Scientific developments in the field of Soil-Structure Interaction

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Introduction

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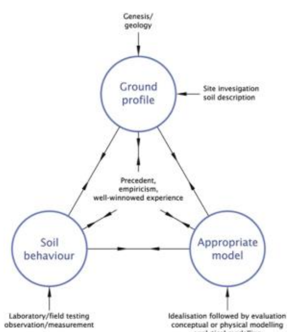
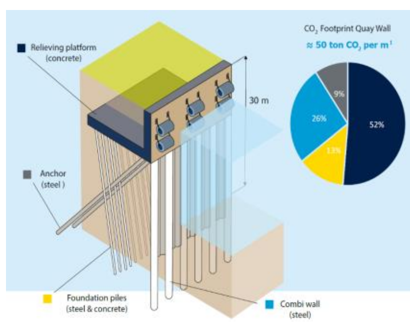




Dutch Practice NEN 9997-1

Experience/empiricism/precedent?

$$q_b = \alpha_p q_{c;Dutch}$$

- Limiting base resistance = 15 MPa
- 2016 update: 30% reduction in α_p

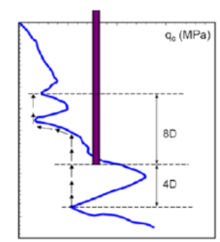
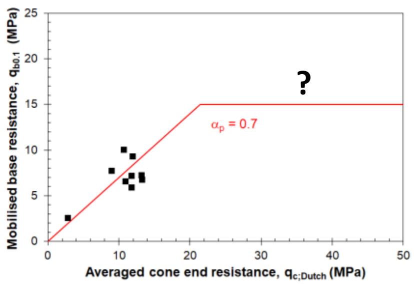


Table 1: Reduction factors for selected pile types from NEN 9997-1

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

Empirical Experience - Dutch Database of instrumented pile tests



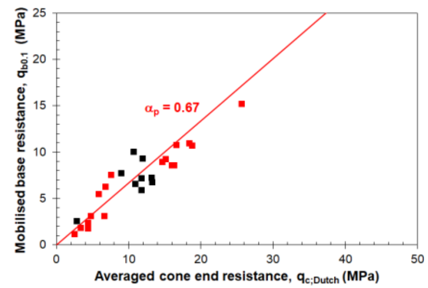
Features of database:

- D_{eq} ranged from 0.28 to 0.45m
- L_{em}/D_{eq} = 1.2 to 21
- $q_{c;Dutch}$ = 2.8 to 13.2 MPa

α_p = 0.7

Limit value set at 15 MPa

Dutch Database of instrumented pile tests



Features of database:

- D_{eq} ranged from 0.28 to 0.45m
- L_{em}/D_{eq} = 1.2 to 21
- $q_{c;Dutch}$ = 2.8 to 13.2 MPa

α_p = 0.67

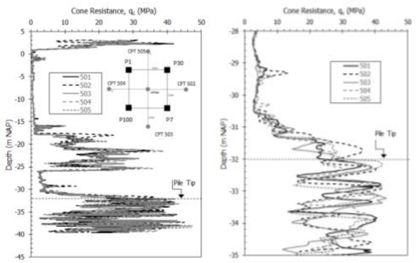
No limit value set at in ISO though max $q_{b0.1}$ = 15 MPa

Case 1 Pile test Waalhaven (2017)

- Since update Eurocode 7 (NEN 9997-1) - Longer foundation piles (5 to 6m in Pleistocene sand)
- More piles (>25%)
- Increase of costs for foundation piles (25% to 50%); significant installation risks; negative CO2 footprint.
- No foundation pile failures are known in Rotterdam
- Much higher risk of damage during installation

Maasvlakte soil conditions: Cone resistance > 30MPa
100 blows per 25 cm!!

Case 1 Pile test Waalhaven (2017)



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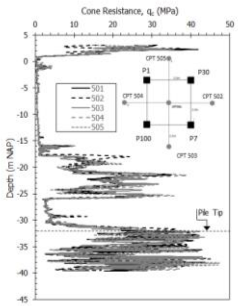

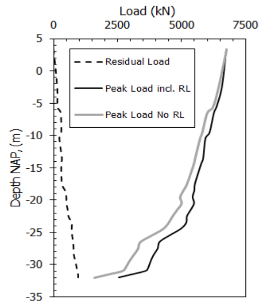

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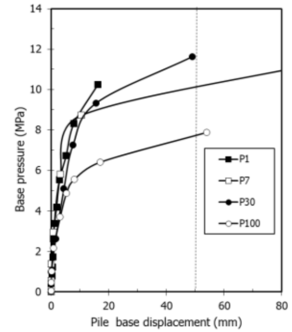

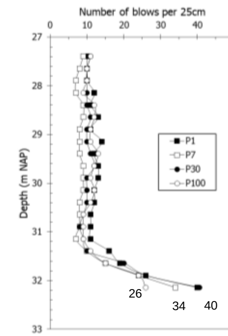

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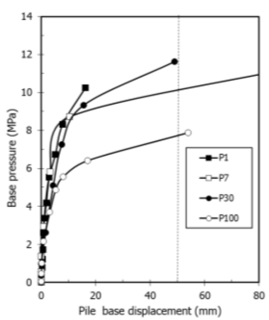
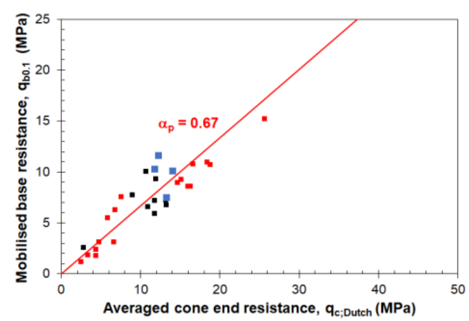


Pile No.	q_{bL} (MPa) excluding residual	q_c;ave (MPa)	α_p
P1	10.26*	11.78	0.87
P7	10.12	14.07	0.72
P30	11.62	12.23	0.95
P100	7.49	13.29	0.56
Ave	**9.87**	**12.84**	**0.77**

Case 1 Pile test Waalhaven (2017)



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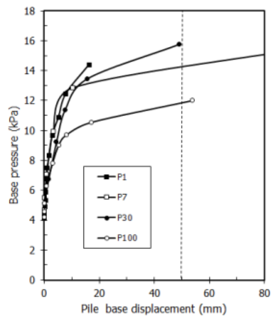


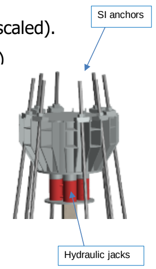
Pile No.	q_{bL} (MPa) including residual	$q_{c;ave}$ (MPa)	α_p
P1	14.39*	11.78	1.22
P7	14.25	14.07	1.01
P30	15.76	12.23	1.29
P100	12.01	13.29	0.90
Ave	**14.10**	**12.84**	**1.11**

Case 2 Foundation pile tests Amaliahaven (2020)

Scope:

- 4# Precast concrete piles 400x400 (scaled).
- 4# SI piles 609/850 (non scaled pile)
- 4# Vibro piles 356/480 (scaled)
- Spider-shaped test frame
- 100# SI anchors.
- Project costs ≈ €2,5 million

⇒Max test load **25,000 kN** !!!



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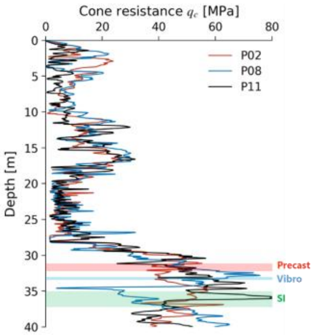

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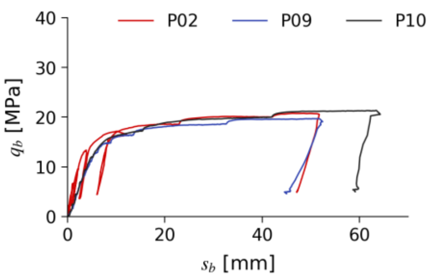
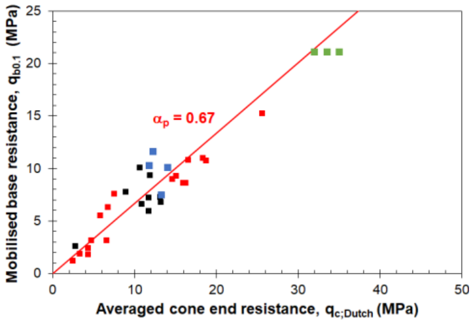


Pile No.	$q_{b0.1}$ (MPa) excluding residual	$q_{c;ave}$ (MPa)	α_p
P02	21.9	34.6	0.63
P09	21.6	32.8	0.66
P10	21.9	32.3	0.68
Ave			**0.66**

Case 2 Foundation pile tests Amaliahaven (2020)



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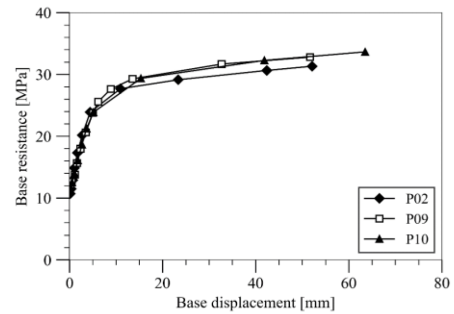


Pile No.	$q_{b0.1}$ (MPa) including residual	α_p
P02	31.9	0.92
P09	31.6	0.96
P10	31.9	0.99
Ave		**0.96**

Without residual load α_p = 0.66

Impact of Axial Load Tests?

Impact of the 1st test programme

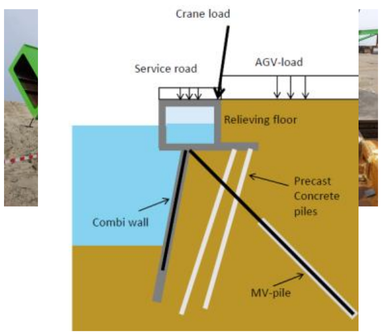
- Cost saving on pile types used in Quay Wall at Amaliahaven = €10 million. In addittion a reduction of 8 kton of CO_2 was achieved.
- Cost Savings on Quay Wall Upgrade at Amazonehaven €4.5 miljoen; ≈ 3 kton less CO_2.
- Projected additional cost savings in 2nd Maasvlakte of €15-20 million; ≈ 30 kton reduction in CO_2.

Case 3 Full scale failure test MV piles

Scope

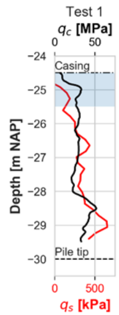
- 6# MV piles type HE600B
- Test load: 11,000 kN
- Results
- Failure load: 8,000-10,500 kN
- 5 a 7 m shorter piles

- Test costs ≈ €750k
- Possible cost reduction ≈ €1m.
- Sustainability ≈ 500 ton less CO_2



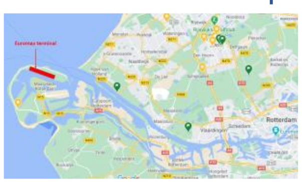
Case 3 Full scale failure test MV piles

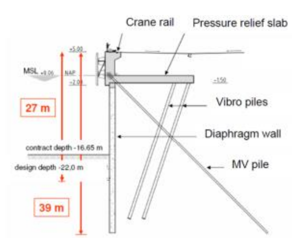
- The shaft friction ratio α_t found was 1.2%.
- Measured shaft friction was much higher than 250kPa (limiting value in design method). Values >600kPa were measured.
- New mobilisation curves.
- High correlation with installation parameters => input for reverse engineering?



MSc thesis: Geotechnical bearing capacity MV piles, Frederike Westerbeke

Case 4 Euromax quay wall



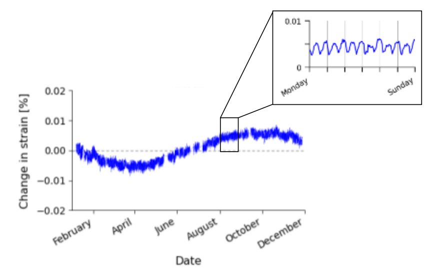


Embedded instrumentation recording each 10 minutes on :

- Diaphragm walls
- MV-piles
- Vibro piles
- Fender
- Bollards
- ...

Case 4 Euromax quay wall

- What are the effects of cyclical loads on quay wall structures?
  - **Tidal:** Low amplitude, high frequency
  - **Temperature:** High amplitude, low frequency
- Should this be accounted for in design models?
- Extensive long-term monitoring data of quay walls across port of Rotterdam



Can we use test results widely?

- Example PISA Project on Monopile Design (Oxford/Imperial/TUD)
- Load tests on 0.273, 0.762 and 2m
- Two sites, one dense sand and one stiff clay
- Method was adopted for design around the world before the end of the project
- Now used in all offshore wind projects for pile diameters +10m

2017 British Geotechnical Association Fleming Award – Savings of €300,000 per offshore wind turbine

Conclusions

- Geotechnical Engineers can play a key role in addressing the grand challenges we face in society
- More data is available to help to give us insights
- It is important that we can use this data to understand mechanisms affecting the performance of geotechnical structures
- This data allows us to iterate between our assumed model and the observed response and to develop true experience