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

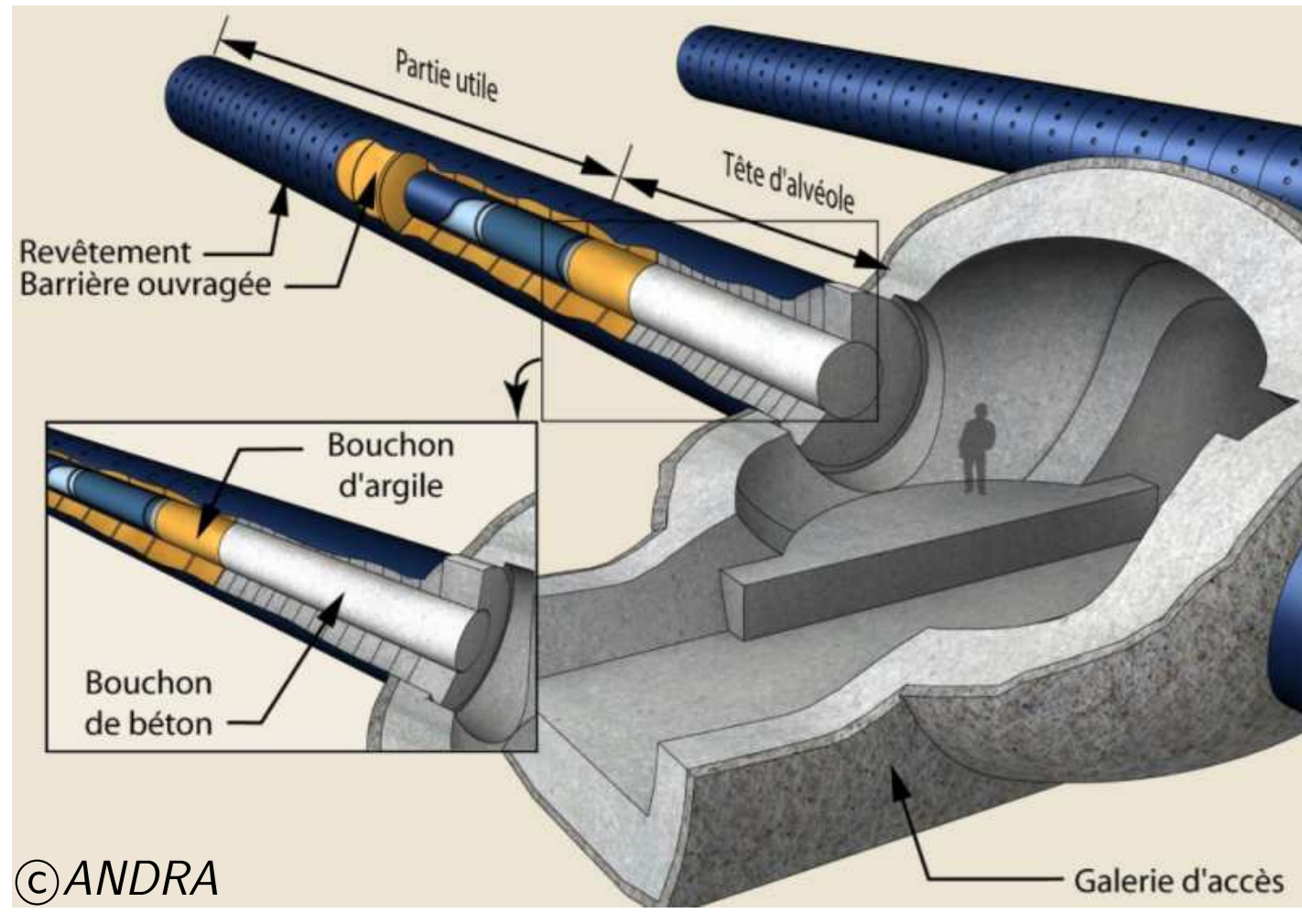
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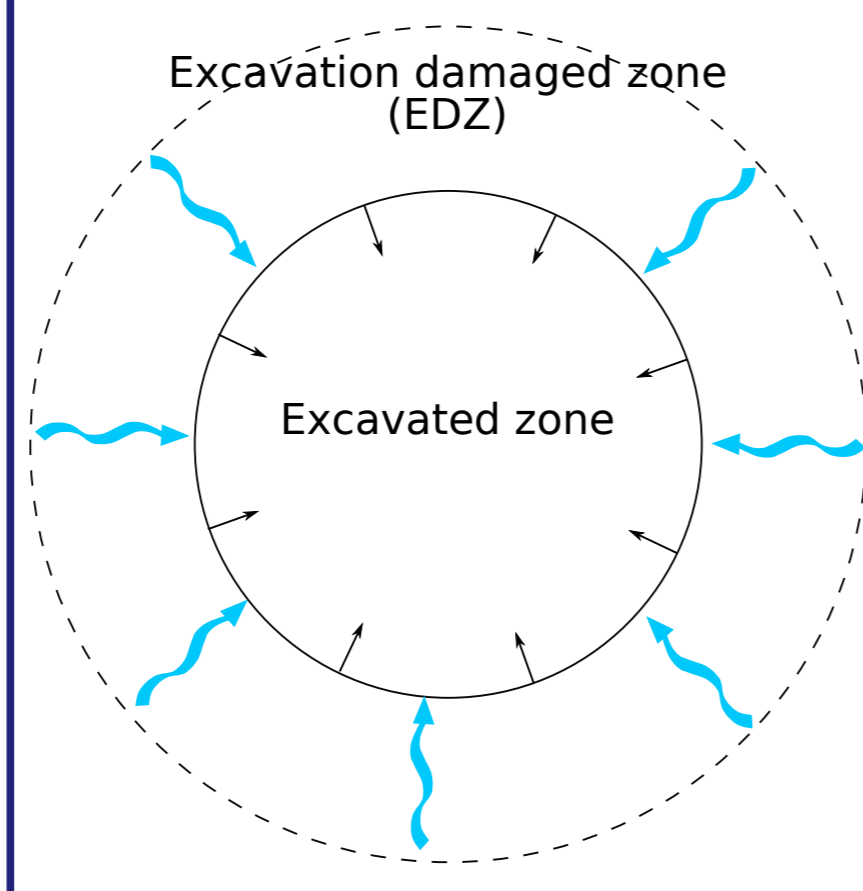


## Context



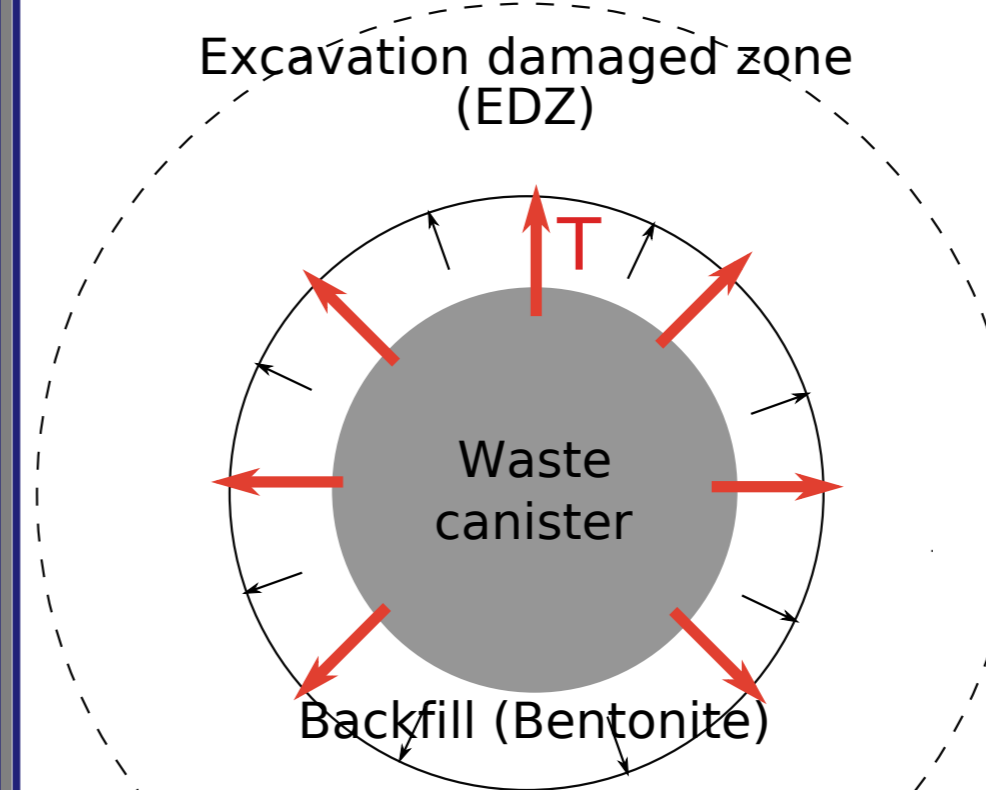
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### Excavation and open-drift stages



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

### Storage stage



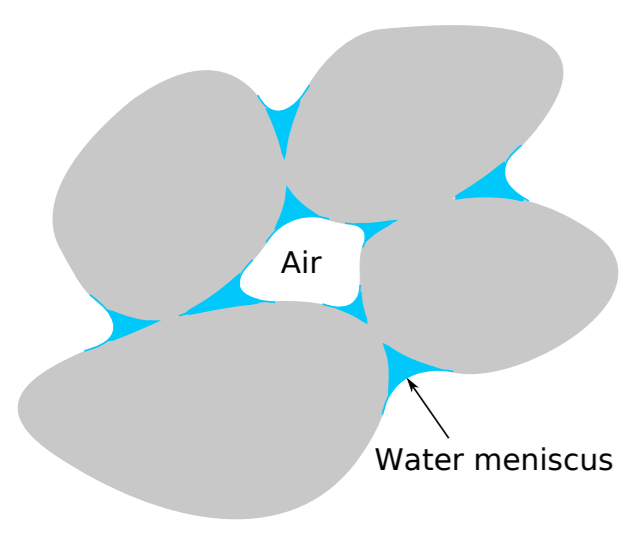
#### Early closure stage

- ▶ 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

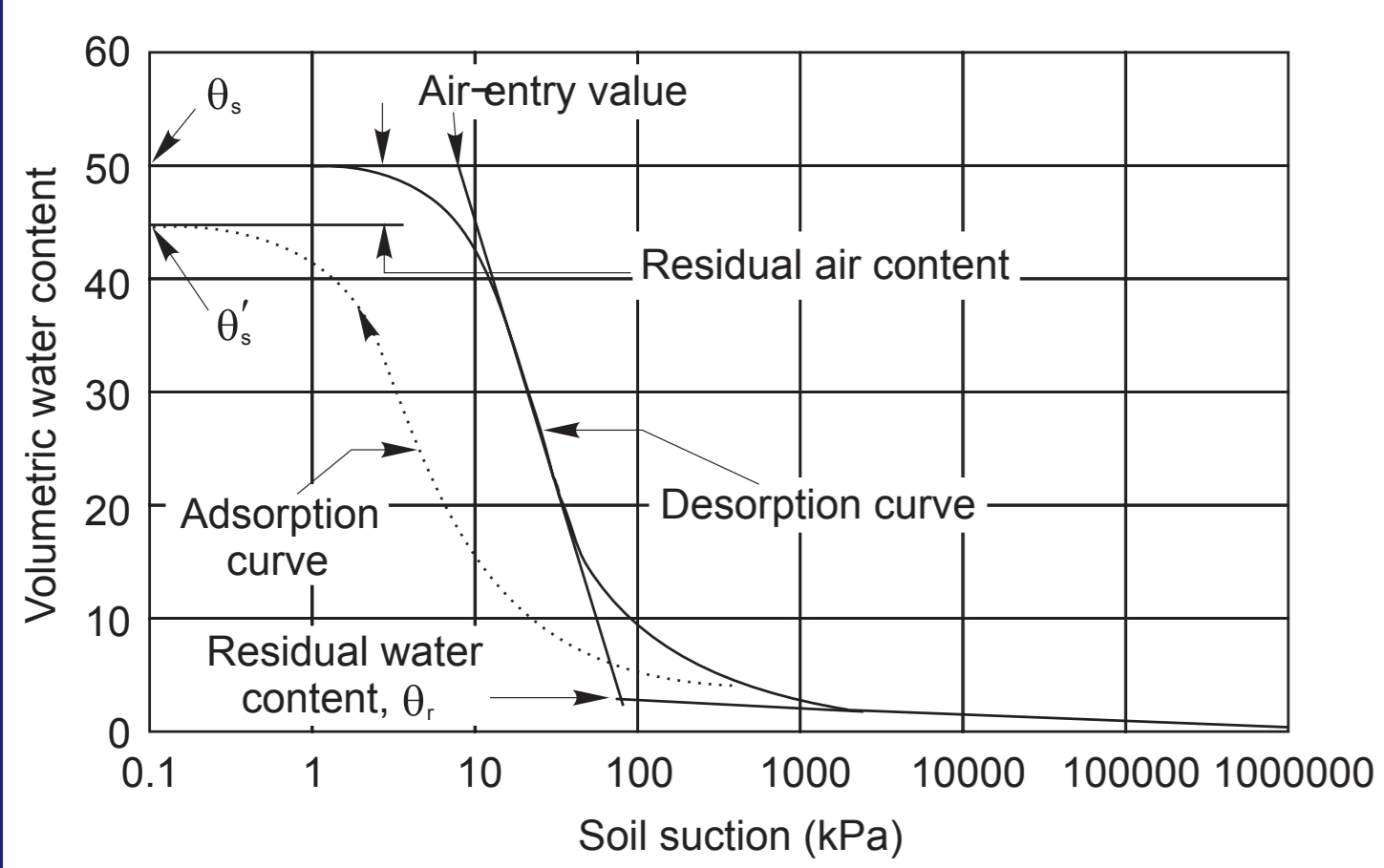
- ▶ **Solid:** soil skeleton
- ▶ **Liquid:** water, dissolved air
- ▶ **Gas:** air and water vapour

### Important parameters

- ▶ Stress
- ▶ Suction
- ▶ Temperature

### Hydraulic behaviour

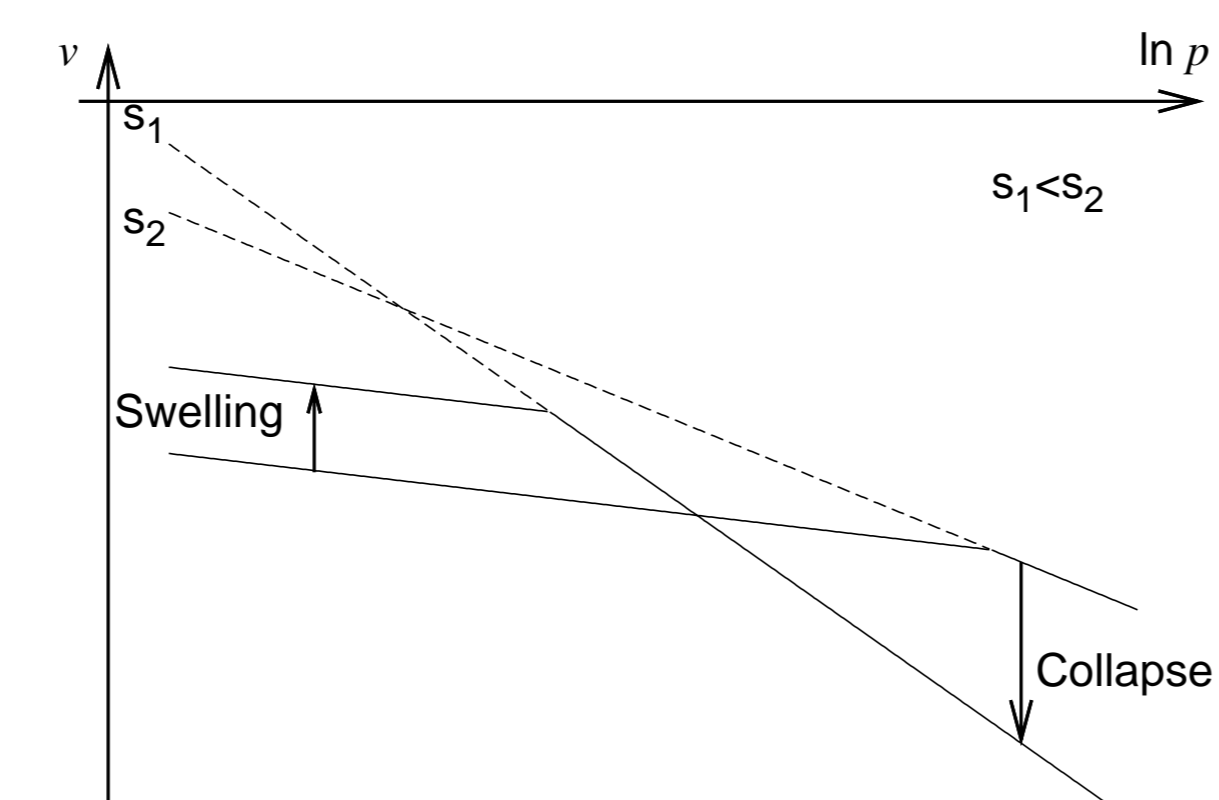
- ▶ Hysteresis of water retention curves



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

### Mechanical behaviour

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

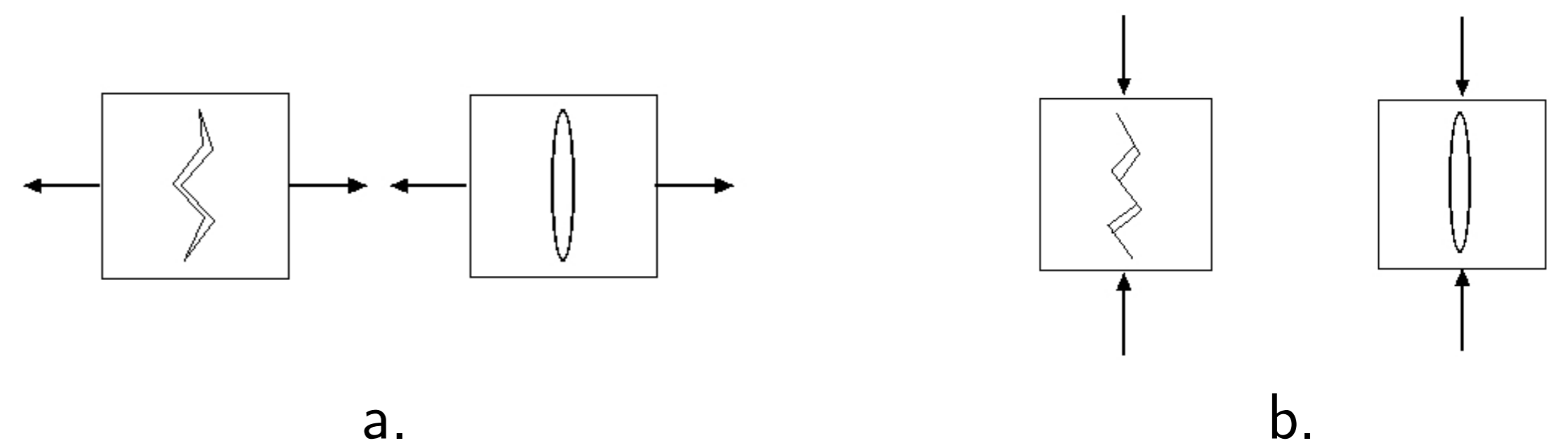


Compression curves. (Alonso, Gens & Josa, 1990)

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

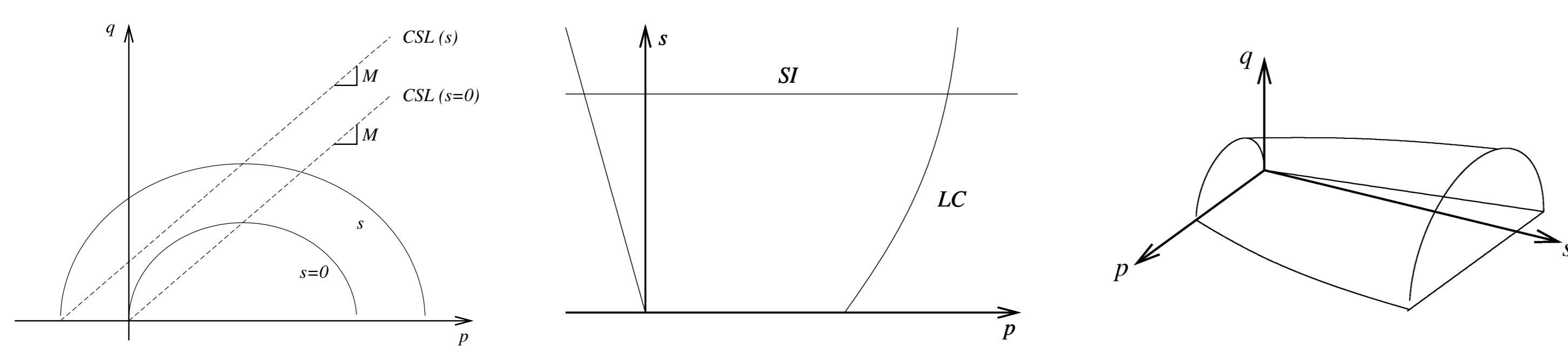
- ▶ Homogenisation procedure  $\Rightarrow$  difficulties of use in practical applications

## 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)

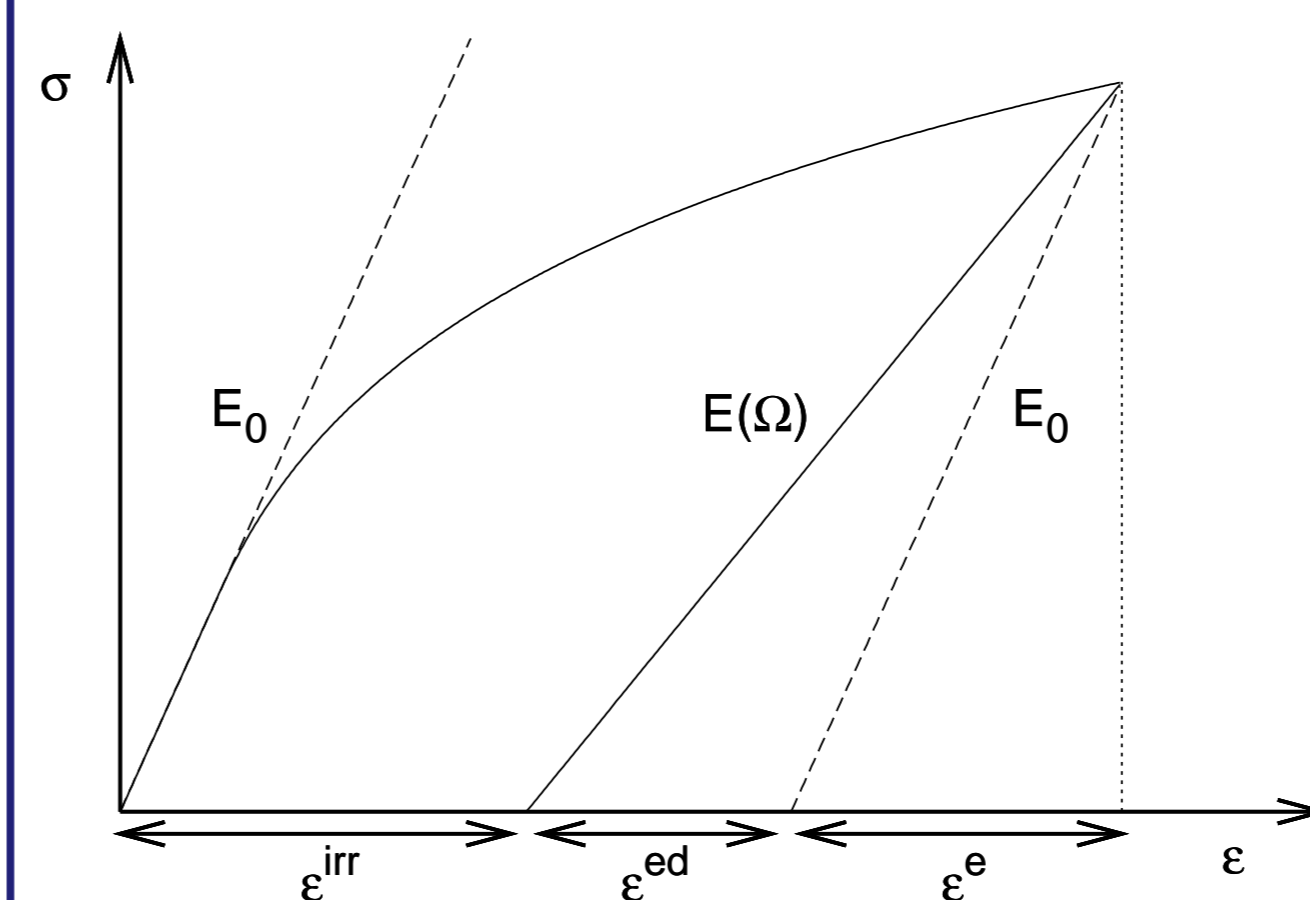
### Choice of stress variables

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

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

$$\begin{cases} \sigma - (u_a - S_r(u_a - u_w)) & \longleftrightarrow \epsilon \\ \phi(u_a - u_w) & \longleftrightarrow S_r \end{cases} \quad (\text{Houlsby, 1997})$$

### 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?