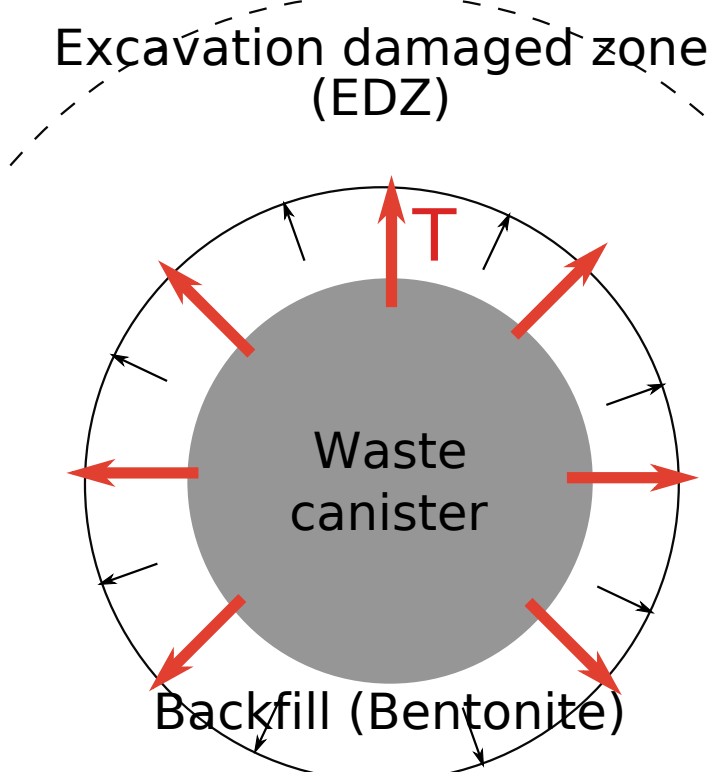
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### Excavation and open-drift stages



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

### Storage stage



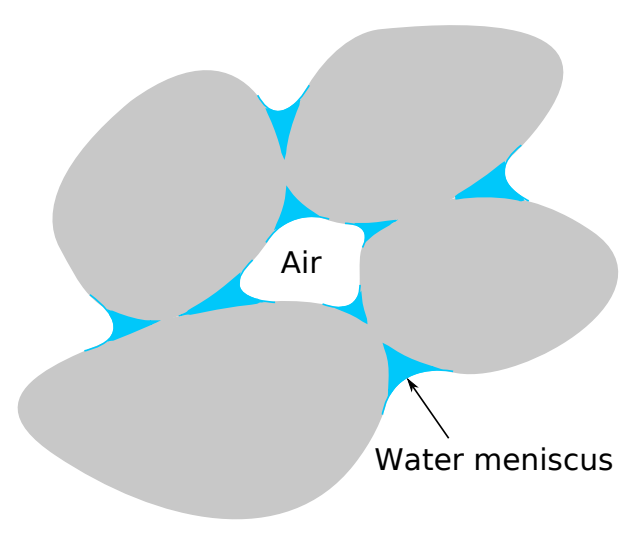
#### Early closure stage

- 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

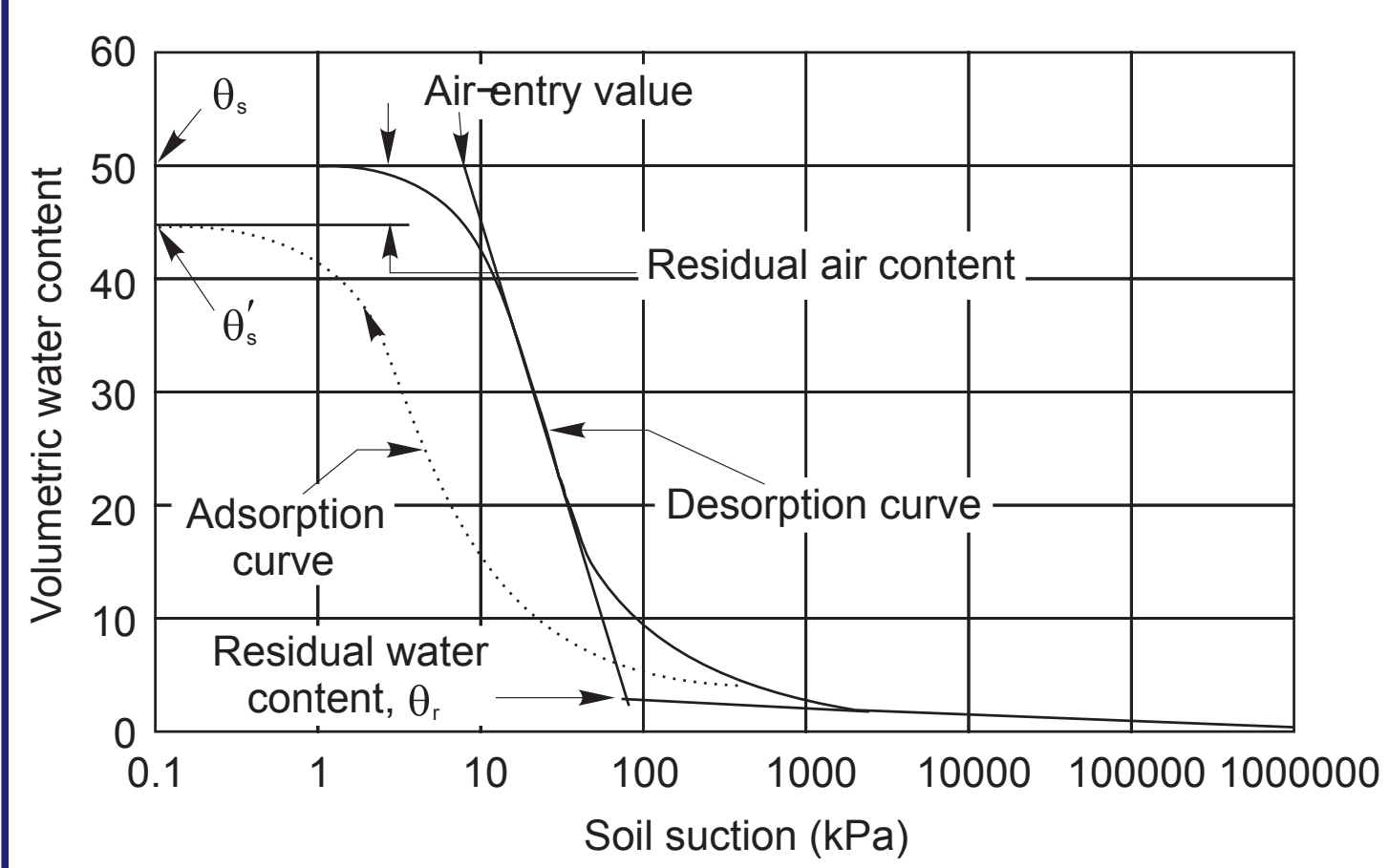
- **Solid:** soil skeleton
- **Liquid:** water, dissolved air
- **Gas:** air and water vapour

### Important parameters

- Stress
- Suction
- Temperature

### Hydraulic behaviour

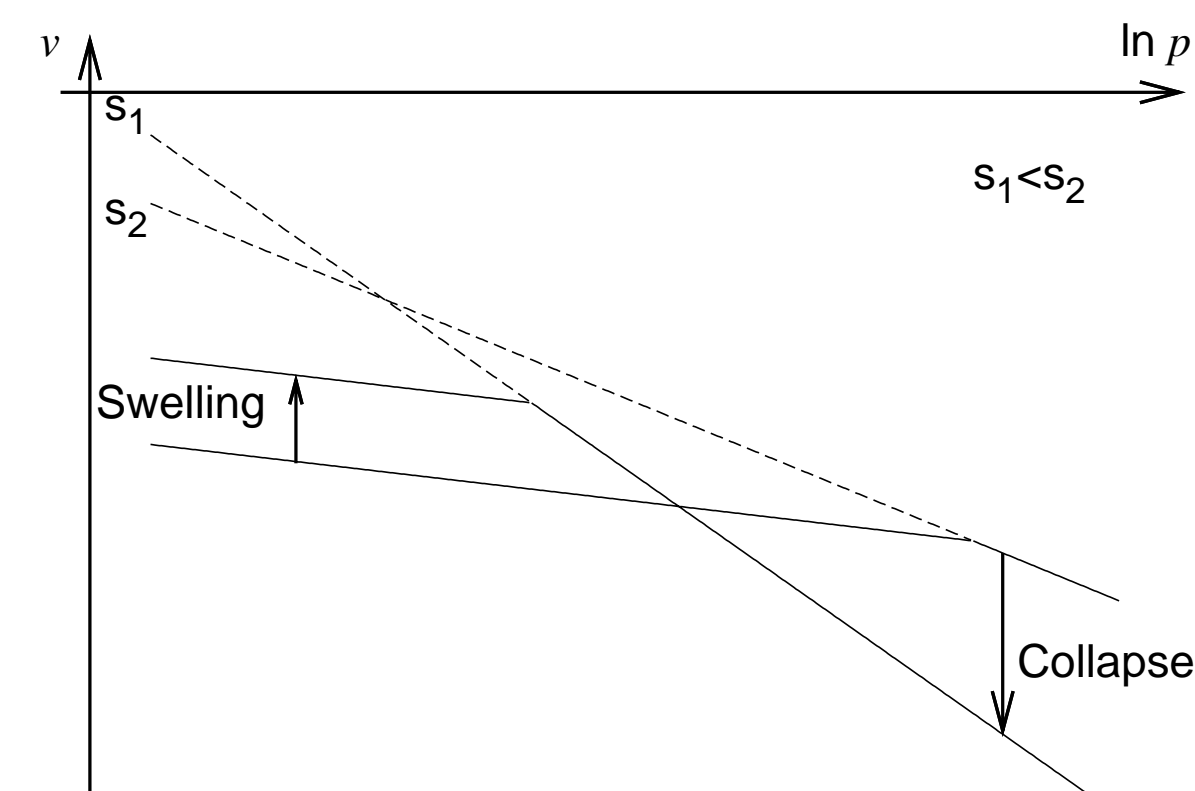
- Hysteresis of water retention curves



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

### Mechanical behaviour

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

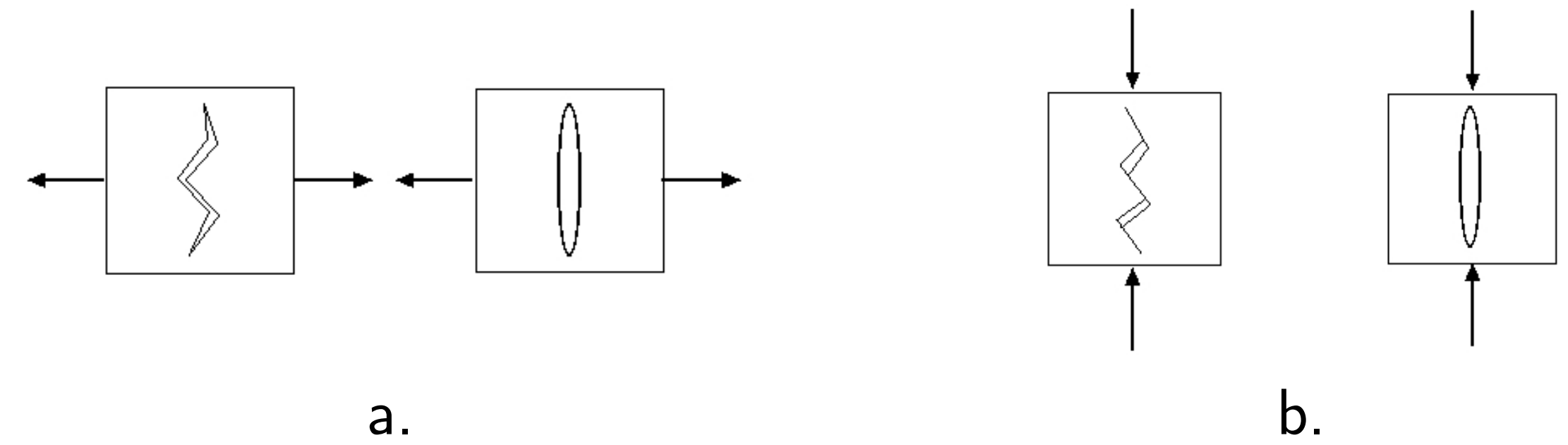


Compression curves. (Alonso, Gens & Josa, 1990)

## 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:  $\Omega = \sum_{j=1}^3 \mathbf{d}_j \cdot \mathbf{\bar{n}}_j \otimes \mathbf{\bar{n}}_j$  (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

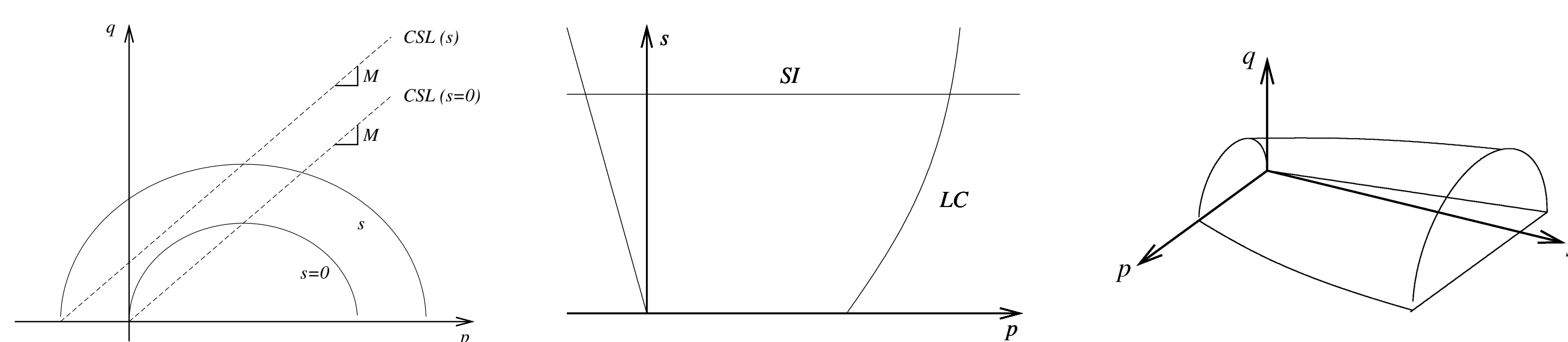
- Homogenisation procedure  $\Rightarrow$  difficulties of use in practical applications

## 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)

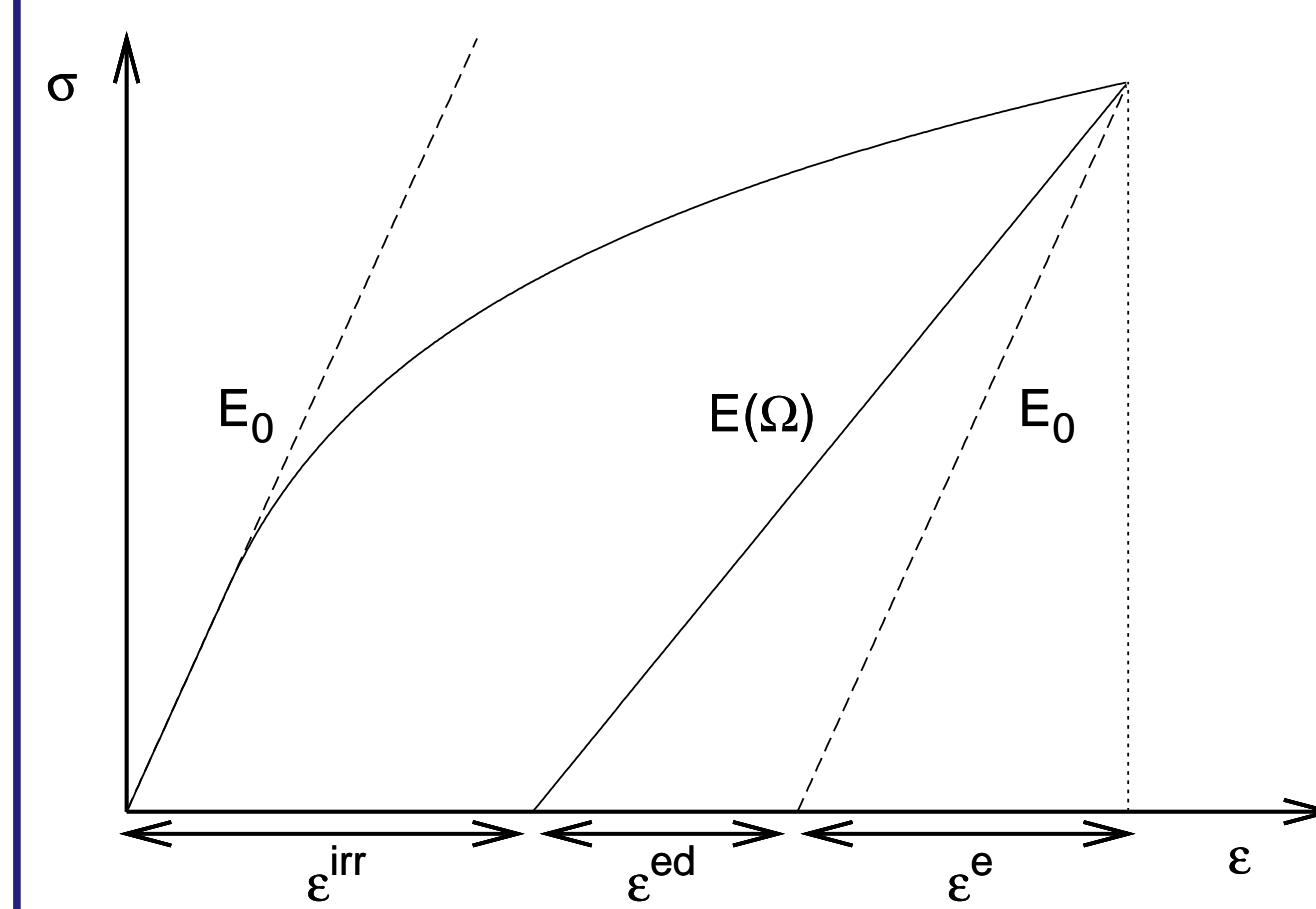
### Choice of stress variables

**Classic models:** use of stress and suction as variables

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

$$\begin{cases} \sigma - (\mathbf{u}_a - \mathbf{S}_r(\mathbf{u}_a - \mathbf{u}_w)) & \longleftrightarrow \epsilon \\ \phi(\mathbf{u}_a - \mathbf{u}_w) & \longleftrightarrow \mathbf{S}_r \end{cases} \quad (\text{Houlsby, 1997})$$

### 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?