Interpretation of Pile Load Tests

DFI & KIVI Pile Load Testing Seminar

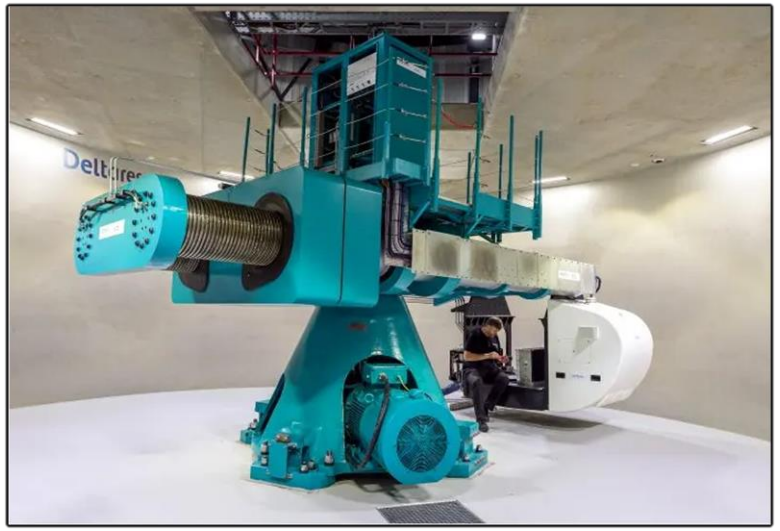
21st October 2021

Deltares TU Delft DFI KIVI

InPAD

Investigation of the Axial Capacity of Piles in Sand

- **Aim:** Refinement of the Dutch pile design method & improving the understanding of pile behaviour
- October 2019 – October 2023
- Field testing, numerical modelling, laboratory testing
- Project partners:
  - Deltares
  - Fugro
  - Gemeente Rotterdam
  - NVAF
  - Port of Rotterdam
  - Rijkswaterstaat
  - TU Delft



NEN 9997-1

$$q_b = \alpha_p q_{c,avg}$$

$$q_s = \alpha_s q_c$$

- 2016 update: 30% reduction in α_p
- Limiting resistances
  - Base resistance: 15 MPa
  - Shaft resistance: 12-15 MPa
- Koppejan 4D/8D averaging method
- Appropriateness of constant α_s for displacement piles?
- Pile aging

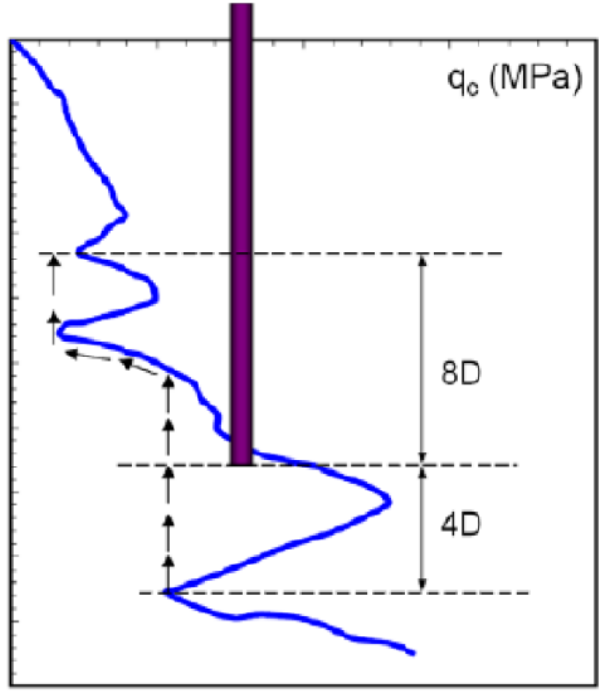


Table 1: Reduction factors for selected pile types from NEN 9997-1

Pile type	α_p	α_s
Bored pile	0.35	0.006
Continuous flight auger	0.56	0.006
Driven cast-in-situ	0.70	0.014
Driven precast	0.70	0.010
Screw injection	0.63	0.009
Steel tubular (open-end)	0.7	0.006

NPR 7201

- Guidance for pile testing: NPR 7201:2017
- Required for reassessing national pile class factors:
  - Static load test until pile failure
  - Minimum 3 piles at two different test sites
  - Pile minimum $8D_{eq}$ (>3m) in founding layer
  - Fully instrumented piles
- Also prescribes site investigation, load test procedure, instrumentation etc.

	Driven precast	**Screw injection**	**Vibro**
Site 1	✓	✓	✓
Site 2	✓	2021/22	

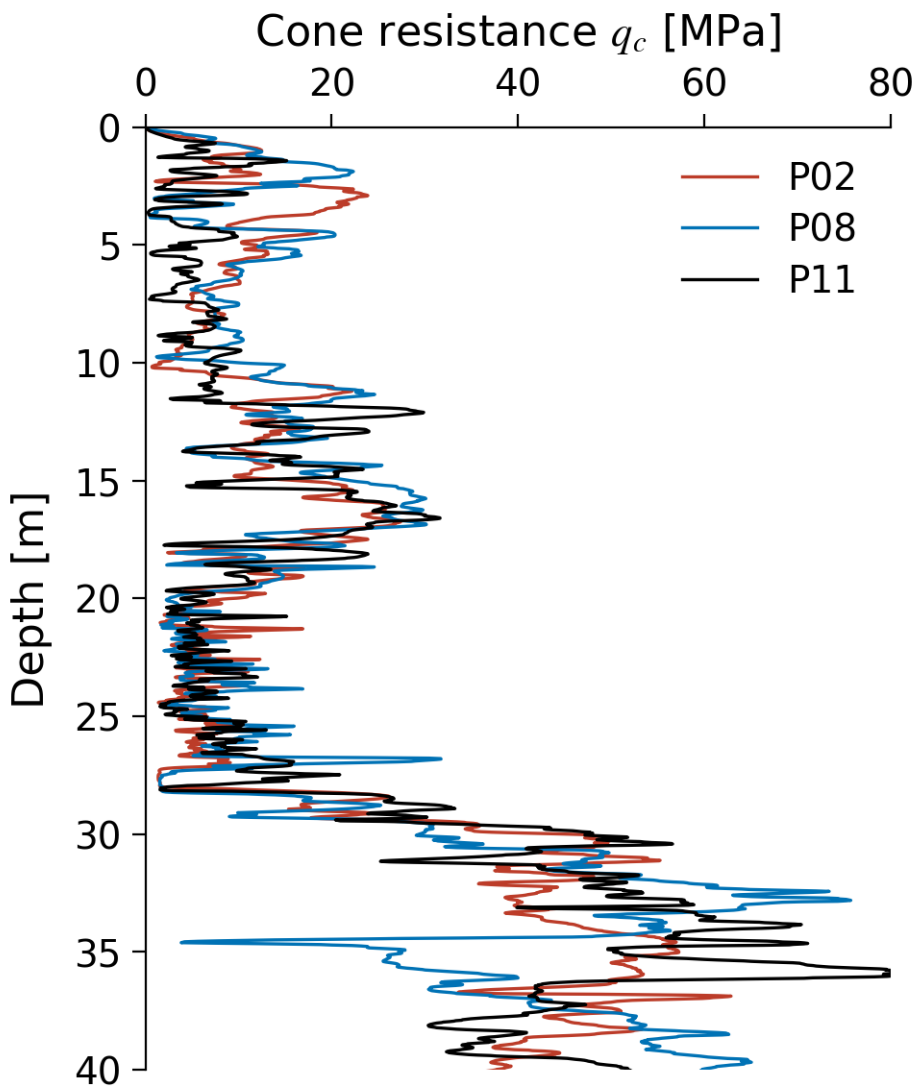
Test Sites

- October 2019 – January 2020: Maasvlakte
  - 4 screw injection
    - Ø 610/850 mm; L ≈ 37 m)
  - 4 vibro
    - (Ø 380/480 mm; L ≈ 32m)
  - 3 driven precast
    - (⧄ 400 mm; L ≈ 21m)
- November 2020 – January 2021: Delft
  - 3 driven precast
    - (⧄ 350 mm; L ≈ 27 m)
- All piles fully instrumented with fibre optics (Brillouin, FBG)

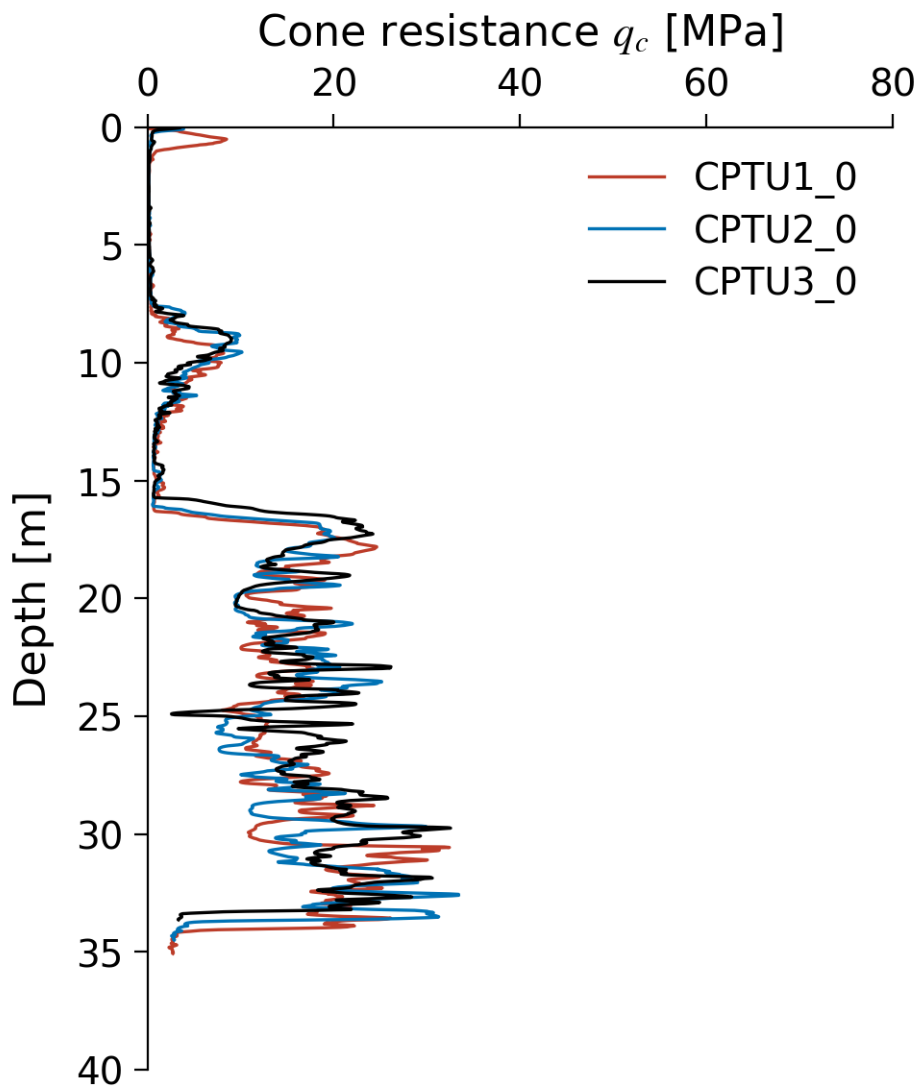
Maasvlakte

Delft

Maasvlakte



Delft

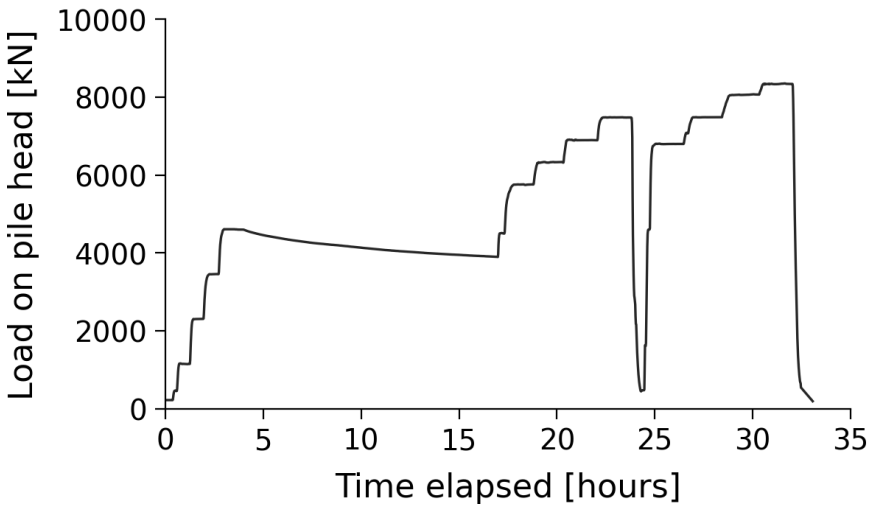


Test Procedure

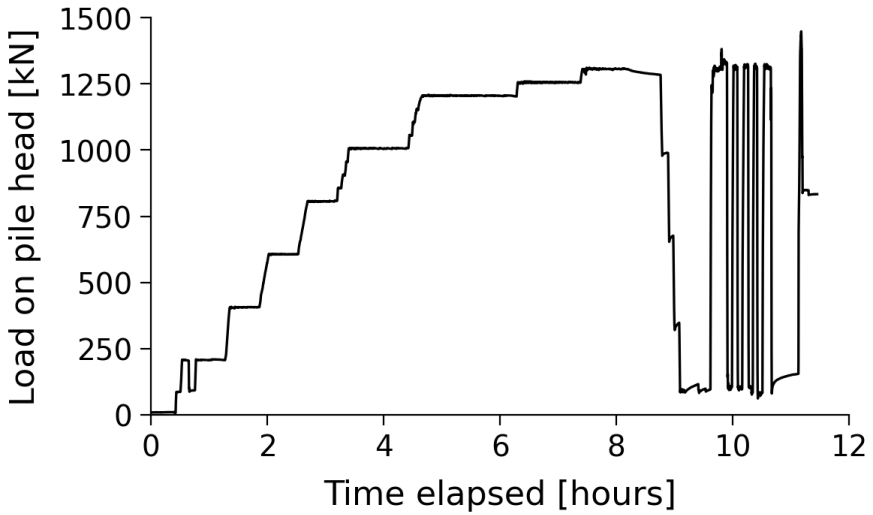
- Loaded incrementally until $0.1D_{eq}$ reached
  - Min. eight load steps
- No unload/reload cycles after every load step
  - Occasional unload/reload cycles to fully mobilise base resistance
- Piles not extracted after installation
- Adjustments to creep criteria

$$k = \frac{s_{0,t} - s_{0,t-15}}{\log_{10}\left(\frac{t}{t-15}\right)}$$

Maasvlakte: P11

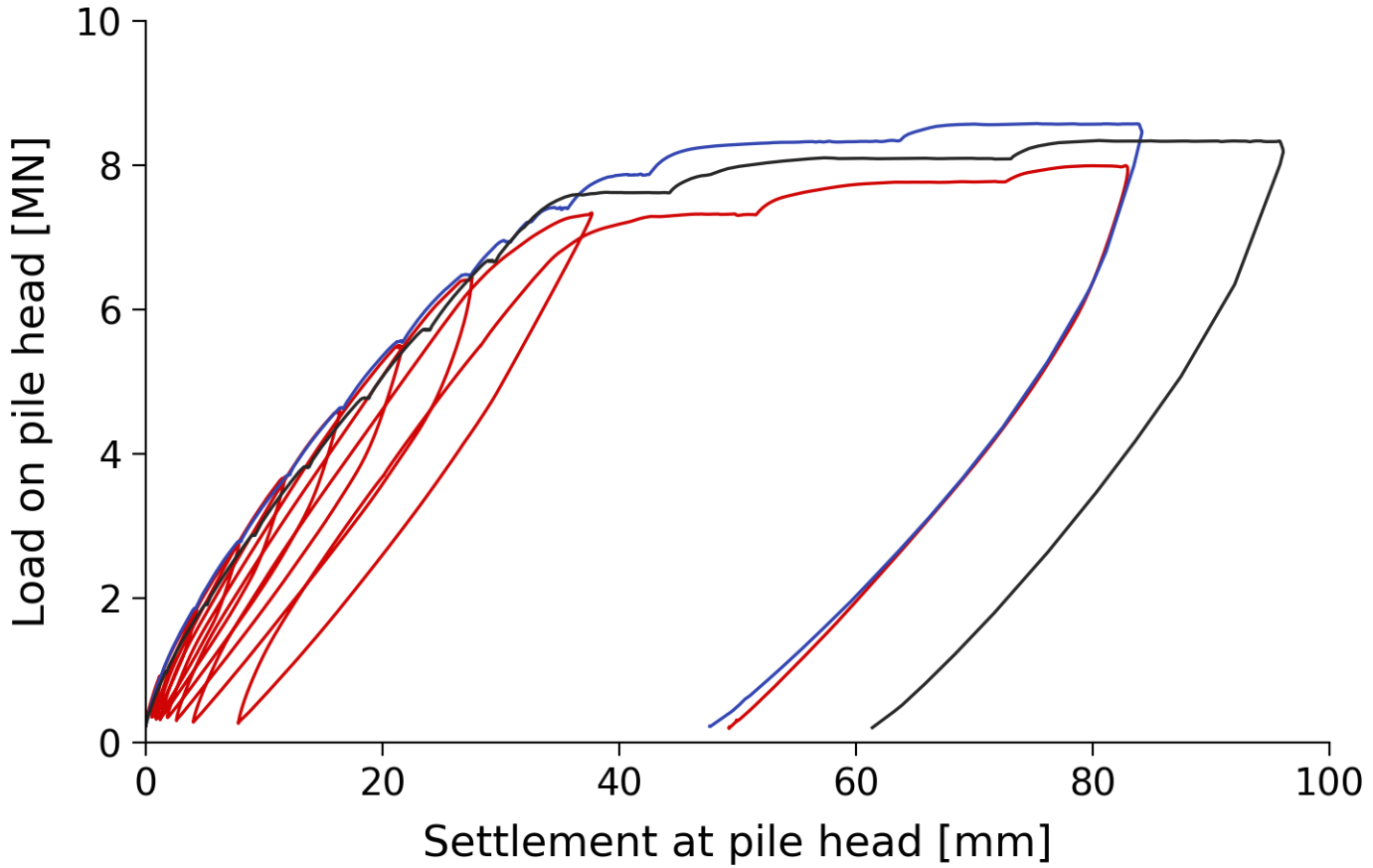


Delft: P02

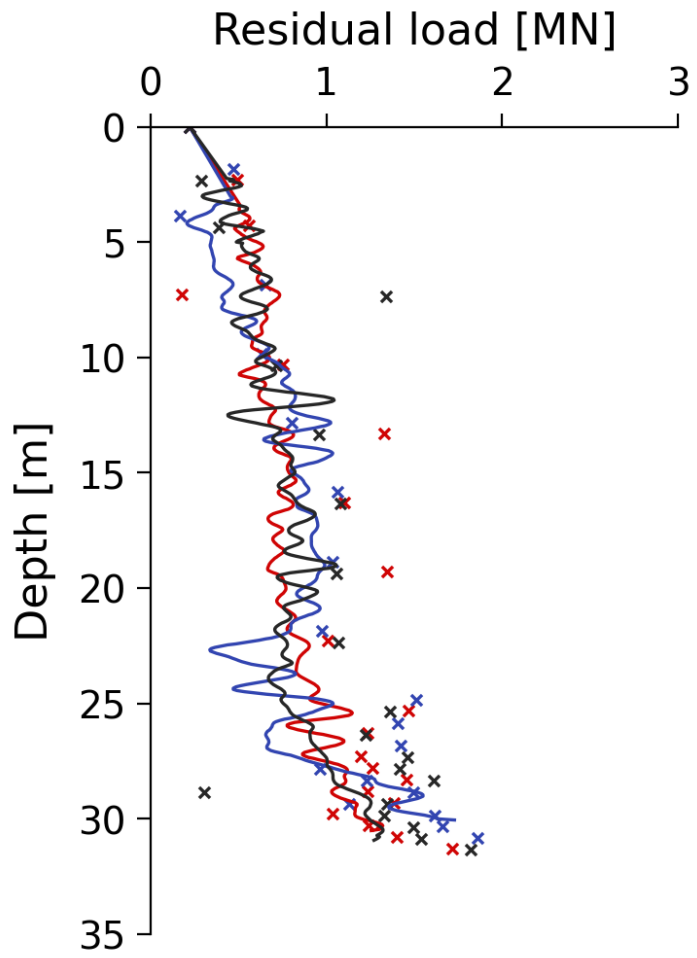


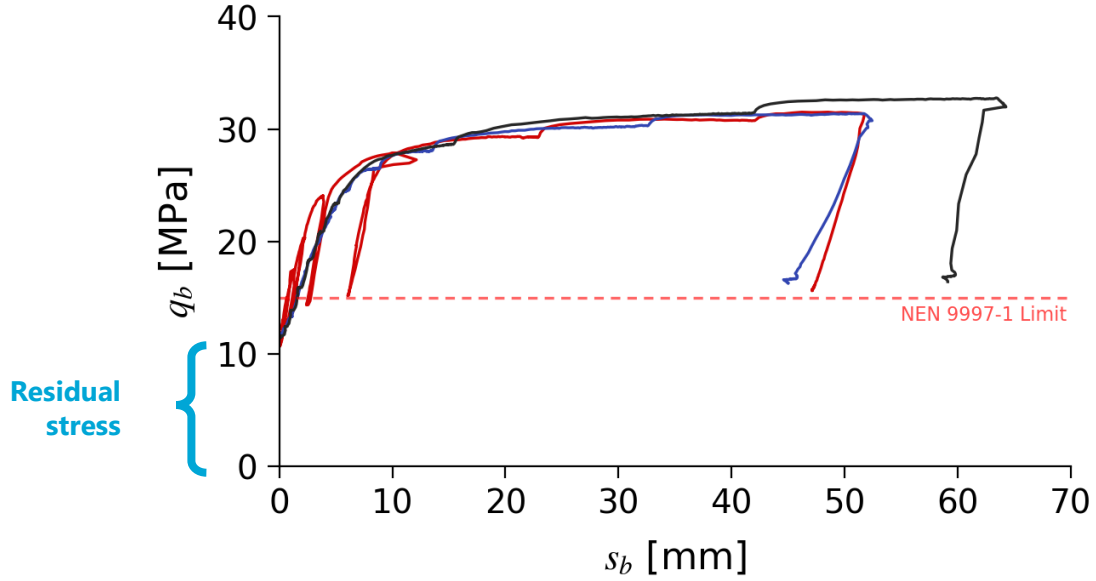
Precast Piles

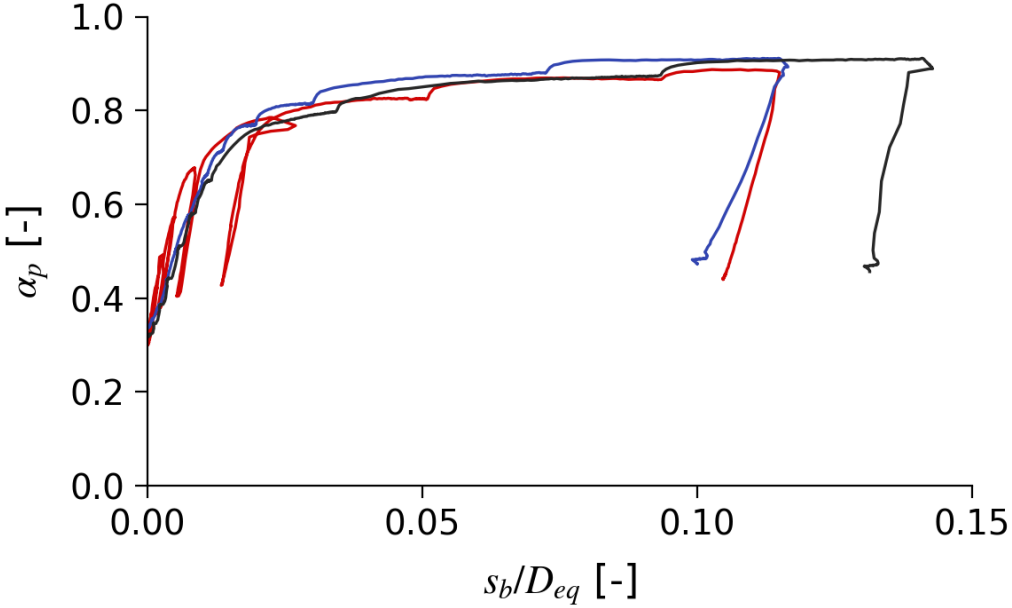
Pile	Pile length (m)	# days between installation & test
P02	31.74	28
P09	31.29	30
P10	31.80	**78**



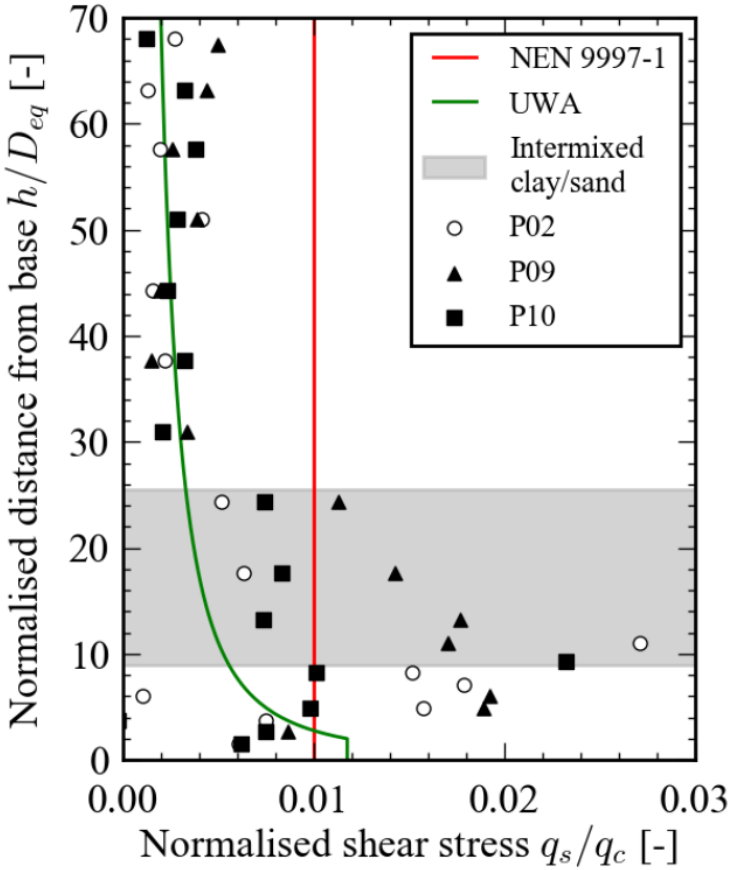
Precast Piles



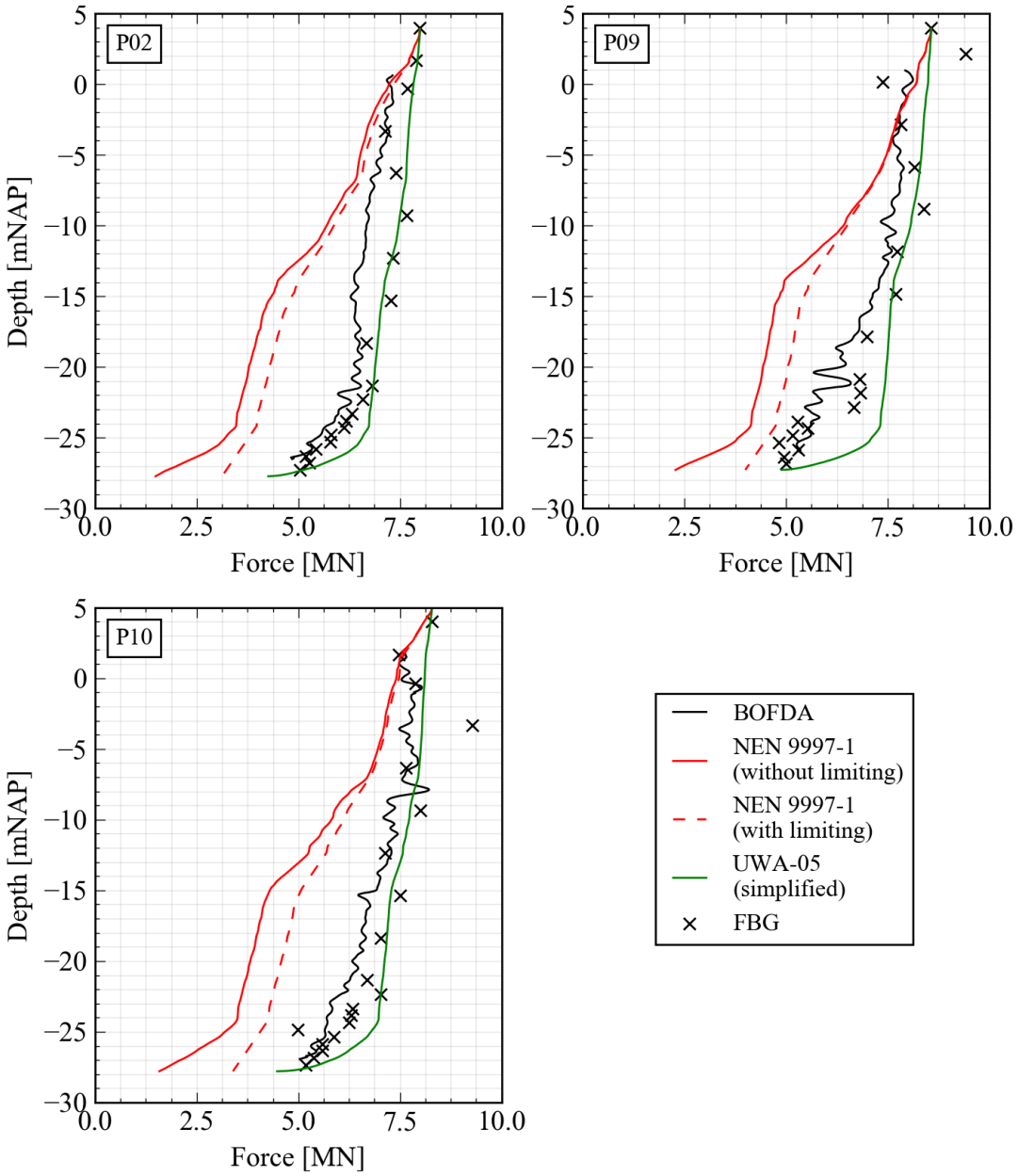




P02 P09 P10

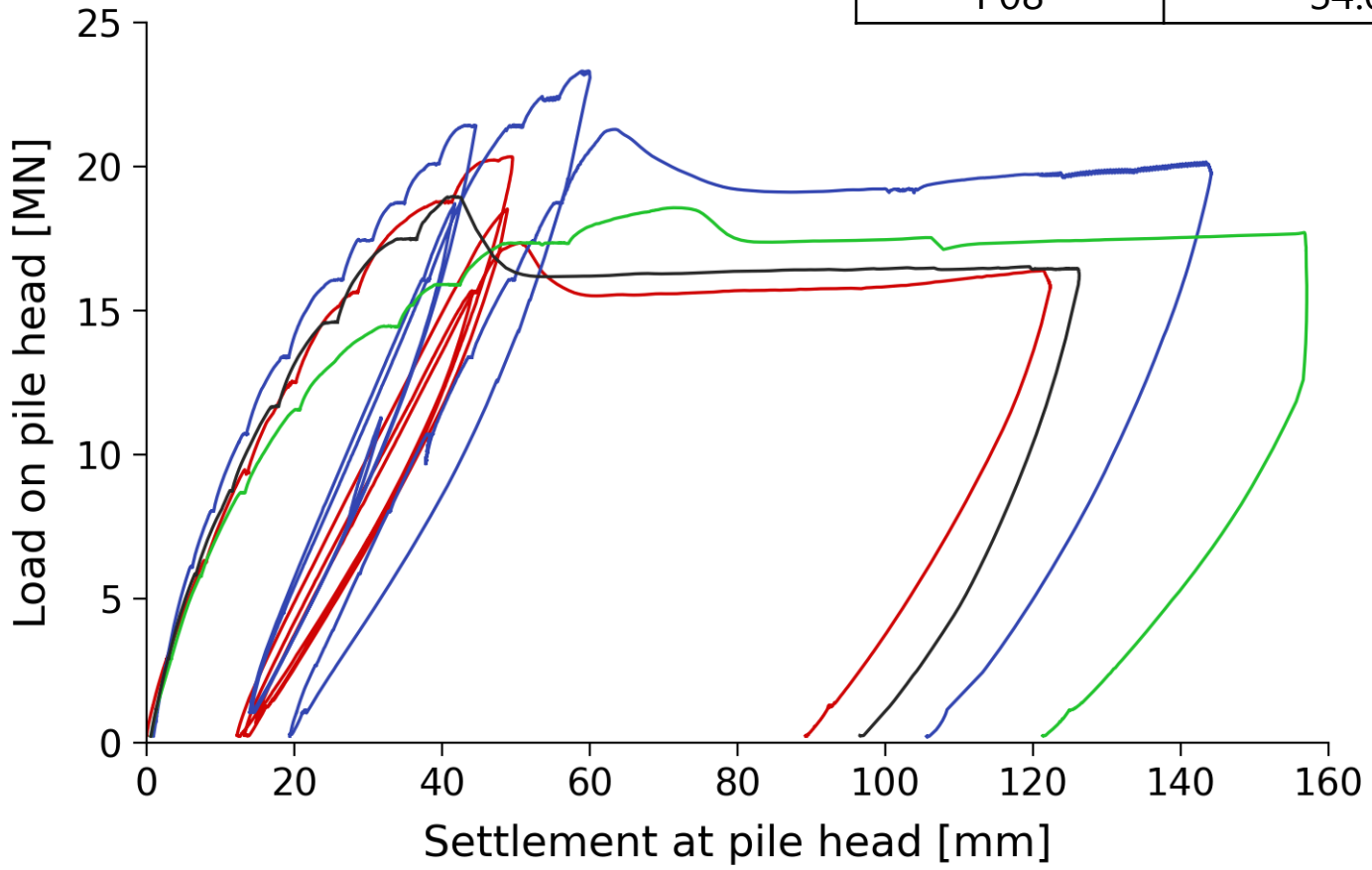


$$\tau_f = \alpha_s \, q_c \, h/D^{-0.5}$$

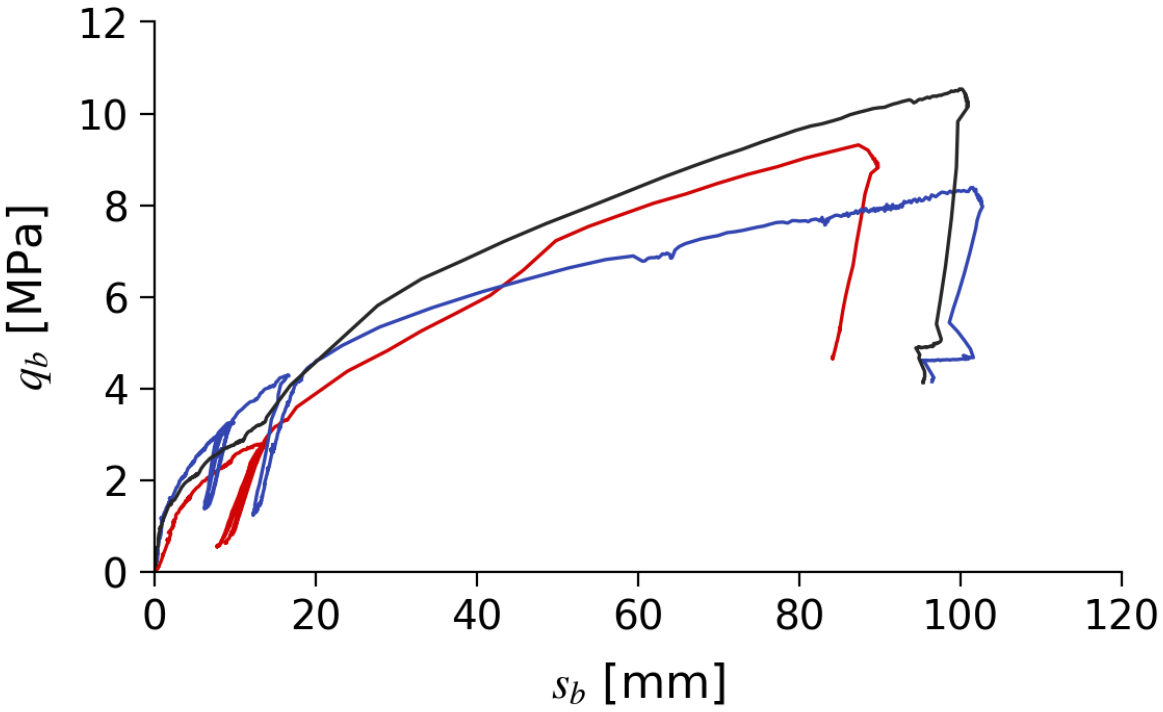


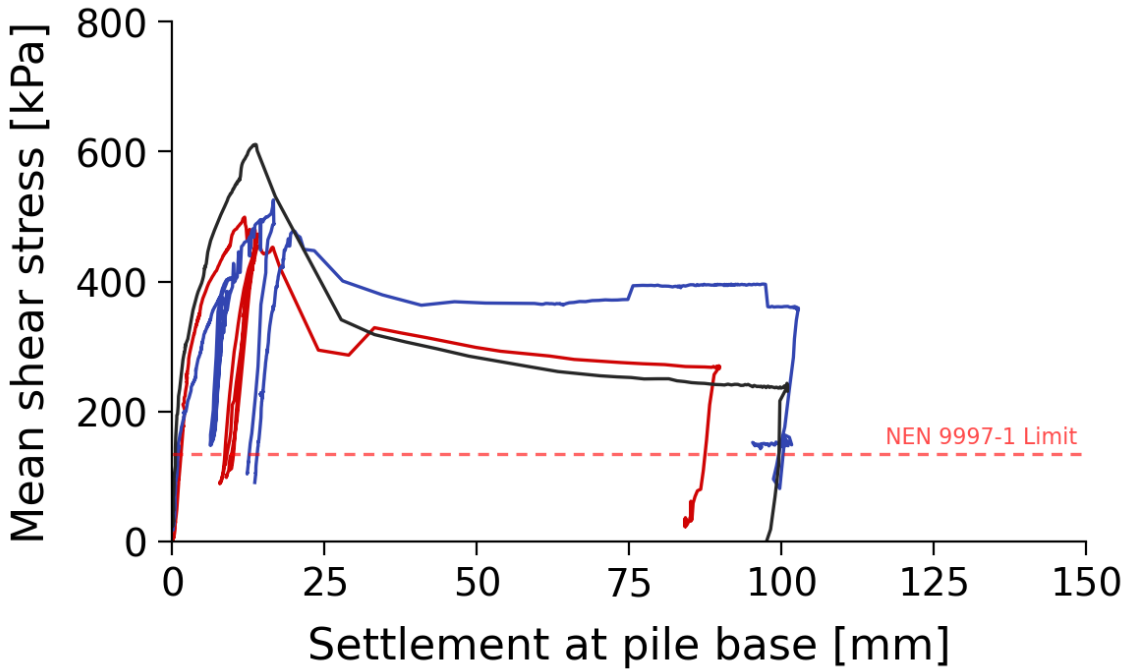
Screw Injection Piles

Pile	Pile length (m)	# days between installation & test
P04	37.02	43
P05	37.06	49
P07	34.98	78
P08	34.06	50



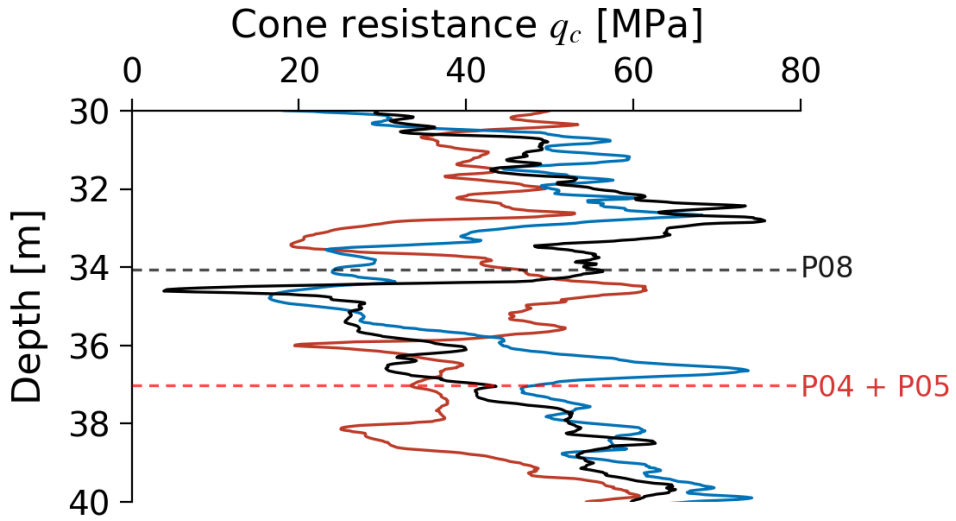
Screw Injection Piles

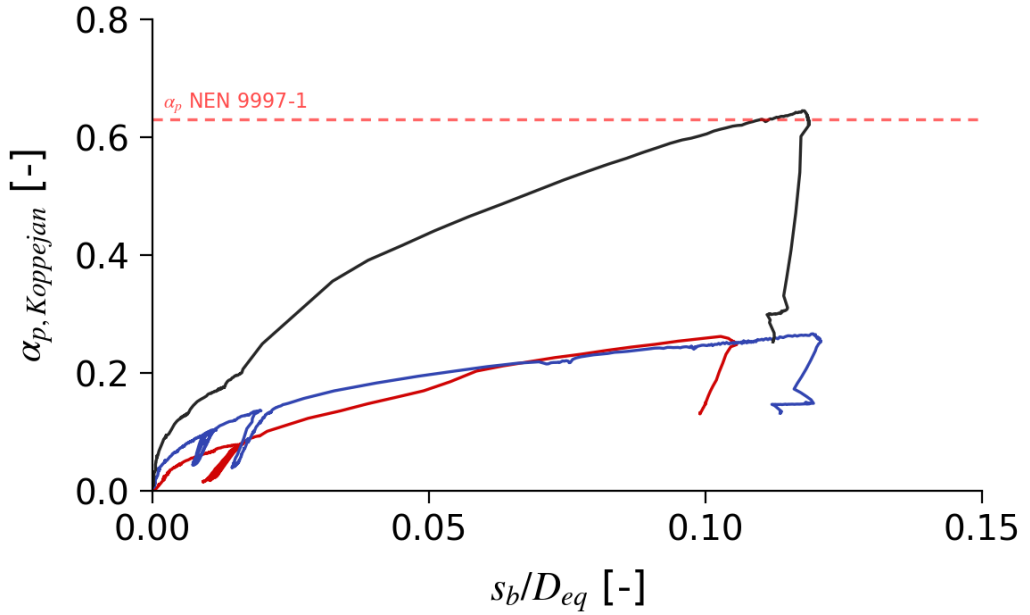


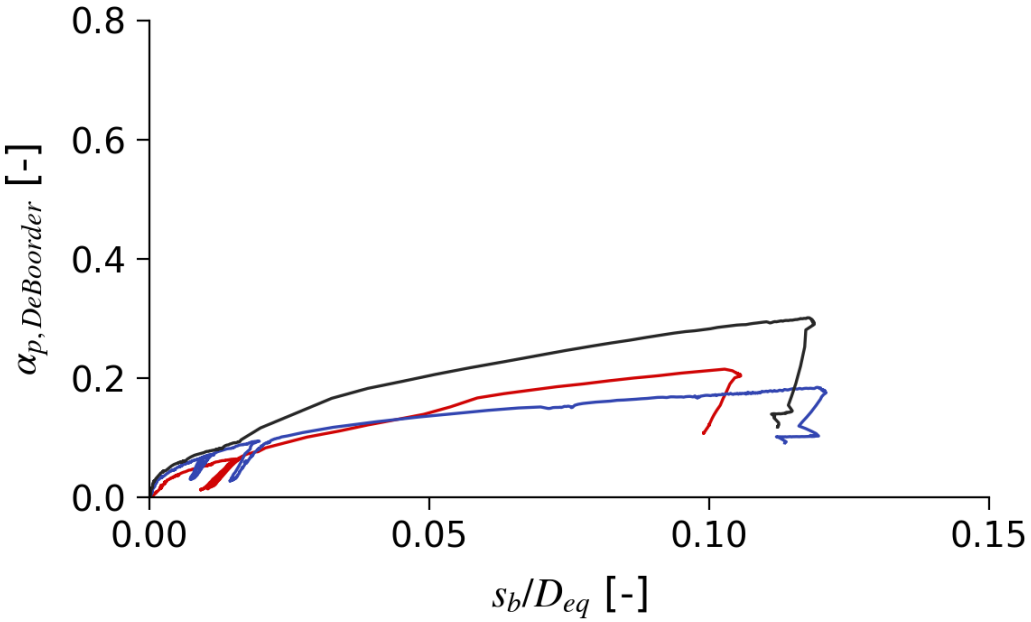


P04 P05 P07 P08

- Behaviour indicative of a soil-replacing pile instead of a soil-displacing pile
- 35-50% sand in outcoming grout => primarily soil replacing in founding sand

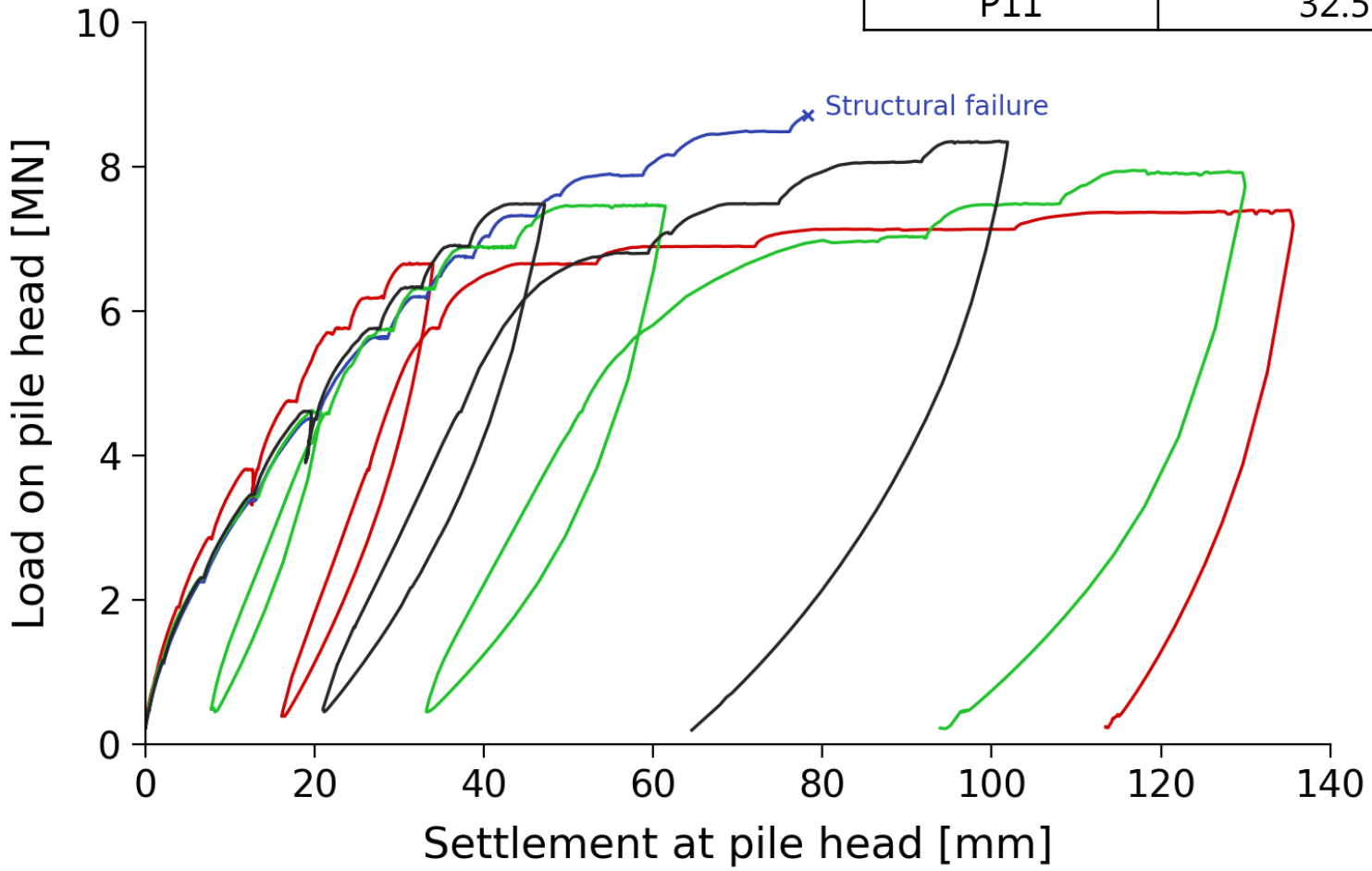






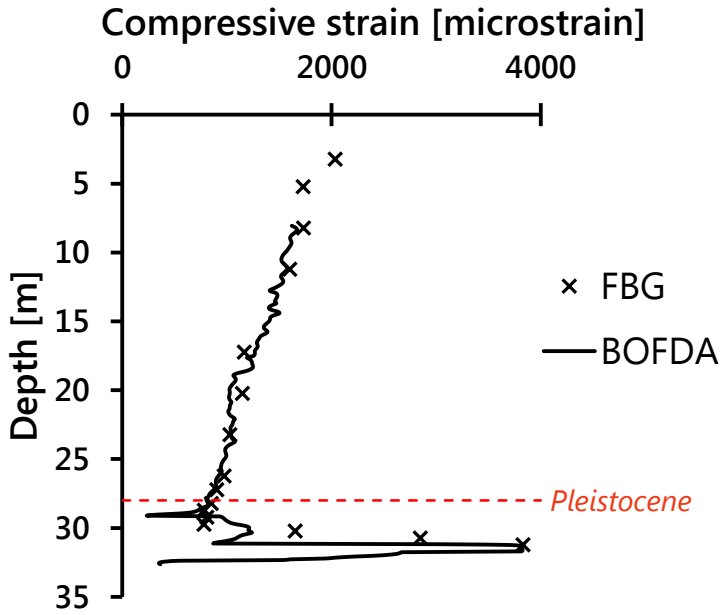
Vibro Piles

Pile	Pile Length (m)	# days between installation & test
P01	32.54	59
P03	32.49	34
P06	32.50	50
P11	32.50	52



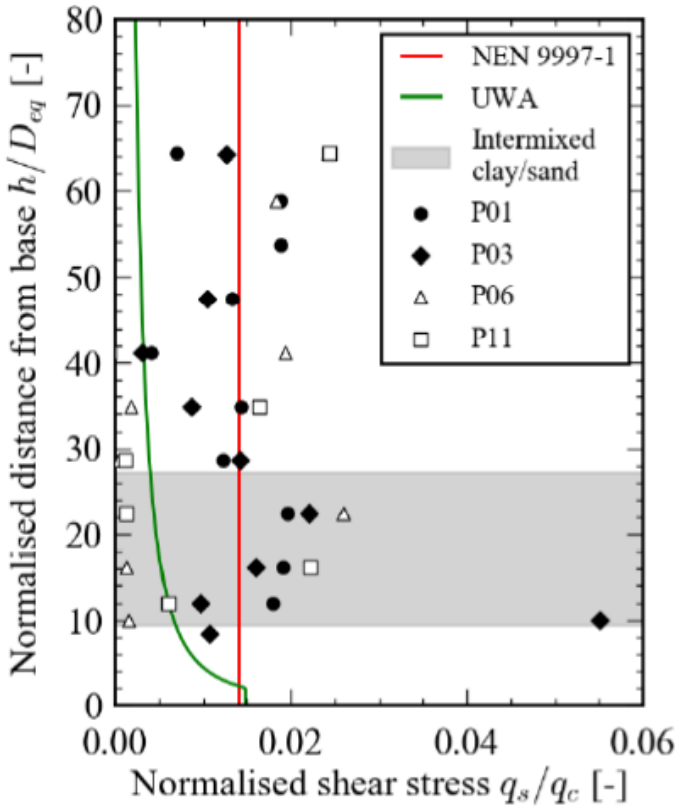
Segregation

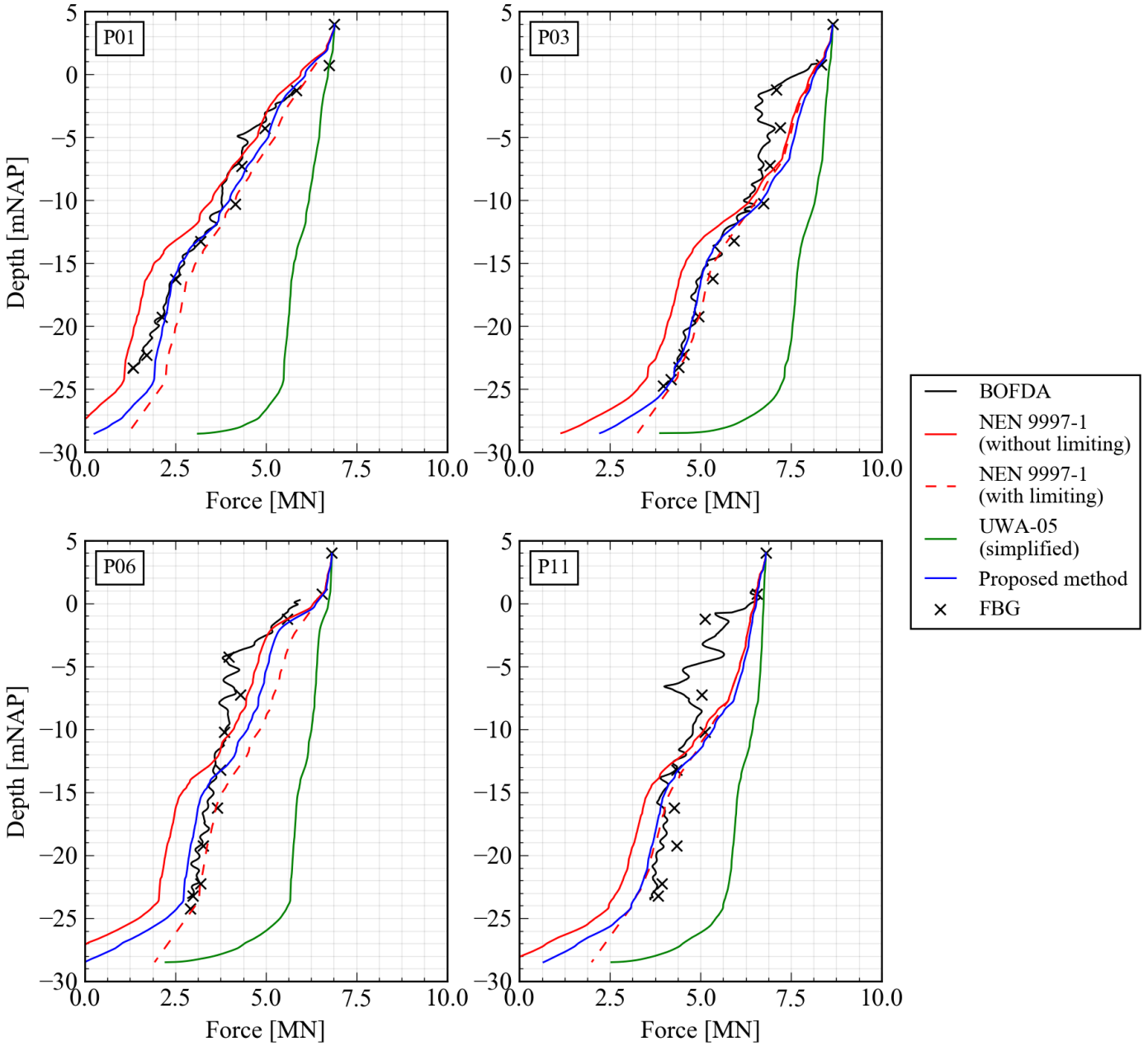
- Large scatter in strain readings across Pleistocene sand
- Previously observed in other projects
  - De Gaag (Geerling & Janse, 1997)
  - Prepal Rijswijk (Geerling & Janse 1993)
- Potentially influenced by concrete quality, reinforcement and high stresses in the Pleistocene sand
- Difficult to interpret readings at the pile base

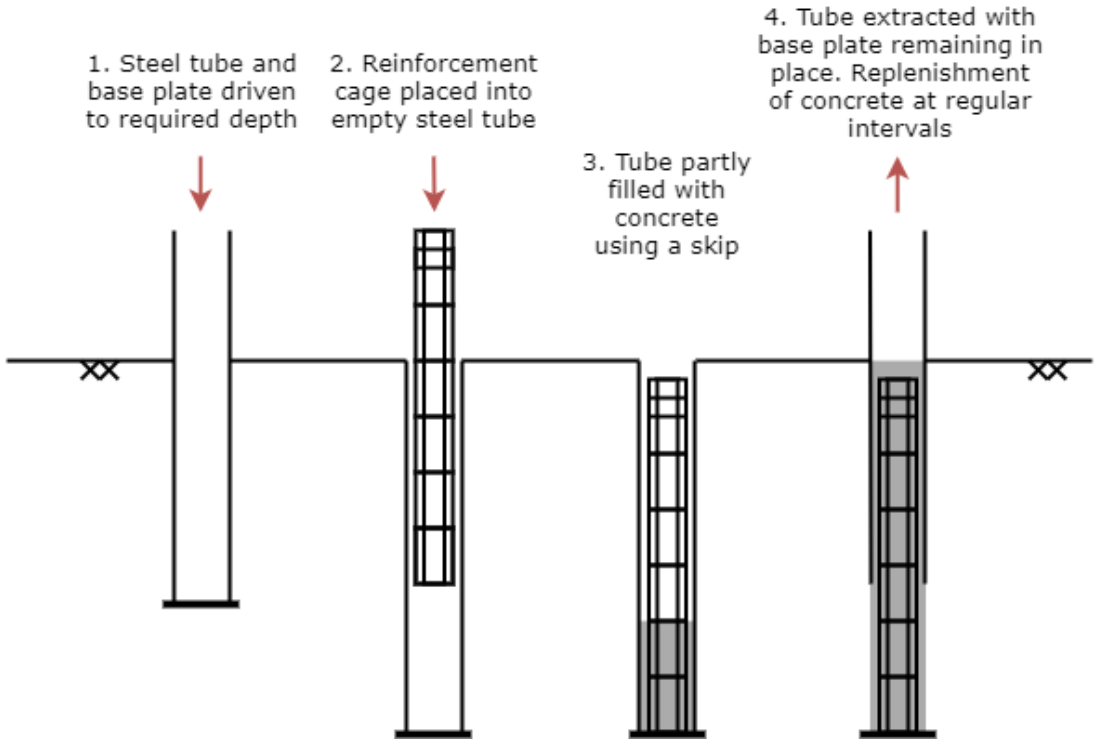


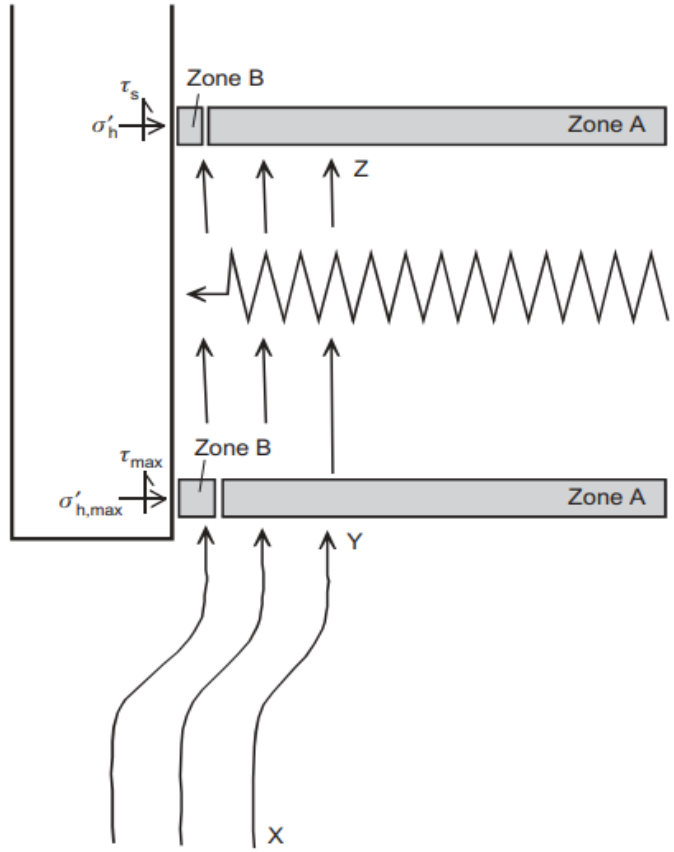
(Geerling and Janse, 1993)

Vibro Piles

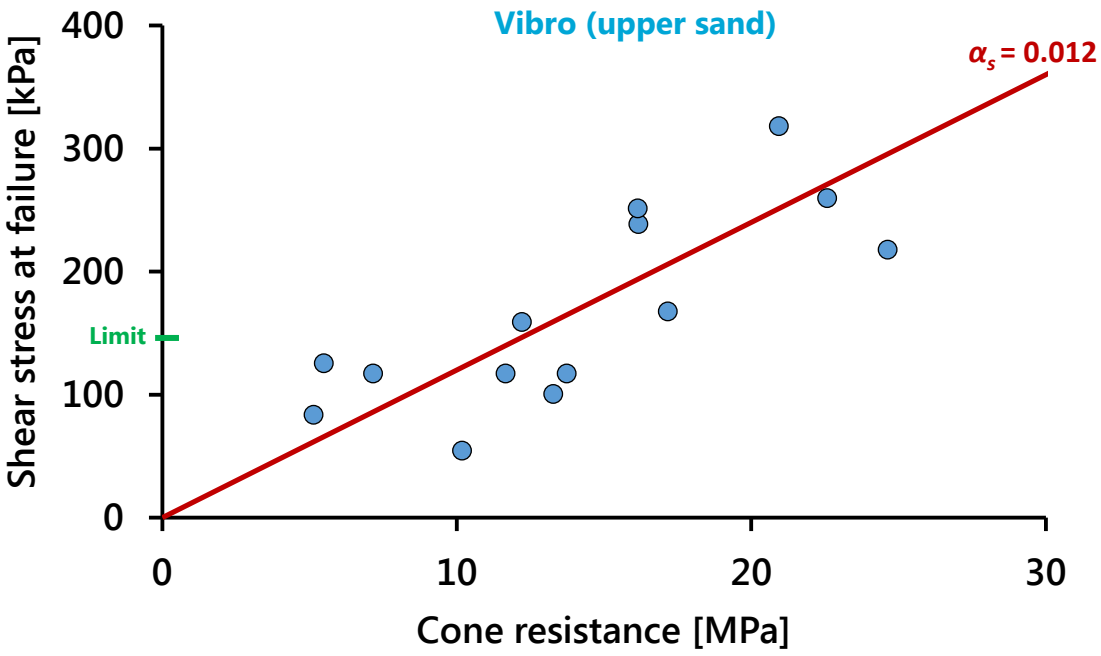

NEN 9997-1
UWA
Intermixed clay/sand
P01
P03
P06
P11
Normalised distance from base h/D_{eq} [-]
Normalised shear stress q_s/q_c [-]
0.00
0.02
0.04
0.06
0
10
20
30
40
50
60
70
80

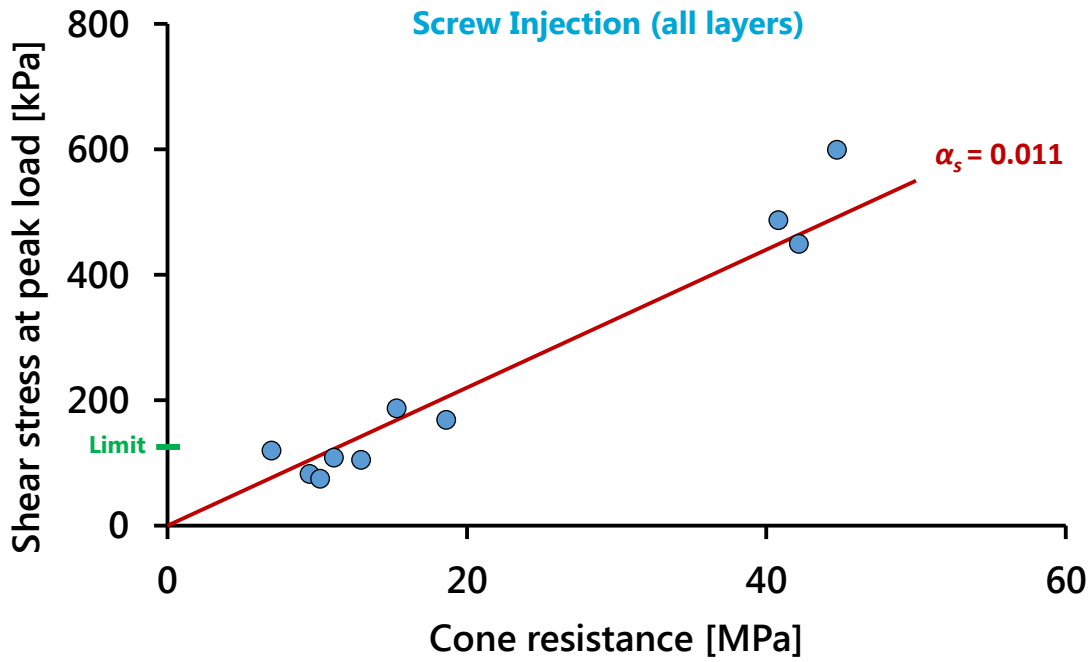

P01
P03
P06
P11
Depth [mNAP]
Force [MN]
BOFDA
NEN 9997-1 (without limiting)
NEN 9997-1 (with limiting)
UWA-05 (simplified)
Proposed method
FBG





(White & Bolton, 2004)


Vibro (upper sand)
α_s = 0.012
Limit
Shear stress at failure [kPa]
Cone resistance [MPa]
0
100
200
300
400
0
10
20
30


Screw Injection (all layers)
α_s = 0.011
Limit
Shear stress at peak load [kPa]
Cone resistance [MPa]
0
200
400
600
800
0
20
40
60

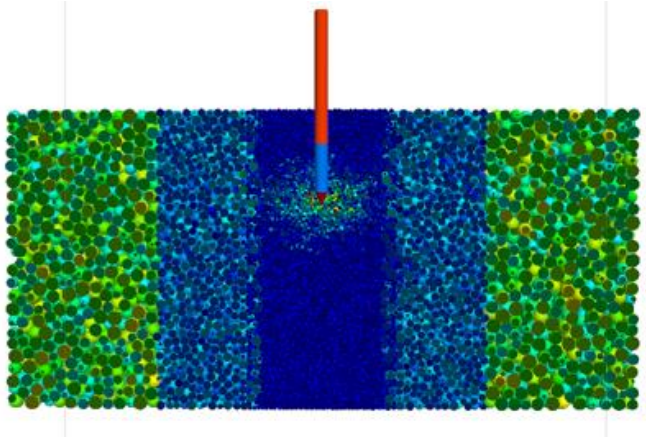
Conclusion

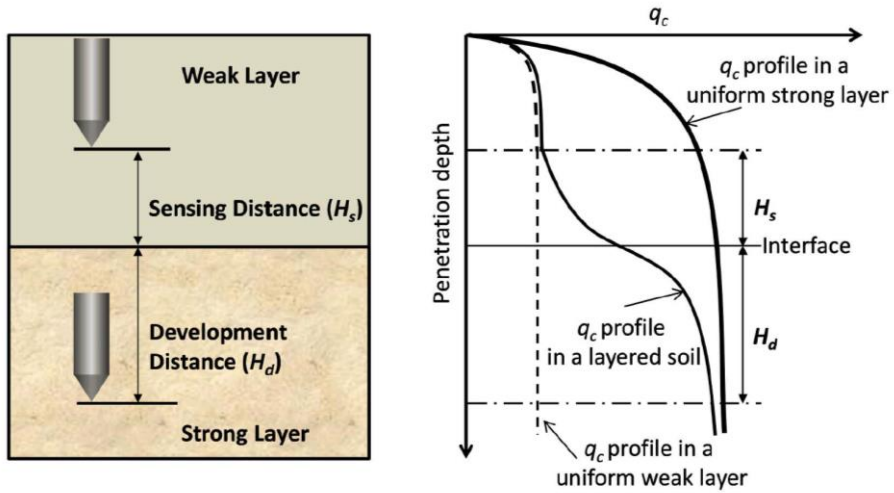
- Field tests have given a clear insight into the individual mechanisms of pile response
  - Mobilisation of SI pile base resistance
  - Friction fatigue in displacement piles
- Clear scope for improving the national standard
- Conservatism of limiting resistances
- Effects of averaging method on derived α_p
- High residual loads developed in the precast piles → significant effect on pile test interpretation and α_p

Future

- Screw injection pile tests at Delft
- SW22: Pilot site
- SI & vibro pile database evaluation
- Reliability/probabilistic-based assessment
- Influence of weak layers & sensing distance
  - Centrifuge testing
  - Instrumented jacked piles (Drukpaal)
- Numerical modelling
  - Modelling the effect of weak layers in FEM & DEM

SW22
ROTTERDAM
20-23 SEPTEMBER 2022
WWW.SW2022.ORG





(Therani et al., 2017)

Questions?

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