On the fundamental relation between soil creep and cyclic pile-soil response

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Background

- Pile foundations are often used for the support of infrastructure (such as railways and roads) on soft soils.
- The piles are often floating piles and hence the bearing capacity is governed by the shaft resistance (=**displacement problem**).
- The current design methods are rather conservative for static loads, incomplete for cyclic loads
- There may be detrimental effects on the creep rate when the pile is subjected to cyclic loads, leading to significant **strength degradation** and **long-term deformations**.
- Also, the cyclic and dynamic pile-soil interface behaviour in sensitive soft soils has not been systematically studied.

Aim

- The aim of the proposed project is to study the interplay between creep and cyclic pile-soil interaction in sensitive soft soils.
  - Fundamental research on the effect of cyclic loading perturbations on the creep rate in soft soils, and its effect on the long term stability of floating piles for static and cyclic loads.
- Focus will be on incorporating cyclic loading effects
    - **viscoplastic model (creep + cyclic effects)**

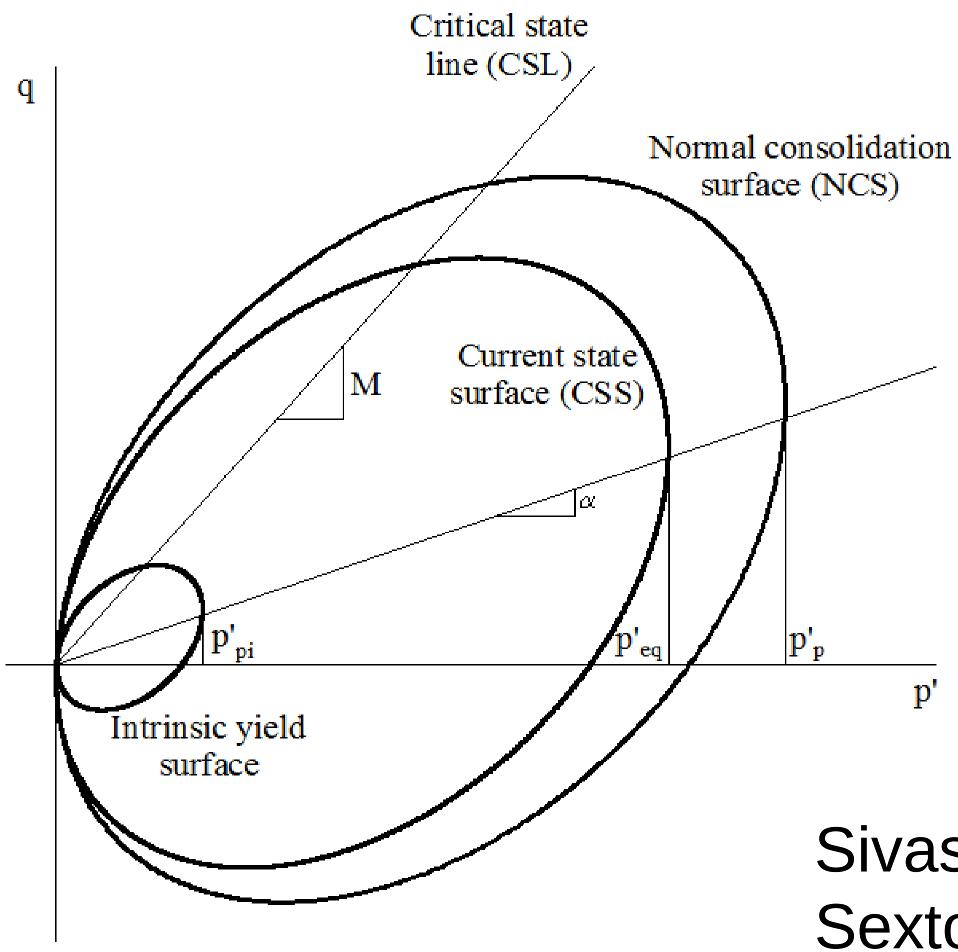
Objectives

- Element testing of high quality soft clay under long term static loading with small cyclic load perturbations.
- Advanced cyclic soil-structure interface testing using constant normal stiffness (CNS) shear box. This allows for systematic study of pile-soil behaviour under appropriate boundary conditions.
- Advanced constitutive and numerical modelling of creep and pile deformation phenomena in soft clays

Methodology & Expected result

- Methodology
  - Literature review (models & data)
  - Basic creep model (Sivasithamparam et al. 2015)
    - UMAT for general FE codes (Plaxis and Tochnog)
    - Automated initial parameter set
    - Theoretical ranges for parameters (Gras et al. submitted)
    - User independent optimisation of parameters
  - Cyclic creep model (Bubble-Creep)
  - Accumulation model (UMAT for general FE) – developed as part of sister project (Deformations of piled slab track on soft soils) & calibration against soft soil data (Wichtmann data on Onsøy clay)
- Expected result
  - Improved predictions of floating pile systems on soft soils

Creep-SCLAY1S model



- Anisotropy (initial & evolution)
- Bonding and destructuration
- Rate-dependency

Sivasithamparam et al. 2015, Sexton et al. 2016

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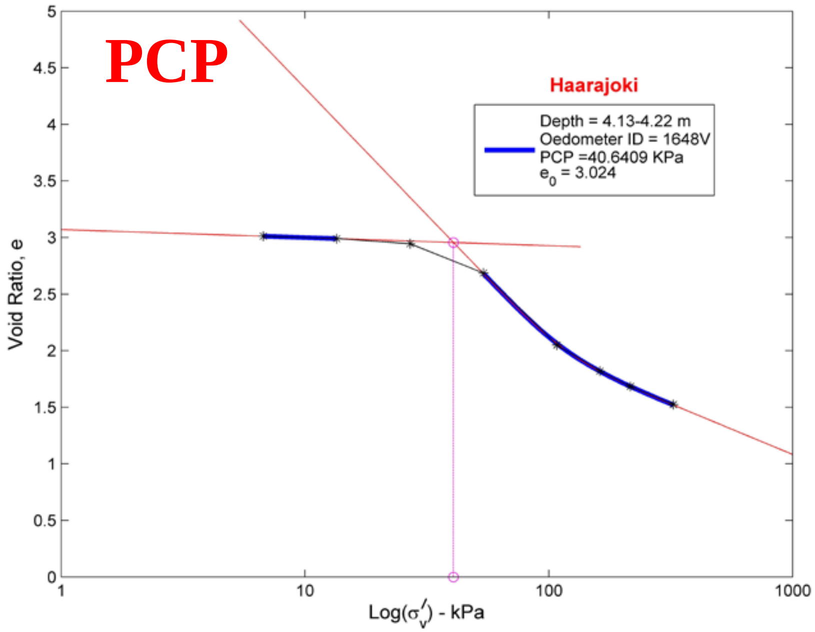
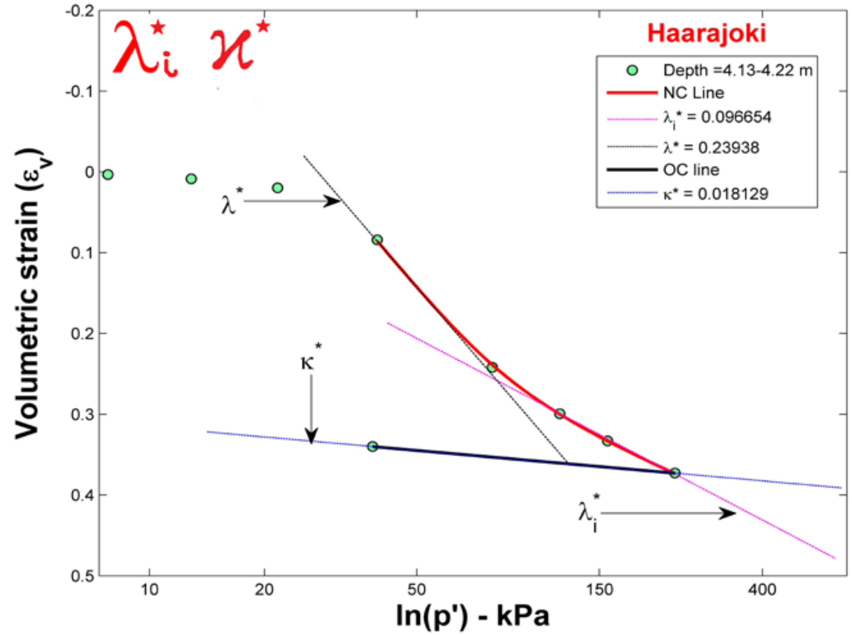
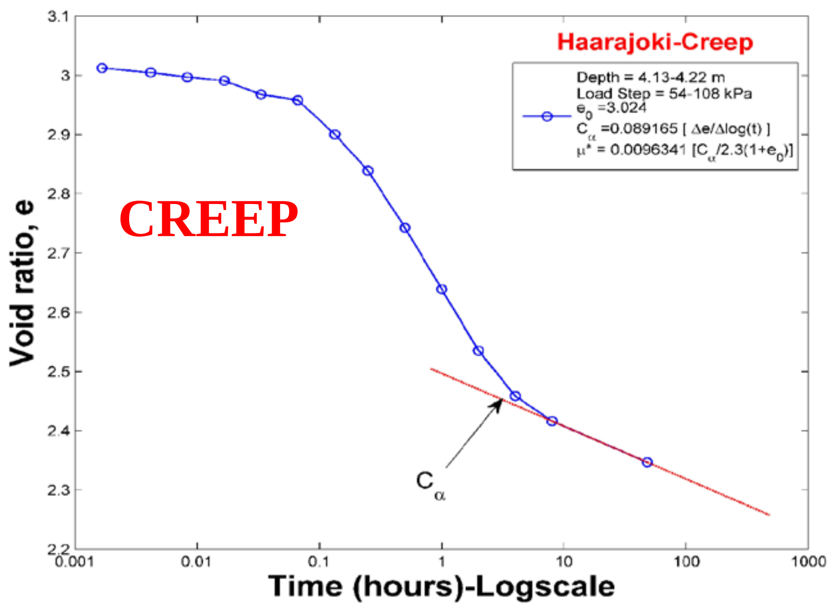
Branschsamverkan i Grunden

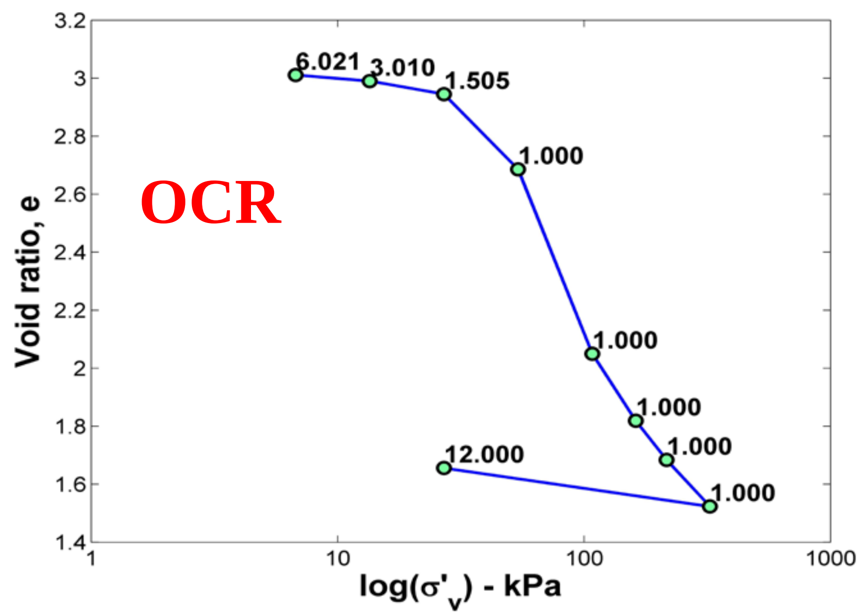
But model has many parameters

Parameter	Definition	unit	value
λ_i^*	Modified intrinsic compression index	[-]	0.076
κ^*	Modified swelling index	[-]	0.011
ν	Poisson's ratio	[-]	0.15
M_c	Stress ratio at critical state in triaxial compression	[-]	1.23
M_e	Stress ratio at critical state in triaxial extension	[-]	0.80
ω	Rate of rotation	[-]	200
ω_d	Rate of rotation due to deviator strain	[-]	0.56
a	Rate of destructuration	[-]	10
b	Rate of destructuration due to deviator strain	[-]	0.30
OCR	Over-consolidation ratio	[-]	1.1
e_0	Initial void ratio	[-]	1.80
α_0	Initial anisotropy	[-]	0.47
χ_0	Initial amount of bonding	[-]	10
μ_i^*	Modified intrinsic creep index	[-]	0.005
τ	Reference time	[d]	1


PCP
Haarajoki
Depth = 4.13-4.22 m
Oedometer ID = 1648V
PCP =40.6409 KPa
e0 = 3.024
Void Ratio, e
Log(σ'v) - kPa
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1
10
100
1000

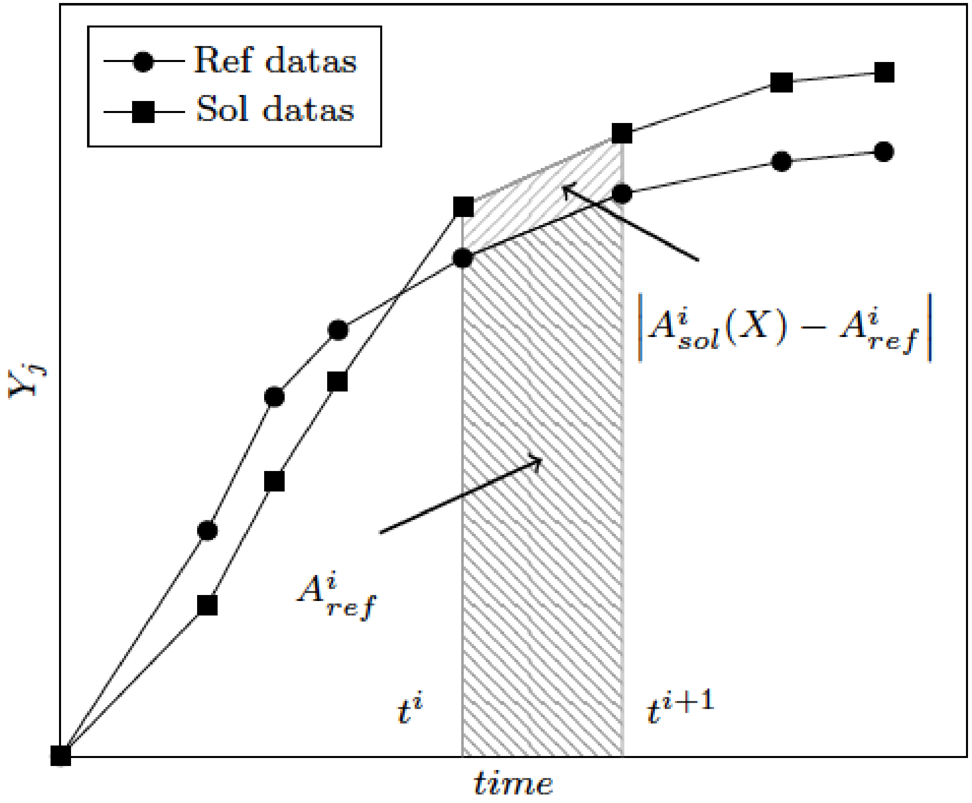

λ*i κ*
Haarajoki
Depth =4.13-4.22 m
NC Line
λi* = 0.096654
λ* = 0.23938
OC line
κ* = 0.018129
λ*
κ*
λ*i
Volumetric strain (εv)
ln(p') - kPa
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
10
20
50
150
400


Haarajoki-Creep
Depth = 4.13-4.22 m
Load Step = 54-108 kPa
e0 =3.024
Cα =0.089165 [Δe/Δlog(t)]
μ* = 0.0096341 [Cα/2.3(1+e0)]
CREEP
Cα
Void ratio, e
Time (hours)-Logscale
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
0.001
0.01
0.1
1
10
100
1000


OCR
6.021
3.010
1.505
1.000
1.000
1.000
1.000
1.000
12.000
Void ratio, e
log(σ'v) - kPa
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1
10
100
1000

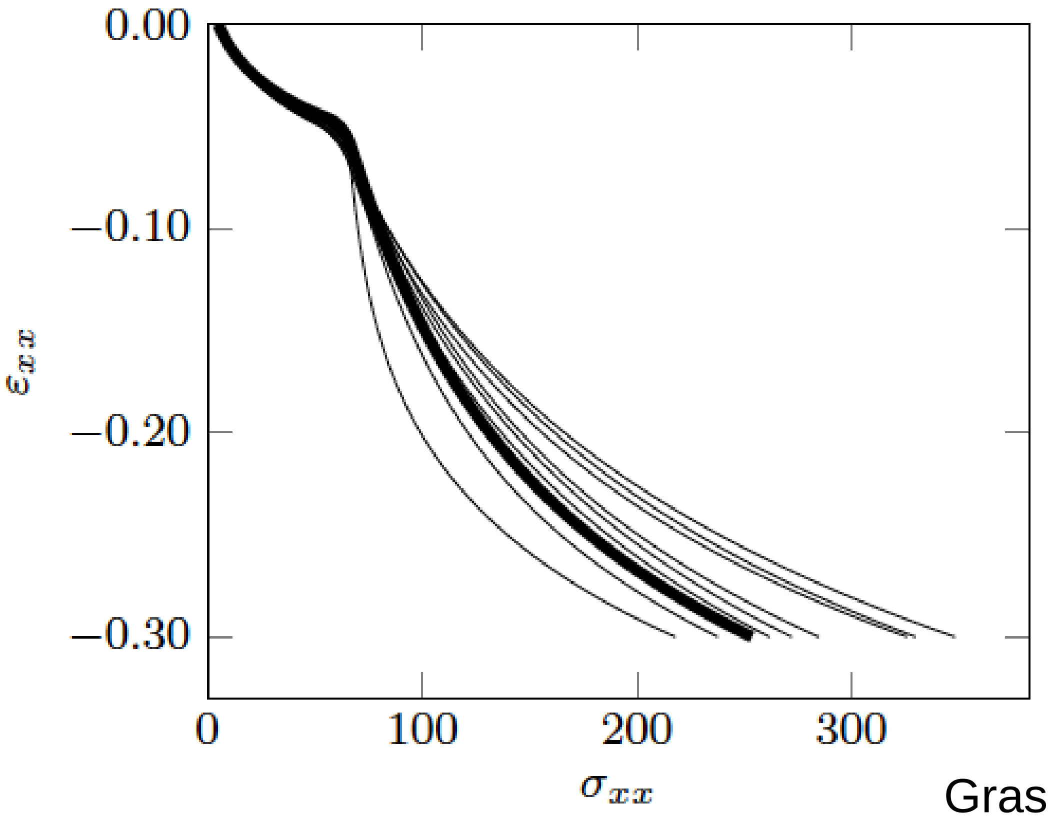
Optimisation

- Minimising error function, use data from several tests using multiple object functions



Optimisation

- Uniqueness, however, is an issue when the parameter sets are compared for a test that is not used in calibration.

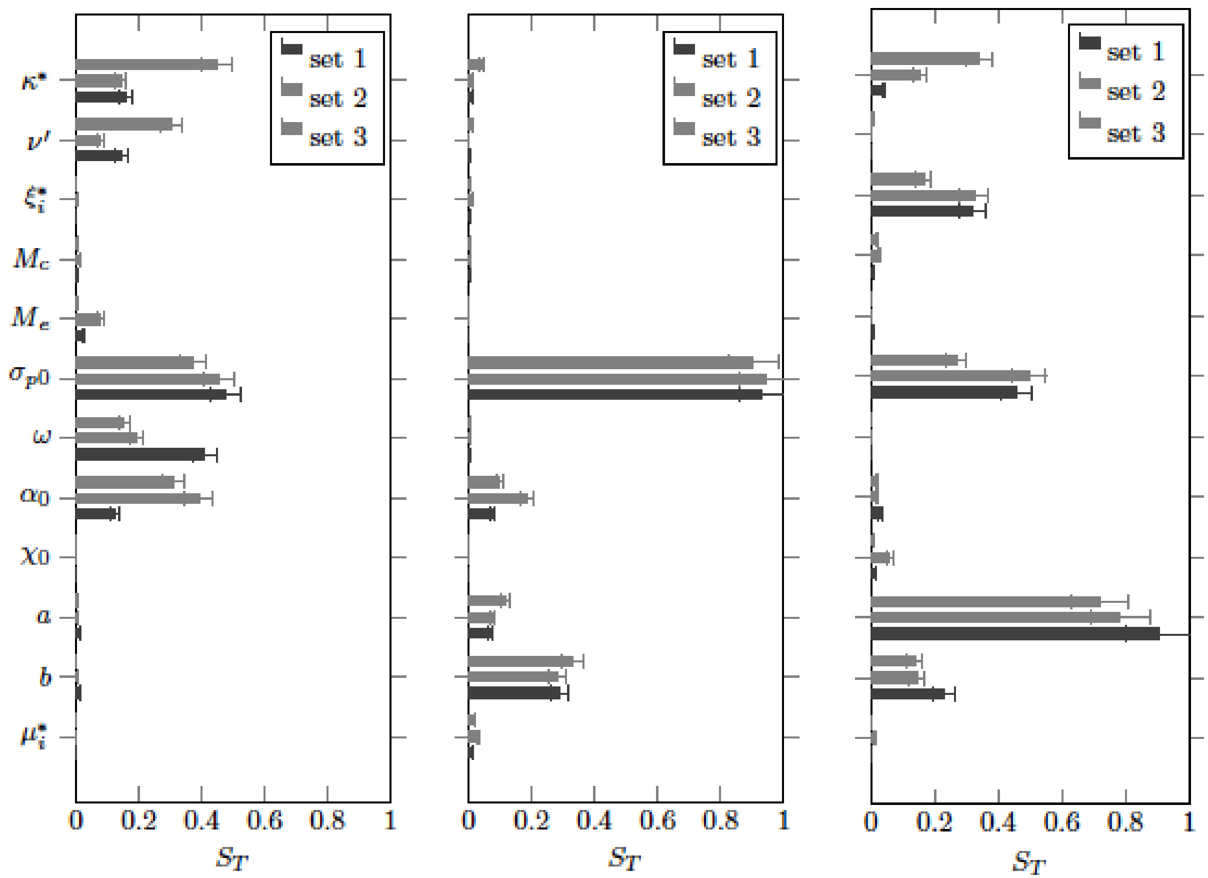


Gras et al, in preparation

Optimisation

- Clever optimisation
  - Only optimise the model parameters that matter for the target function
  - Do notoptimise trusted values (M, λ_i).
- This requires a sensitivity analysis using best estimate for uncertainties in the determination (real world)
- Three artificial datasets, so that you know the baseline value for later comparisons
- Morris (relative importance) and Sobol (quantifies influence)

Sensitivity



CAUE CAUC CRS

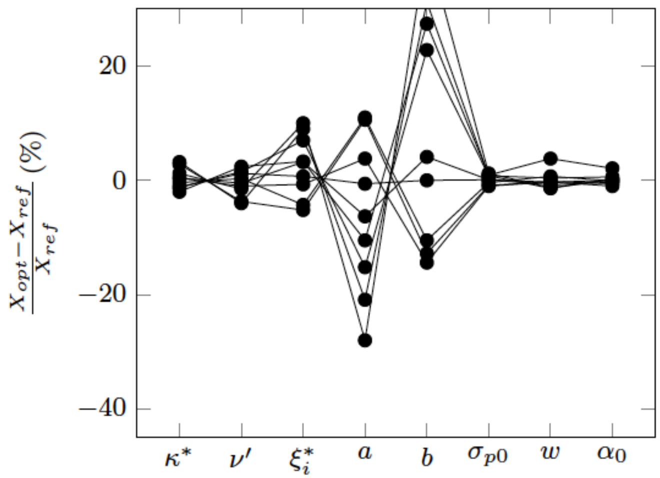
Sensitivity

- Summary sensitivity analysis

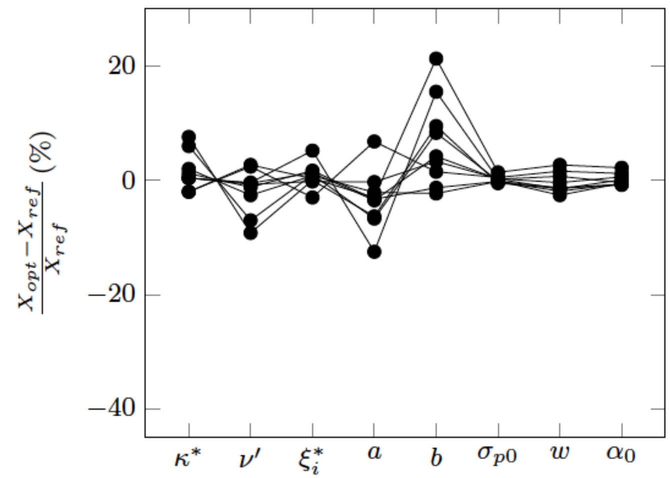
Loading Path	range 1: most sensitives	range 2: most important
CADE	σ_{p0}, M_e, M_c, κ^*, ν', α_0, ω	ω, σ_{p0}, α_0, κ^*, ν', a, b
CADC	σ_{p0}, M_c, ξ_i^*, a	σ_{p0}, a, b, M_c, ξ_i^*
CRS	ξ_i^*, σ_{p0}, a, M_c, κ^*	a, σ_{p0}, ξ_i^*, b, κ^*
CAUE	σ_{p0}, M_e, α_0, κ^*, ν', M_c	σ_{p0}, α_0, ω, κ^*, ν'
CAUC	σ_{p0}, M_c, ξ_i^*, $\alpha 0$	σ_{p0}, b, $\alpha 0$, a

Optimisation

- Do several runs and take the one with the smallest error



(a) smooth data



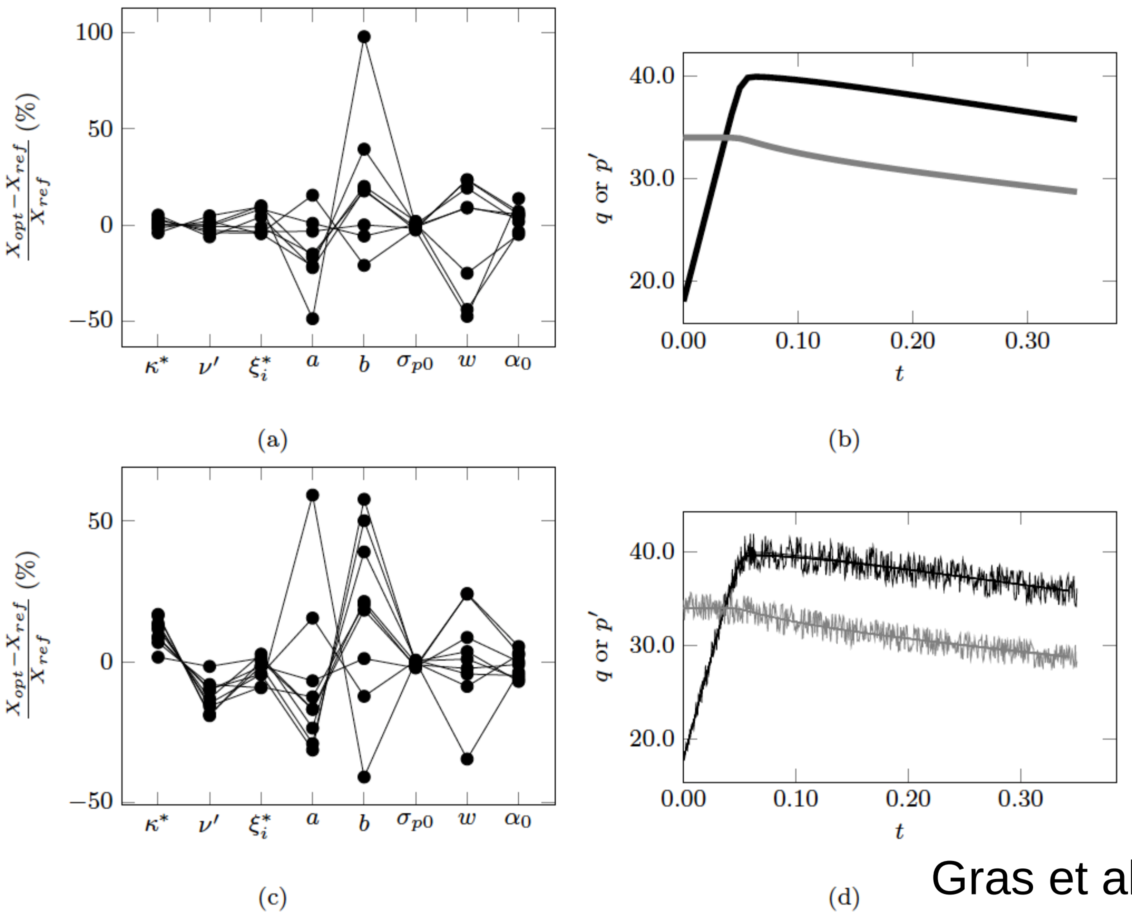
(b) noisy data

nr test	1	2	3	4	5	6	7	8	9
error smooth (%)	0.12	0.41	0.52	0.46	0.16	0.44	0.33	0.33	0.19
error noise (%)	1.69	1.70	1.73	1.94	1.69	1.76	1.86	1.73	1.73

(c) Error function

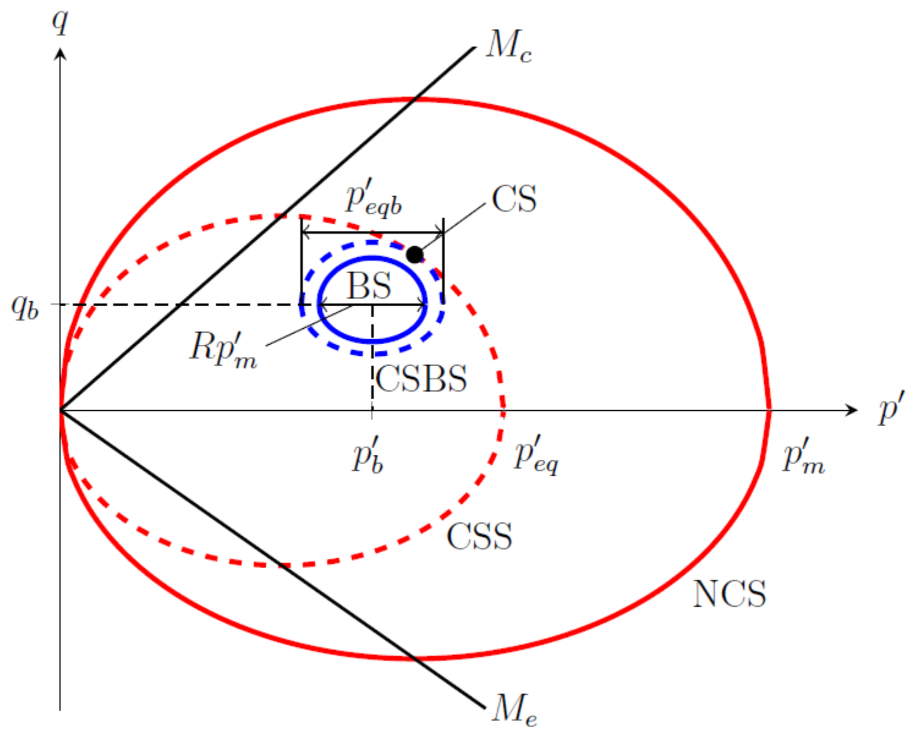
Optimisation

- You can fit clean & noisy experimental data very well



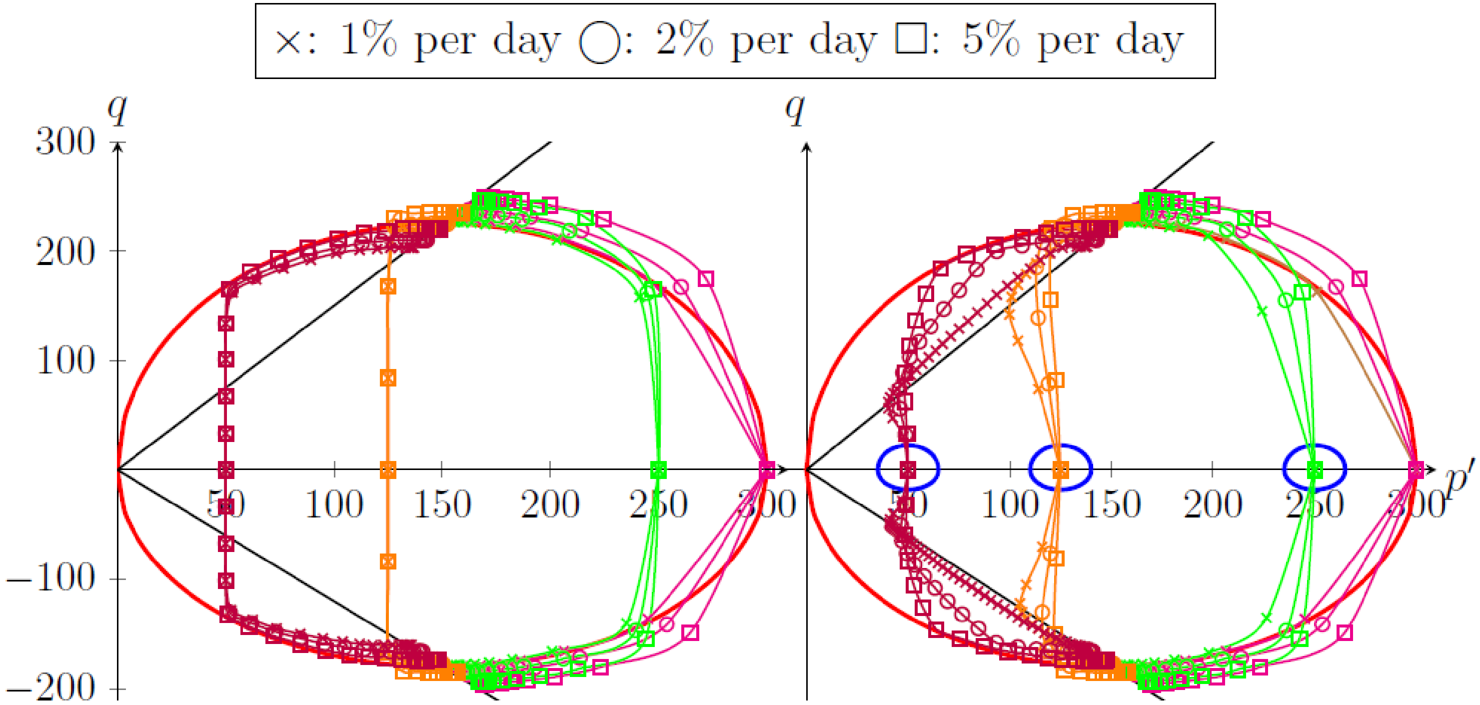
Gras et al, in preparation

Bubble Creep model



NCS: Normal Consolidation Surface
CSS: Current Stress Surface
BS: Bubble Surface
CSBS: Current Stress Bubble Surface
CS: Current Stress

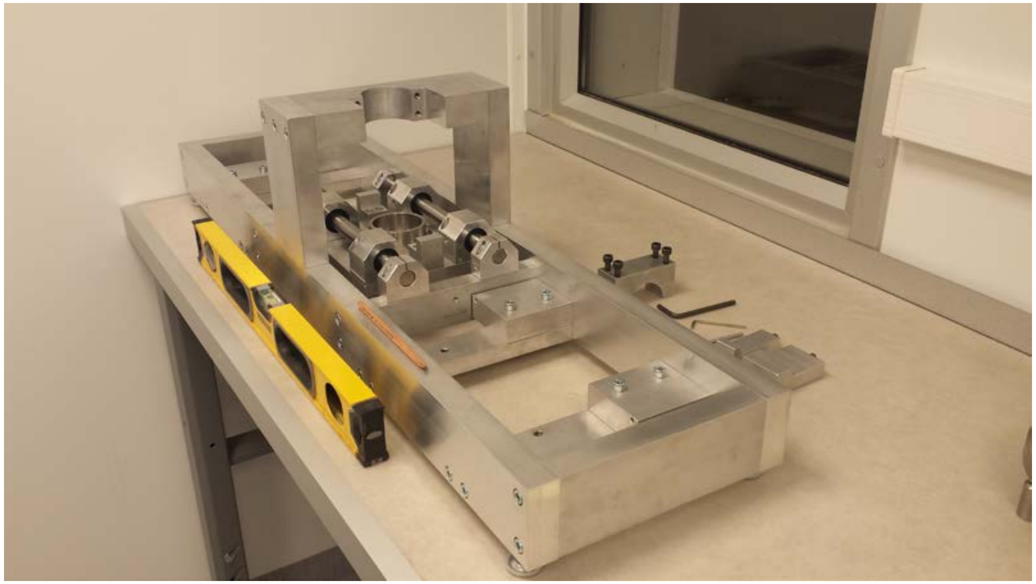
Results from bubble model



(a) previous model

(b) proposed model

Constant stiffness shear box



Future work

- Complement tests on cyclic temperature perturbations with mechanical perturbations
- Try to find alternative for Bubble formulation (as that is too slow for real boundary value problems)
- Cyclic interface tests with new CNS shear box