Excellensområden järnväg
4: Anläggningskonstruktioner
Interaktion jord - konstruktion

CHALMERS

Spatial variability of lime-cement mixed clay in different length scales

Dawn Wong
Jelke Dijkstra
Joosef Leppänen
Vijayshree Sadasivan
Chalmers University of Technology

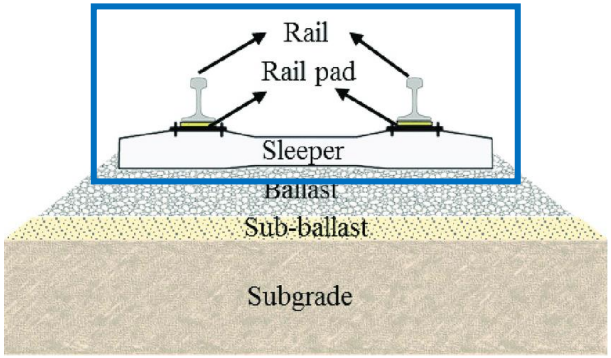
Agenda

- Introduction and background
- Site description and methods
- Spatial variability at different length scales
- RFEM analysis
- Conclusions

Background

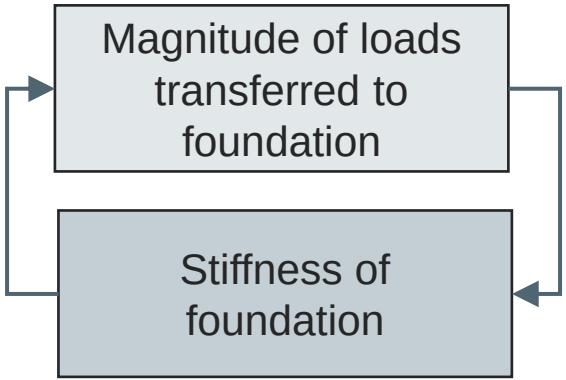
- Need to expand capacity of railway infrastructure
  - More traffic
  - Higher train loads
  - Faster trains
- Want to minimize maintenance costs and unexpected operational delay

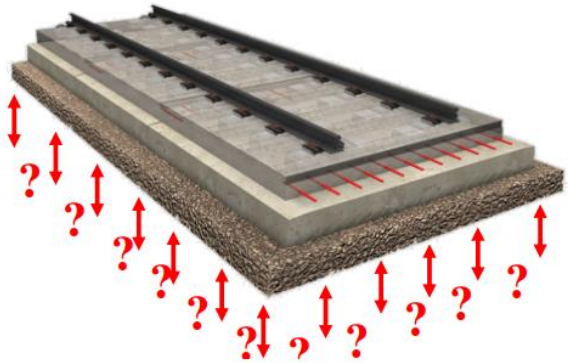
Background



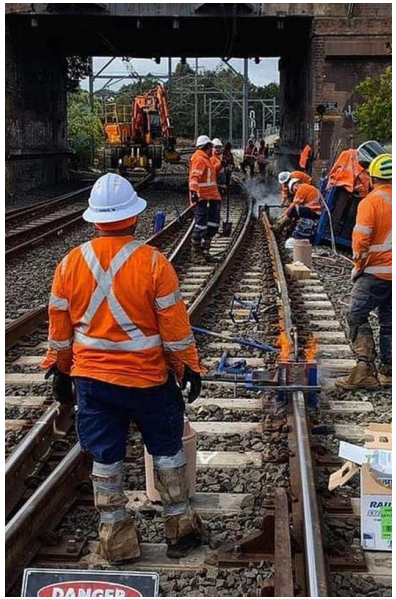
- Good knowledge on track interaction
- Limited knowledge on impact of soil and foundation

- Classic soil-structure-interaction problem where:





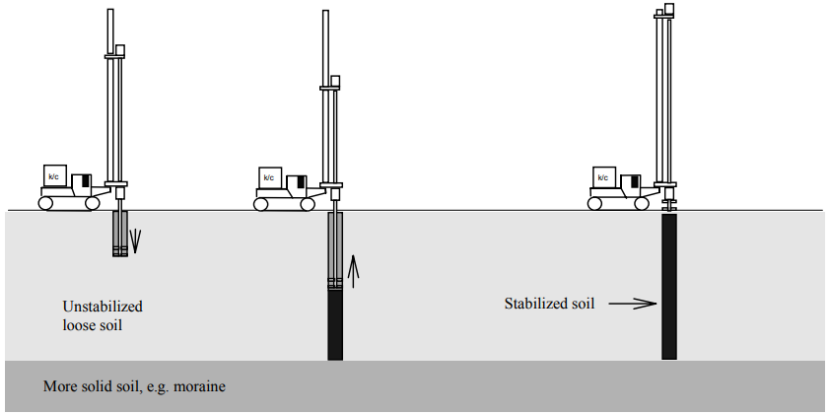
Need to consider soil-structure system as a whole

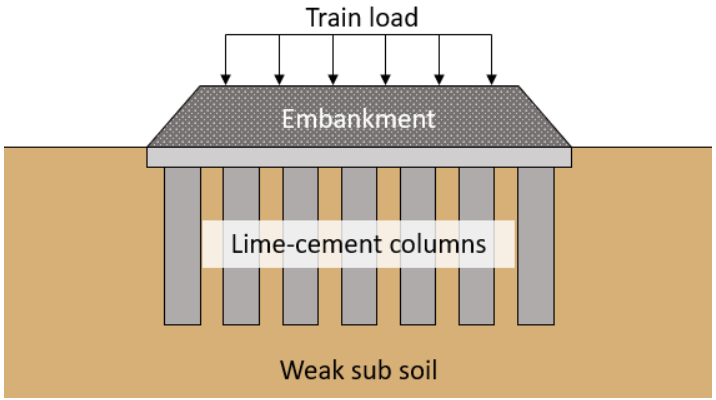


Uncertainty of system

- **Biggest uncertainty** in soil-structure system is **soil**
  - Degradation of geomaterials
  - Variability of in-situ soil
- Railways on soft soils require a foundation
  - Need to consider green solutions
  - Variability introduced from construction

Lime-cement columns

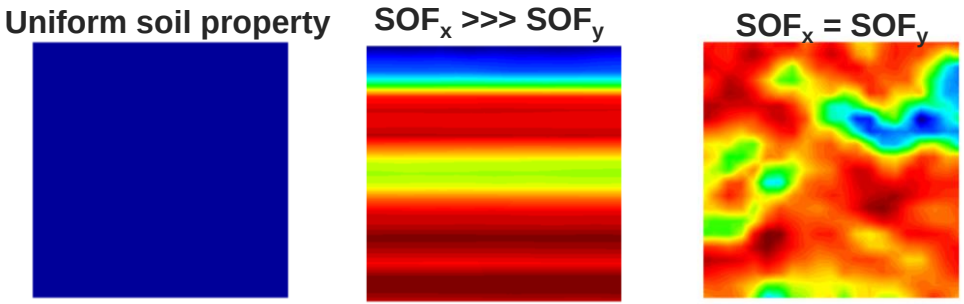


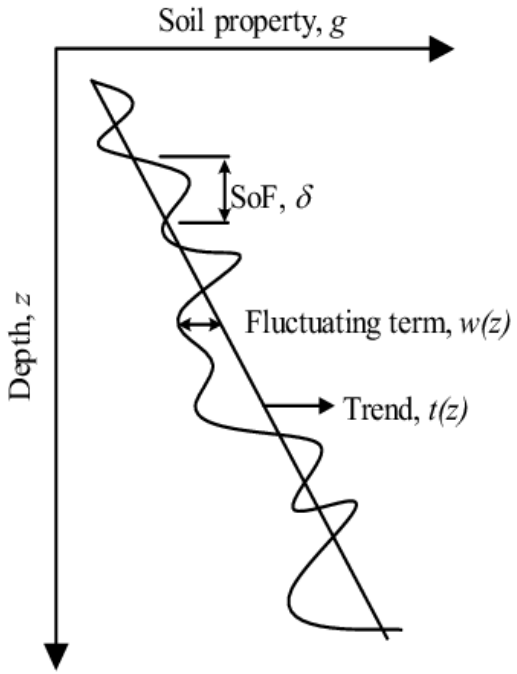


- **Lime-cement columns** (LCC) are low carbon solution to strengthen soft soils
- Strength and stiffness not uniform in the column

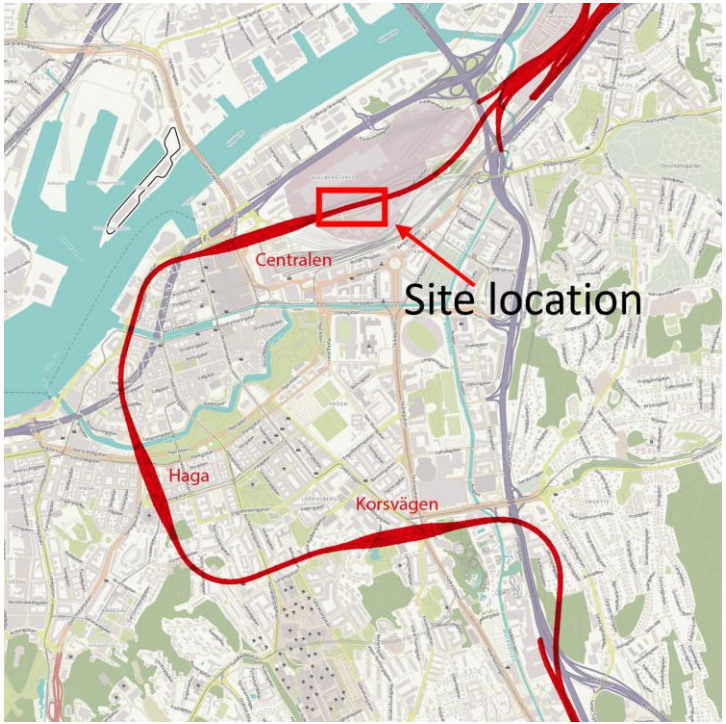
Scale of fluctuation

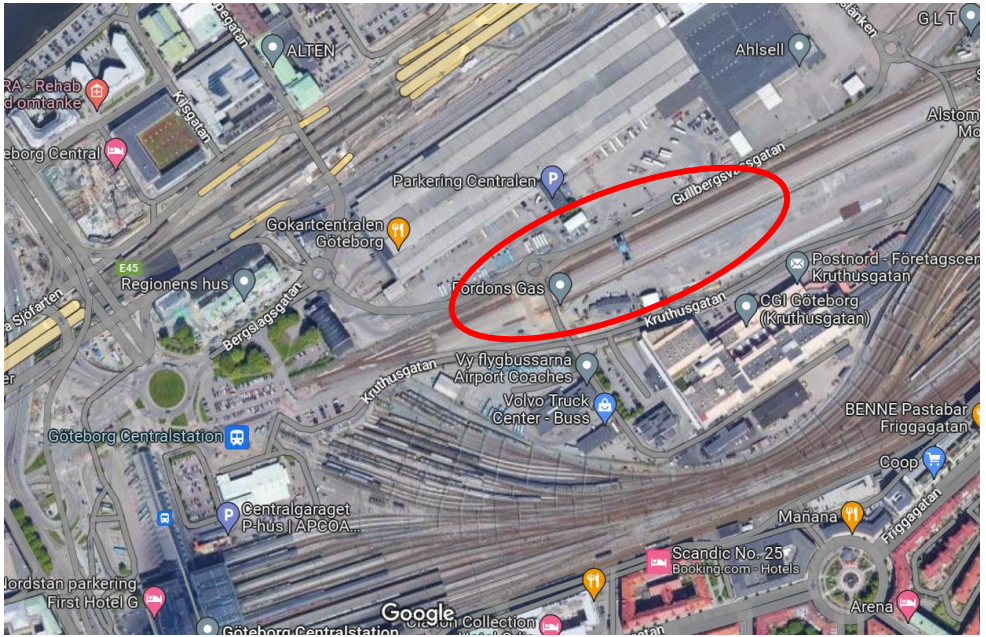
- SOF↓, more variability
- SOF↑, more uniformity
- SOF commonly measured in x, y, and radial directions





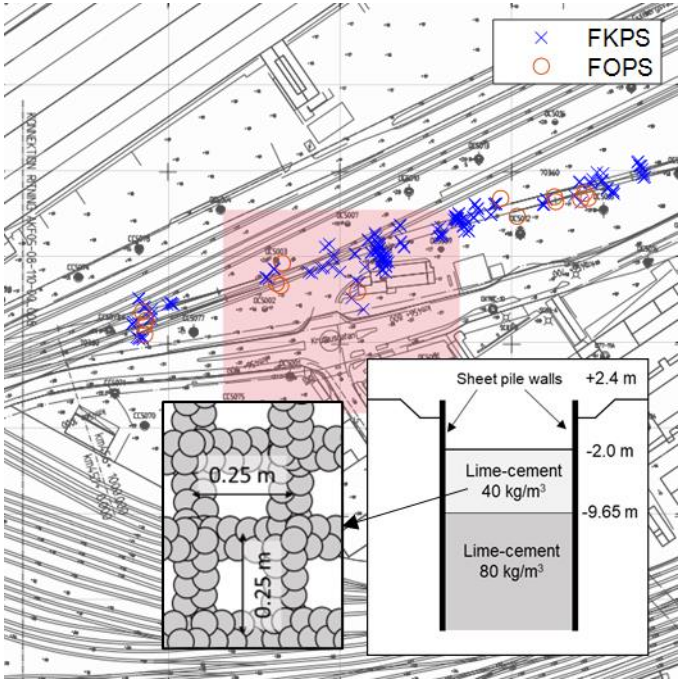
Site description – E02 Centralen, Västlänken (NCC, Trafikverket)



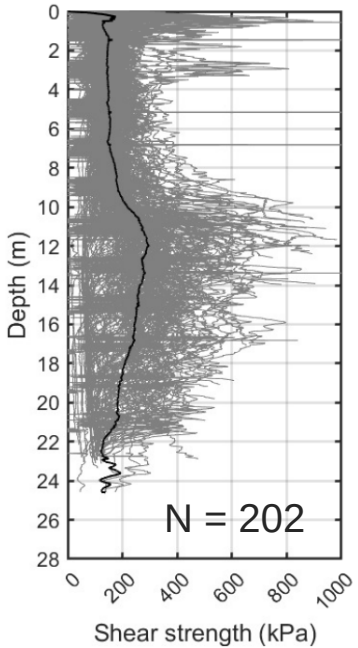


Field measurements

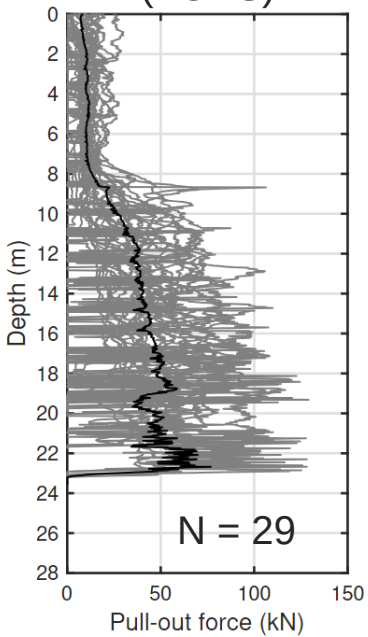
Plan view of test locations



Column penetration tests (FKPS)



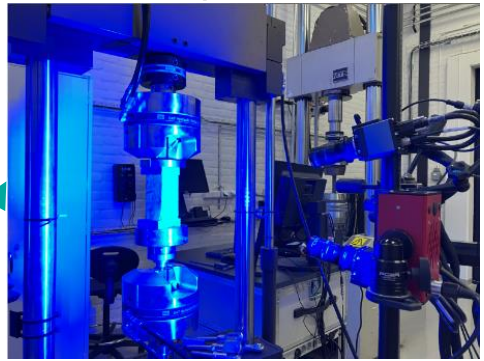
Reverse Column penetration tests (FOPS)



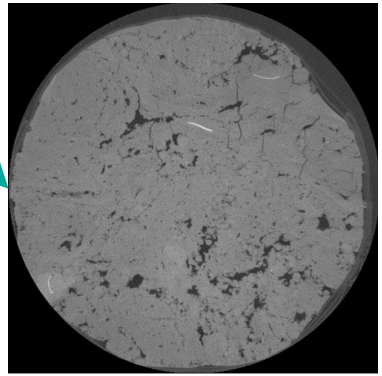
Block samples obtained from site

Example of LCC sample

Uniaxial compression with DIC



XCT

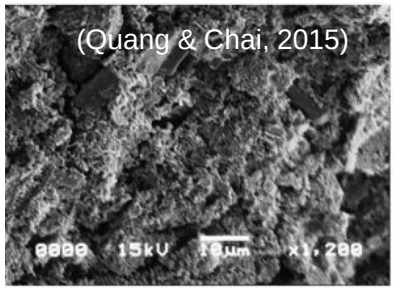


Laboratory tests:

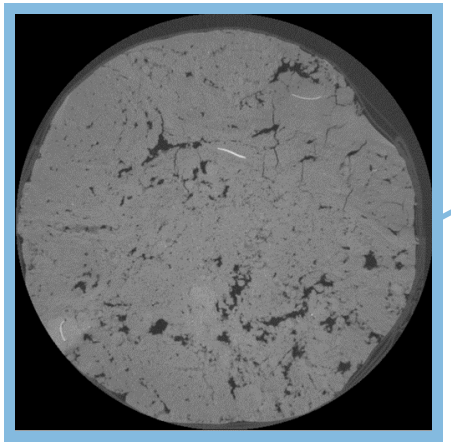
- Unconfined compression tests coupled with digital image correlation (DIC)
- X-ray computed tomography (XCT)

Variability at different length scales

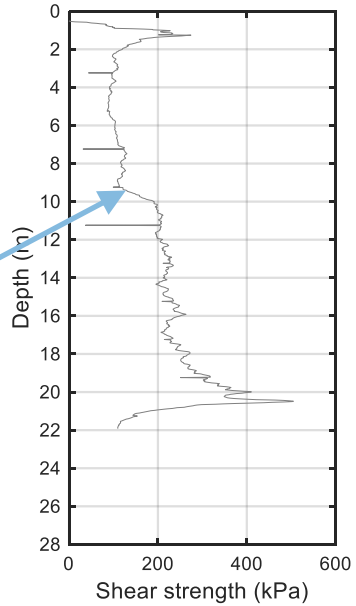
microscale variation



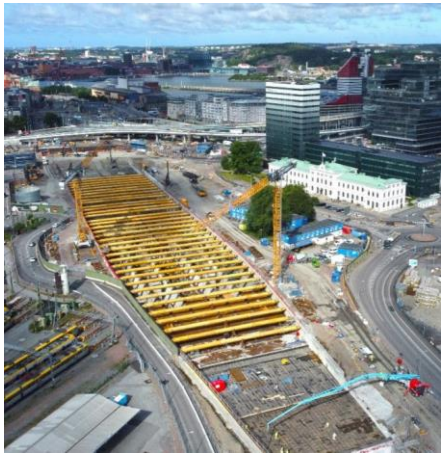
Intra-column variation



Inter-column variation



global variation



Increasing length scale

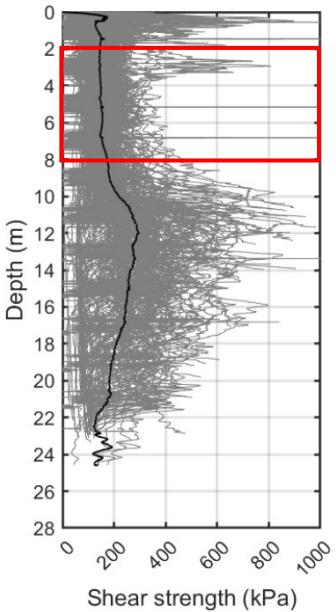
10^{-6} m

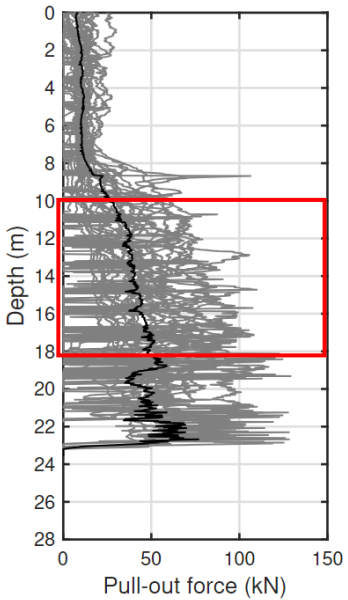
10^{-3} m

10^{0} m

10^{1} m

Field scale SOF



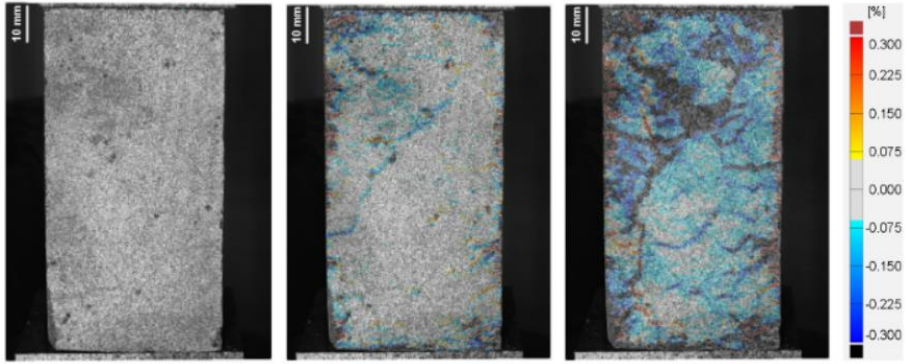


Variability of shear strength at field scale

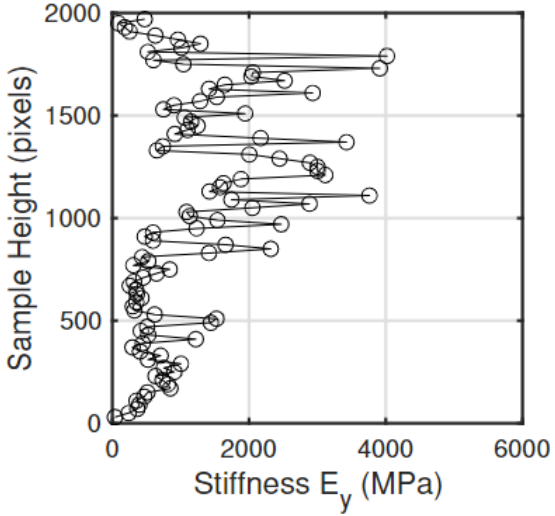
Reference	SOF_y (m)	SOF_x (m)
Larsson et al. (2005a)	-	< 0.15 (radial) < 0.35 (orthogonal)
Al-Naqshabandy et al. (2012)	0.2 m to 0.7 m	2 m to 3 m
Bergman et al. (2013)	0.11 m to 0.77 m	3 m to 4 m
This study	0.4 m to 3.47 m 1.39 (average) 0.31 m to 1.96 m 0.93 (average)	0.05 m to 6.91 m 1.30 (average) 0.14 m to 11.4 m 6.73 (average)

Laboratory scale SOF – DIC

Vertical strain field from DIC



Stiffness variation along height

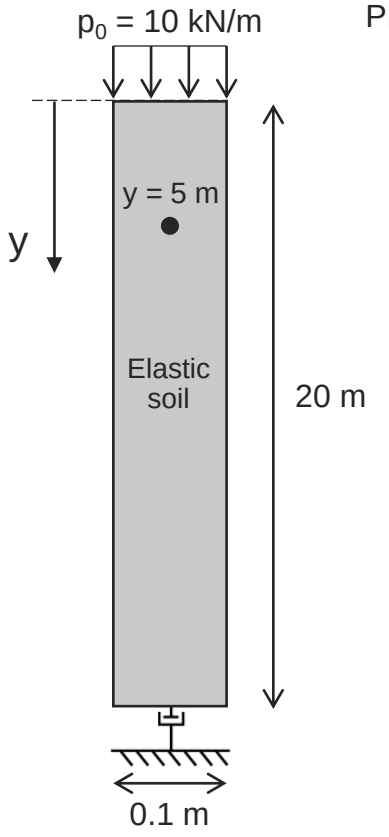


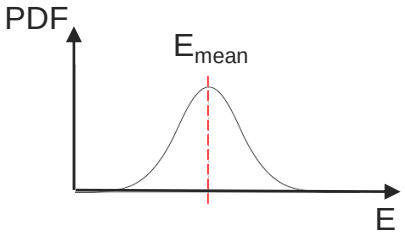
Variability of stiffness at laboratory scale

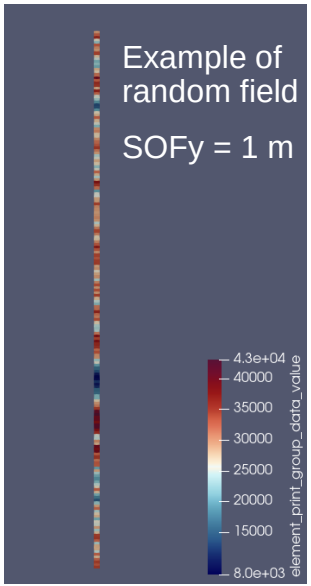
Sample	E (MPa)	Average E_{local} (MPa)	Standard Deviation E_{local} (MPa)	SOF_{Axis0} (mm)
S13	319	974	670	5.4 (96 pixels)
S14	229	1194	937	13.0 (219 pixels)

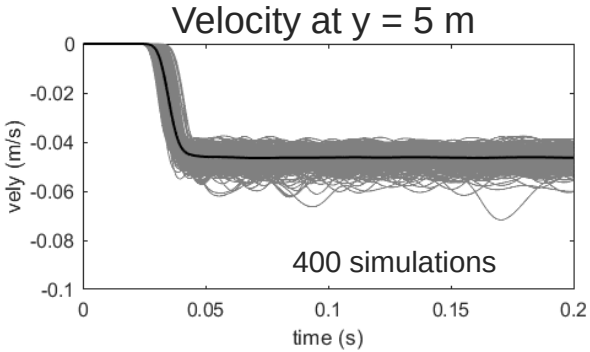
Incorporating variability in FEA

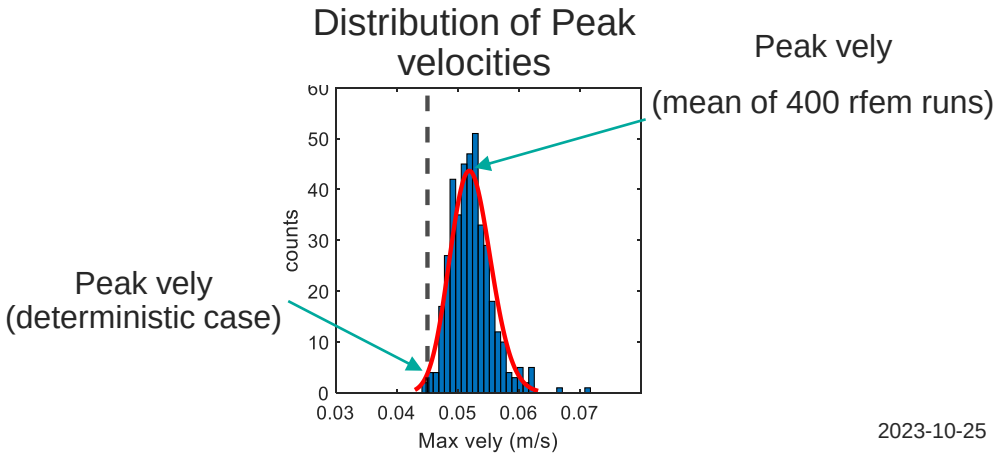
1D wave propagation











Conclusions

- Need to consider soil-structure as a system with variability
- Variability exists at different length scales
- An integrated approach needed to estimate variability of strength and stiffness
- Scales of fluctuations obtained will be used in RFEM analysis

CHALMERS
UNIVERSITY OF TECHNOLOGY

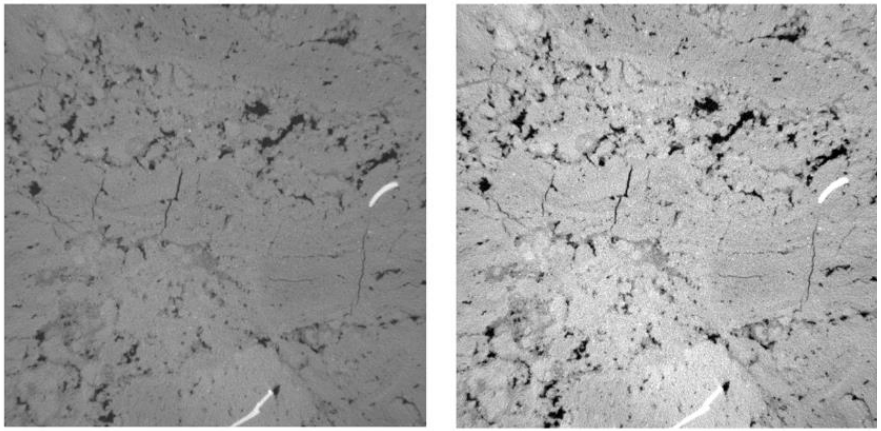
TRAFIKVERKET

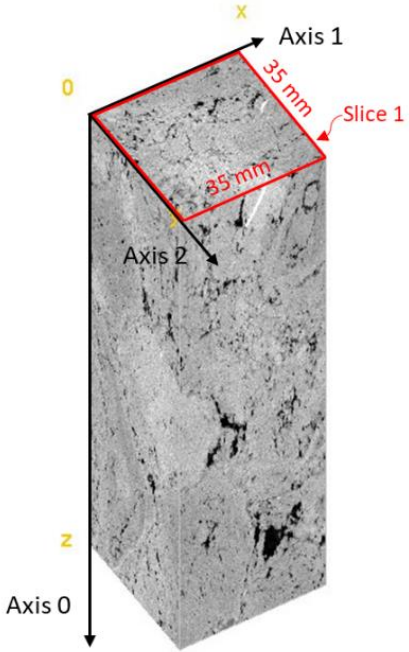
FORMAS

Branschsamverkan i Grunden

CHALMERS

Laboratory scale SOF – XCT





Sample	SOF_{Axis0} (mm)	SOF_{Axis1} (mm)	SOF_{Axis2} (mm)
S1	1.28	1.99	1.85
S2	0.79	0.96	1.50
S3	1.13	1.59	1.40
S4	1.30	1.75	1.77
S5	1.03	1.30	1.35
S6	0.95	1.20	1.31
S13	-	2.1	2.1
S14	-	6.3	3.8