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Application of the intergranular strain concept on barodesy

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Introduction

- Difficulty of modelling the **reloading behaviour** of soils
- ***Ratcheting* effects** in basic hypoplastic and barodetic models with $\mathring{\mathbf{T}} = \mathbf{f}(\mathbf{T}, \mathbf{D}, e)$
- Importance of consideration of the **deformation history**

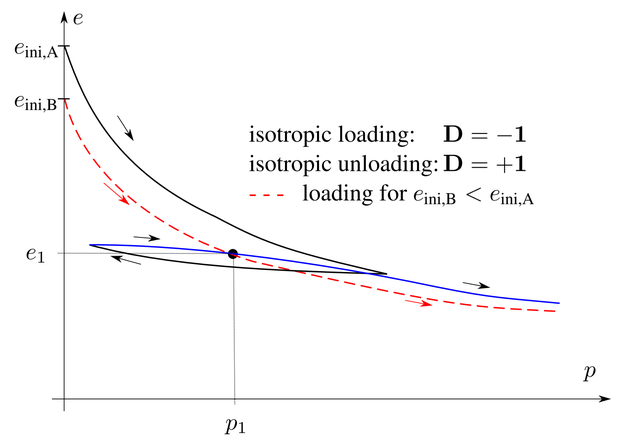


Figure 1: Same void ratio e_1 and pressure p_1 but different stiffness. Figure slightly modified from [1].

The **concept of intergranular strain** has proven as a good approach for hypoplastic models.
⇒ Extension of the intergranular strain concept to **barodesy**.

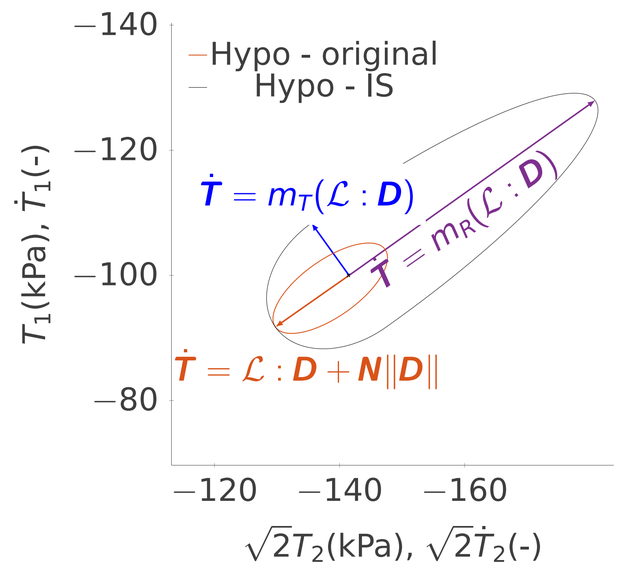
Intergranular strain concept (IS) [2]

- Elastic behaviour in small-strain range
- Stiffness increase for changes in the deformation direction
- *Intergranular strain* tensor δ as memory of former deformations

Basic structure of hypoplasticity:

$$\mathring{\mathbf{T}} = \mathcal{L} : \mathbf{D} + \mathbf{N}\|\mathbf{D}\| \qquad (1)$$

$\mathring{\mathbf{T}}_{el} = \mathcal{L}$:**D** represents an elastic stress rate. Stiffness is increased by scaling factors m_R and m_T.



$\mathbf{D}^0$ actual deformation
δ^0 intergranular strain

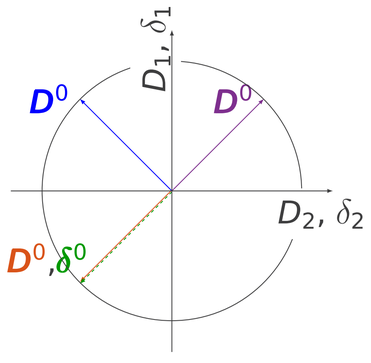


Figure 2: Response envelope for clay hypoplasticity [3] using the intergranular strain concept with predefined intergranular strain direction δ^0.

Barodesy [4, 5]

- Nonlinear material model based on the asymptotic behavour of soil
- Similarities to hypoplasticity
- Stress rate as a function of the actual stress **T**, stretching **D** and void ratio e

$$\mathring{\mathbf{T}} = \mathbf{f}(\mathbf{T}, \mathbf{D}, e) \qquad (2)$$

In contrary to hypoplasticity, no explicit formulation for parts linear in **D** is available.

How to obtain elastic behavior for intergranular strain? [6]

Required material behaviour:

- Reversible stress for small strain cycles
- Incremental elastic behaviour
- Consistent to barodesy

Defining elastic $\mathring{\mathbf{T}}_{\text{el}}$ and non-elastic $\mathring{\mathbf{T}}_{\text{ne}}$ parts

$$\mathring{\mathbf{T}} = \mathring{\mathbf{T}}_{\text{el}} + \mathring{\mathbf{T}}_{\text{ne}} \qquad (3)$$

IEM: Internal elastic model

Incremental elastic behaviour by using **the odd part** of the barodetic function:

$$\mathring{\mathbf{T}}_{\text{el}}(\mathbf{T}, \mathbf{D}, \mathbf{Q}) = -\mathring{\mathbf{T}}_{\text{el}}(\mathbf{T}, -\mathbf{D}, \mathbf{Q}), \qquad (4)$$

- Adopting the IS interpolation scheme
- Using the properties of barodesy

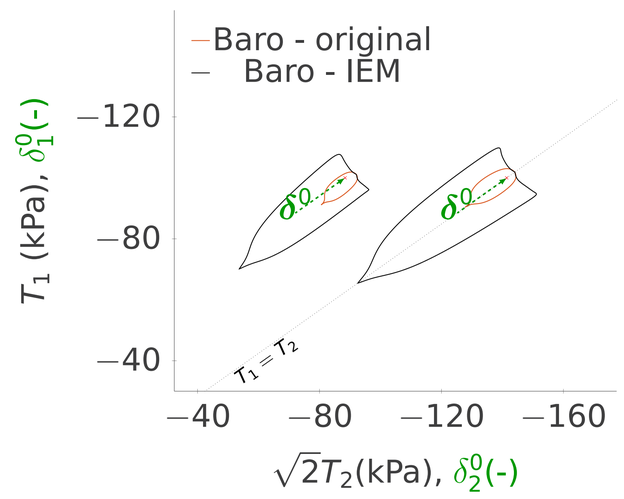


Figure 3: Response envelopes of barodesy using the IEM-approach

EEM: External elastic model

Additional **external elastic model**:

$$\mathring{\mathbf{T}}_{\text{el}} = 2G\left(\mathcal{I} + \frac{\nu}{1-2\nu}\mathbf{I}\otimes\mathbf{I}\right) : \mathbf{D} \qquad (5)$$

- Interpolation between elastic model and barodesy
- Calibration of the elastic parameters on barodetic stress response

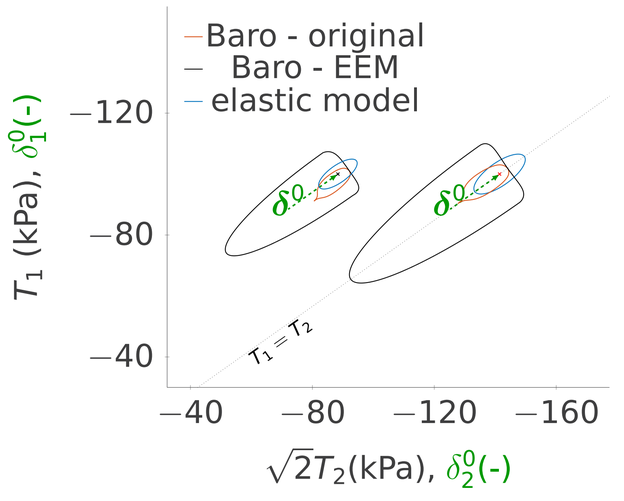
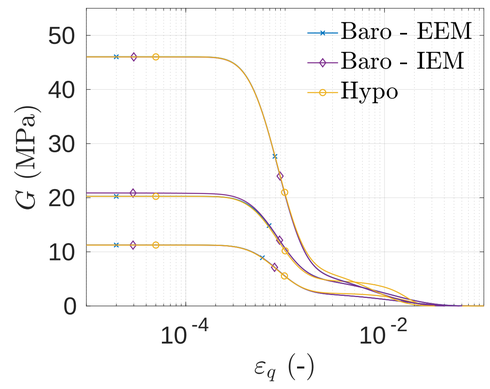


Figure 4: Response envelopes of barodesy using the EEM-approach

Simulation results



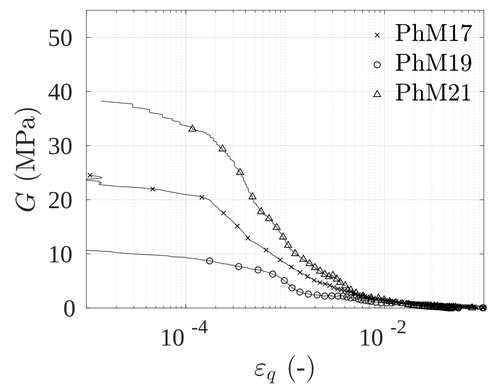


Figure 5: Stiffness degradation using the IS-approaches compared with clay hypoplasticity [3] and experiments from [7]

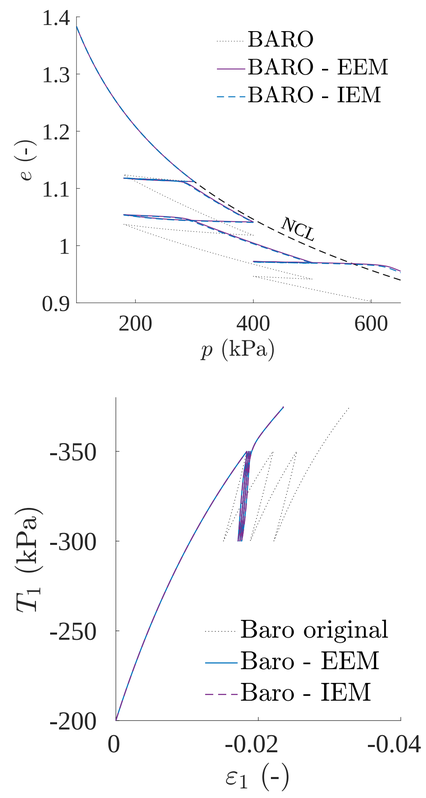


Figure 6: Simulated element tests with barodesy

Summary & Outlook

- Application of the IS-concept to barodesy
- Approaches applicable for all models formulated as rate equations
- Main problems of the IS-concept still occurring (e.g. overshooting, ratcheting...)
- Outlook: Possibility of further development of the IS Model

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