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U.PORTO

FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

Modelling the long term cyclic behaviour of Porto silty-sand stabilised with cement

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3rd year PRODEC

Supervisors

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Introduction

- Studied material: Silty sand originated by complete degradation of Porto granite saprolitic soil (Viana da Fonseca, 1996, 2003);
- Uncemented and cemented mixtures with 3%, 5%, and 7% of Portland cement (CEM I 52,5 R) and two initial void ratios (0.60 and 0.75)
- Objectives:
  - Experimental study: complete set of long term cyclic triaxial tests (1 million cycles)
  - Development and calibration of a new constitutive model with kinematic hardening and destructuration

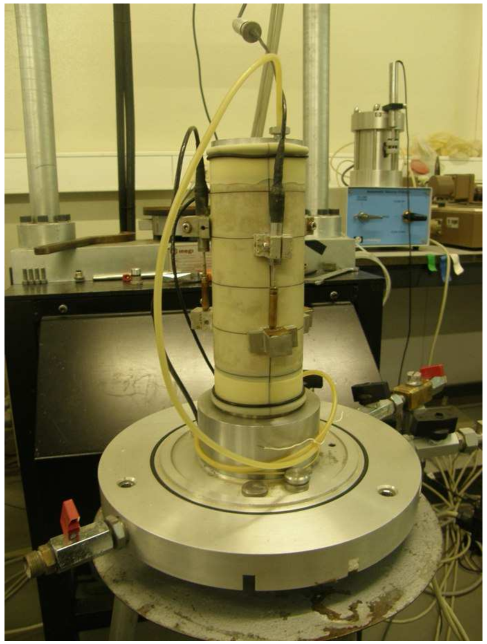
Cemented soil: mechanical behaviour and testing

- Mechanical behaviour: increase in preconsolidation pressure, strength and stiffness (Leroueil & Hight, 2003)
- The mixture was already studied in monotonic and static conditions by Rios (2011) in LabGeo of FEUP
- Soil-cement behaviour in cyclic conditions
  - Lack of studies on long term behaviour (>20000 cycles)
  - Lack of a theoretical base for constitutive modelling

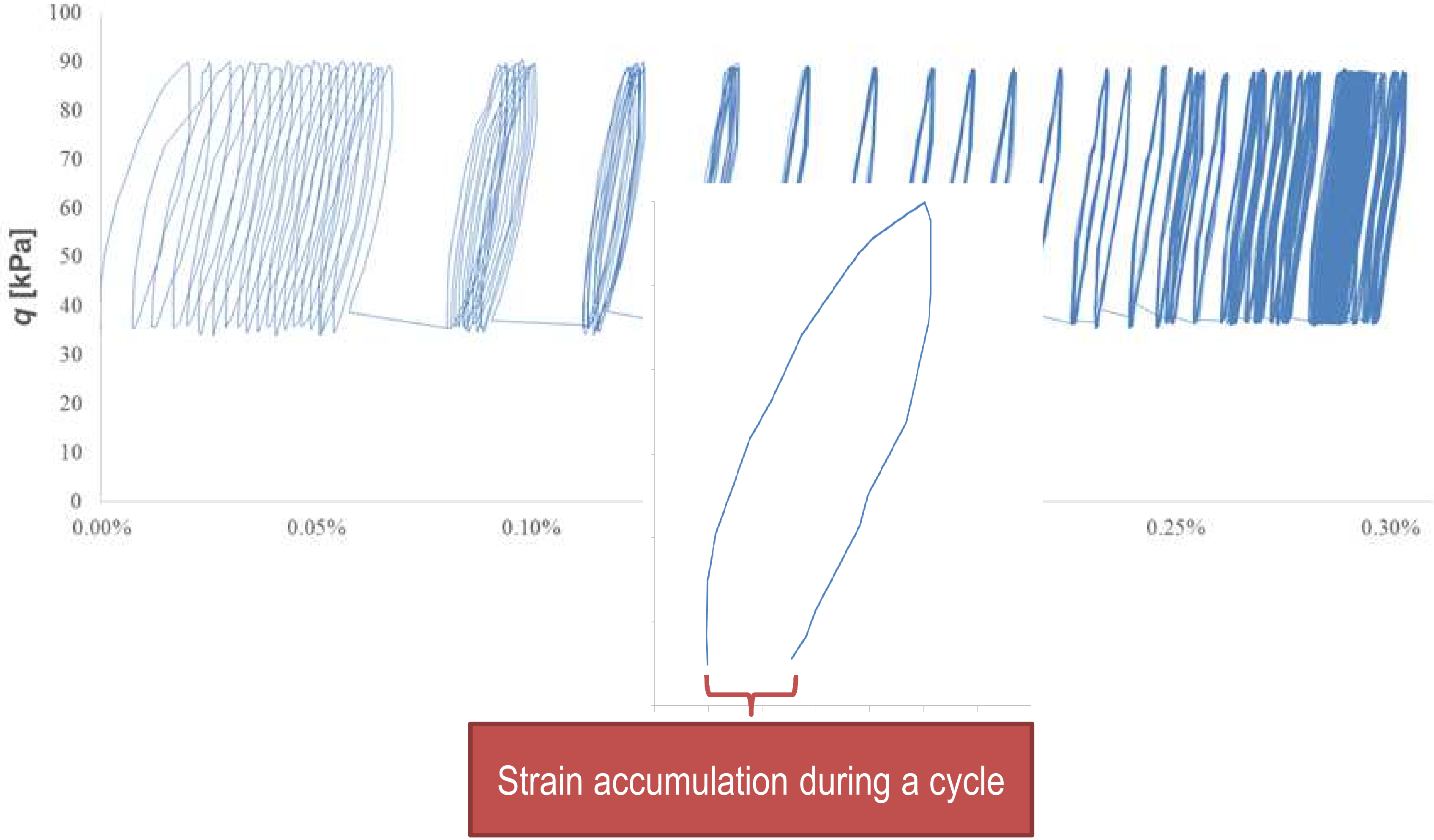
Necessity for a long term experimental program and for a new approach in modelling

Experimental program: cyclic triaxial tests

- Long duration → up to 10^6 cycles at 1 Hz
- 8 different soil-cement mixture: four different cement contents (0%, 3%, 5%, 7%) and two initial void ratios (0.60 and 0.75)
- Cyclic deviatoric stress applied in sinusoidal form in a range from 10% to 20% of the ultimate deviatoric stress (Rios, 2011)
- Tests in drained and undrained conditions
- Three different confining pressures: low (dry side of CS), high (wet side), intermediate



Results: hysteretic cycle



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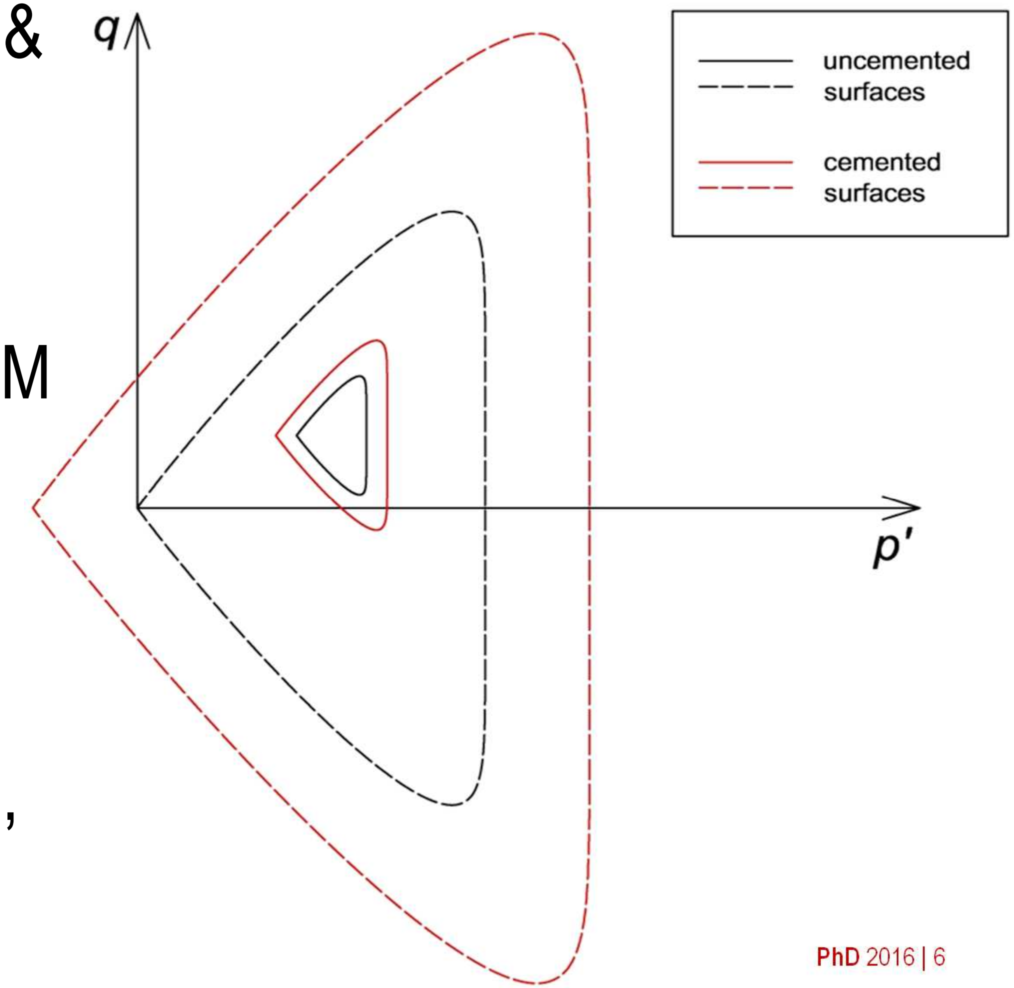
Constitutive modelling

- Kinematic hardening (Bubble model, Al-Tabbaa & Wood, 1989) + Destructuration (Gens & Nova, 1993)
- Yielding surface from CASM model (Yu, 1998) already calibrated in monotonic conditions (Rios, 2016)
- Six parameters need to be calibrated (R, B, Ψ, X_0, b_1, b_2)



Model calibration: parameters

Model	Parameter	Meaning
CASM (Yu, 1998)	κ, ν, λ, N, M	Classic parameters of the Critical State theory framework
	n, r	Additional shape parameters for the yield surface
Bubble (Al Tabbaa & Wood, 1989)	R	Ratio between bubble and reference surface
	B	Interpolating parameters regulating the magnitude and variation of the kinematic hardening modulus
	Ψ	
Bonding (Gens & Nova, 1993)	X_0	Initial level of bonding
	b_1	Parameters linking the development of plastic deformation with the loss of bonding
	b_2	

Parameters to calibrate

Implementation of the model in MATLAB®

Input of the model parameters including size and position of the bubble and initial level of bonding. Definition of the cyclic stress path $[\sigma_f' - \sigma_i']$

Calculation of the yielding point $[\sigma_Y']$ using an iterative method and definition of purely elastic and elasto-plastic domain

Elastic domain: computation of elastic strain increment through **INTEGRATION** of the elastic constitutive relations

$$[\Delta\varepsilon^E] = [C^E]\,[\Delta\sigma']$$

Elastoplastic domain $[\sigma_f' - \sigma_Y']$ through **SUBSTEPPING ALGORITHM**:

- A try load increment is set: $[\Delta\sigma_{ss}'] = \Delta T\,[\sigma_f' - \sigma_Y']$

- Numerical integration of the constitutive equations is performed on the load increment with **MODIFIED EULER METHOD**

$$[\Delta\varepsilon_{ss}^P] = [C^P]\,[\Delta\sigma_{ss}']$$

If the error made in the numerical integration is less than the user defined tolerance ($||E|| < SSTOL$) then the program proceeds to next step, else the load increment is reduced ($\Delta T_{new} < \Delta T$) and the iteration is repeated

Calculation of the accumulated strain

Repeat for n cycles

Plotting results in a .csv text file

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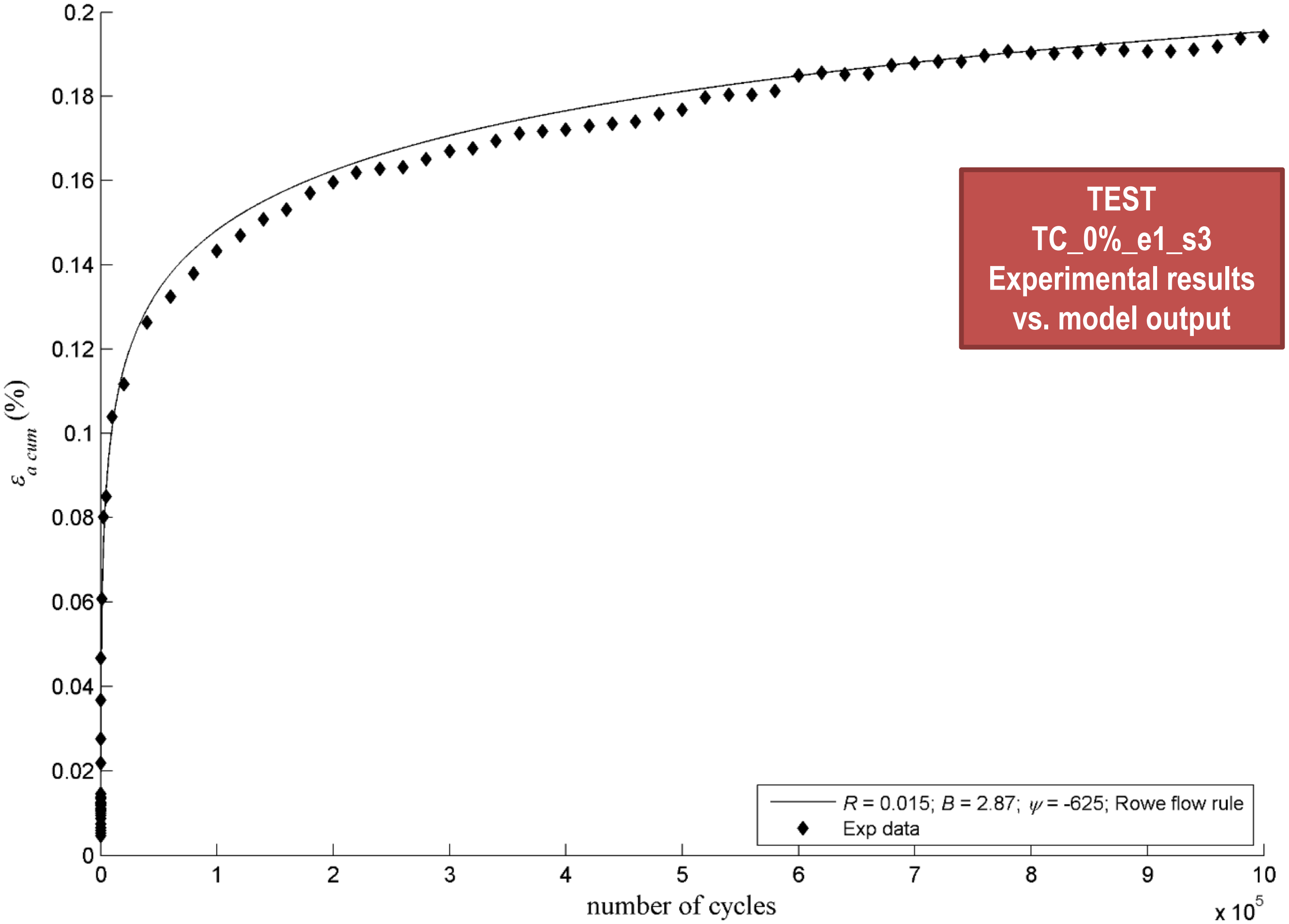
Example of a result

Axial Strain



TEST
TC_0%_e1_s3
Experimental results
vs. model output

Conclusions

- The experimental program confirmed the importance of the high number of cycles, since the material keep evolving far beyond 20000 cycles
- The model is capable of reproducing well the evolution of axial strain. Nevertheless, volumetric strain is not represented as well as the axial strain. To overcome this drawback two solutions can be adopted:
  - Change the flow rule (dilatancy)
  - Change the isotropic hardening rule (extra parameters would be requested)