

Branschsamverkan i Grunden

Prediction of degradation of railways on soft soils

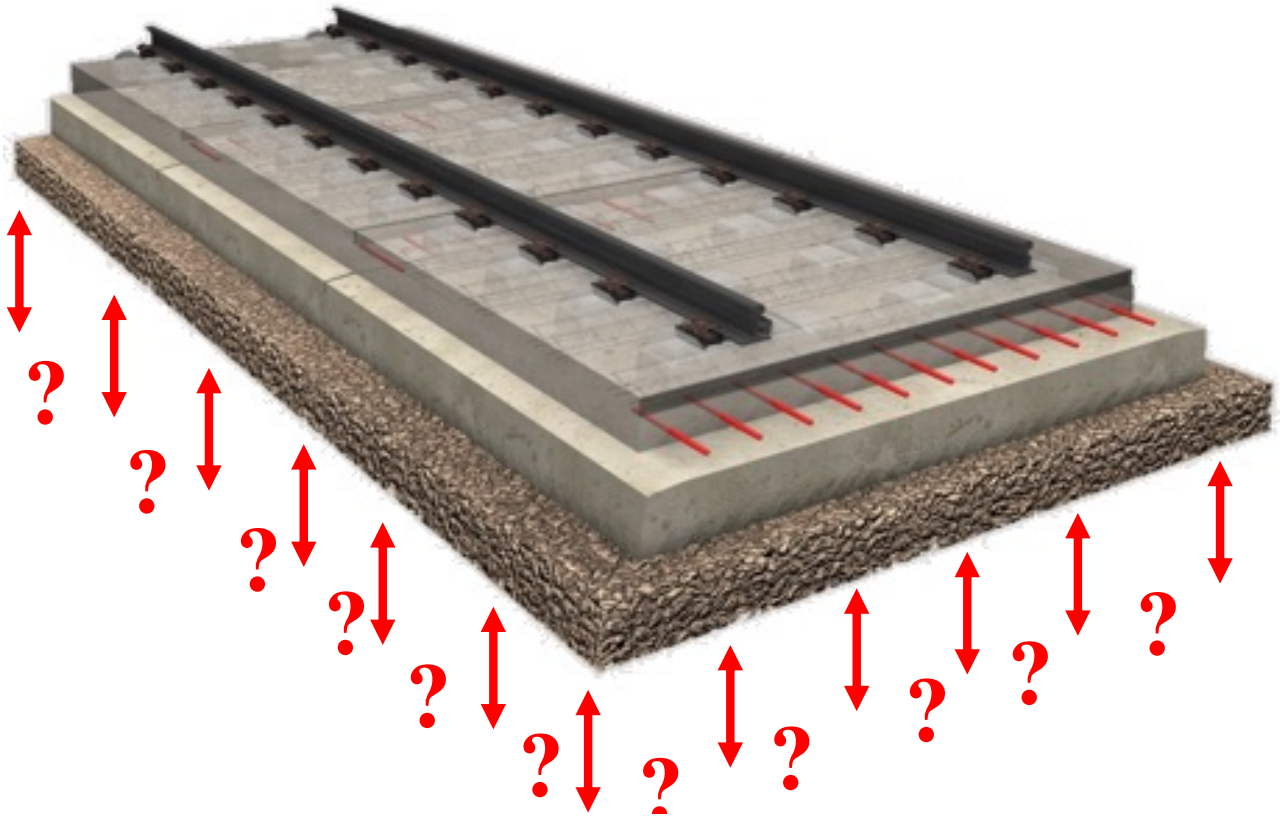
Jelke Dijkstra, Hossein Tahershamsi & Reza Ahmadi Naghadeh

Projektet organisation

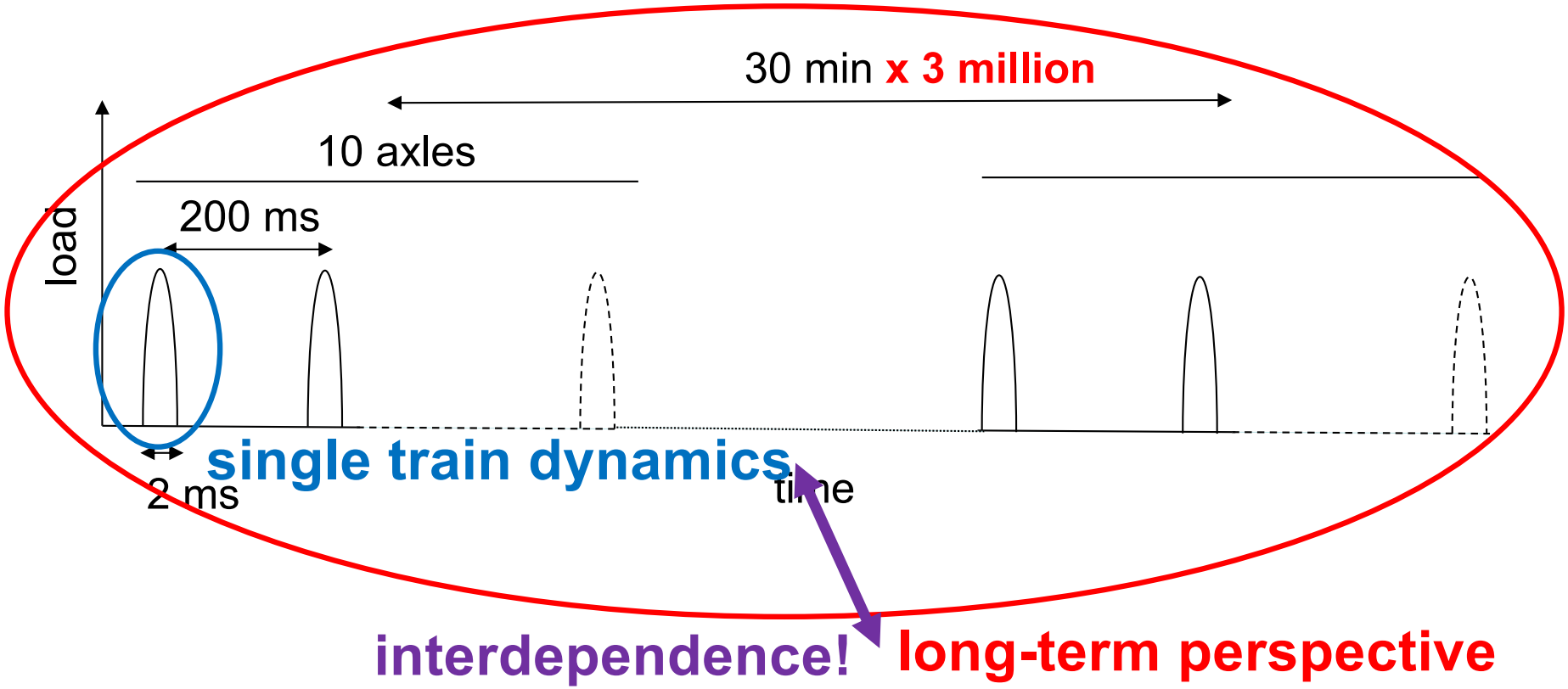
- Jelke Dijkstra (PI)
- Hossein Tahershamsi (PhD student, since Sep 2017)
- Reza Ahmadi Naghadeh (PostDoc for experimental)
- Johan Jonsson (contact personTrafikverket)
- Minna Karstunen (Expert)
- Bruno Zuada Coelho (Deltares, Expert)

Background

- Technical system for track-sleeper-slab (ballast) system rather homogeneous throughout Europe, still some places require substantially more maintenance than other places -> **SOIL**

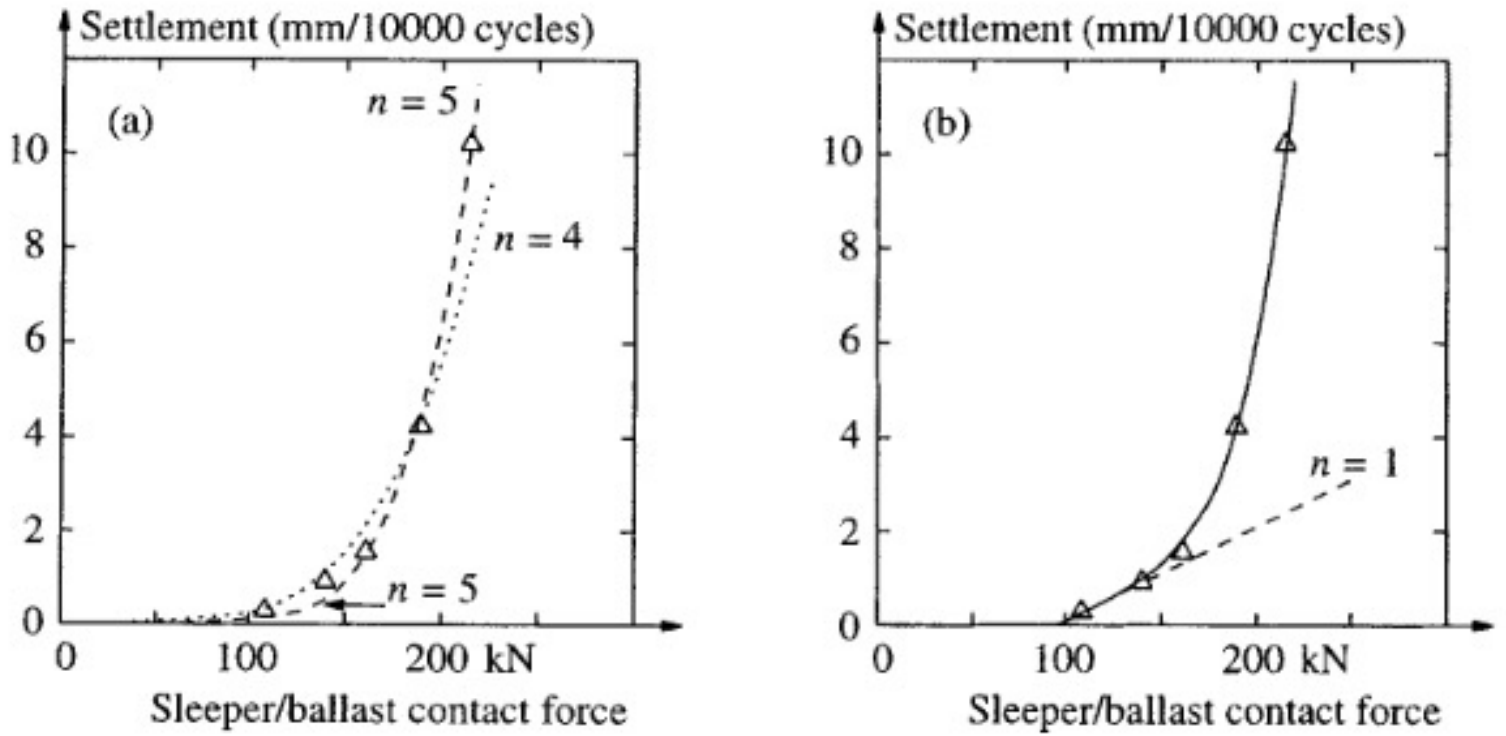


Background


30 min x 3 million
10 axles
200 ms
load
2 ms
time
single train dynamics
interdependence!
long-term perspective

Background

- Sometimes accumulation function introduced in analyses



Sato's measurements from Dahlberg (2001)

Multiple trains

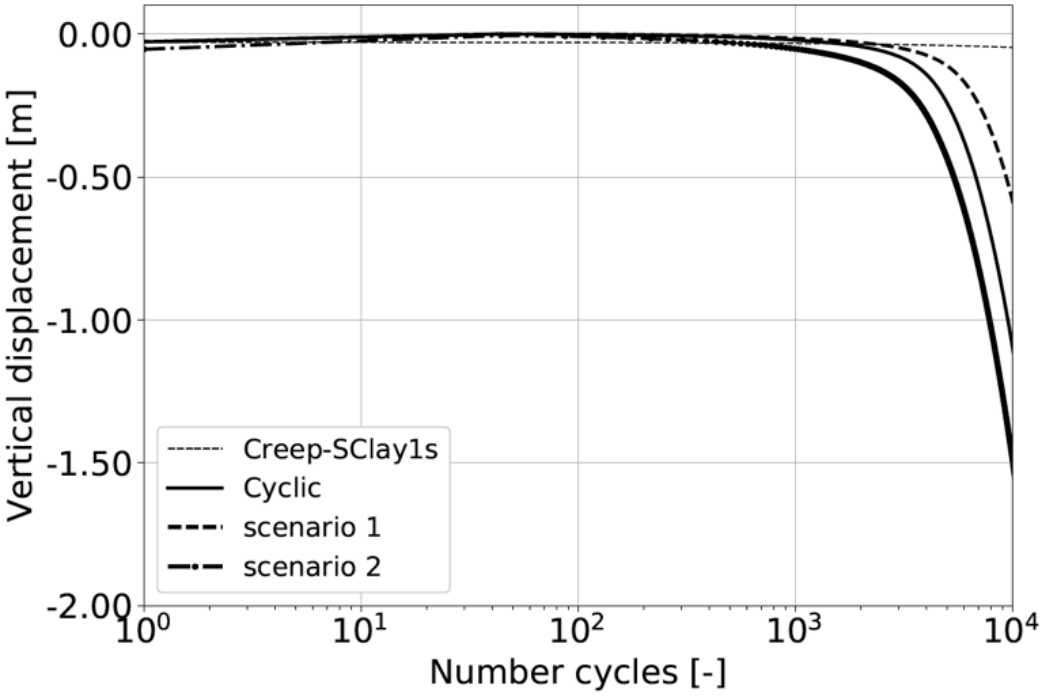
- Not all deformation originates in ballast (or embankment)
- Consolidation and creep in soft soils
  - From embankment construction
  - Accelerated by cyclic loading
  - Will influence the emerging dynamic response



creep only



cyclic effects

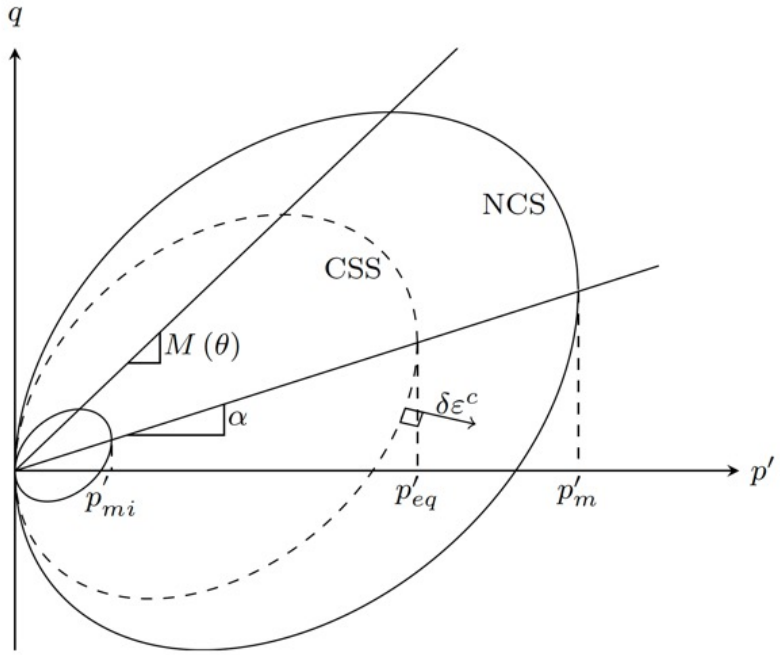


Linking quasi-static and dynamic

- Currently **impossible** to model all in one simulation, i.e. both the slow and the fast (due to numerical error accumulation)
  - Solution: decouple fast and slow
- **Quasi-static** analyses for the slow processes
  - Difficulty remains in modelling cyclic ratcheting
  - Requires a strain accumulation model for clay
- **Dynamic** analyses for the fast processes
  - The dynamic analyses for a single train are rather 'simple' - time domain FE with dynamic coupled porewater formulation
  - But what is the stiffness, damping or effective stress state? **this has to be linked with the slow analyses**

Creep-Sclay1sc model

- Modelling many loading cycles with an accumulated deformation
- Suiker model for sand and subgrade
- Chalmers model for clay (amplitude & loading period dependent)



[Gras et al. 2018]

$$\varepsilon_{ij} = \varepsilon^{e}_{ij} + \varepsilon^{vp}_{ij}$$

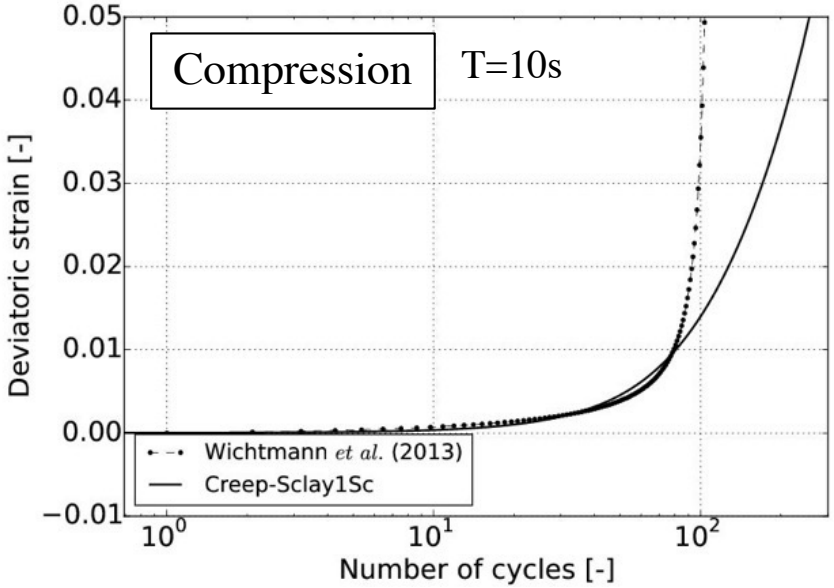
$$\varepsilon^{vp}_{ij} = \varepsilon^{c}_{ij} + \boxed{\varepsilon^{cyc}_{ij}}$$

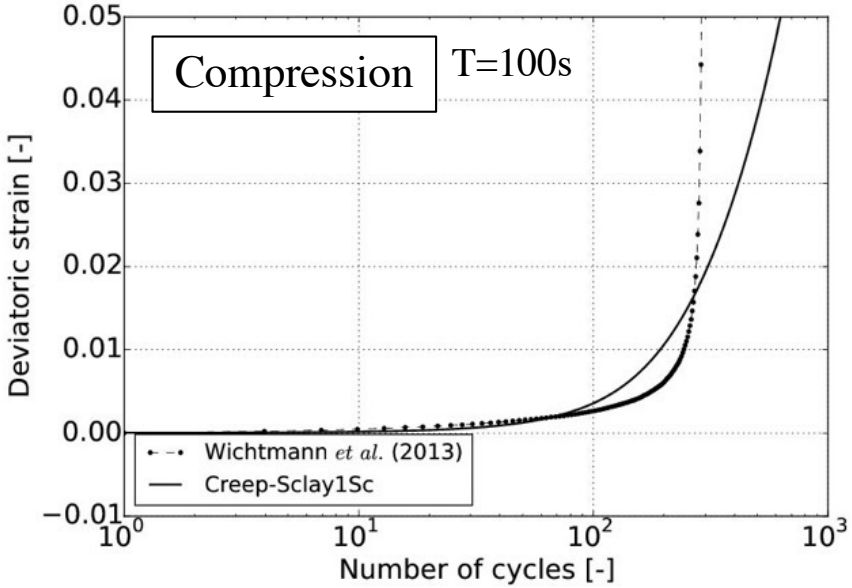
$$\varepsilon^{c}_{ij} = \dot{\Lambda}\frac{\partial p'_{eq}}{\partial \sigma'_{ij}}$$ Creep-Sclay1s

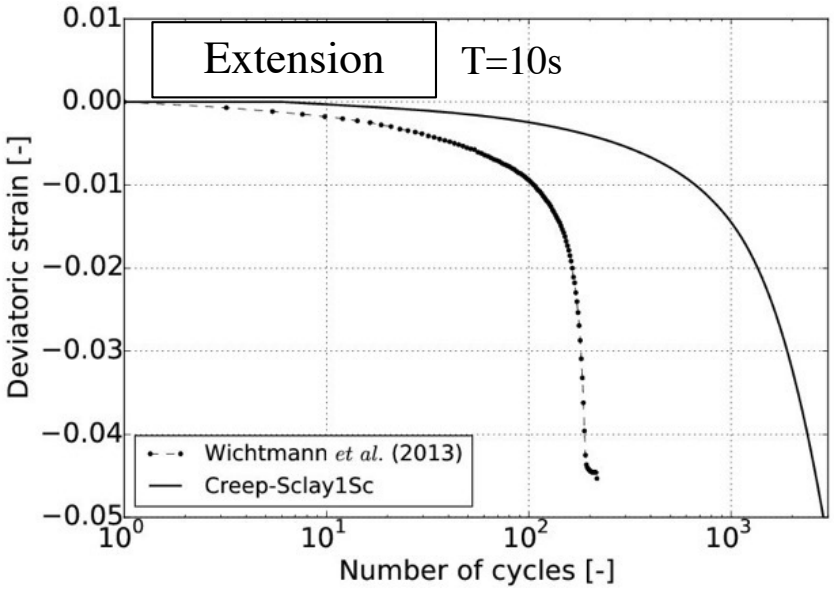
$$\dot{\varepsilon}^{vp}_{ij} = \left[\boxed{\dot{\Omega}} + \dot{\Lambda}\right]\frac{\partial p'_{eq}}{\partial \sigma'_{ij}}$$ Creep-Sclay1sc

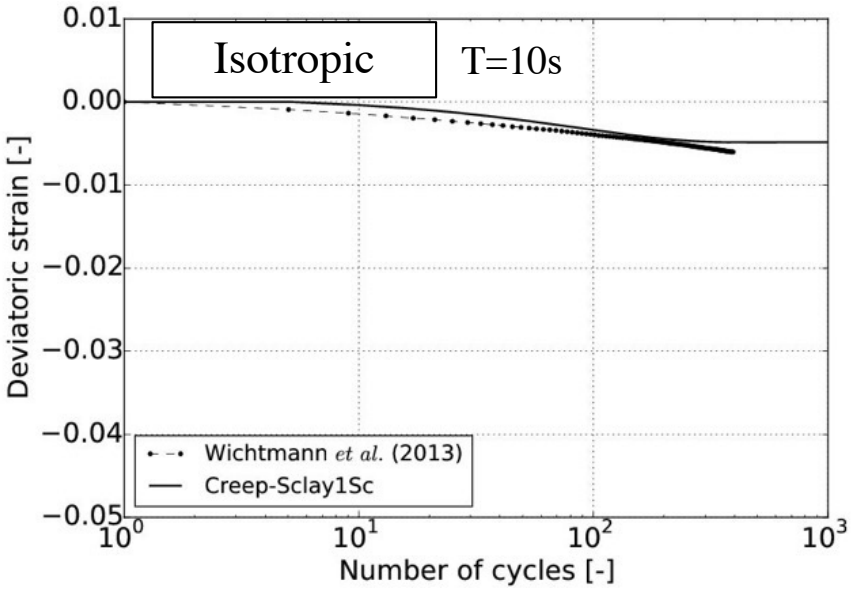
Cyclic loading

Model works for static and cyclic triaxial loading, also at boundary value level





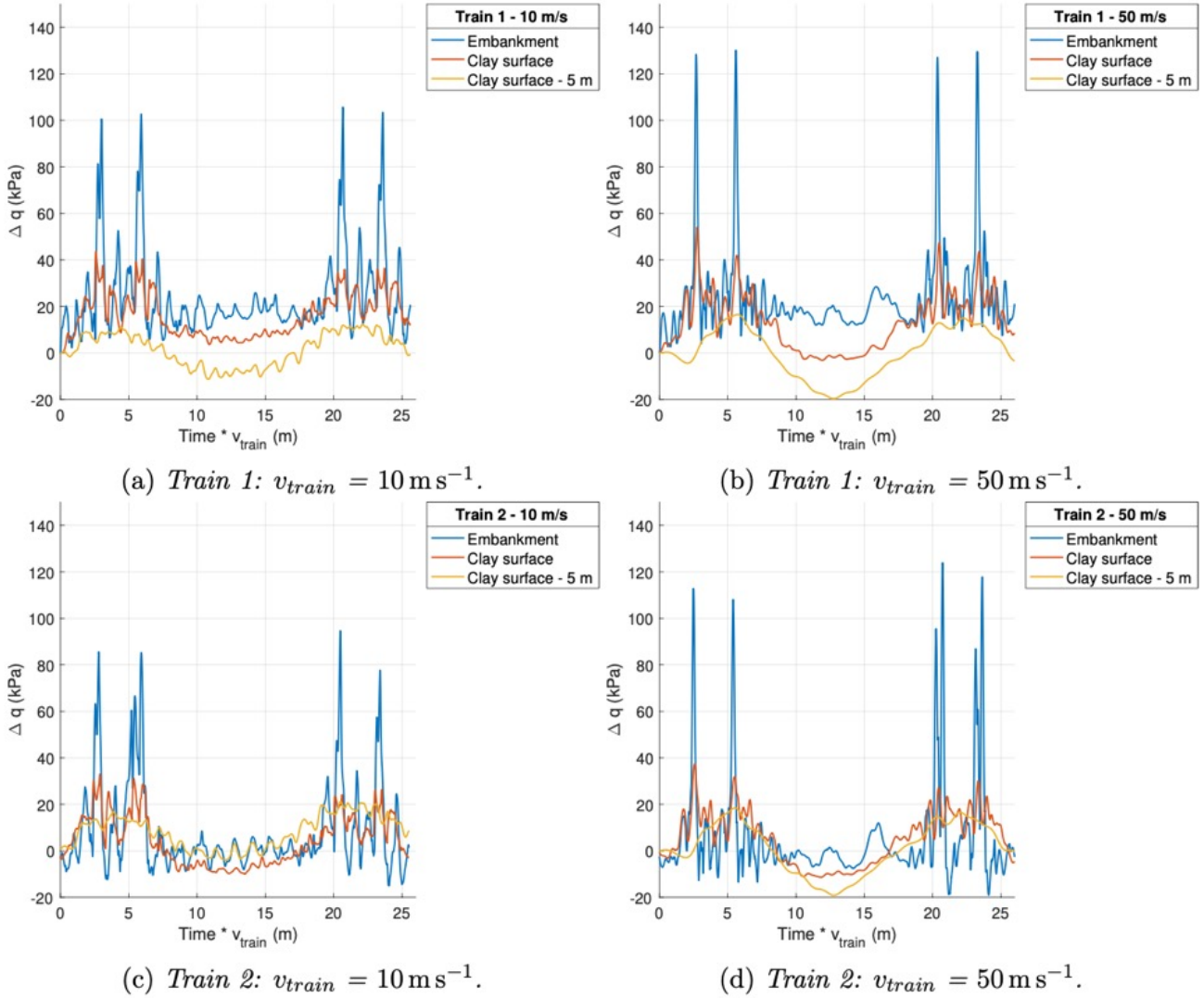




Results (with degradation)

1st train
cycle 0

2nd train
cycle 100 000



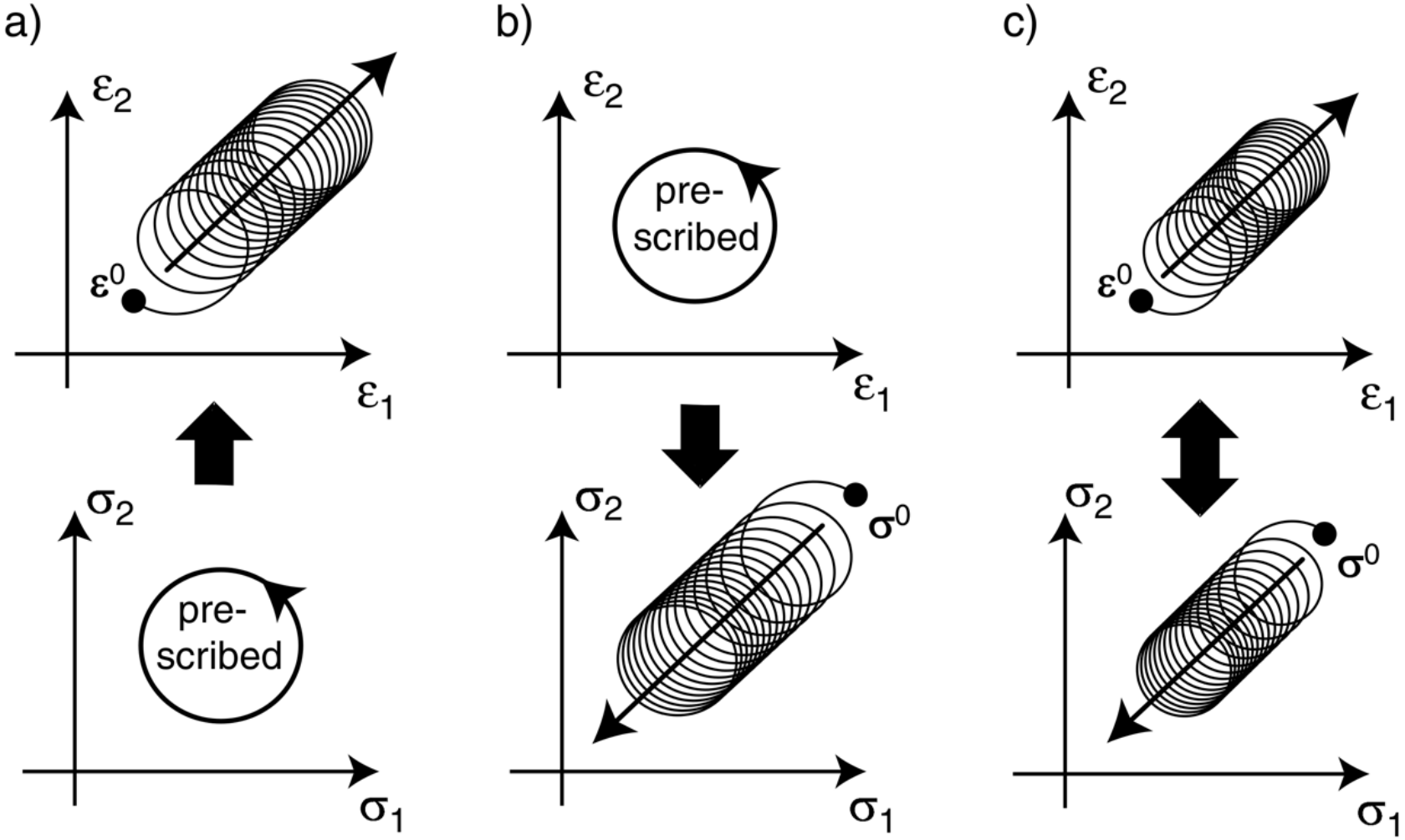
(a) *Train 1:* $v_{train} = 10\,\mathrm{m\,s^{-1}}$. (b) *Train 1:* $v_{train} = 50\,\mathrm{m\,s^{-1}}$.

(c) *Train 2:* $v_{train} = 10\,\mathrm{m\,s^{-1}}$. (d) *Train 2:* $v_{train} = 50\,\mathrm{m\,s^{-1}}$.

Figure 3.2: Δq *for train 1 (before cycle 1) & train 2 (after cycle 100k);* $x = 25\,\mathrm{m}$*; with stiffness degradation in model.*

We need more data

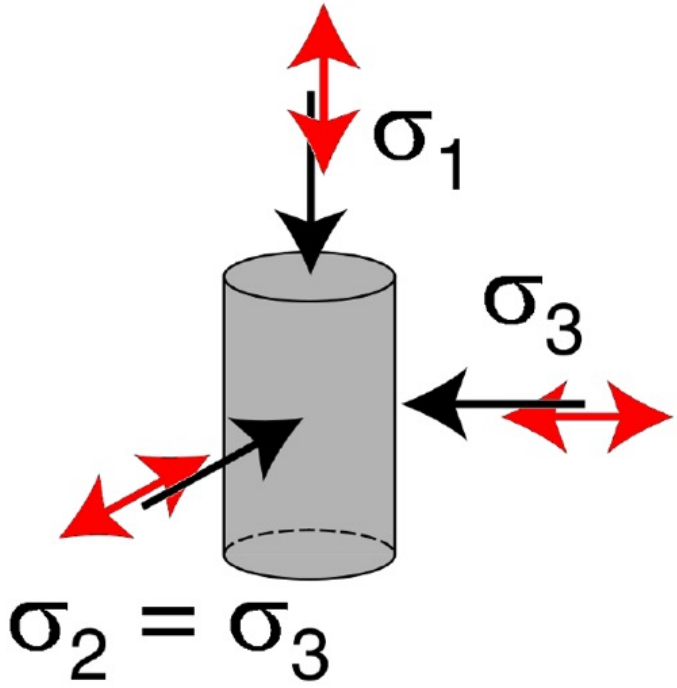
- Evolution of small strain stiffness as function of loading cycles



Wichtmann (2005)

We need more data

- Cyclic triaxial data is most relevant to achieve this goal
  - Controlled state of stress, emerging strain accumulation (and change in stiffness & damping)
  - Uniaxial load cycle (constant cell pressure σ_3, varying σ_1)





We need more data

- Cyclic triaxial data is most relevant to achieve this goal
  - Controlled state of stress, emerging strain accumulation (and change in stiffness & damping)
  - Uniaxial load cycle (constant cell pressure, varying σ_1)

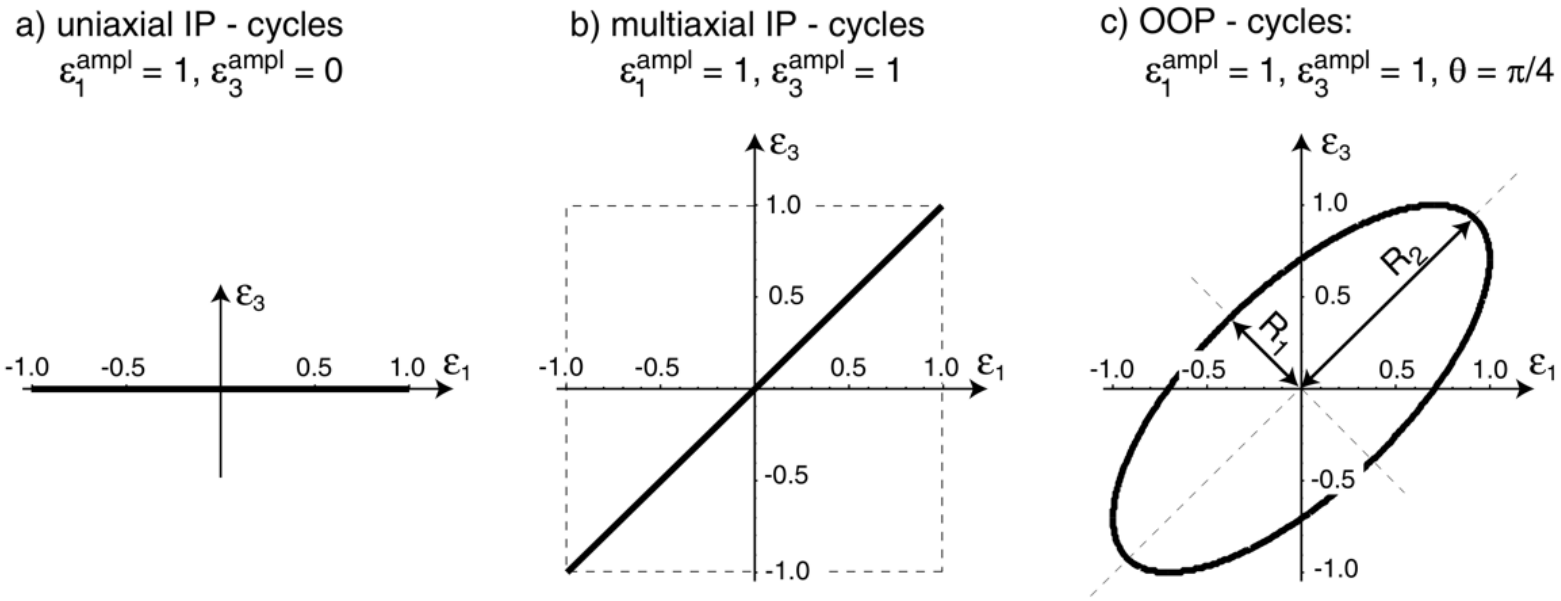
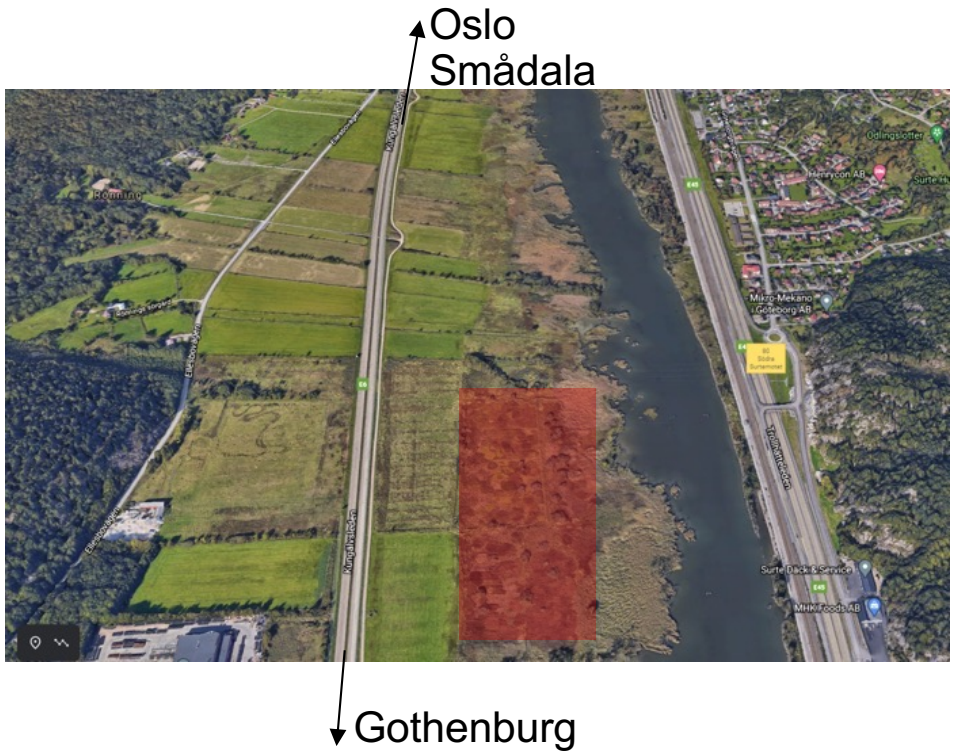


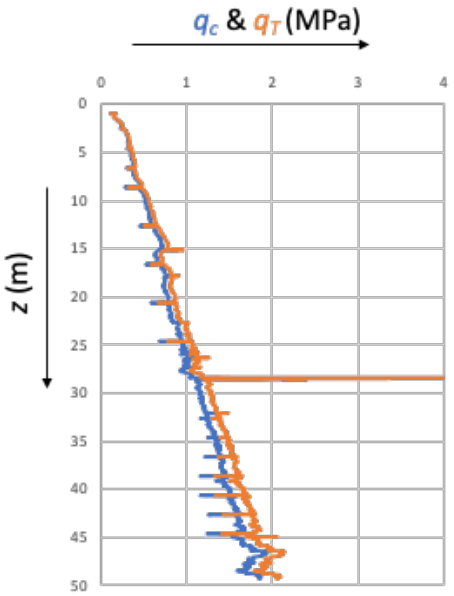
Figure 2.4: *Distinction between uniaxial IP-, multiaxial IP- and OOP-cycles*

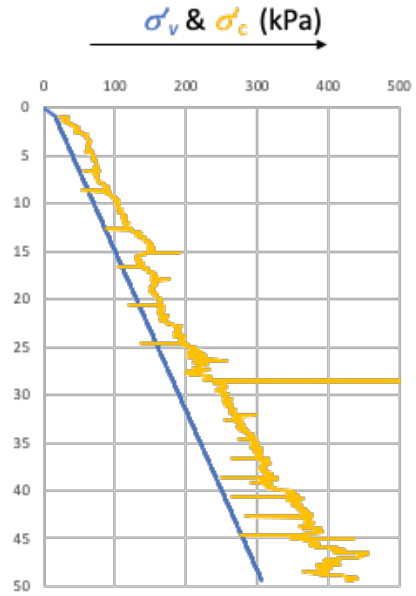
Wichtmann (2005)

Kärra test programme

- Samples from new Kärra test site with sensitive clay

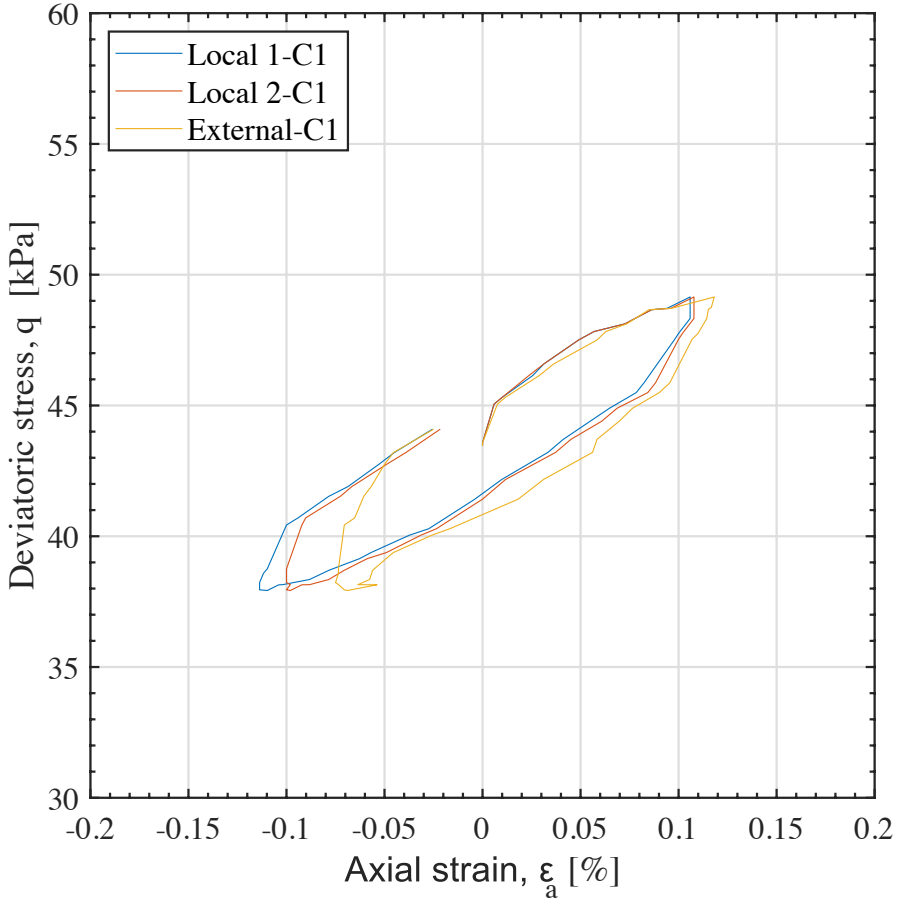






Kärra test programme

- External *vs.* local measurements



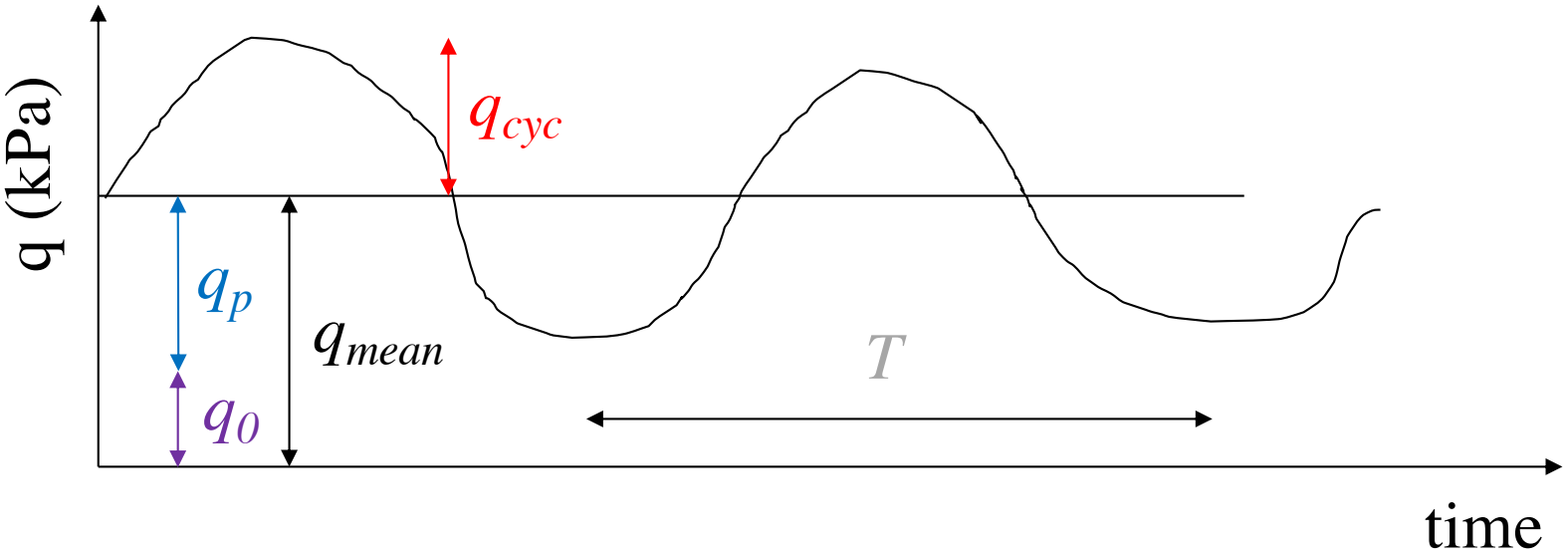
Kärra test programme

- Test programme

No.	Test Name	q_0 (kPa)	p'_0 (kPa)	q_m (kPa)	q_p (kPa)	$q_m/2s_u$	q_{cyc} (kPa)	$q_{cyc}/2s_u$	Status		N_f
1	Test 01 (9m)	28	42	-	-	-	0 (Mon)	-	Completed	F	-
2	Test 02 (8m)	25	42	-	-	-	0 (Mon)	-	Completed	F	-
3	Test 03 (7m)	22	42	-	-	-	0 (Mon)	-	Completed	F	-
4	Test 04	28	42	47	19	0.71	5	0.076	Completed	PCF	-
5	Test 05	28	42	28	0	0.42	5	0.076	Completed	PCF	-
6	Test 06	28	42	28	0	0.42	10	0.15	Completed	PCF	-
7	Test 07	28	42	28	0	0.42	20	0.3	Completed	CF	45000
8	Test 08	28	42	37	9	0.56	20	0.3	Completed	CF	580
9	Test 09	28	42	28	0	0.42	28	0.42	Completed	CF	5800
10	Test 10	28	42	10	-18	0.15	29	0.44	Completed	CF	9000
11	Test 11	28	42	20	-8	0.3	38	0.58	Completed	CF	70

CF: Cyclic failure, PCF: Post cyclic failure, MF: Monotonic failure

Test programme



Note:

q_0 = anisotropic consolidation

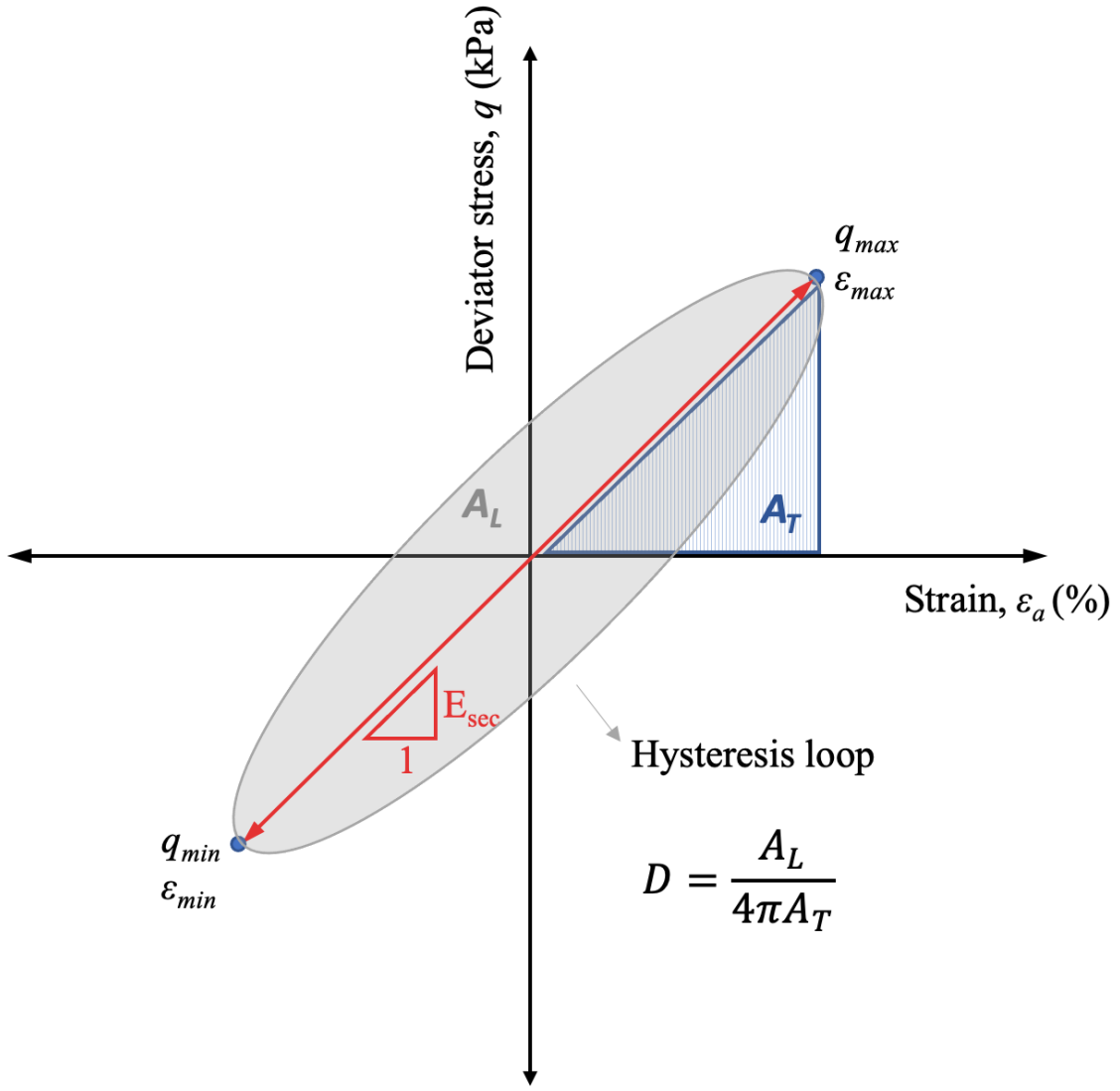
q_p = undrained pre-shearing

q_{cyc} = undrained cyclic uniaxial loading

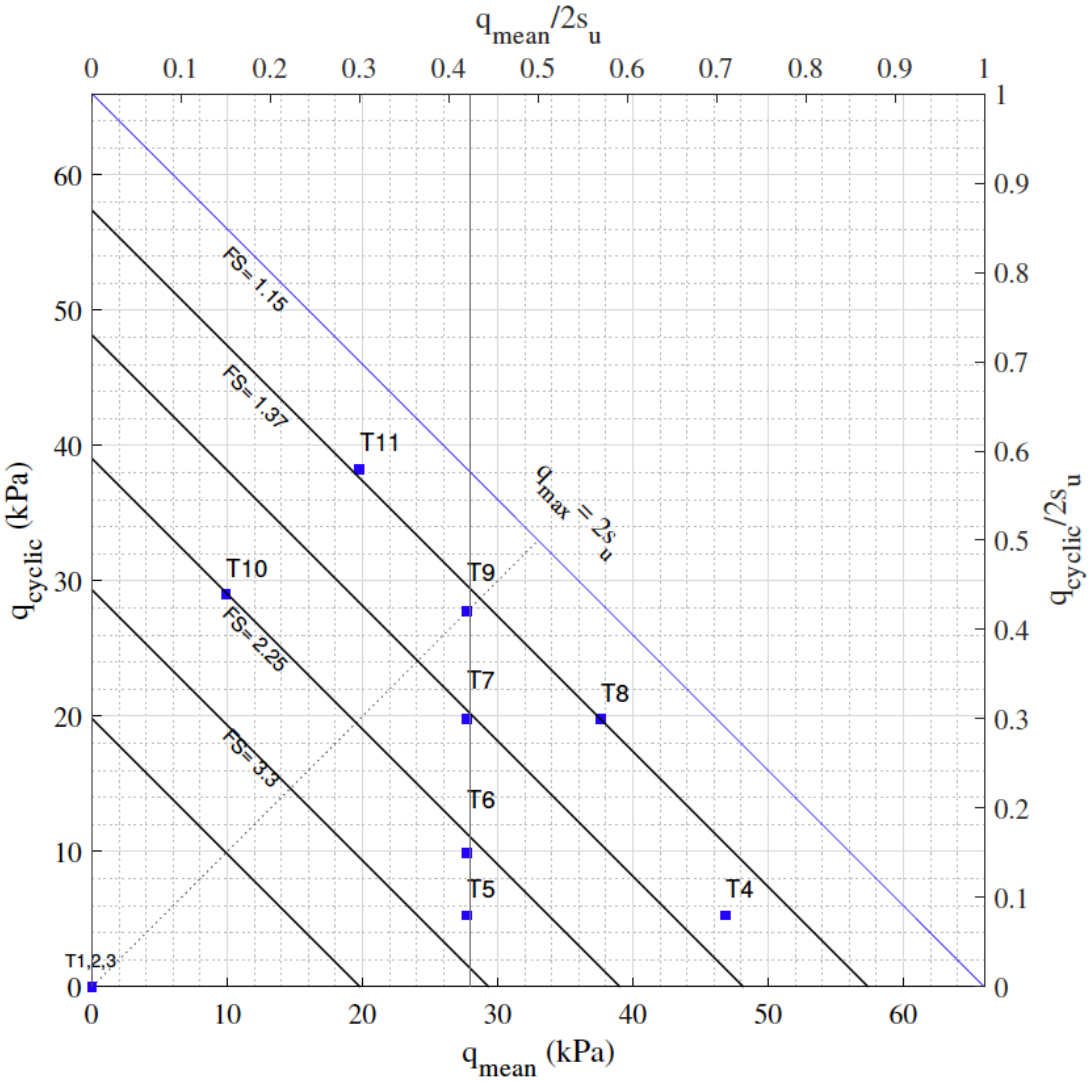
T = 180 s; (proper tracking of pwp)

Test programme

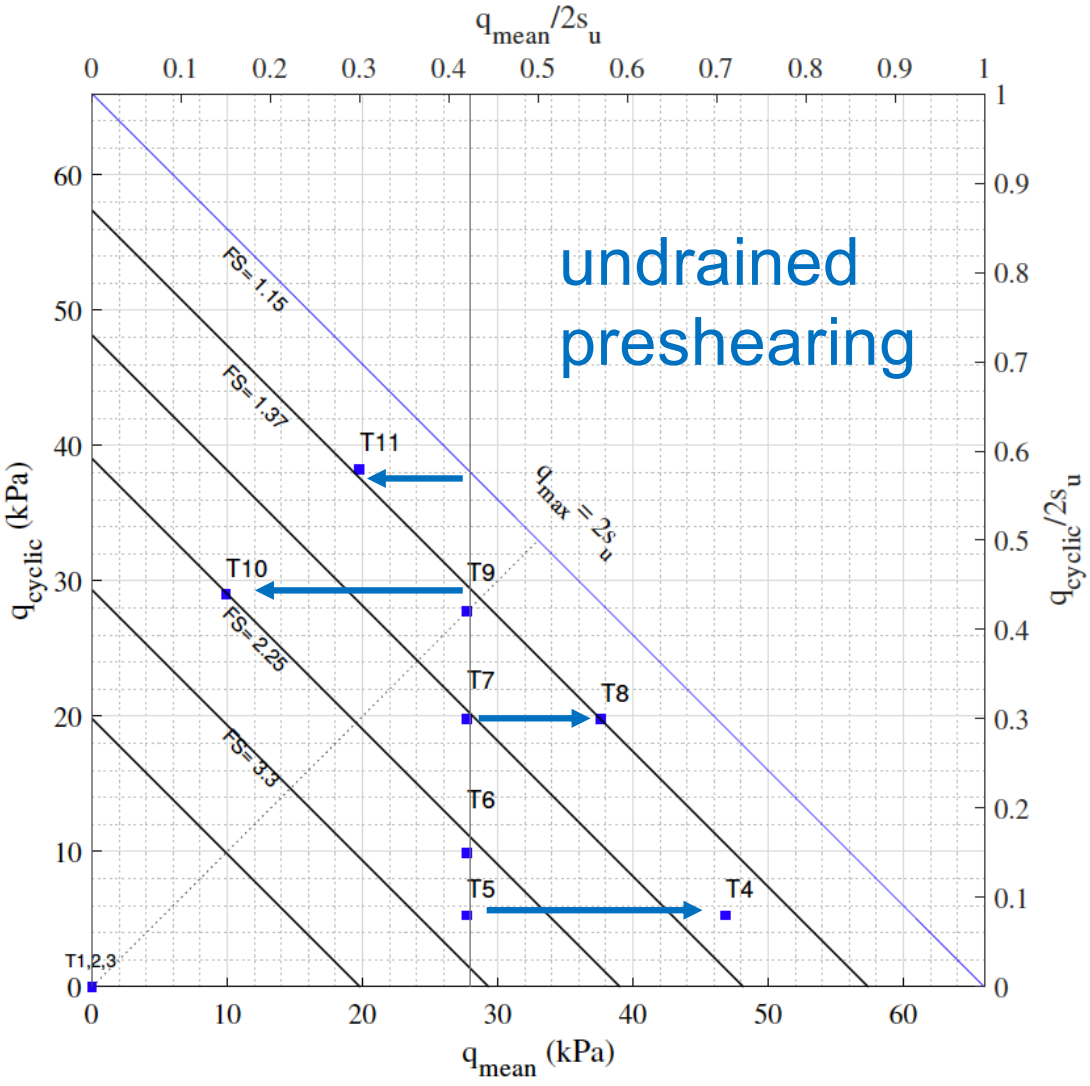
- Secant stiffness E_{ta}
- Damping ratio D



Test programme

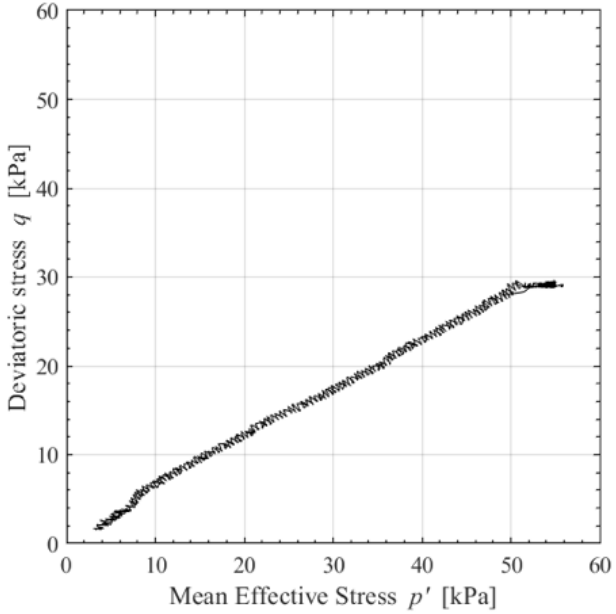


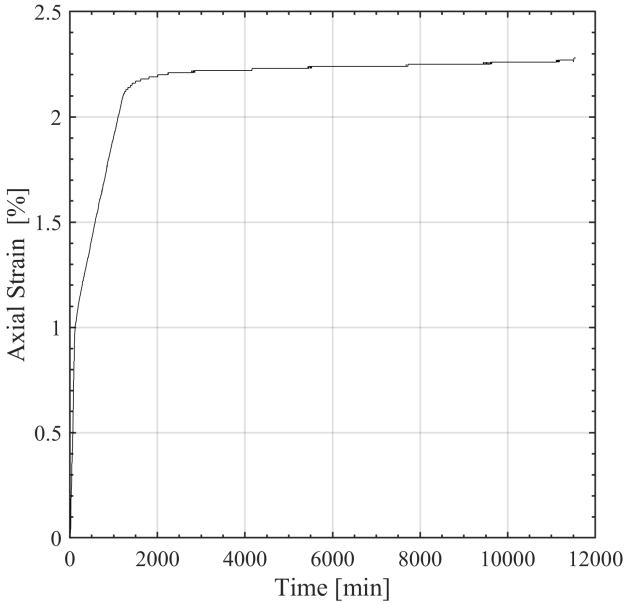
Test programme

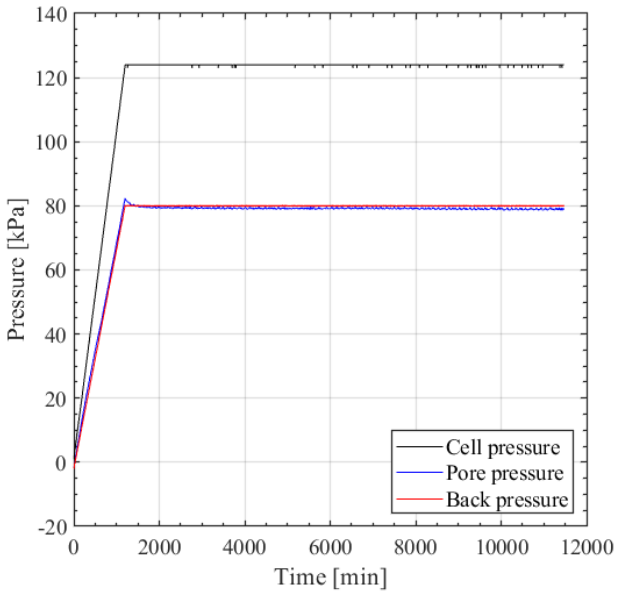


Consolidation

K_0-consolidation to in-situ stress state (K_0=0.6)

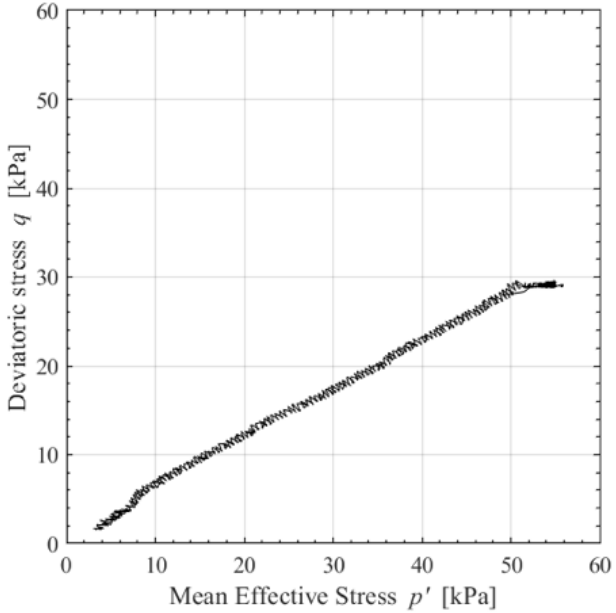


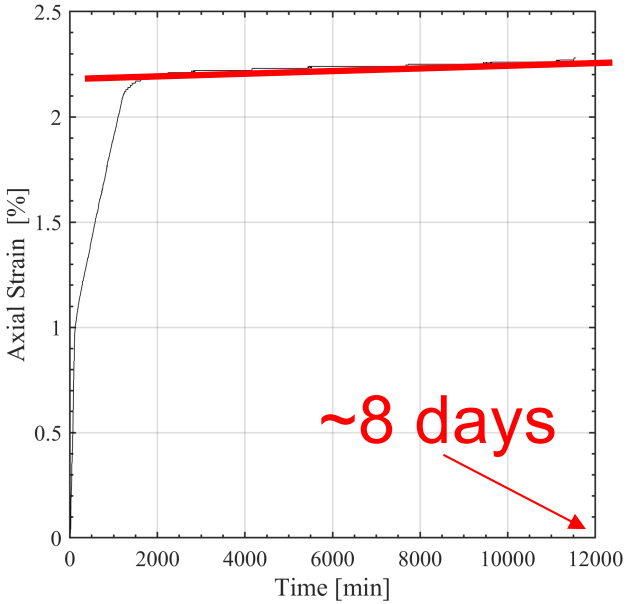


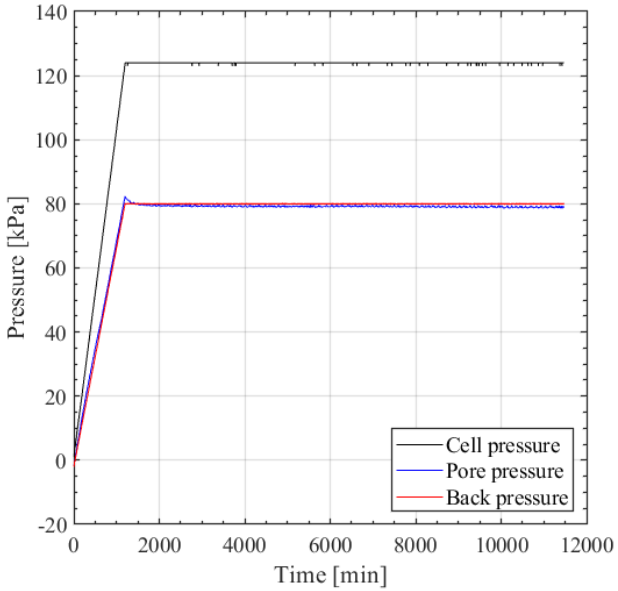


Consolidation

K_0-consolidation to in-situ stress state (K_0=0.6)



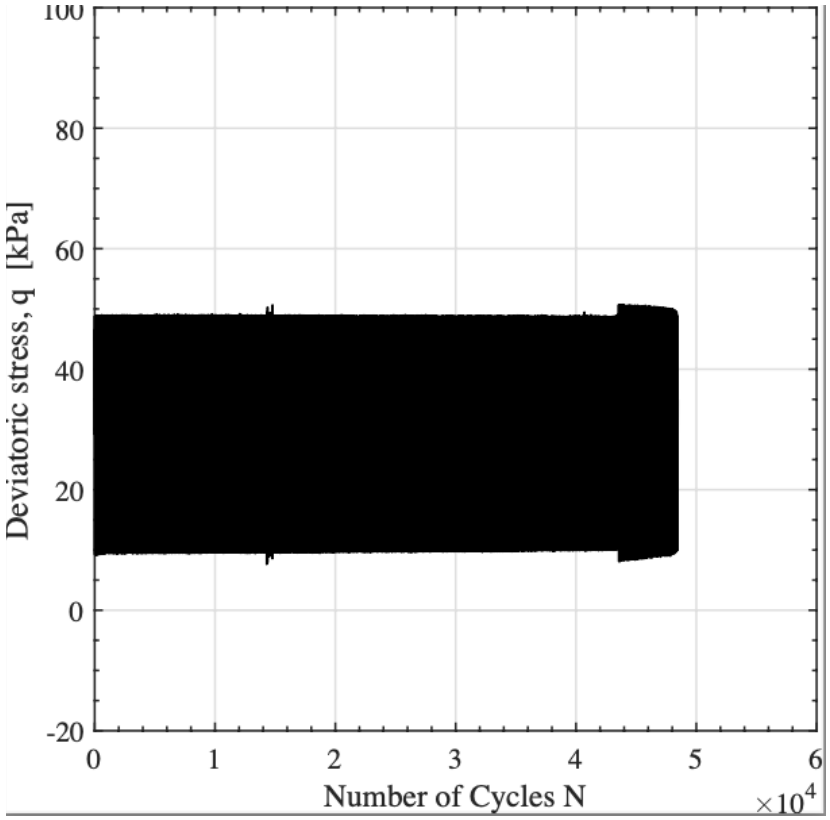


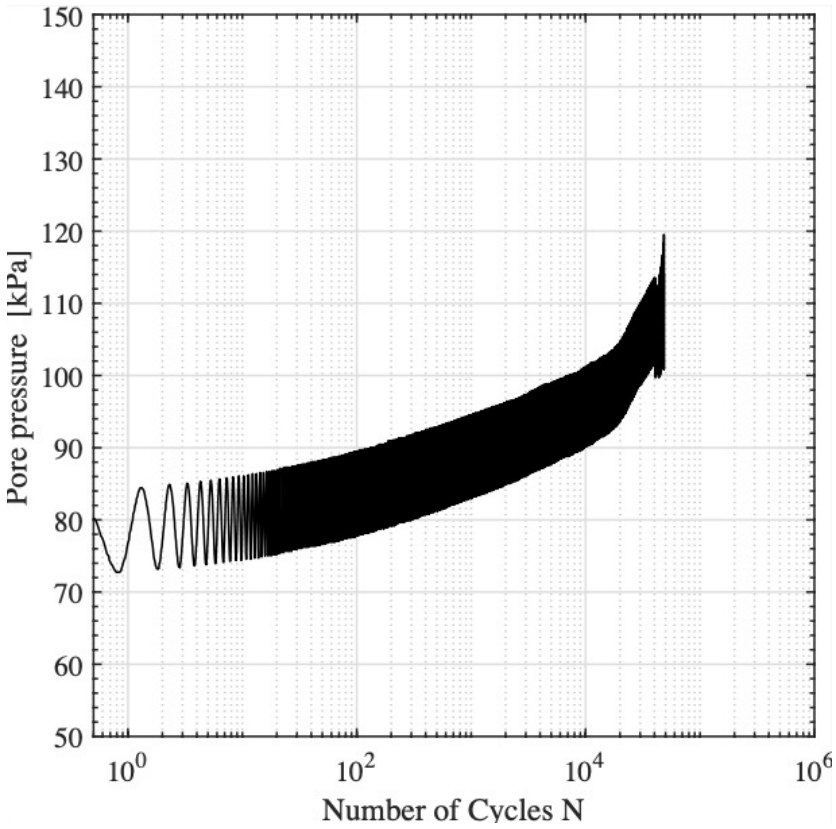


EoC deviatoric creep of 0.02% per day before cyclic loading

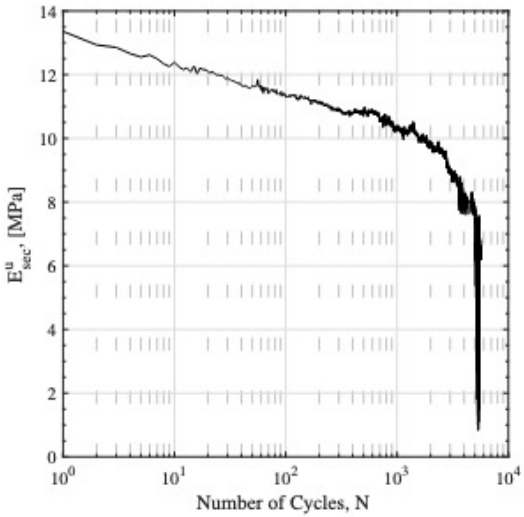
Typical measured response

Test 07 (90 days)

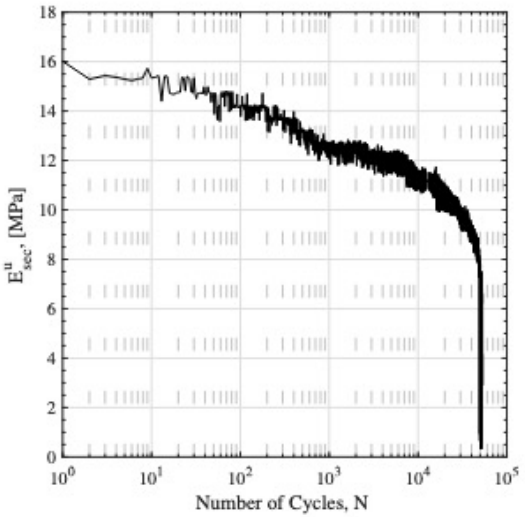




E_{sec} no pre-shear

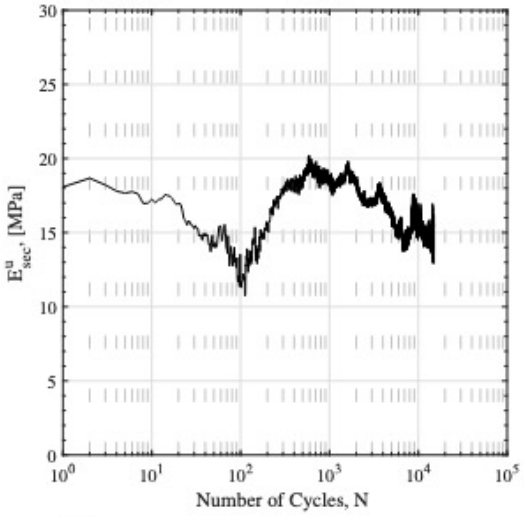


(a) $q_{mean} = 28\,\text{kPa}$; $q_{cyc} = 28\,\text{kPa}$

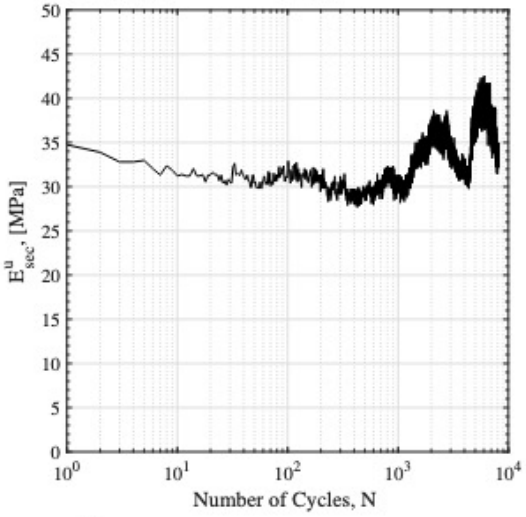


(b) $q_{mean} = 28\,\text{kPa}$; $q_{cyc} = 20\,\text{kPa}$

Large amplitude



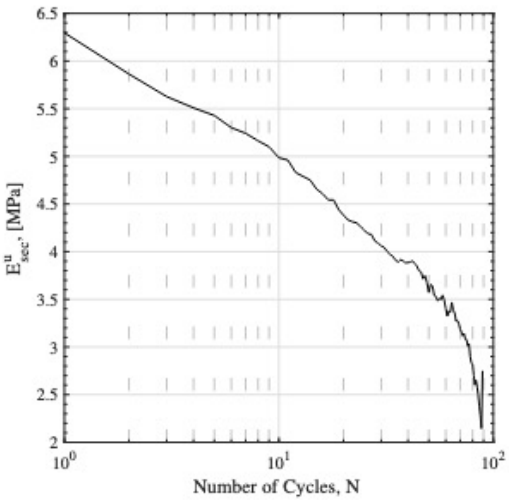
(c) $q_{mean} = 28\,\text{kPa}$; $q_{cyc} = 10\,\text{kPa}$



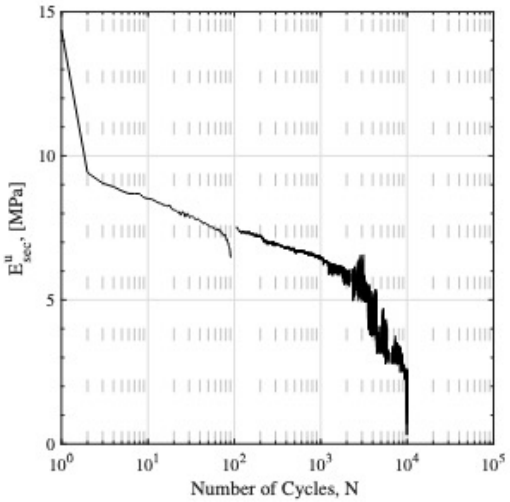
(d) $q_{mean} = 28\,\text{kPa}$; $q_{cyc} = 5\,\text{kPa}$

Small amplitude

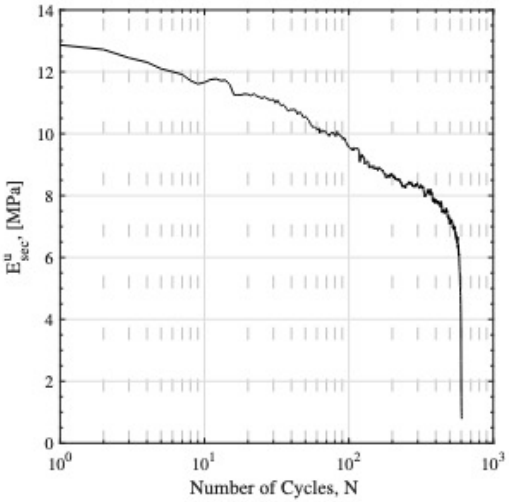
E_{sec} with pre-shear



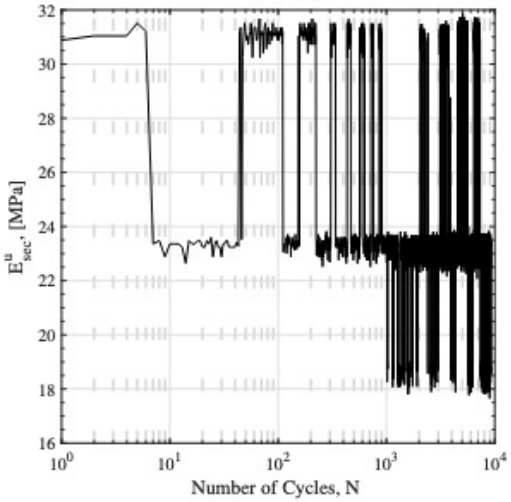
(a) $q_{mean} = 20\,\text{kPa}$; $q_{cyc} = 38\,\text{kPa}$



(b) $q_{mean} = 10\,\text{kPa}$; $q_{cyc} = 29\,\text{kPa}$



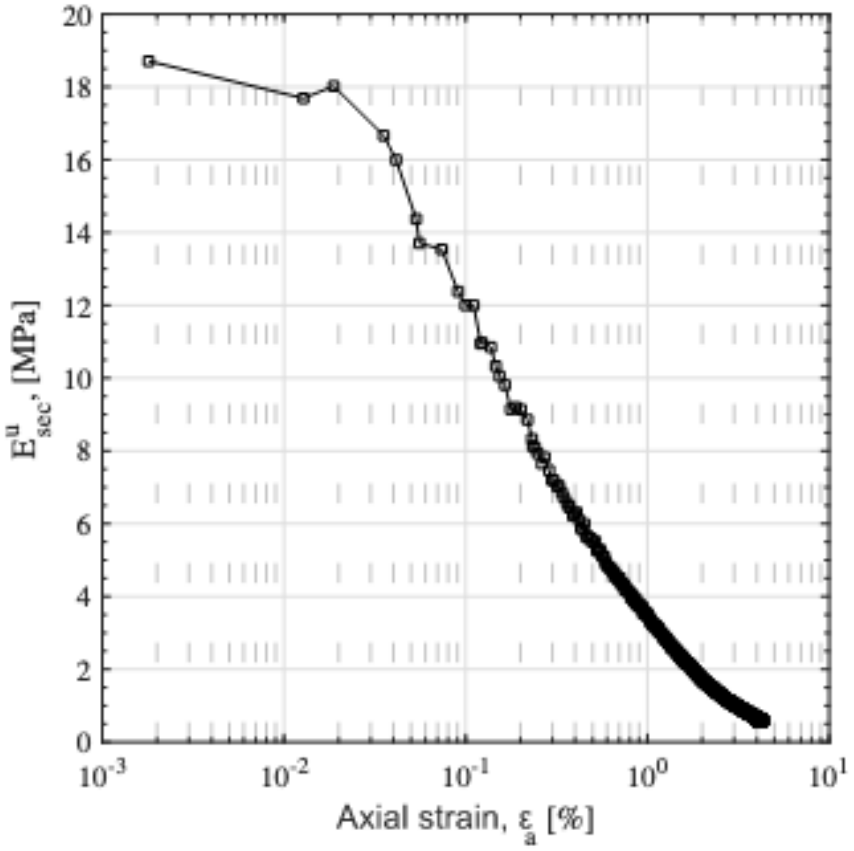
(c) $q_{mean} = 37\,\text{kPa}$; $q_{cyc} = 20\,\text{kPa}$



(d) $q_{mean} = 47\,\text{kPa}$; $q_{cyc} = 5\,\text{kPa}$

Small amplitude

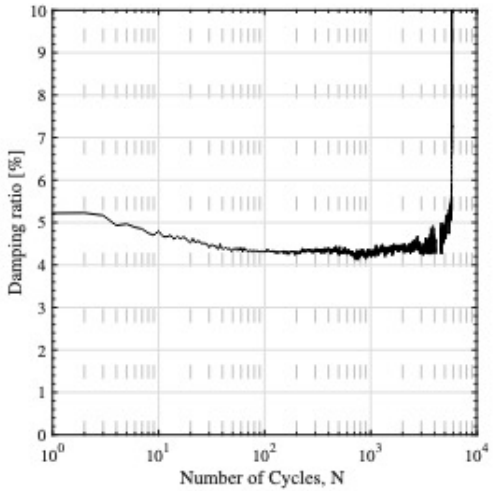
E_{sec} from monotonic test



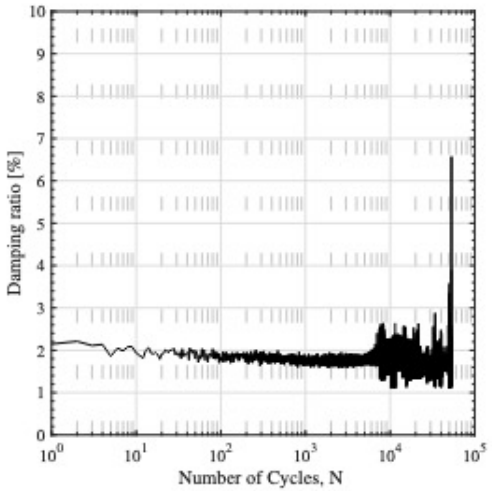
Damping ratio

- Damping rather stable irrespective of loading conditions or pre-shear, some (inclusive) tendencies
  - Damping is 3-5% until onset of failure
  - Damping reduces with larger pre-shear stress

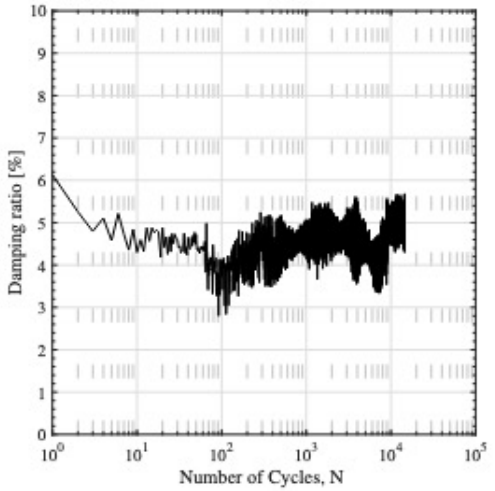
Damping ratio



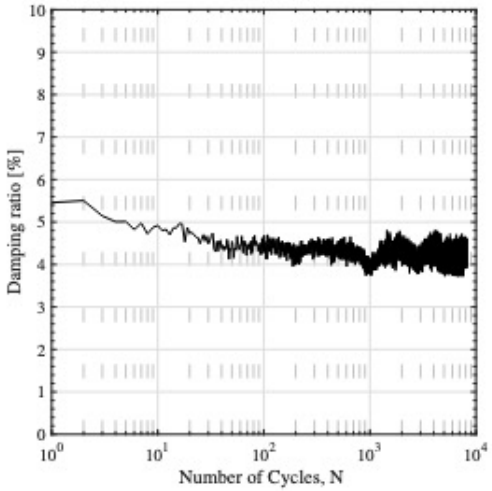
(a) $q_{mean} = 28\,\text{kPa}$; $q_{cyc} = 28\,\text{kPa}$



(b) $q_{mean} = 28\,\text{kPa}$; $q_{cyc} = 20\,\text{kPa}$



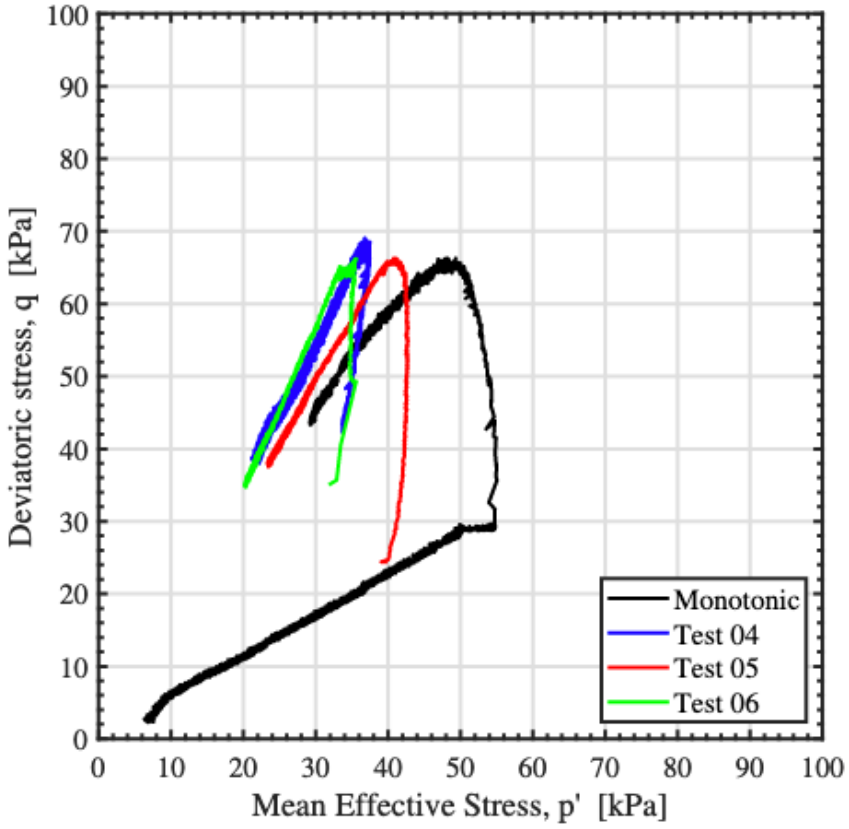
(c) $q_{mean} = 28\,\text{kPa}$; $q_{cyc} = 10\,\text{kPa}$



(d) $q_{mean} = 28\,\text{kPa}$; $q_{cyc} = 5\,\text{kPa}$

Post-cyclic shear

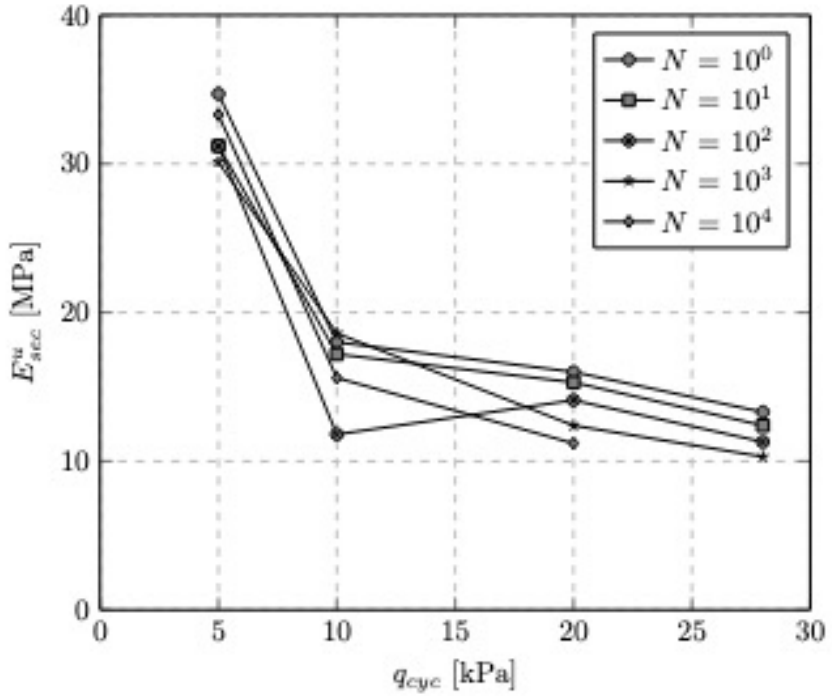
- Undrained shear strength unaffected by cyclic loading (at small amplitude)



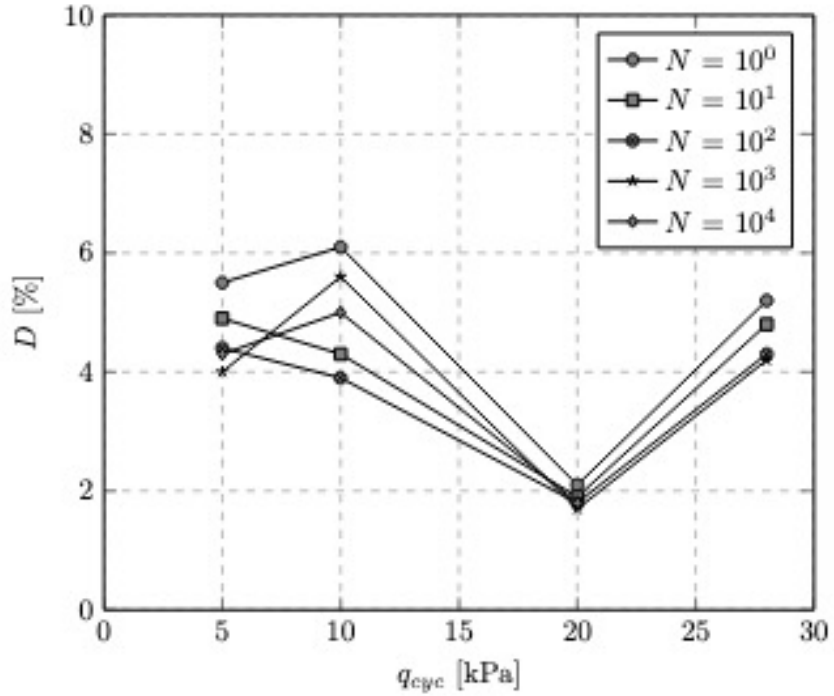
(c) *Stress paths.*

Summary figure

- Clear trends for ‘clean data’ without undrained pre-shearing



(a) E^u_{sec}.

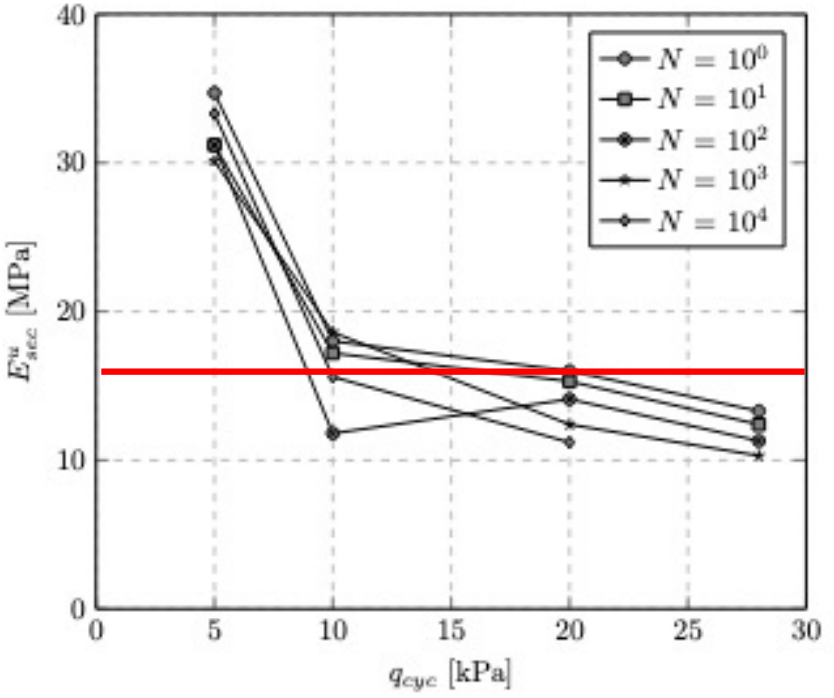


(b) *Damping ratio D.*

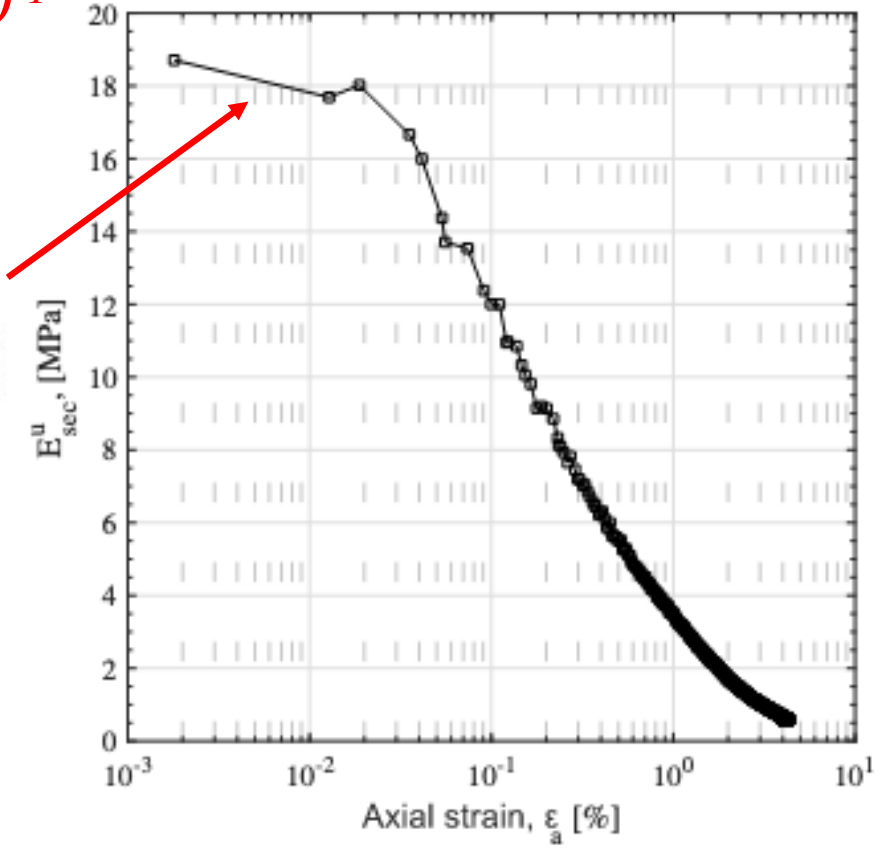
Summary figure

- Without undrained pre-shear

$\varepsilon_a \sim 10^{-5}$ $\varepsilon_a \sim 10^{-1}$

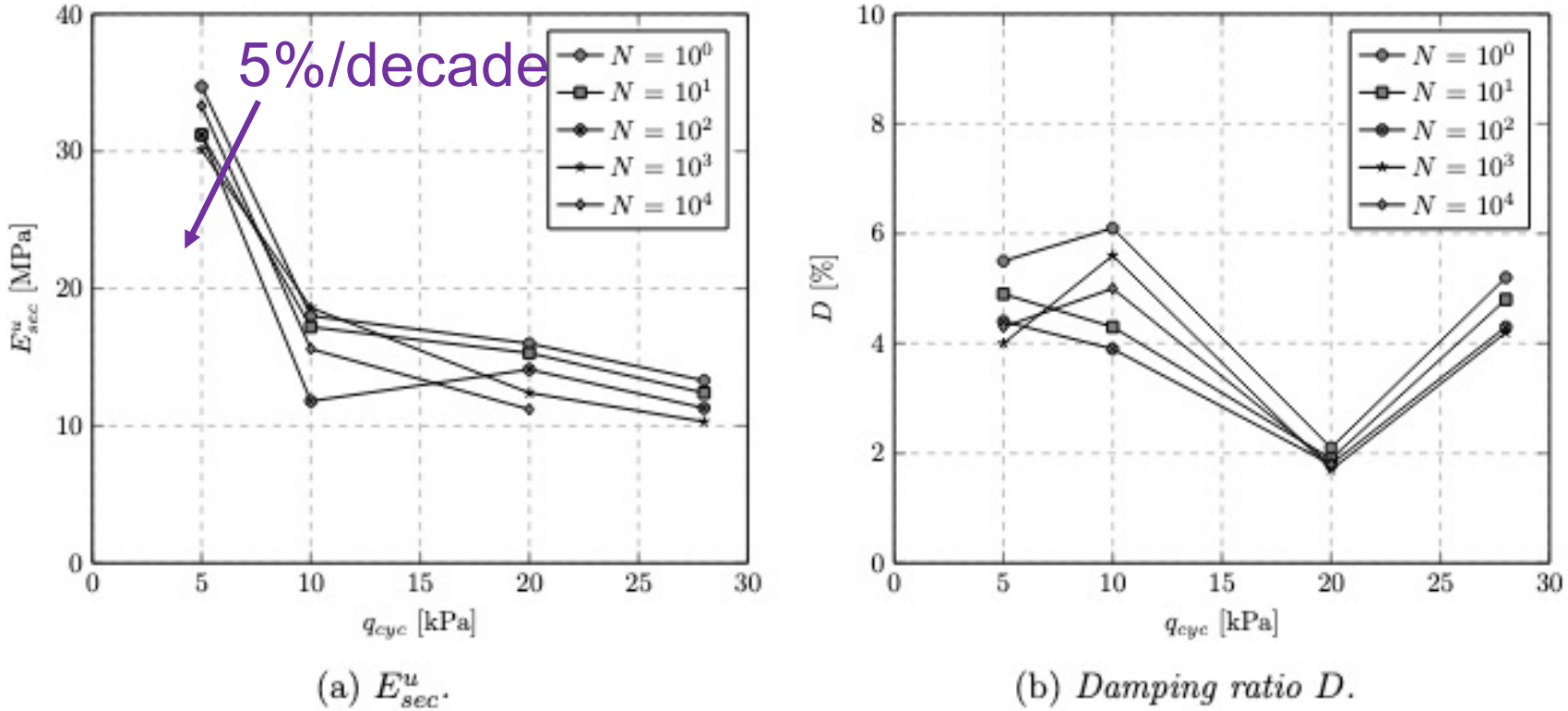


(a) E^u_{sec}.



Summary figure

- Up to 25% stiffness reduction (without undrained pre-shear)



(a) E^u_{sec}.

(b) *Damping ratio* D.

Conclusions

- Stiffness degrades with 5%/decade until failure (for this loading period; which is conservative)
- Damping is stable (until failure)
- At small load amplitudes we approximate ‘small-strain’ stiffness
  - Adding an undrained unload/reload in std. triax test gives a lot of information
- Pre-shearing (*e.g.* embankment loading) has a substantial effect on subsequent cyclic response

Conclusions

- Undrained shear strength unaffected for tests with small cyclic loading amplitude
- Deviatoric creep is significant and needs to be accounted for in analyses of cyclic strain accumulation
- More testing under way
  - Deep mixed clays (new TRV project)
- Data already used to modify elastic stiffness matrix in Creep-SCLAY1s and Creep-SCLAY1sc

Conclusions

- Strain accumulation from cyclic loading is creepy behaviour …
- … this shouldn't come as a surprise:

JANBU, N. (1985). *Géotechnique* **35,** No. 3, 241–281

Soil models in offshore engineering

N. JANBU*

$$u_{\text{cum}} = \frac{\Delta\sigma_d}{r_u} \ln\left(\frac{N}{N_0}\right)$$