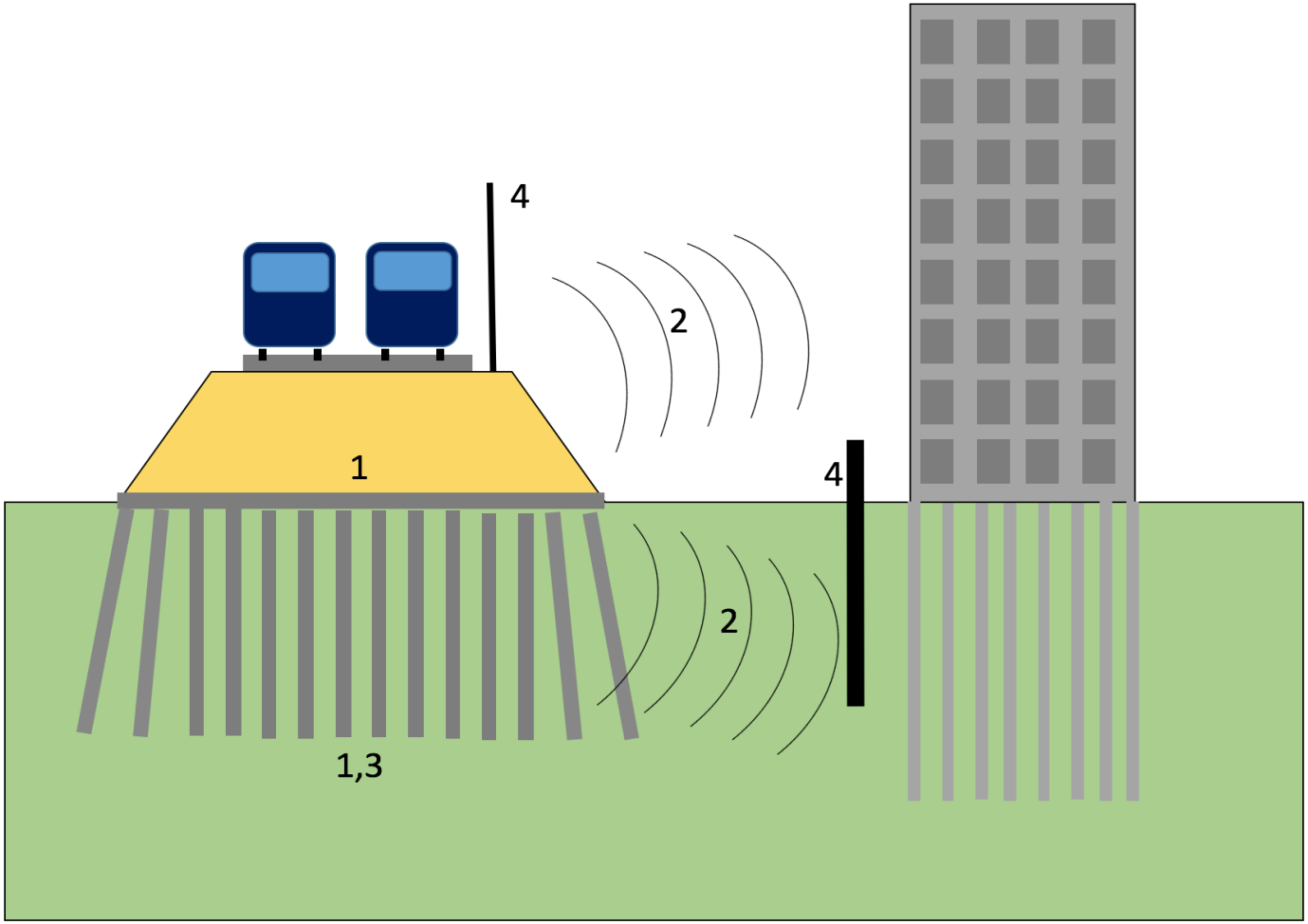
Branschsamverkan i Grunden

Långsiktig deformation spår/platta för cyklisk belastning- Funktionskrav

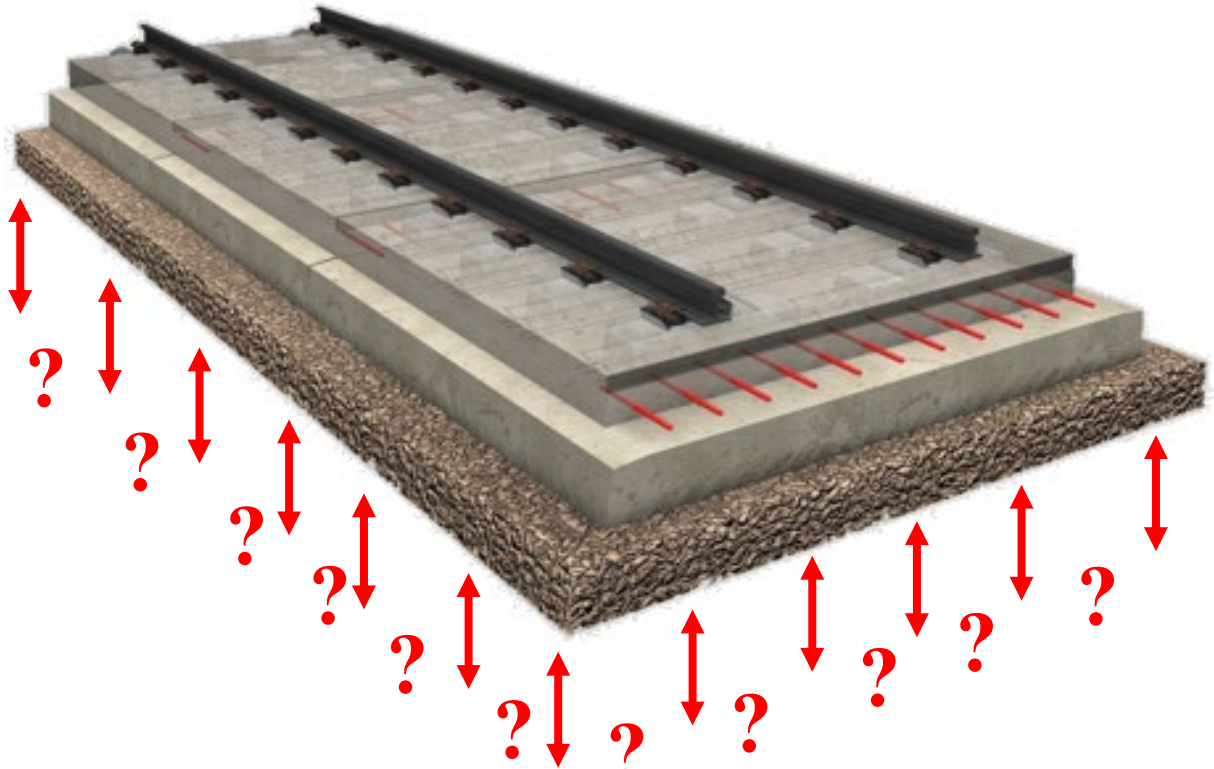
Jelke Dijkstra, Bruno Zuada Coelho & Hossein Tahershamsi

Background



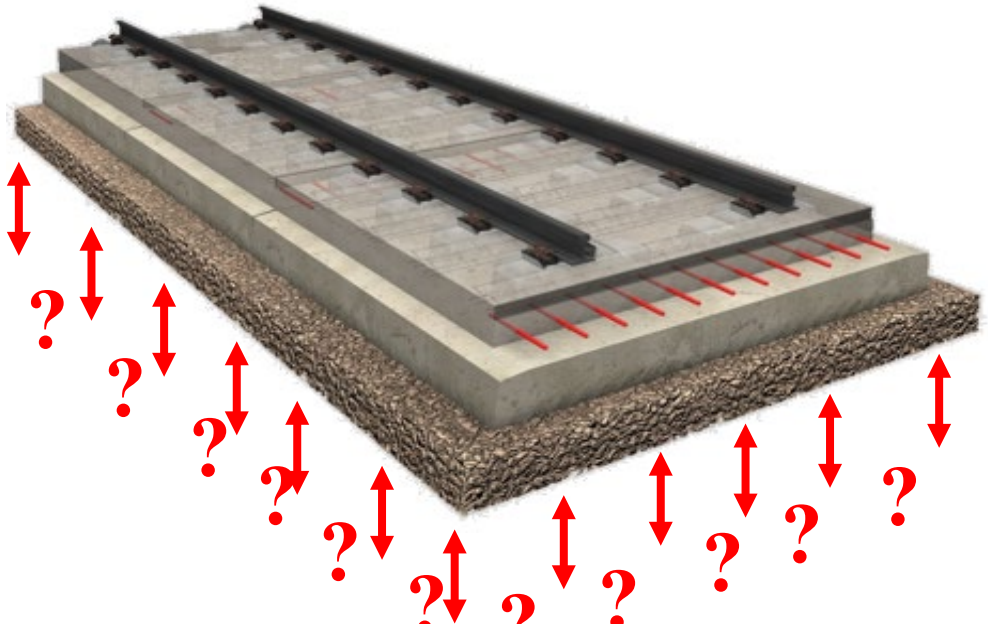
Background

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



Background

- Classic soil-structure-interaction problem where
  - Magnitude of loads transferred to the foundation depends on stiffness in foundation system (embankment, soil, piles)
  - Stiffness of foundation depends on (historic) loads transferred from track system



Background

- Geotechnical design of foundations of physical railway infrastructure focused on assessing
  - Stability (ULS)
  - Settlements (SLS)

- For complex projects complemented with assessment of dynamic response of track-foundation-system
  - Critical track velocities (ULS)
  - Vibrations in the soil (SLS)

Background

- Geotechnical design of foundations of physical railway infrastructure focused on assessing
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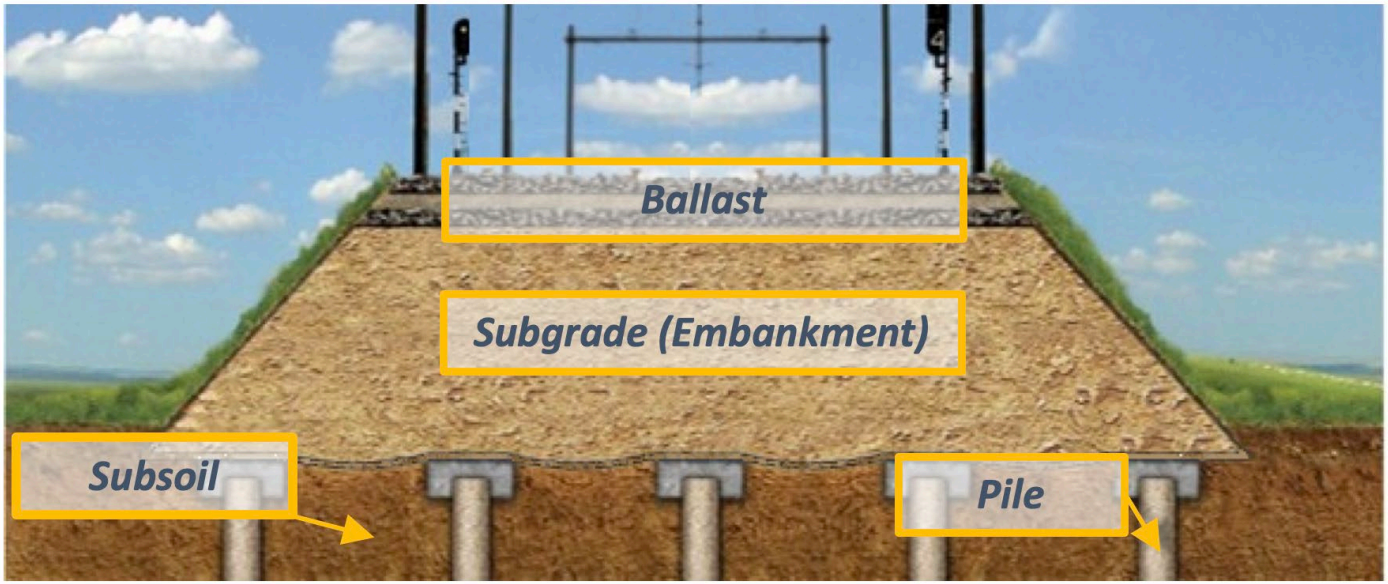
processes physically linked

analysis is not

what about guidelines?

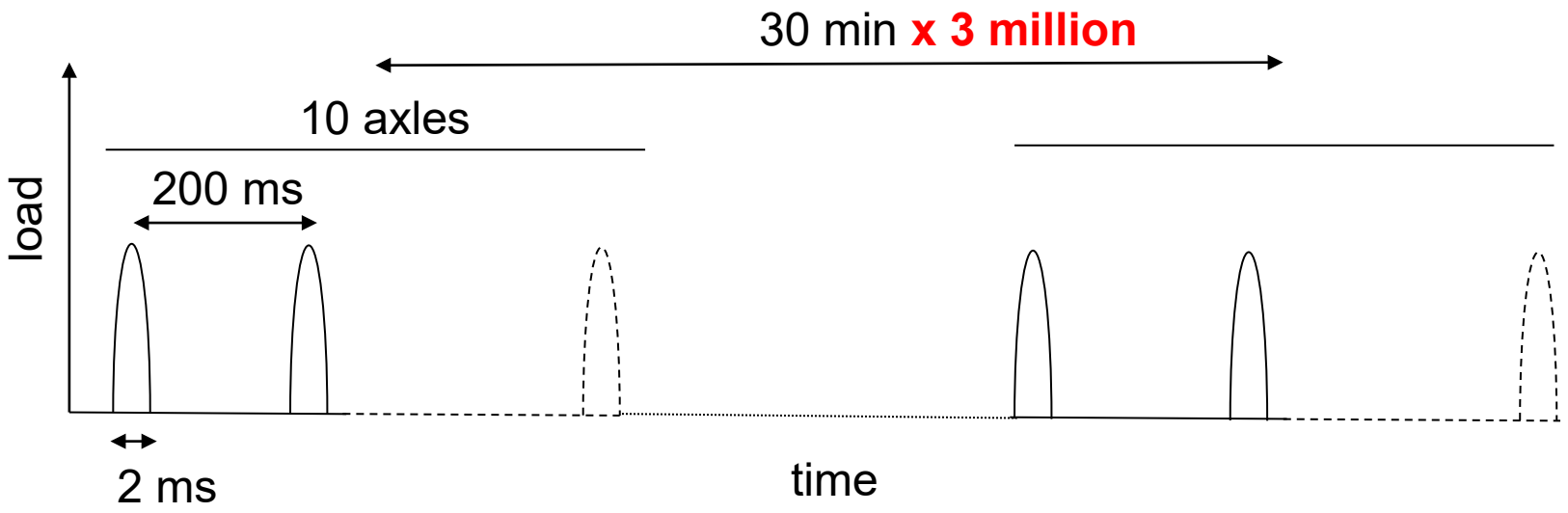
Background

- Not all deformation originates in ballast or subgrade
- Consolidation and creep in soft soils
  - From embankment construction
  - Accelerated by operation
  - Impacts emerging dynamic response (stiffness, damping)

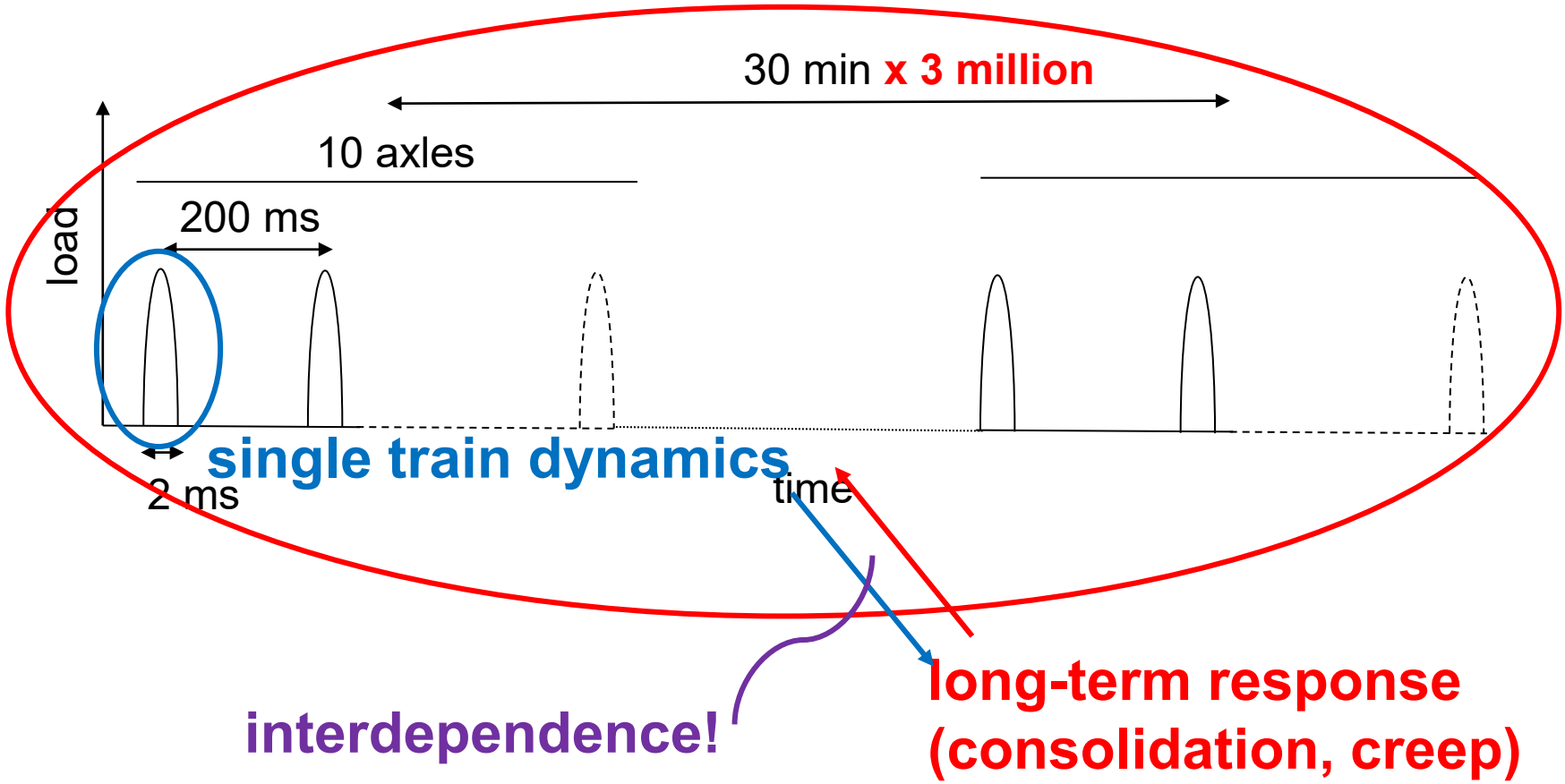


Embankment on piled foundation: section

Background



Background


30 min x 3 million
10 axles
200 ms
load
2 ms
single train dynamics
time
interdependence!
long-term response
(consolidation, creep)

Background

- Two projects within BIG, TrV_2015-108250 & TRV 2016 -106277, basically investigating:
  - Effect of repeated dynamic loading on long-term foundation response ⟶ quasi-static approach
  - Effect of long-term response (changes in the ground) on single train ⟶ dynamic response

Static, quasi-static, dynamic

- Static: load is constant (*e.g.* self weight)
- Quasi-static: change in variable load does not lead to inertial effects
- Dynamic: variable load leads to additional inertial effects cannot be neglected

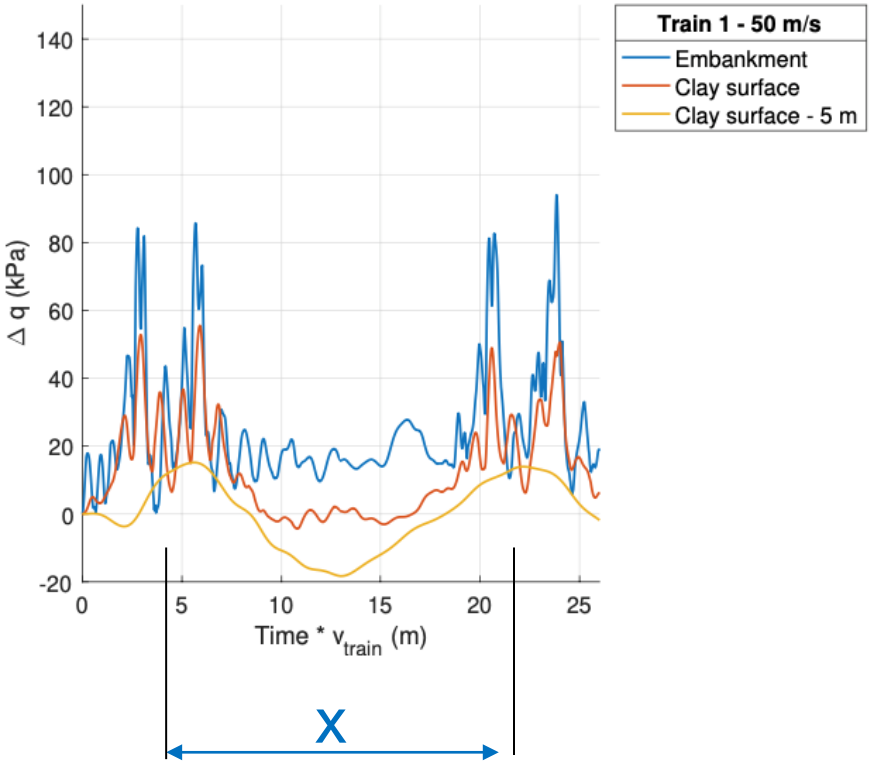
- A (harmonic) cyclic load is considered quasi-static when the angular velocity ω and amplitude A produce a negligibly small gravitational acceleration compared to g

$$A\omega^2 << g$$

Long-term foundation response

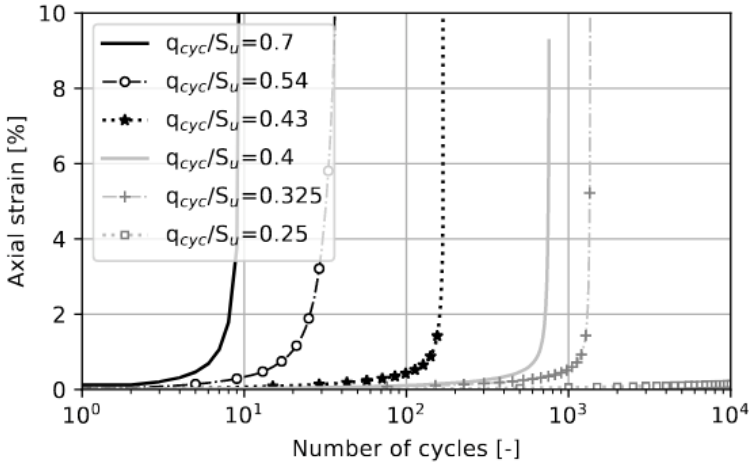
- Only the low frequencies reach the soil below the embankment
  - Quasi-static cyclic loads to model multiple trains
  - Period *T* directly proportional to distance between wheelsets x



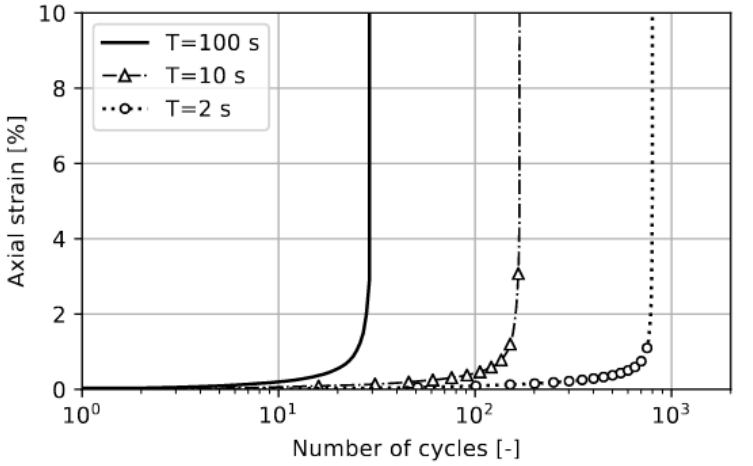


Cyclic response of soft clay

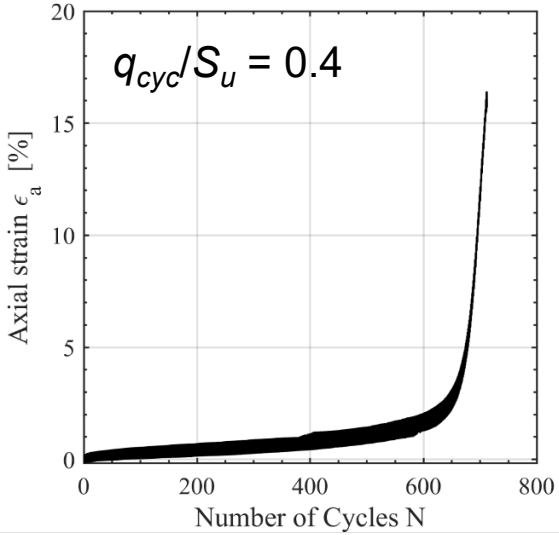
- Cyclic response of Onsøy
- Onset of failure dependent on:
  - Loading amplitude q_{cyc}
  - Loading period T



(b)



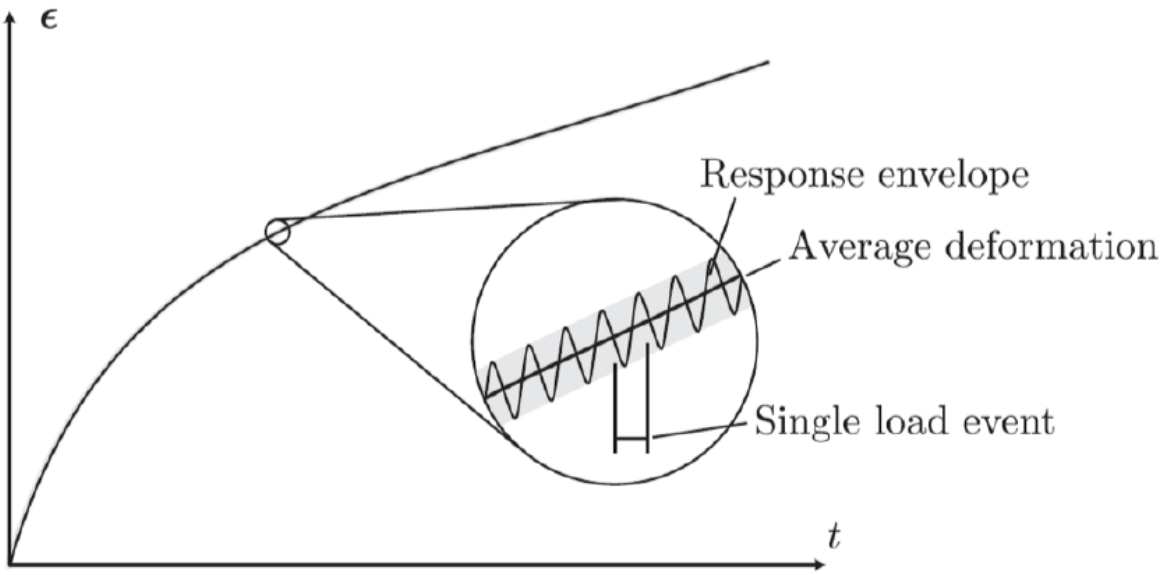
data from Wichtmann (2013)



data from Utby

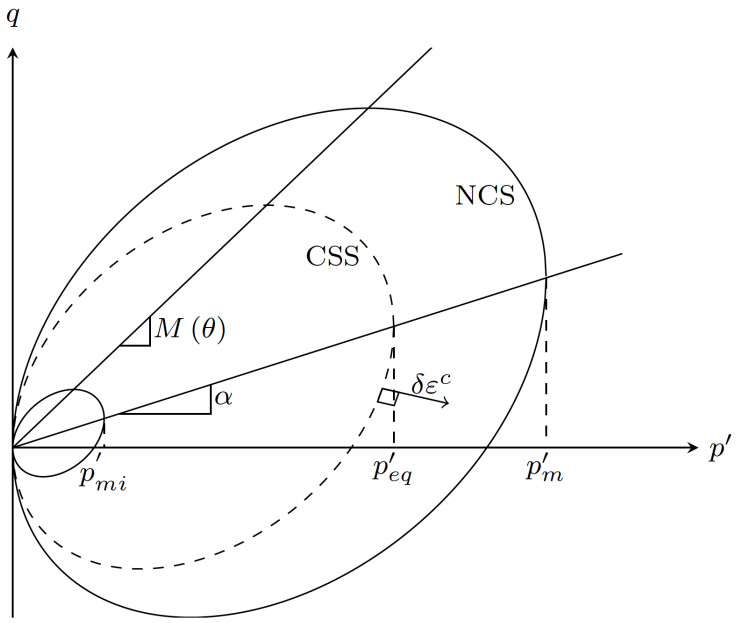
Explicit vs. implicit modelling

- Implicit
  - Capture the complete load cycle with many strain increments using stress-strain relation in constitutive model
- Explicit
  - Direct relation between number of load cycles (or time) and accumulated strain



Creep-Sclay1sc model

- New Chalmers strain accumulation model for clay is explicit
  - Still captures amplitude & loading period dependence



[Gras et al. 2018]

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

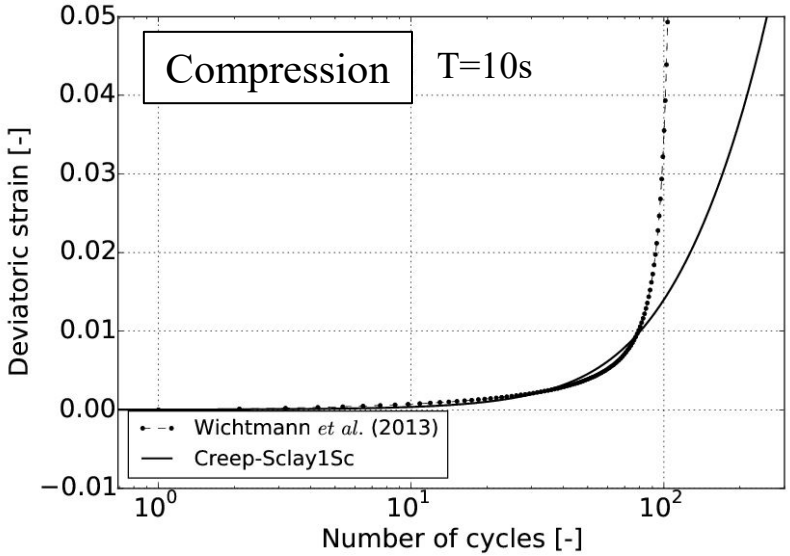
$$\varepsilon^{vp}_{ij} = \varepsilon^{c}_{ij} + \boxed{\varepsilon^{cyc}_{ij}}$$

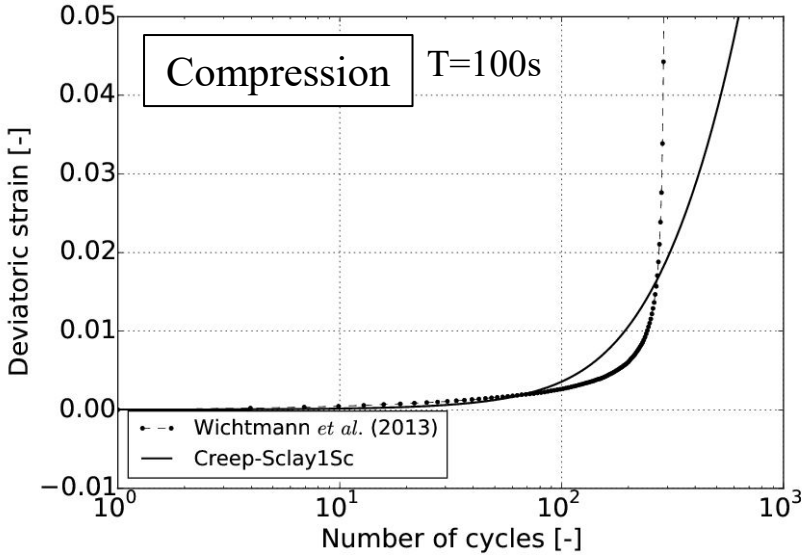
$$\varepsilon^{c}_{ij} = \dot{\Lambda}\frac{\partial p'_{eq}}{\partial \sigma'_{ij}} \qquad \text{Creep-Sclay1s}$$

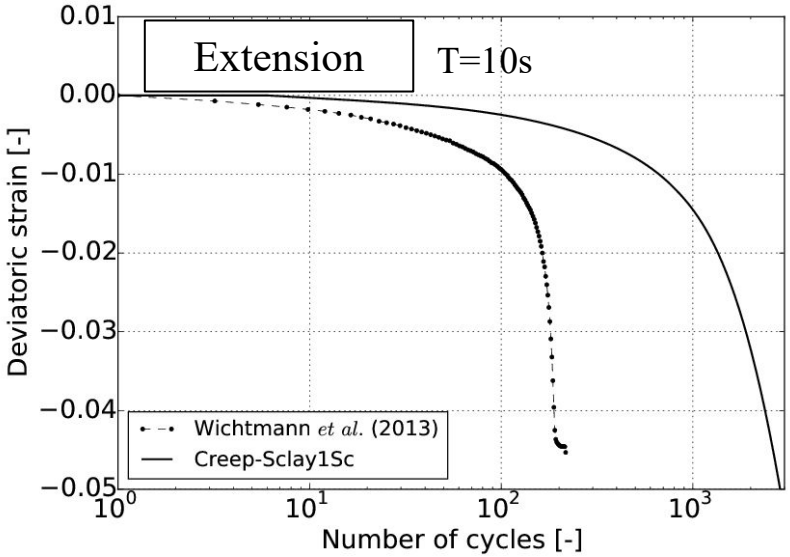
$$\dot{\varepsilon}^{vp}_{ij} = \left[\boxed{\dot{\Omega}} + \dot{\Lambda}\right]\frac{\partial p'_{eq}}{\partial \sigma'_{ij}} \qquad \text{Creep-Sclay1sc}$$

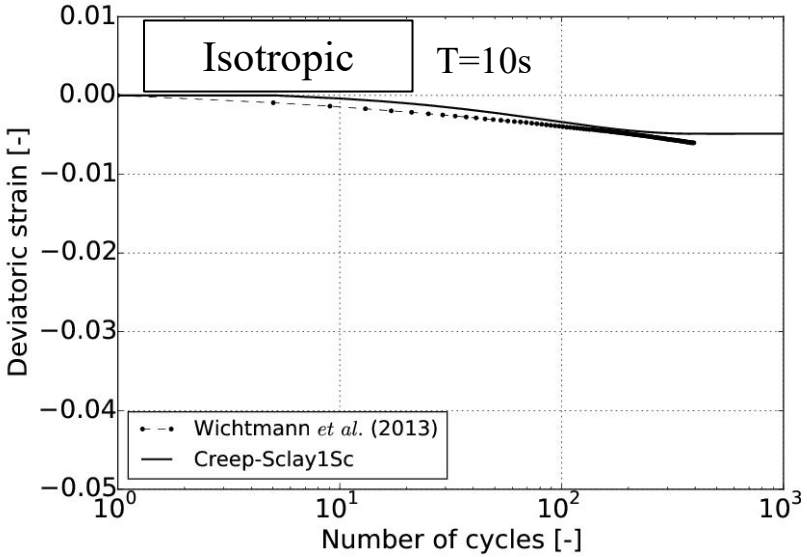
Cyclic loading

Model works for static and cyclic triaxial loading after calibration

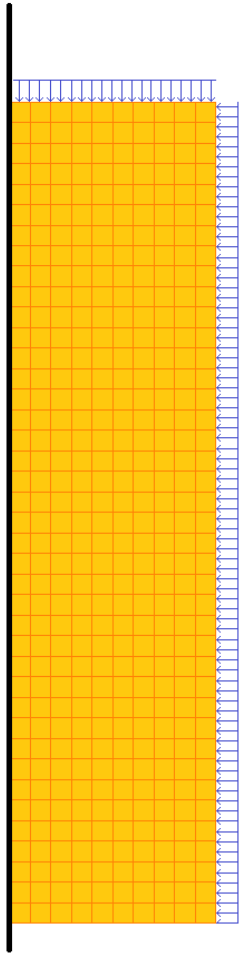


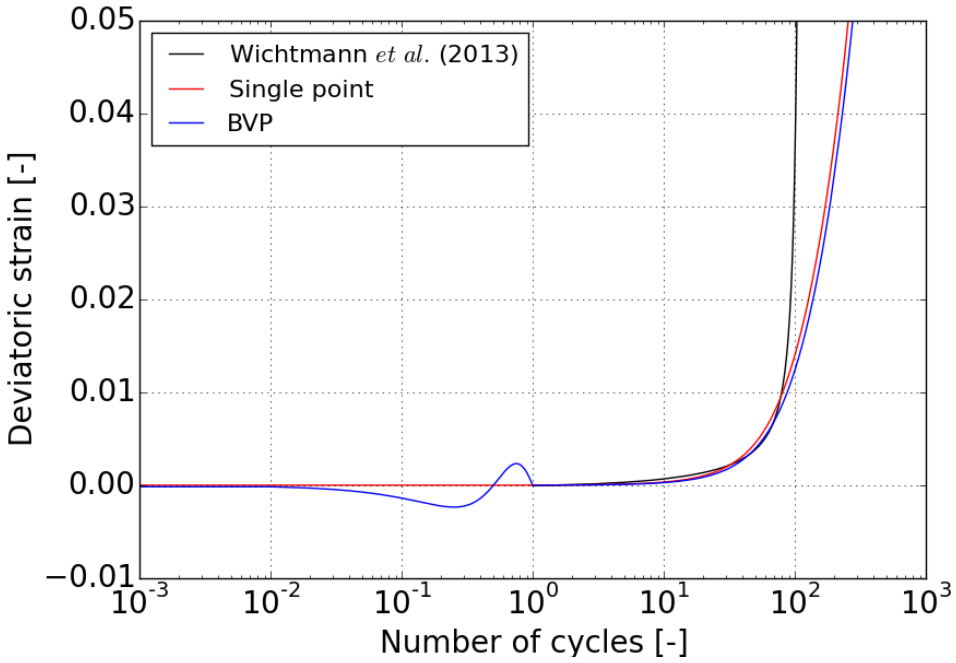






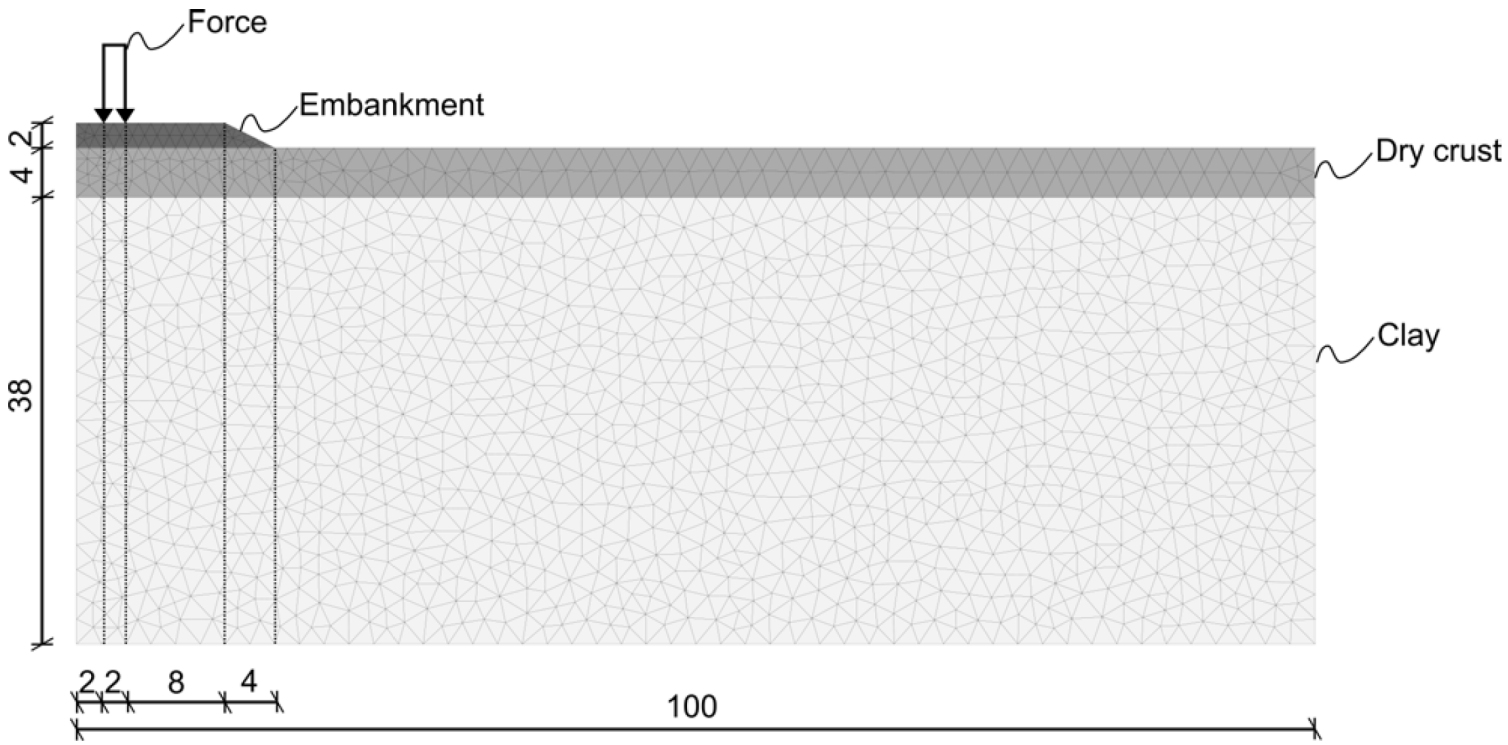
Boundary value level





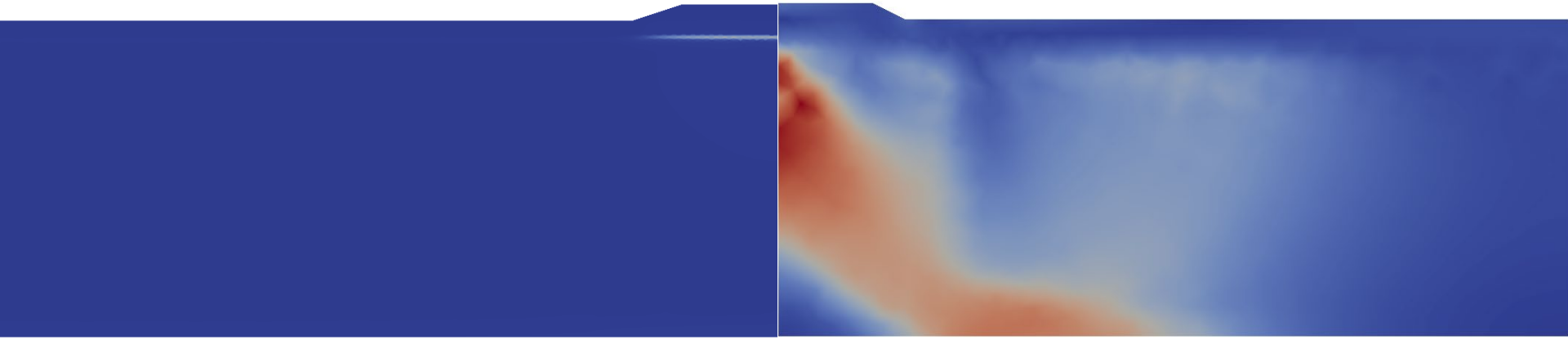
Reference case

- Railway embankment on Onsøy clay



Reference case

- Railway embankment on Onsøy clay after 5000 cycles

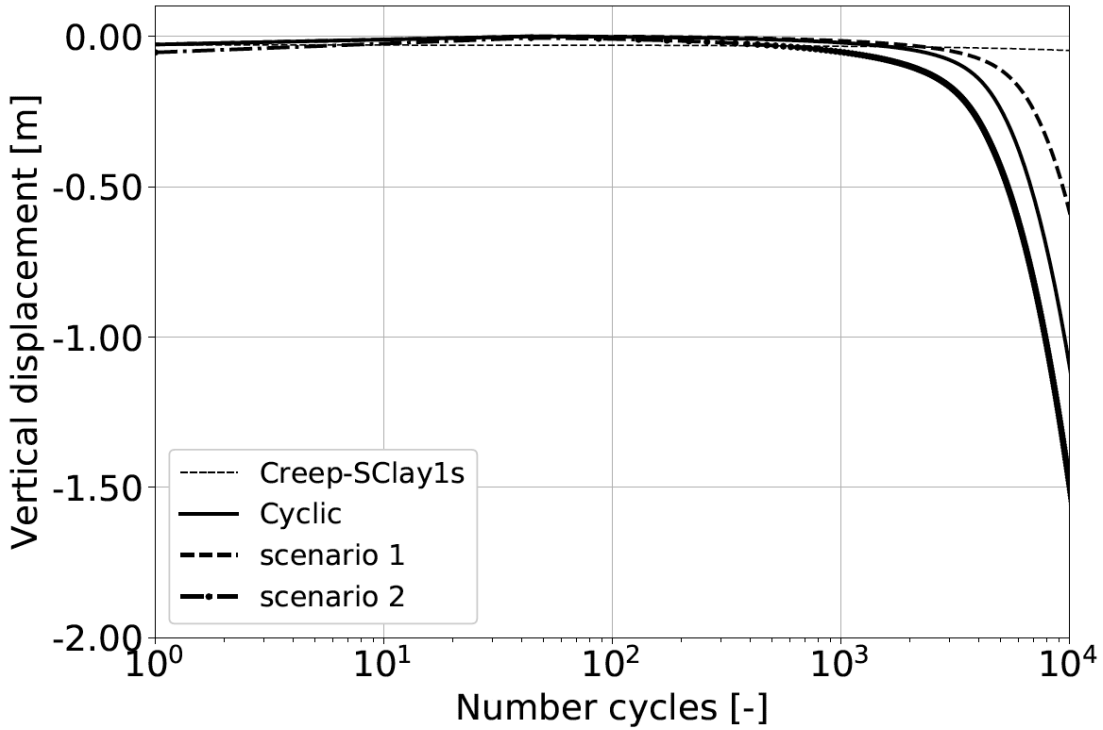


SC1Sc
creep

Sc1Scs
cyclic

Effect of amplitude & period

- Reference case: 100 kN/m; $f = 1\ s^{-1}$
- Scenario 1: 100 kN/m; $f = 2\ s^{-1}$
- Scenario 2: 200 kN/m; $f = 1\ s^{-1}$

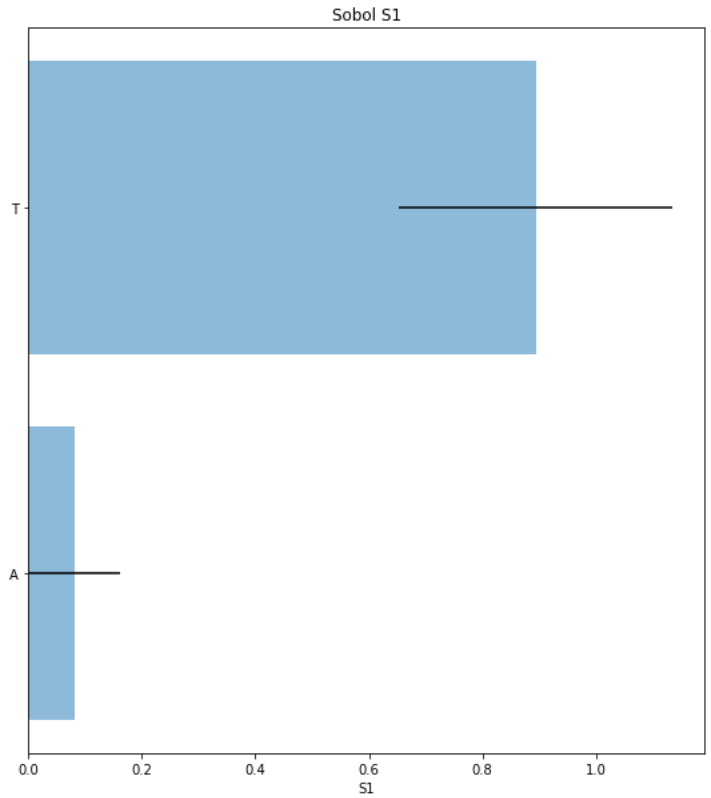


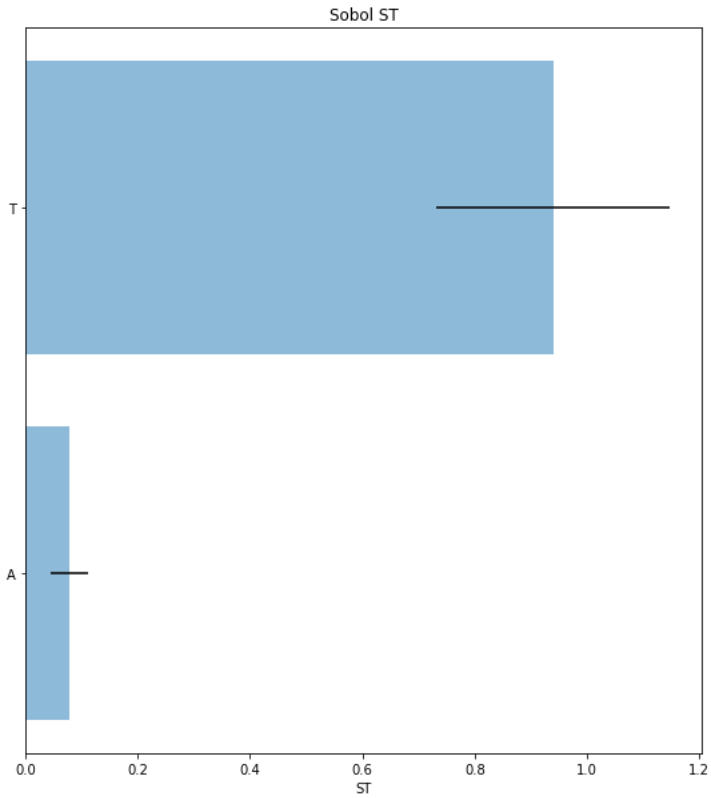
Effect of amplitude & period

- GSA analyses (600 realisations) for settlements at the centre line

T

A

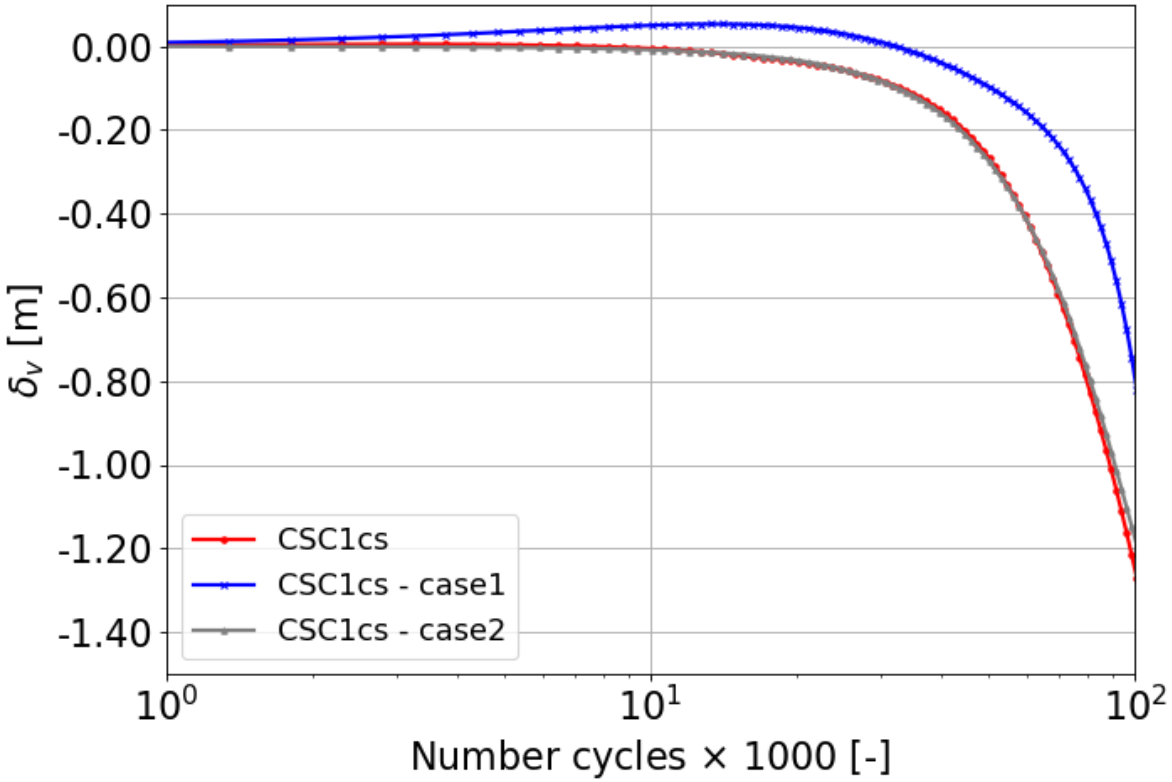


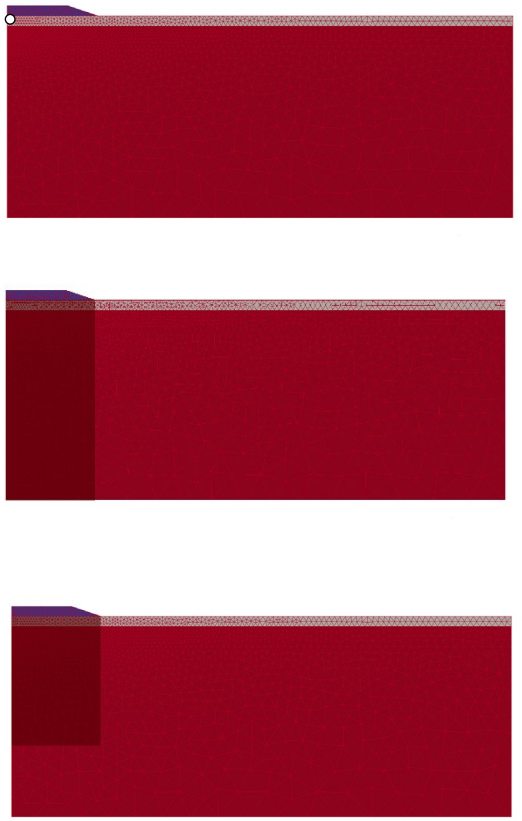


First order index

Total order index

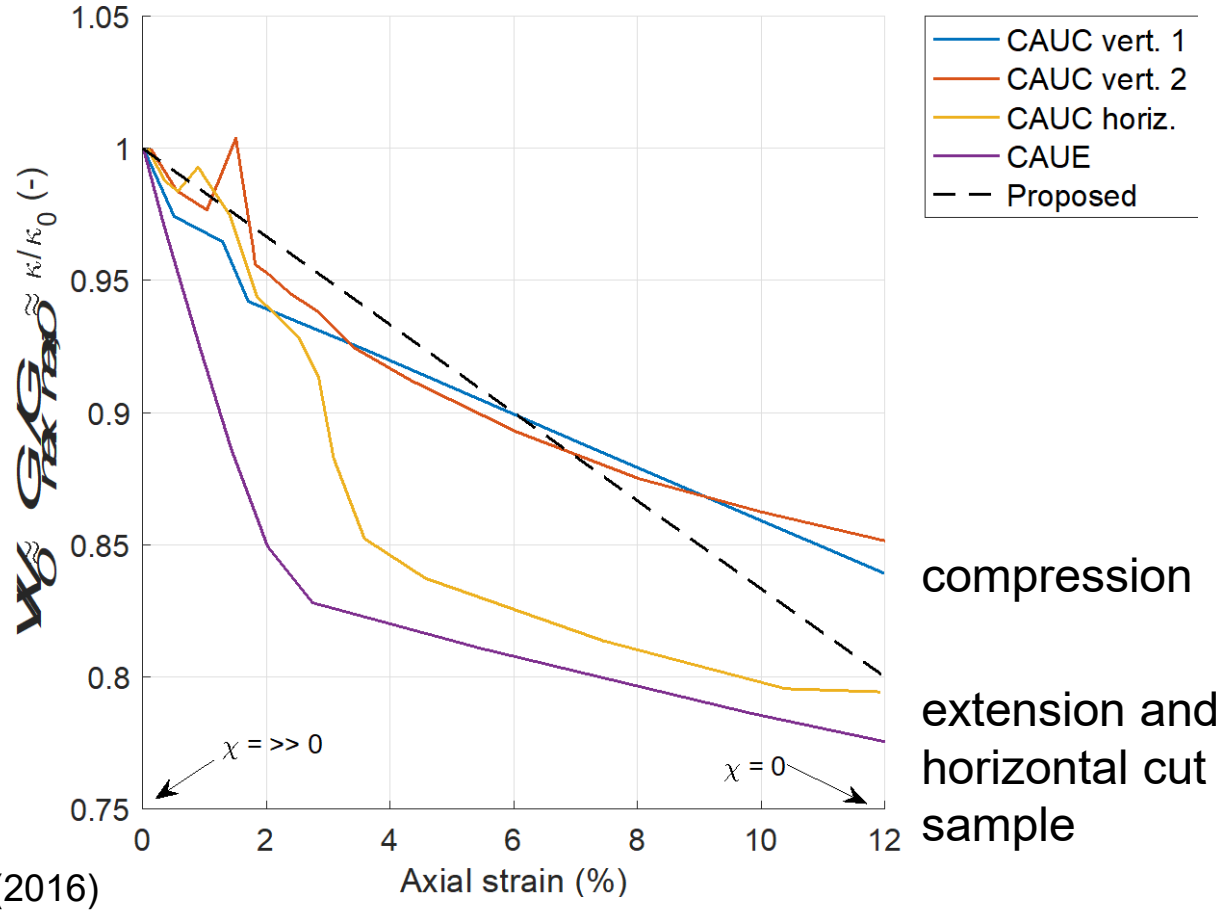
Ground improvement





Impact on dynamic response

- Link ‘dynamic’ stiffness evolution with ‘quasi-static’ material degradation χ



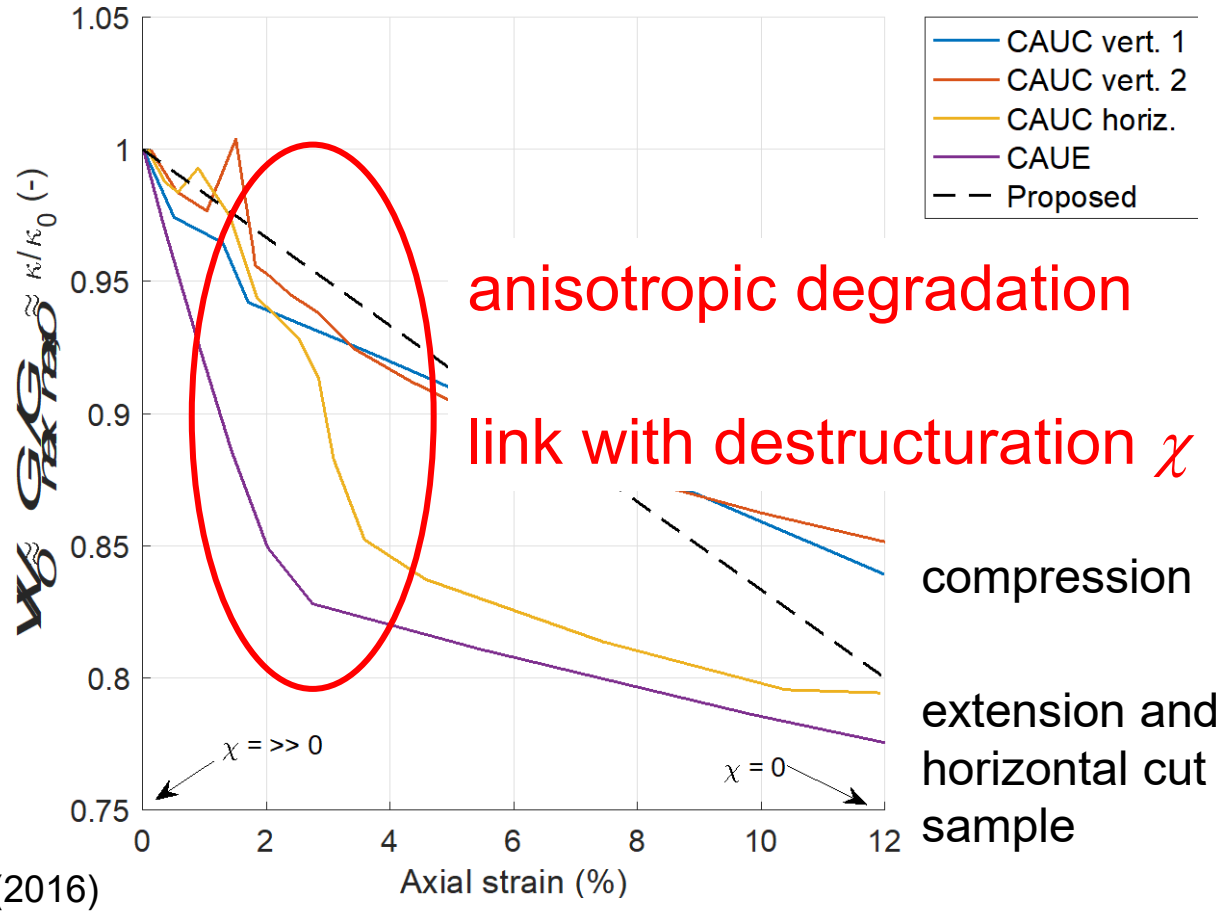
compression

extension and horizontal cut sample

Data from Wood (2016)

Quasi-static model

- Linking ‘dynamic’ stiffness evolution with ‘quasi-static’ material degradation χ



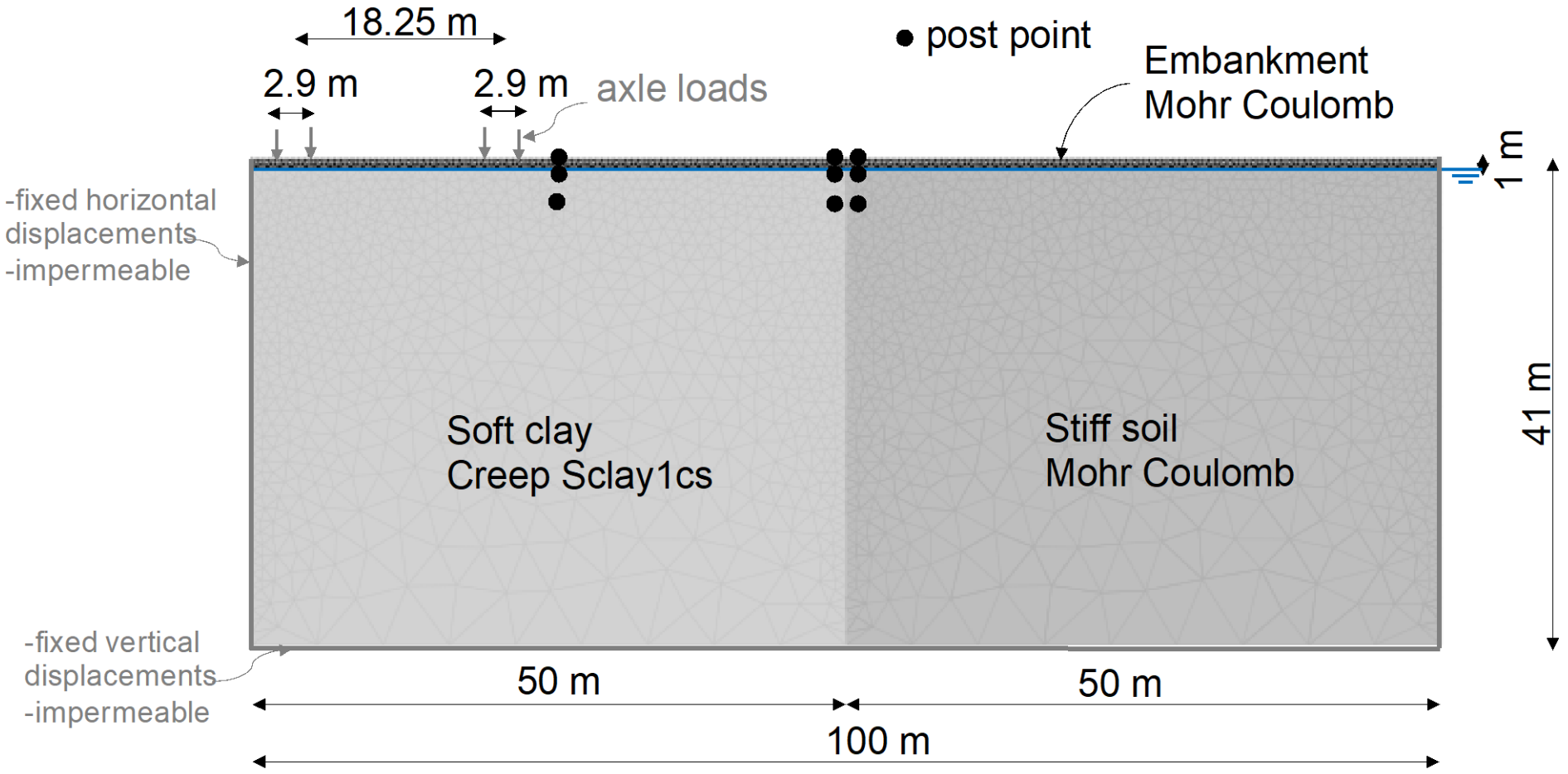
Data from Wood (2016)

Simple case

- Longitudinal section of transition zone from soft to stiff soil
  - Idealised (somewhat unrealistic) case
  - Mohr Coulomb for embankment and stiff soil
  - Creep-Sclay1sc for soft clay with strain accumulation
- Dynamic load before and after 100 000 load cycles
- Moving train load at two train velocities (10 and 50 m/s)
- One X2000 carriage with two sets of 2 axles with F_{axle} = 60 kN

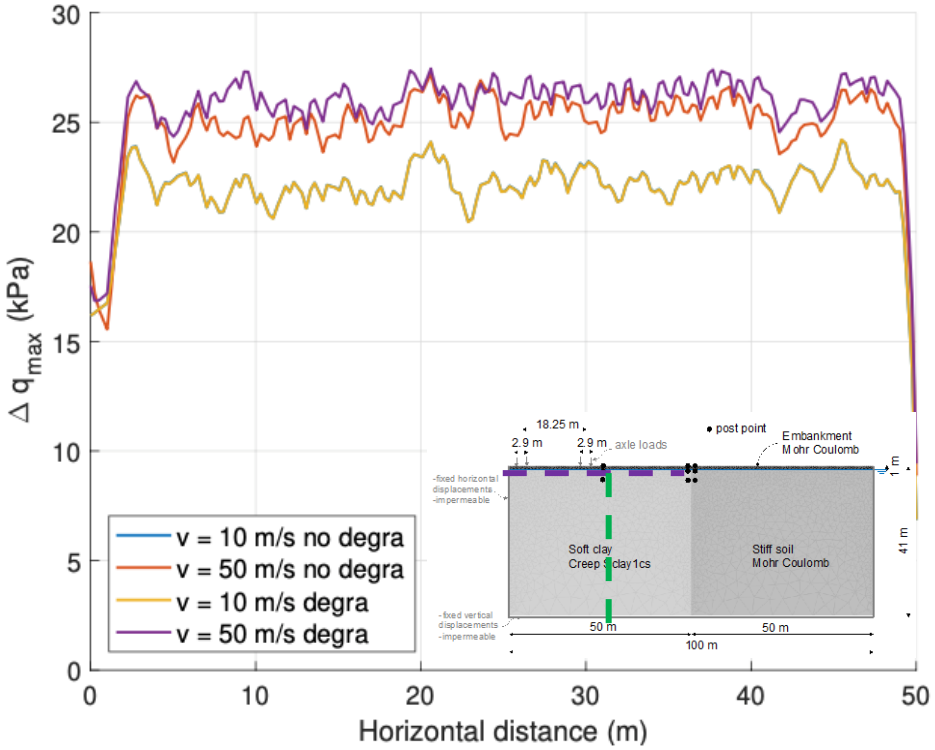
Simple case

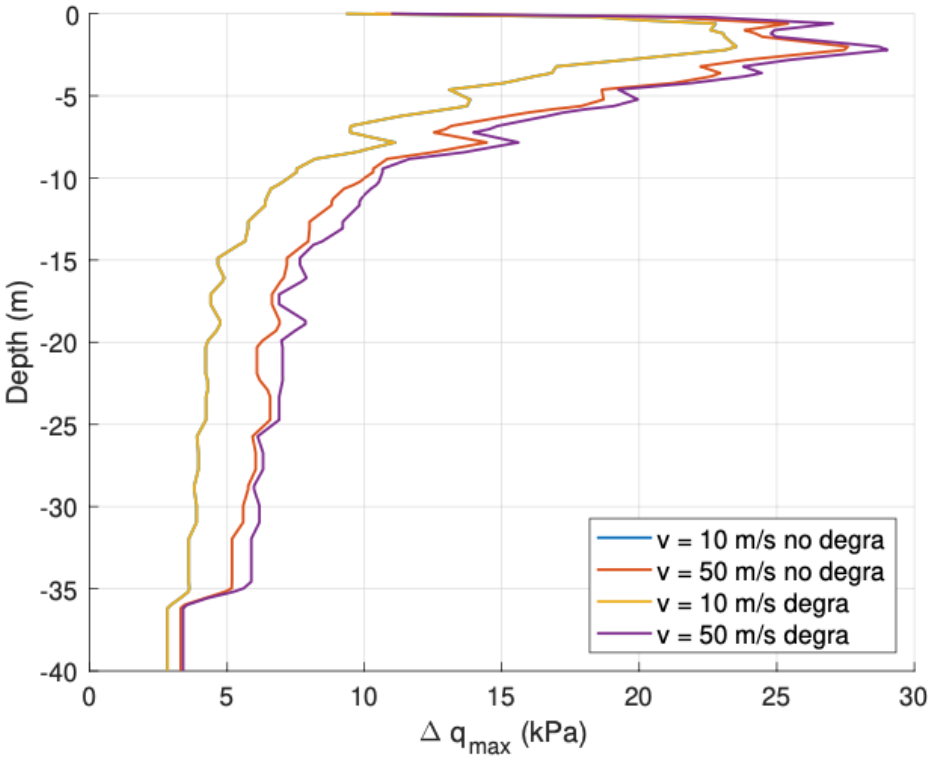
- Longitudinal section of transition zone from soft to stiff soil



Modelling procedure

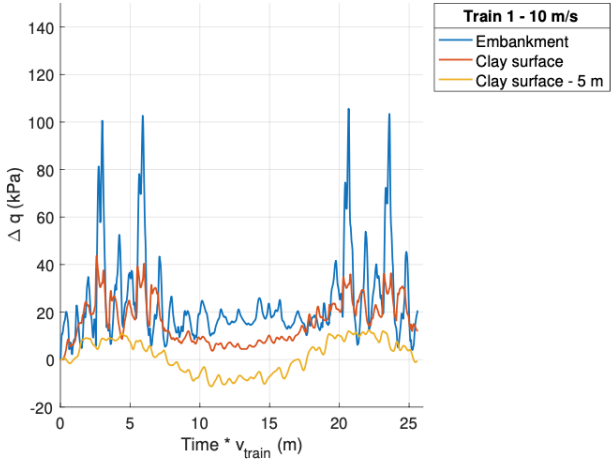
- Dynamic analysis of single train initialises Creep-Sclay1sc
  - Max amplitude q_{max} as function of location in domain



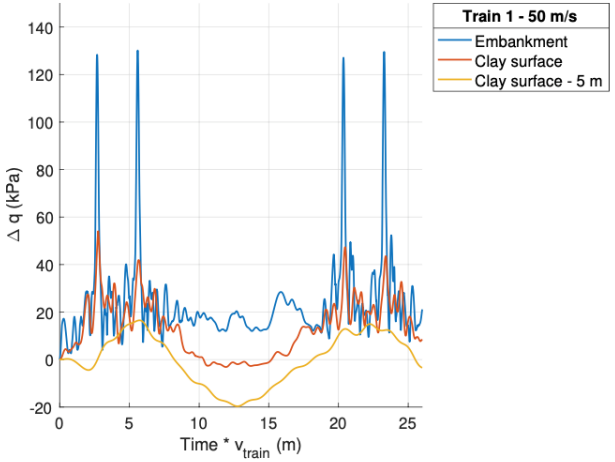


Results (with degradation)

1st train
cycle 0

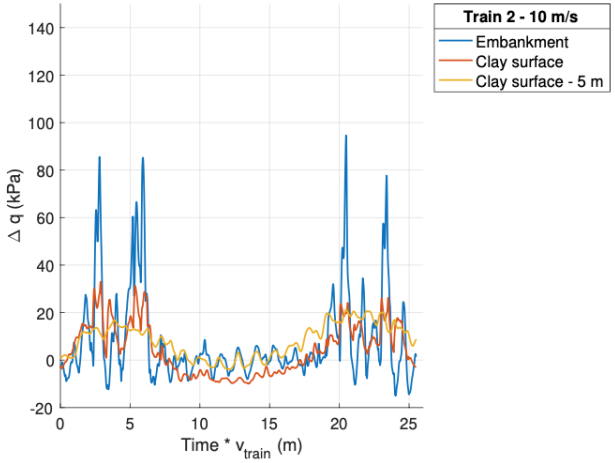


(a) *Train 1:* $v_{train} = 10\,\mathrm{m\,s^{-1}}$.

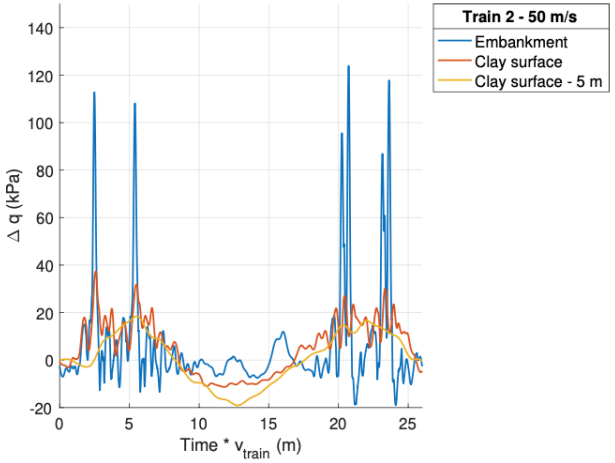


(b) *Train 1:* $v_{train} = 50\,\mathrm{m\,s^{-1}}$.

2nd train
cycle 100 000



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

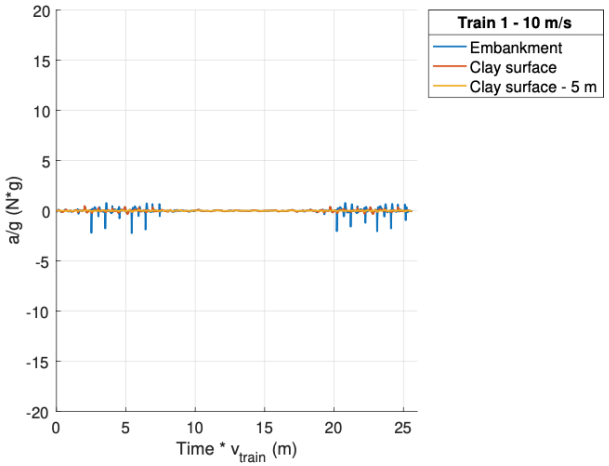


(d) *Train 2:* $v_{train} = 50\,\mathrm{m\,s^{-1}}$.

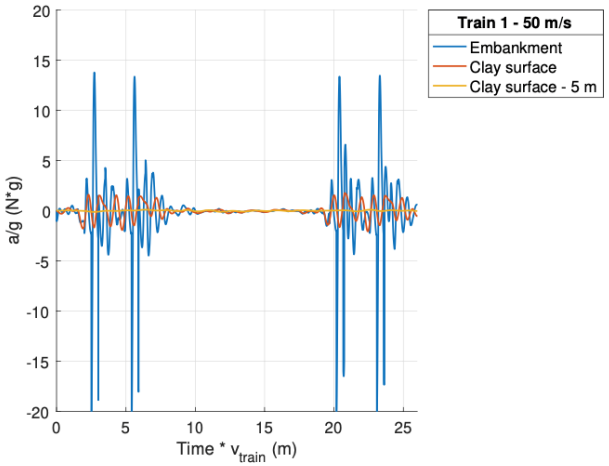
Figure 3.2: *Δq for train 1 (before cycle 1) & train 2 (after cycle 100k); $x = 25\,\mathrm{m}$; with stiffness degradation in model.*

Results (with degradation)

1st train
cycle 0

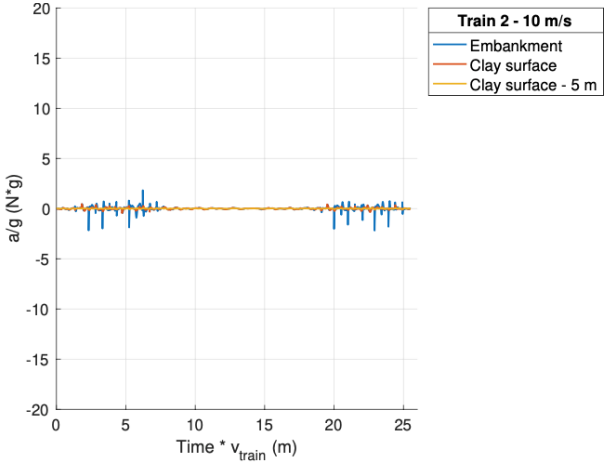


(a) *Train 1:* $v_{train} = 10\,\mathrm{m\,s^{-1}}$.

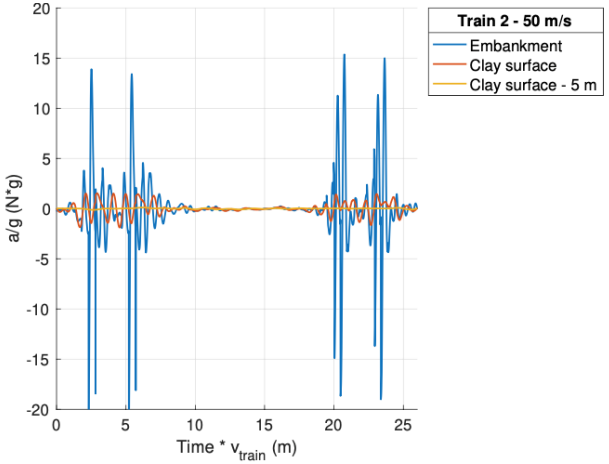


(b) *Train 1:* $v_{train} = 50\,\mathrm{m\,s^{-1}}$.

2nd train
cycle 100 000



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



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

Figure 3.20: $\frac{a}{g}$ *for train 1 (before cycle 1) & train 2 (after cycle 100k);* $x = 25\,\mathrm{m}$*; with stiffness degradation in model.*

Conclusions

- New constitutive model for prediction of strain accumulation in natural soft clays presented and calibrated against lab. data
  - Quasistatic and explicit modelling approach
  - Effects of loading period and amplitude are captured
- Boundary value analyses indicate
  - Take period as the distance between wheel-sets
  - Cyclic creep effects are more pronounced than ‘ordinary creep’
  - Effect of loading period is more important than loading amplitude (for the range tested). This is corroborated by experimental data
  - Link between quasi-static and dynamic properties established for destructuration mechanism in clay

What is next

- Intricate interactions between train loads, railway system and foundation preclude guidelines that prescribe certain methods and their associated technical properties

- Rather, it would be more prudent to specify a measurable system response for operation over the lifetime of the structure
  - Relative deformations, such as differential settlements along the track (wavelength of disturbance) and horizontal movements
  - Vibrations

- The models developed in these projects can help achieve this future, as well as identify the governing performance metric
  - SLS for vibrations perhaps more stringent than ULS stability