AIM OF PILE LOAD TESTS &

TEST CAMPAIGN PORT OF ROTTERDAM

CAN WE BRIDGE THE GAP BETWEEN THEORY AND PRACTISE?

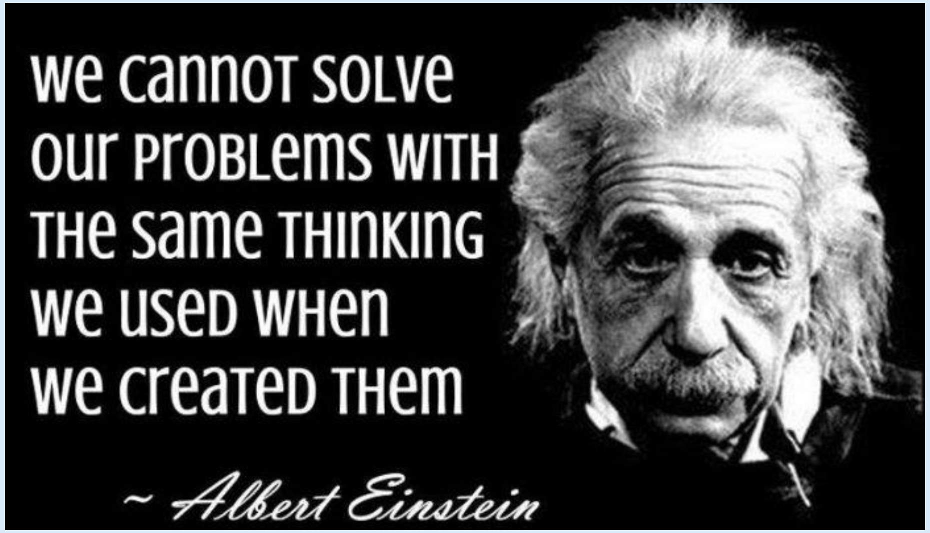
Egbert van der Wal & Alfred Roubos, Port of Rotterdam

21 October 2021, The Hague, Netherlands

Port of Rotterdam

Introduction: Egbert van der Wal

- Head of engineering department Port of Rotterdam.
- Captain for the Smart Port roadmap Future proof port infrastructure.
- Member of several national & international committees (CROW, PIANC, COPRI, DFI)



SMART PORT Port of Rotterdam

Enterprise strategy 2020-2024

Mission:
"the port of Rotterdam creates economical and societal value together with customers and stakeholders to realise sustainable growth in a world class port."

We realise efficient and reliable logistical chain

Smart partner in logistic chain

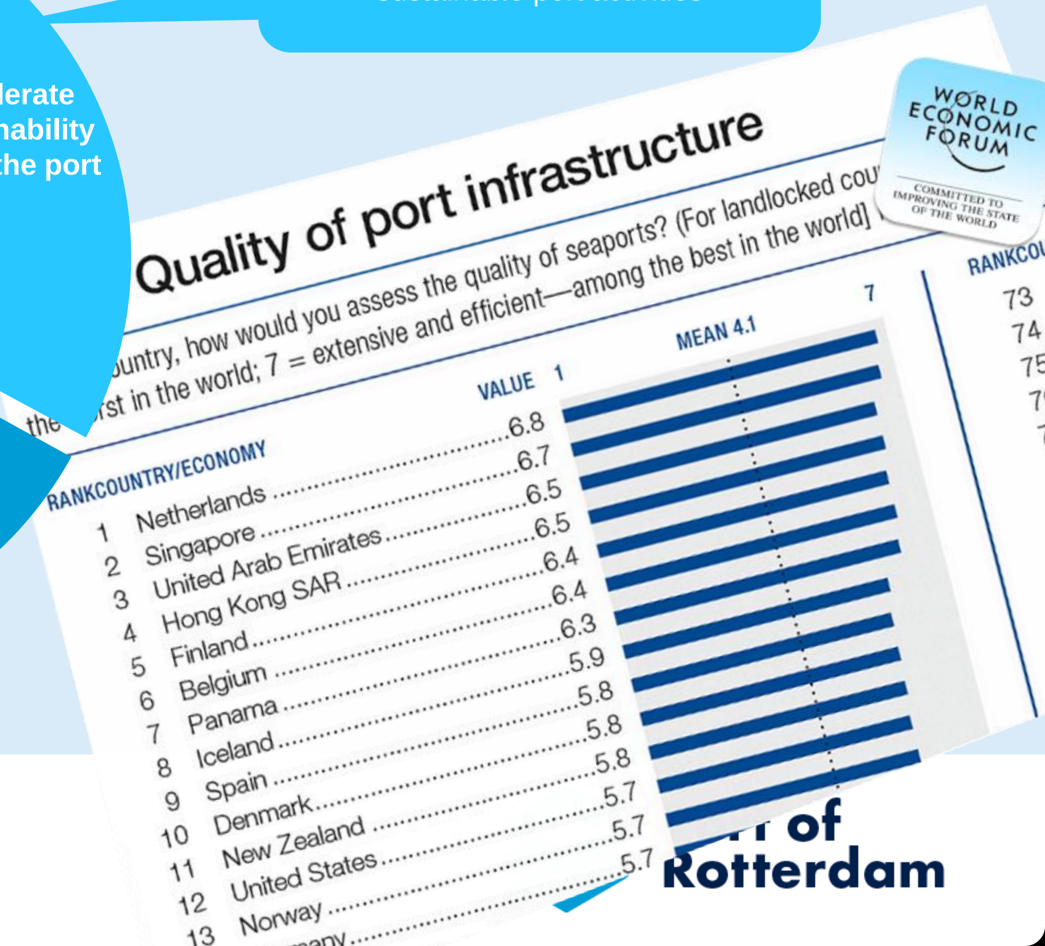
We help businesses to improve their environmental footprint and attract sustainable port activities

Accelerate sustainability within the port

We are the developer of a leading, safe, efficient and sustainable port in which our tenants can successfully do business

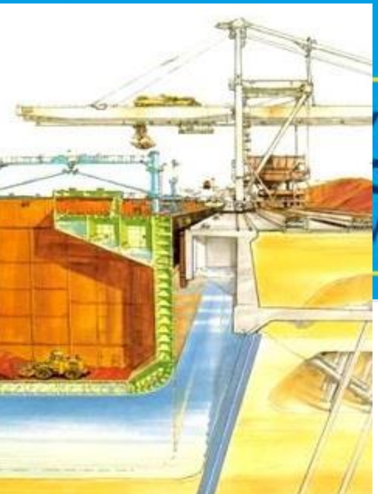
Enterprising and effective organization

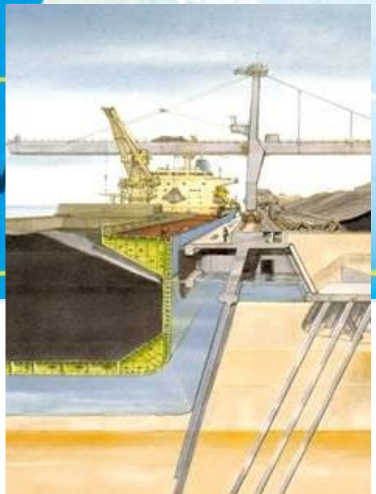
Through an integral approach, working together and our clear focus we are and effective entrepreneurial and client focused organisation.

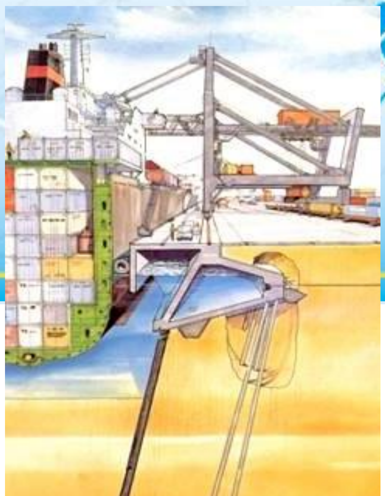


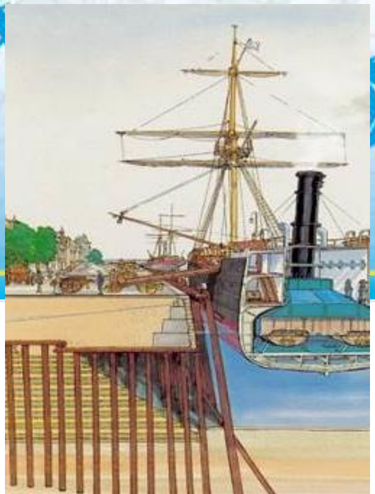
Challenge!

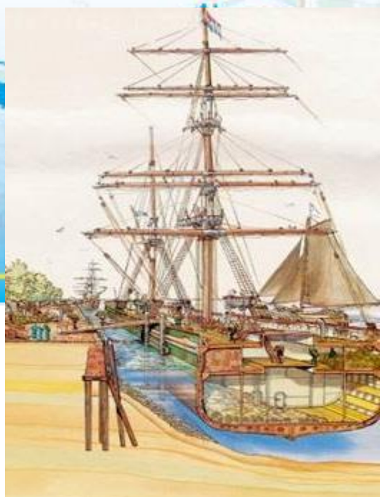

2008 - 2030
1970 - 2008
1960 - 1970
1948 - 1957
1929 - 1949
1934 - 1946
1906 - 1922
1400 - 1800
1800 - 1900












AIR QUALITY
INUNDATION
ALLIANCES CONTANIER SECTOR
AUTONOMOUS SHIPPING
LARGER VESSELS
ENERGY TRANSITION
ELEKTRIFICATION
AGING ASSETS
AUTONOMOUS VEHICLES
MOBILITY QUESTIONS
POPULATION GROWTH
Port of Rotterdam

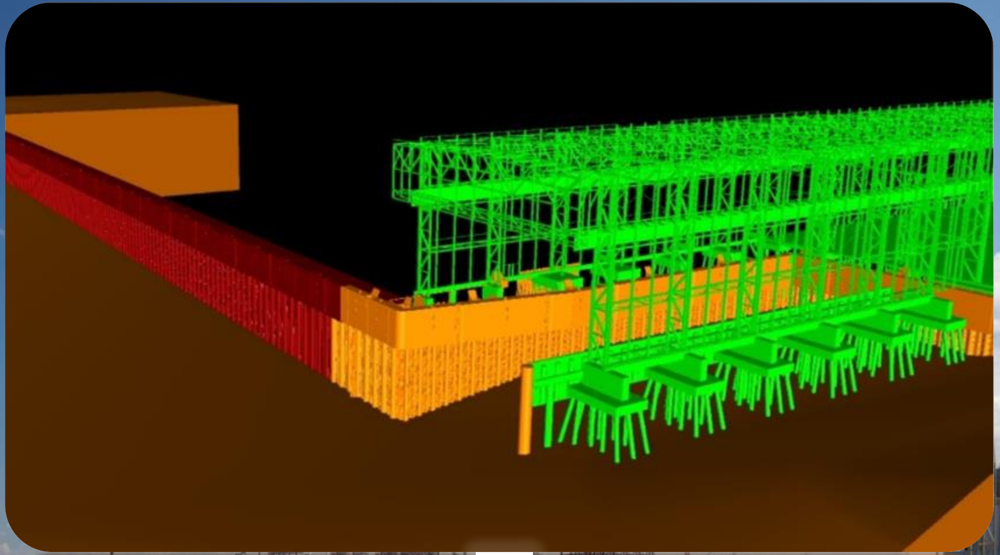

Port of Rotterdam
Port Network
Water depth
Parking places
Deformation quay wall
Push barges
Traffic growth
Waste containers
Berthing velocity
Ship handling
Degradation
Container handling
Bollard loads
Fender forces
Hydro meteo

Programme Infra innovation (I^2)

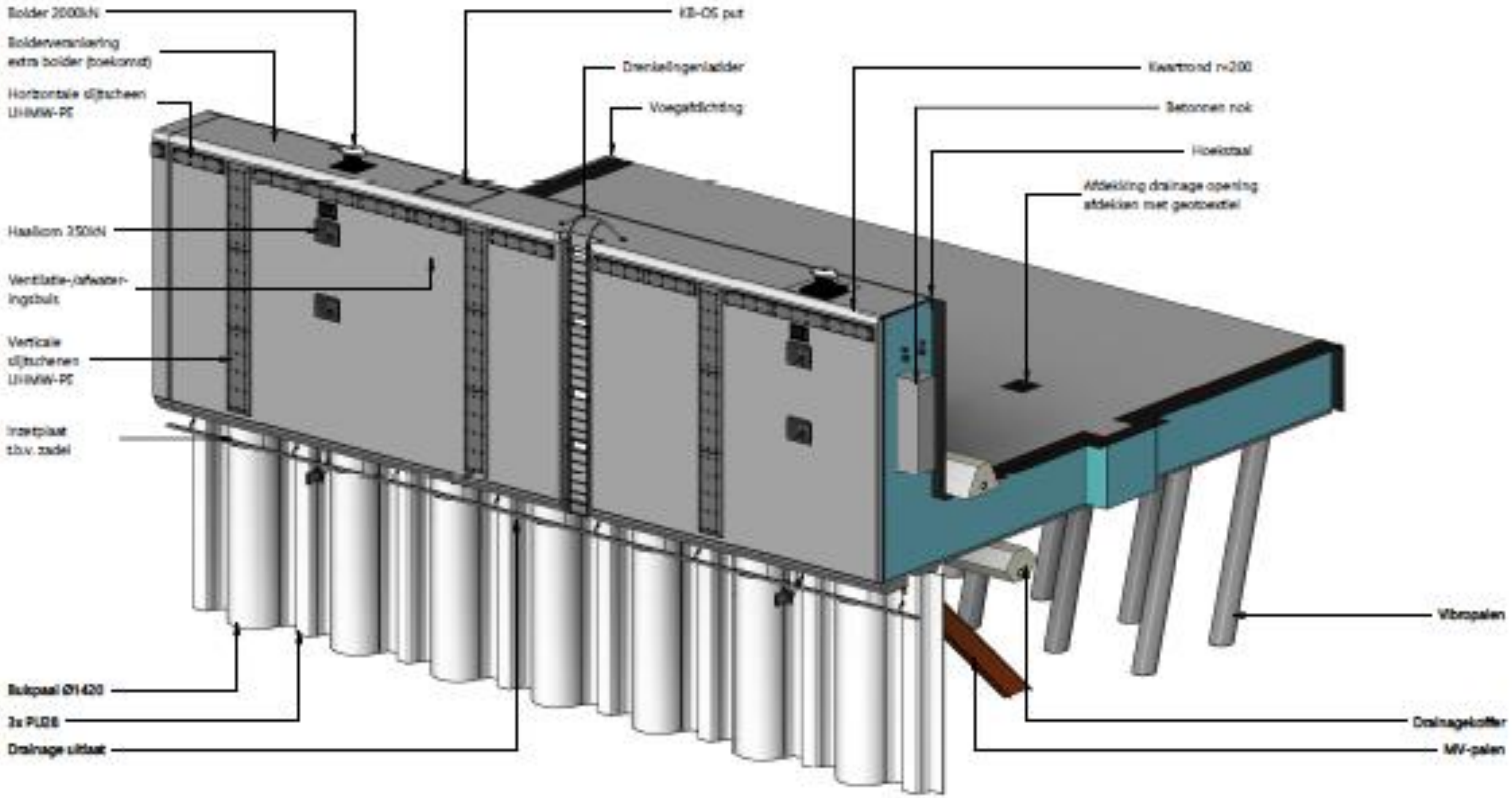
Enhancing business opportunity's for our tenants ***by maximizing the capabilities of port infrastructure through cutting edge engineering solutions.***

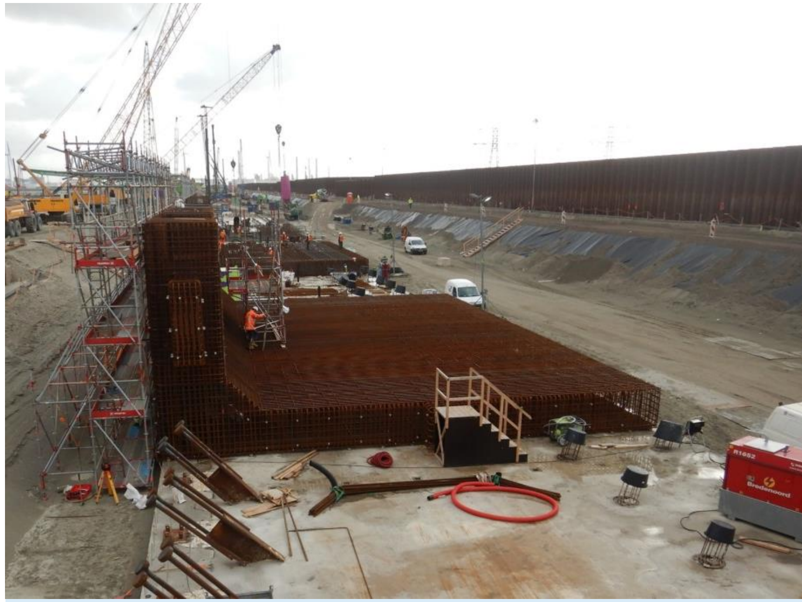
Infra Innovation

OPTIMISE DESIGN, CONSTRUCTION,
ASSET MANAGEMENT & USE
OF MARITIME PORT INFRASTRUCTURE.



QUAY WALLS ≠ public building or bridge!!





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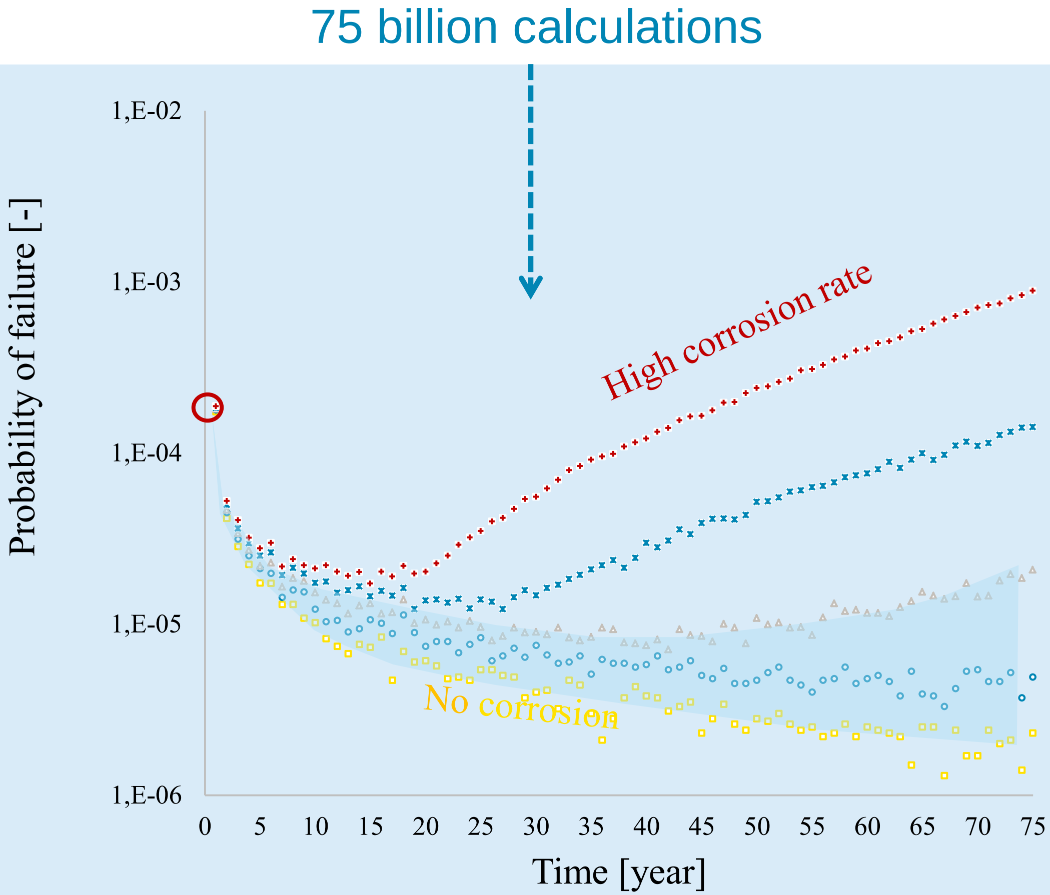
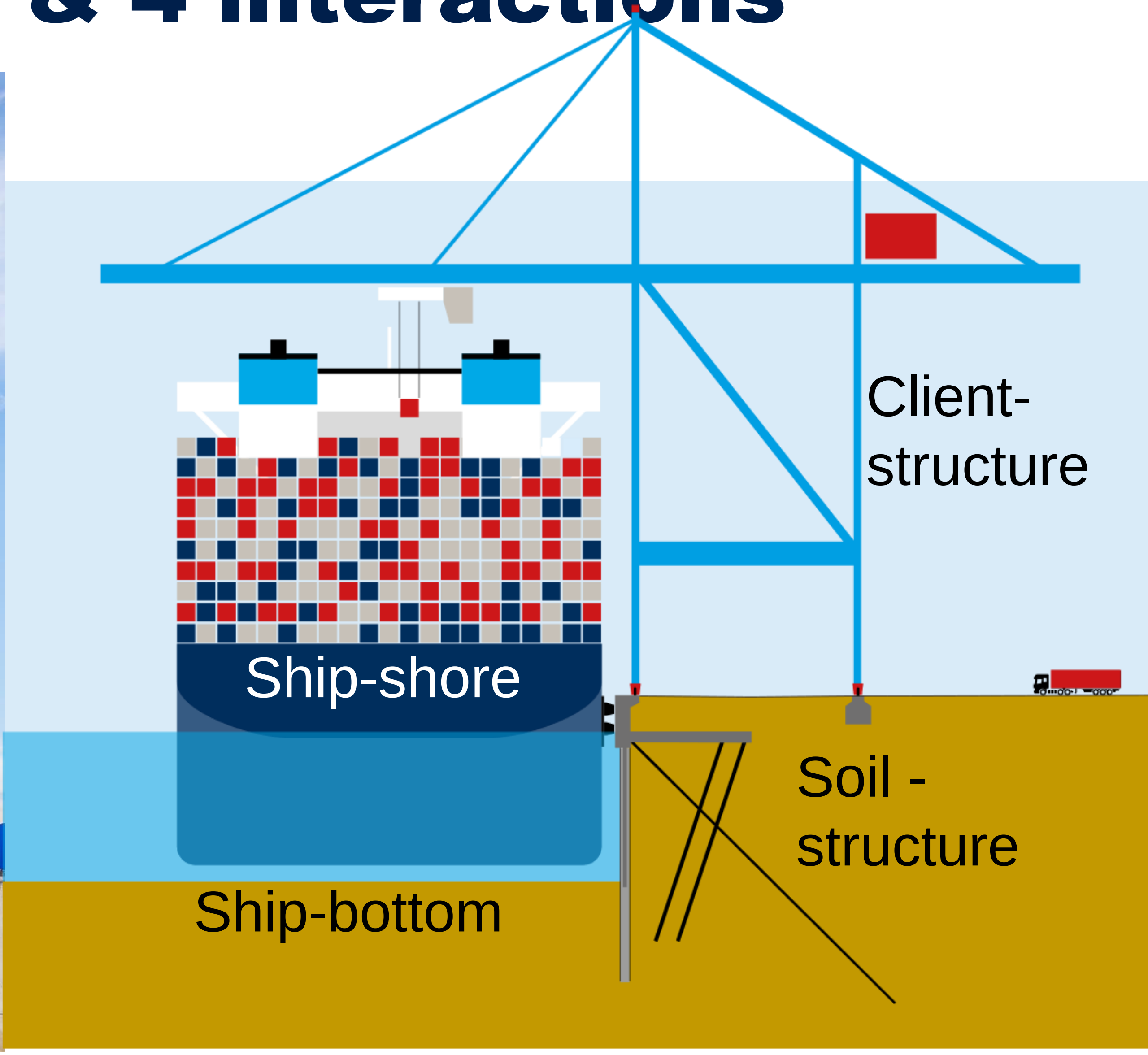
EXTEND SERVICE LIFE OF OUR QUAY WALLS

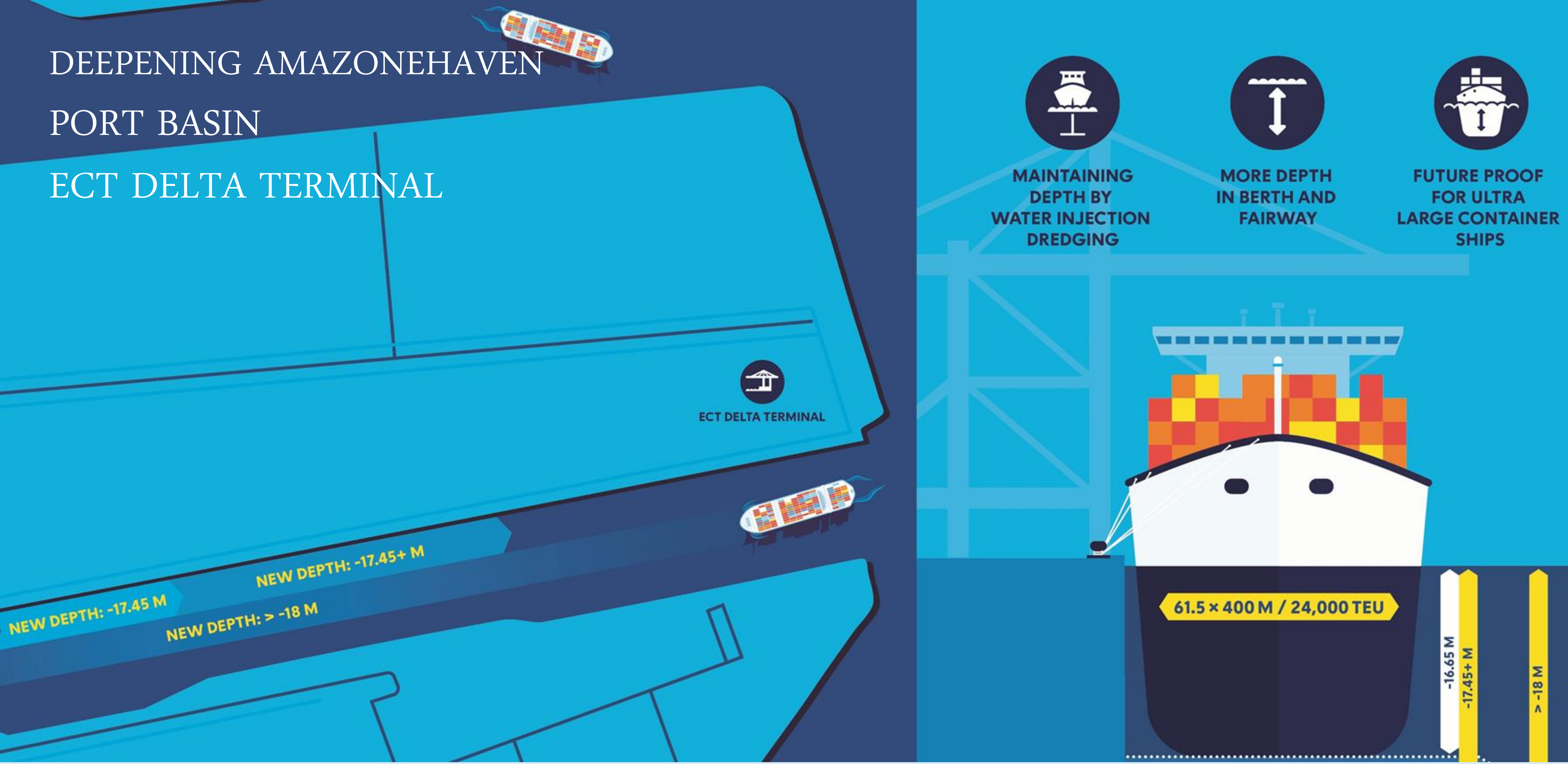


Focus on STRUCTURE & 4 interactions



Port of
Rotterdam

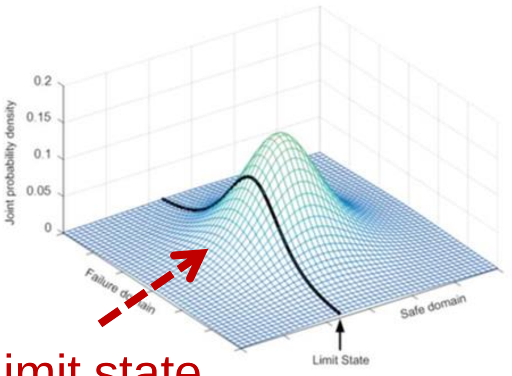
DEEPENING AMAZONEHAVEN
PORT BASIN
ECT DELTA TERMINAL



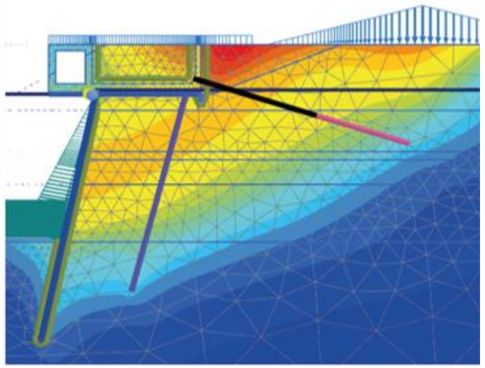
Test load Amaliahaven (500 elephants!)

TRENDS IN QUAY-WALL ENGINEERING

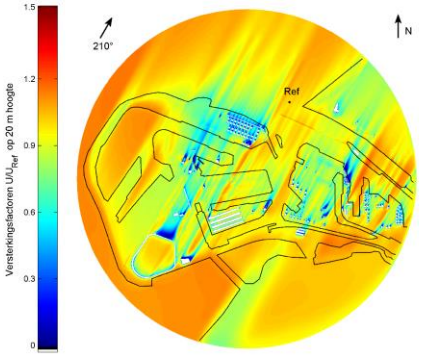
1) Reliability-based assessment

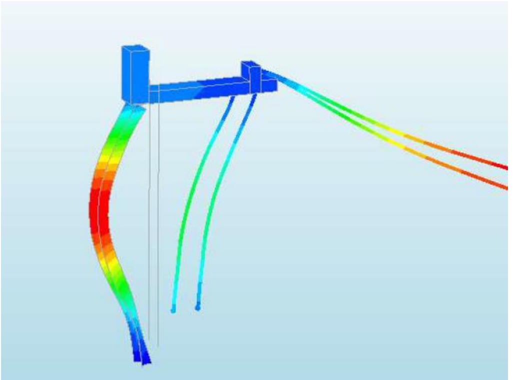


Limit state

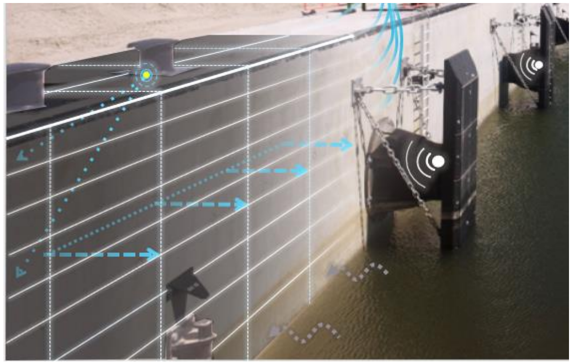


2) Advanced calculation models

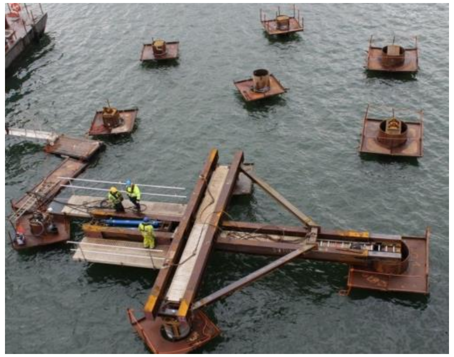




4) Sensors & digitisation



3) Stress testing (full scale field tests)



Introduction: Alfred Roubos

- Port Engineer (15 years) Port of Rotterdam Authority
- Researcher TU Delft (2016); Doctoral defence Oct. 2019.
- Member of several national & international committees (CEN, NEN, CROW, PIANC, BS)

Involved in 4 large full scale field tests:

- Full scale field test Beneluxhaven (2014)
- Load test precast concrete piles Kramer (2017)
- MV pile test Mississippihaven (2018)
- Foundation pile test Amaliahaven (2020)

Test 1 Belenuxhaven

What is a flexible dolphin?

≈ 4.755 in Rotterdam, 693 assets ownend by PoR ; €60.000,- to €300.000,- per pile

Breasting & mooring dolphins, slackening structures & crash barriers.

Functions:

1. Absorb berthing energy.
2. Transfer mooring loads.
3. Protection of vessel.
4. Protection of jetty.

Test 1: Full scale field test flexible dolphins (2014)

Motivation:

- High quality port infrastructure
- No guidelines in Eurocodes and uniform design approach
- Insight into reliability of existing assets
- Facilitate knowledge development (together with our partners)
- Sustainable use of materials (savings up to 15%)
- Reduction of site investigation UXO's

⇒ Expected benefits > € 2.000.000,-

⇒ Total project costs full scale field test ≈ € 715.000,-

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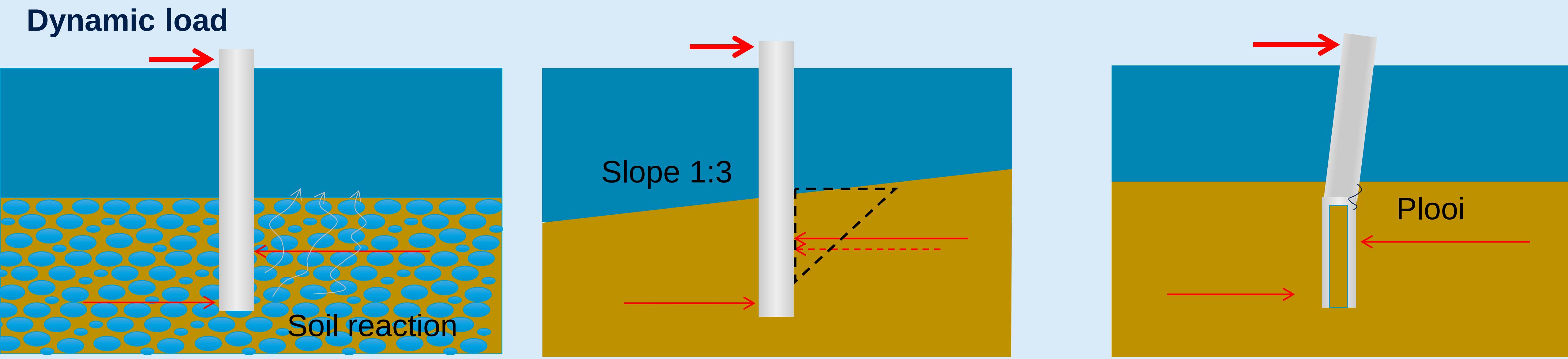
Test 1: Full scale field test flexible dolphins (2014)

- Static versus dynamic soil behaviour
- Effects of sloping seabed
- Local buckling



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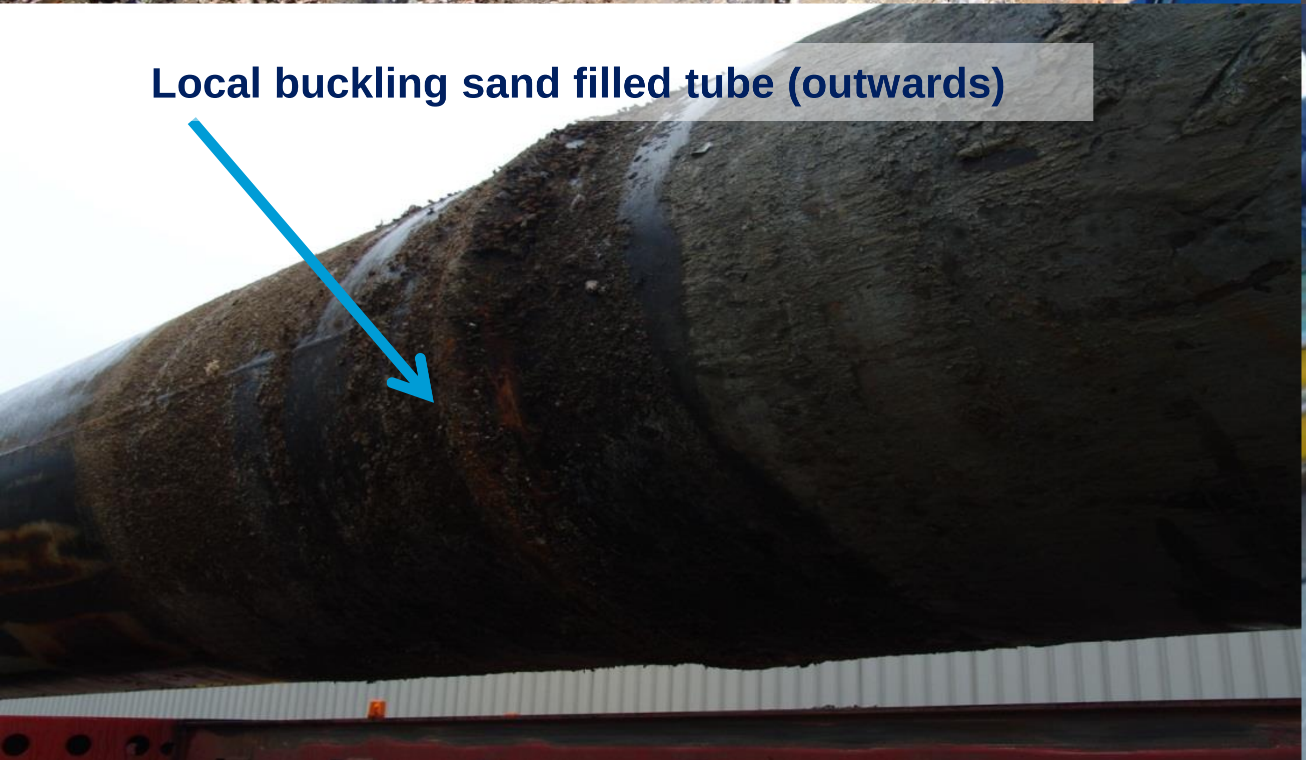
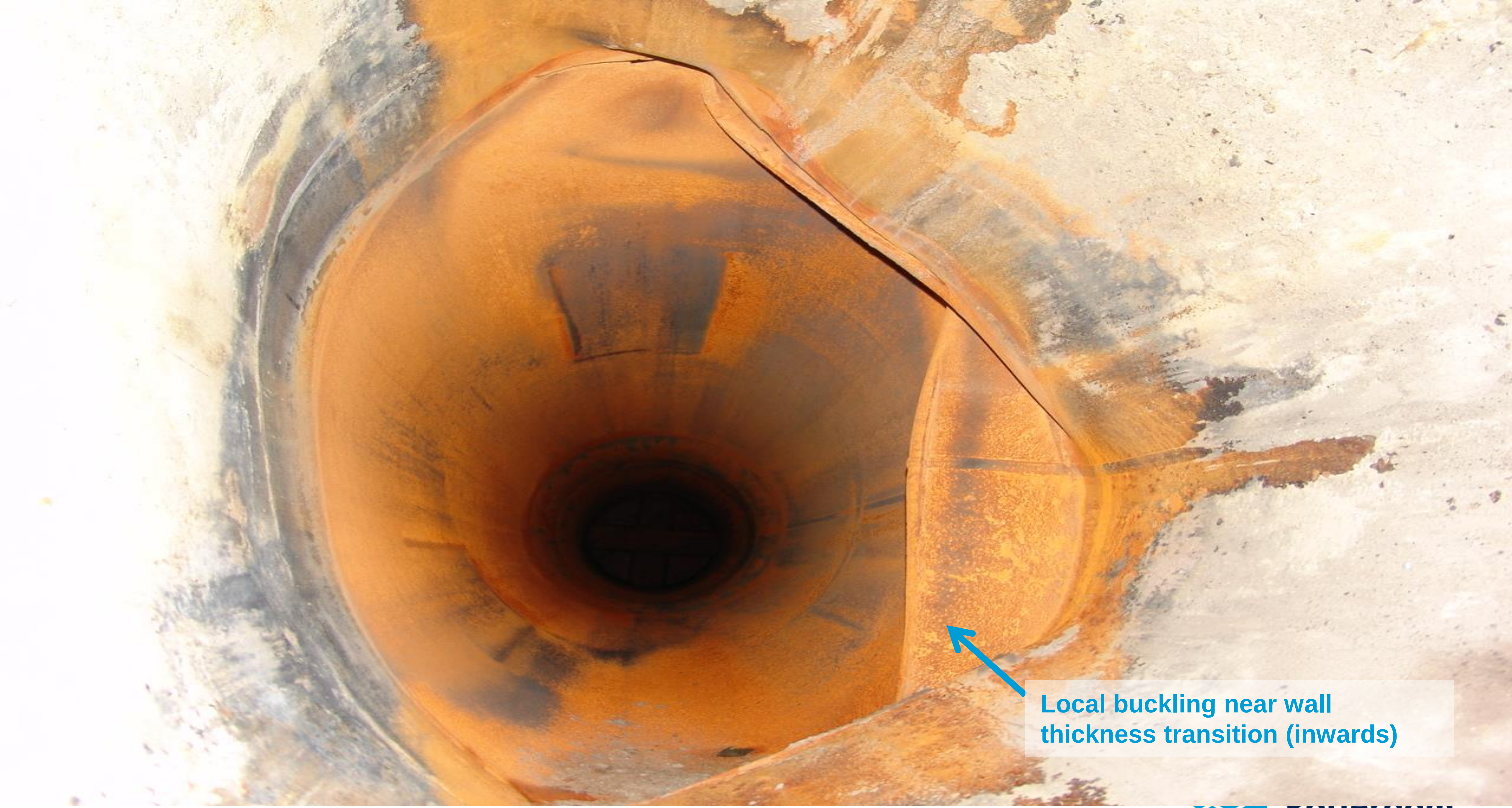
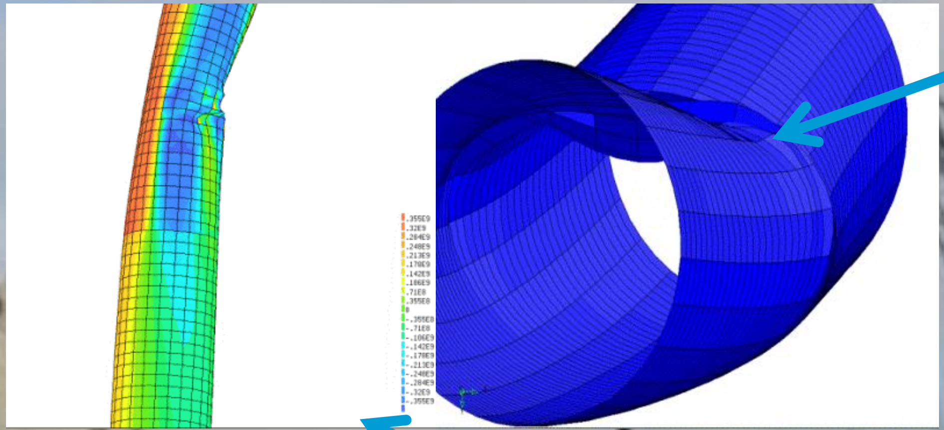
Local buckling empty tube (inwards)


Local buckling sand filled tube (outwards)


Local buckling near wall
thickness transition (inwards)

Predicting & measuring

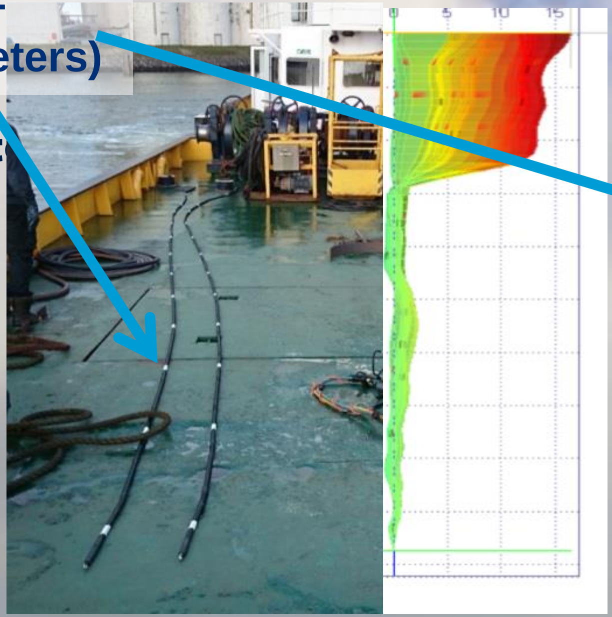
Innovative combination of software and measurements syst

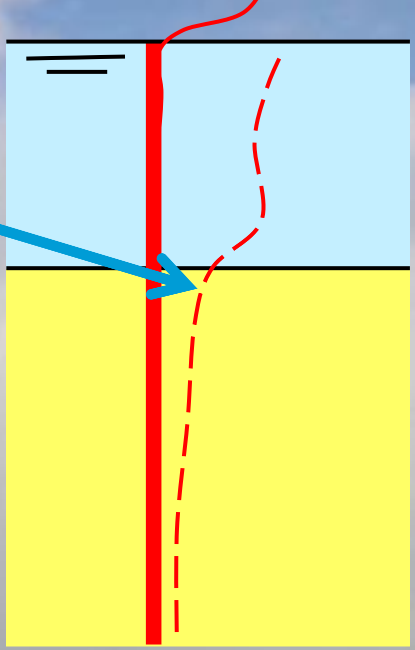


Local buckling

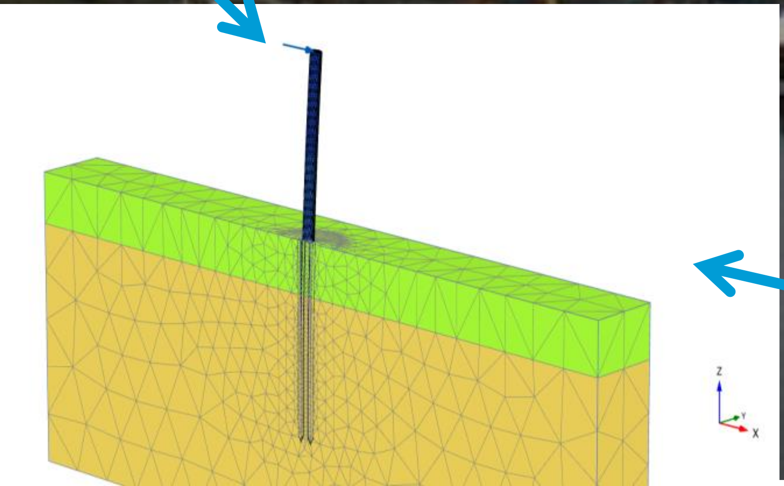
DIANA

SAAF (inclinometers)

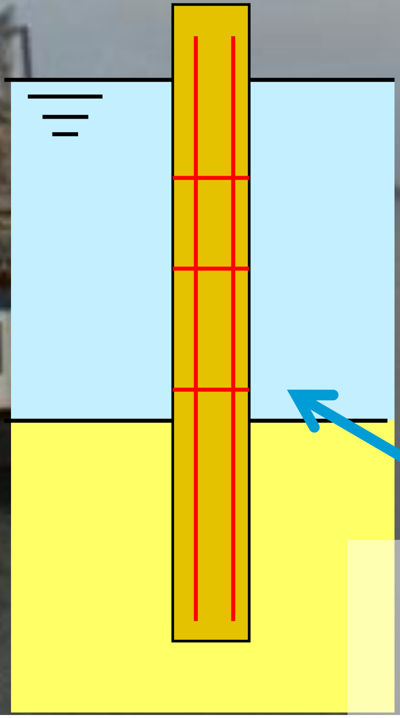


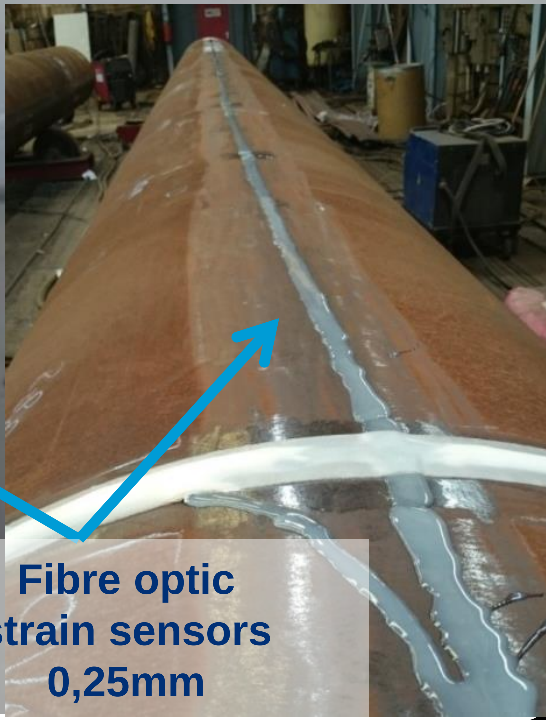


Berthing load



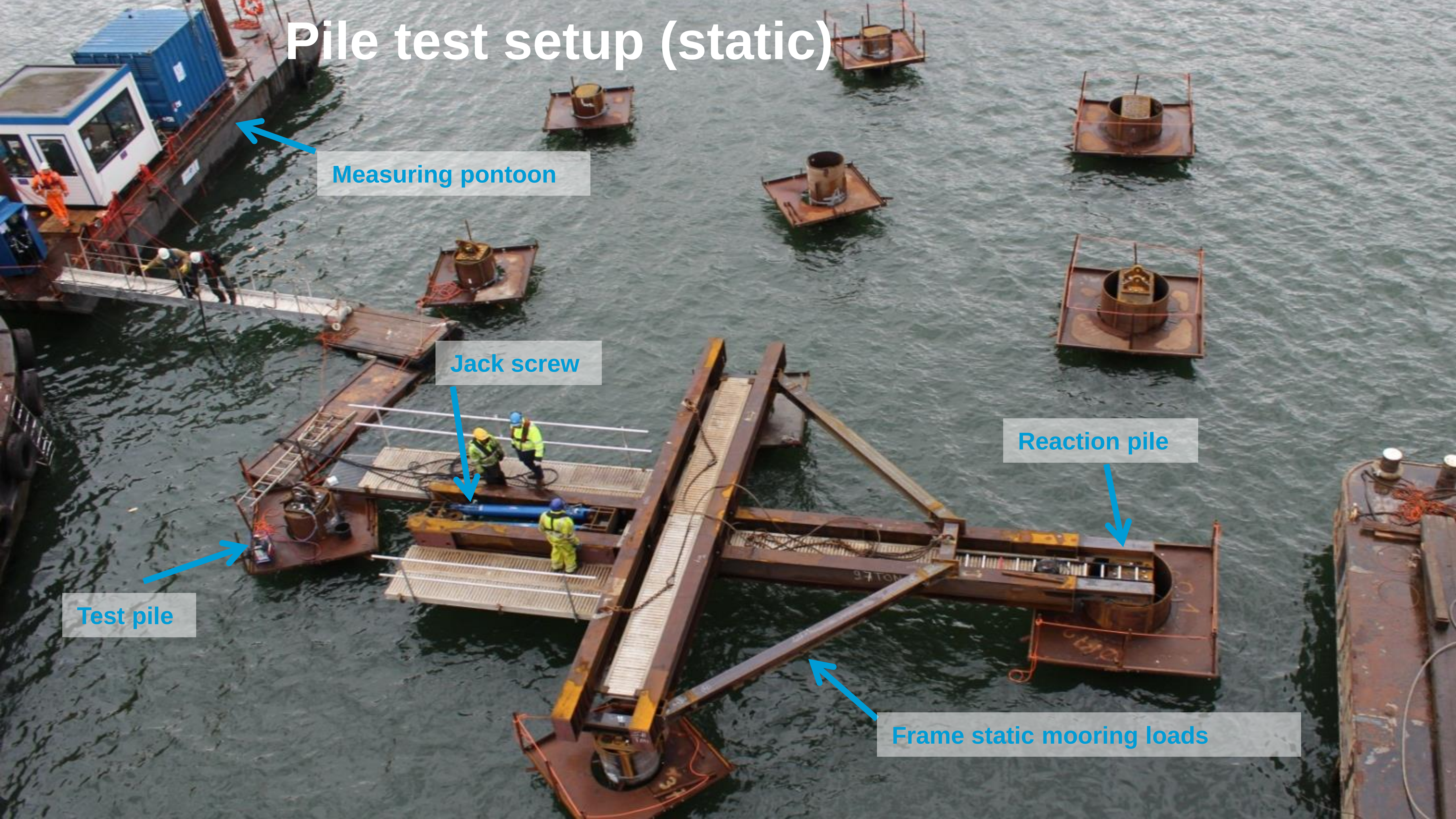
Benchmarks:
- Plaxis 3D
- Dsheet
- Blum

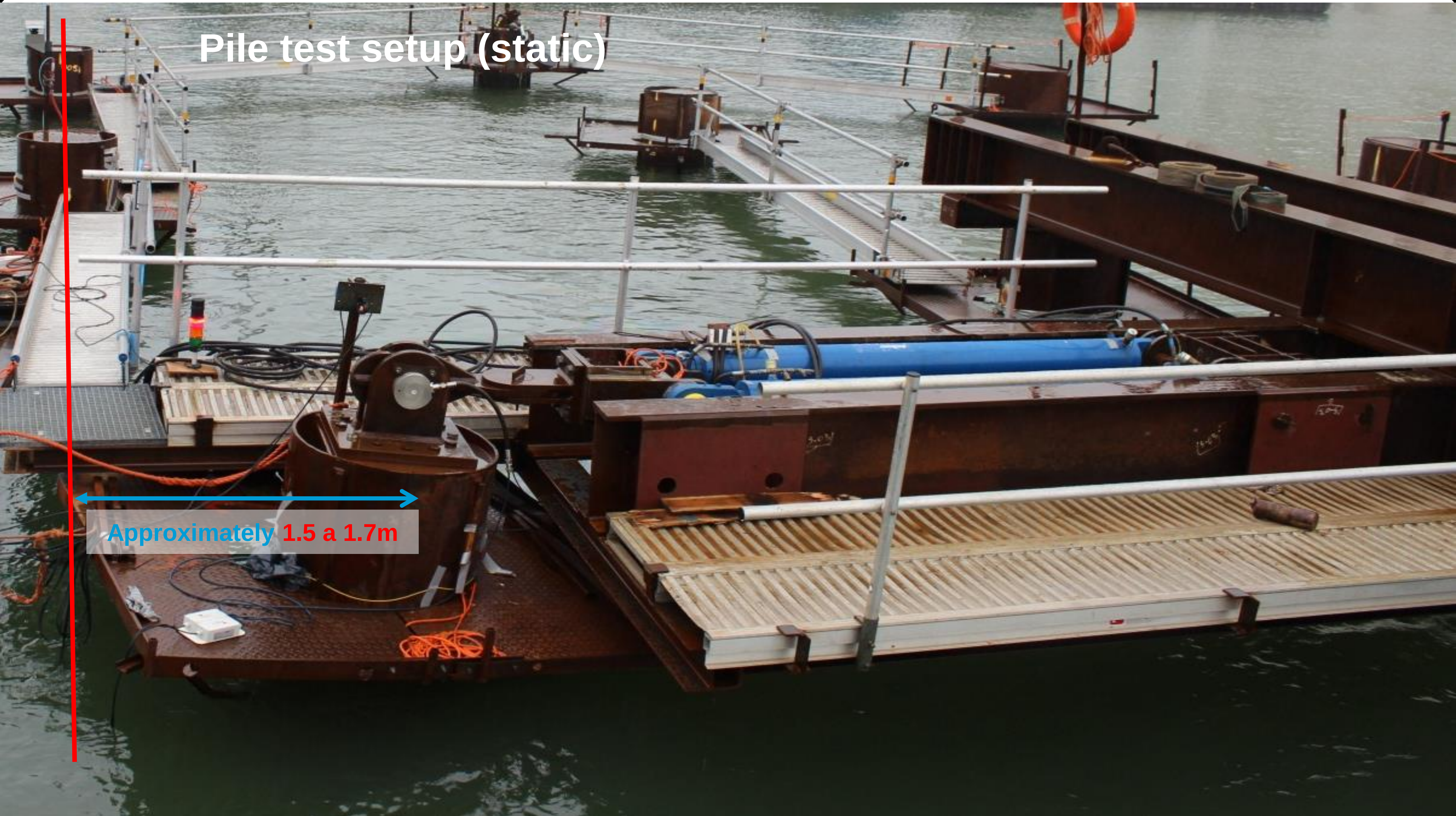




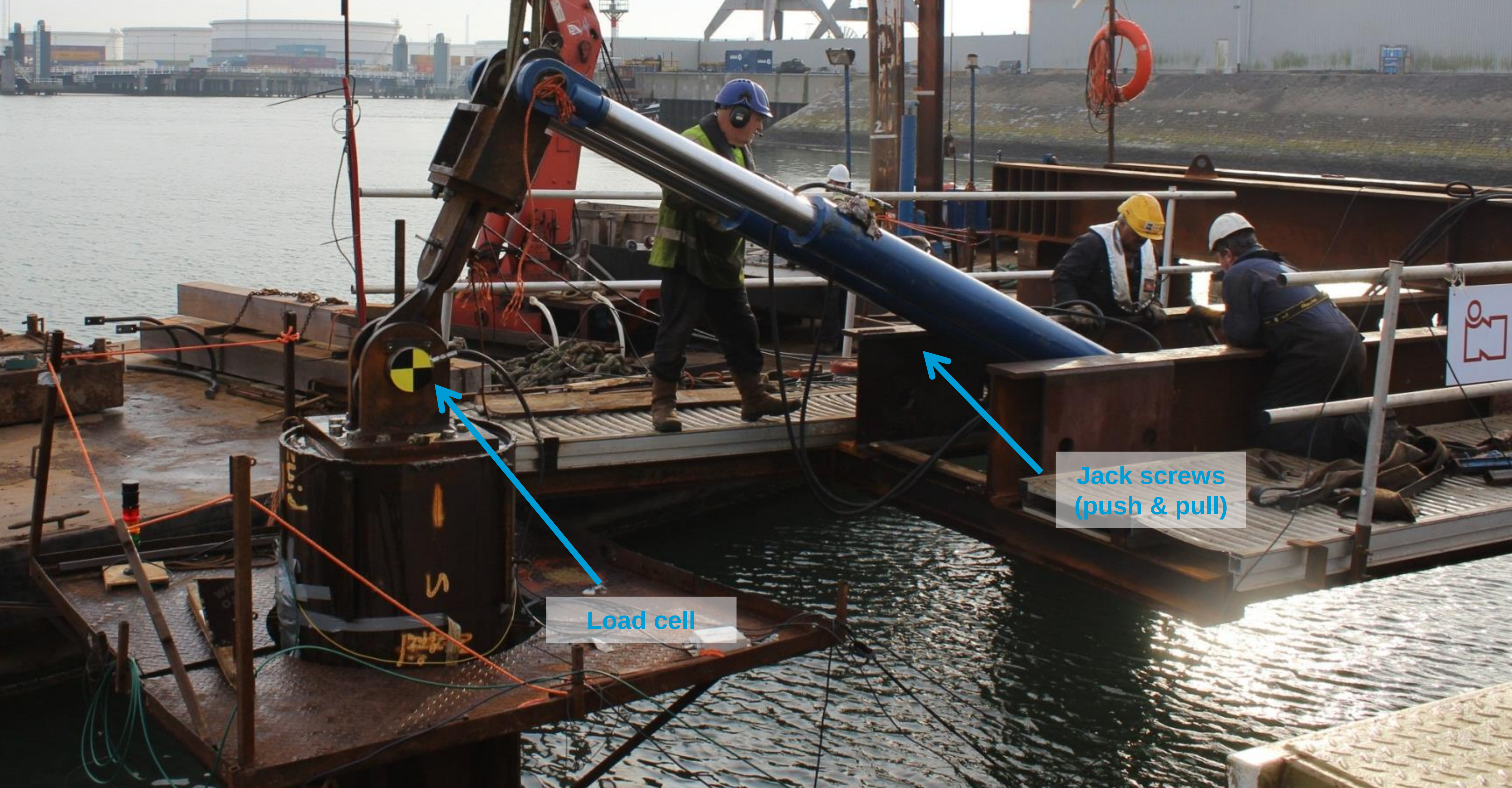
Fibre optic strain sensors 0,25mm

Pile test setup (static)




Pile test setup (static)
Approximately 1.5 a 1.7m

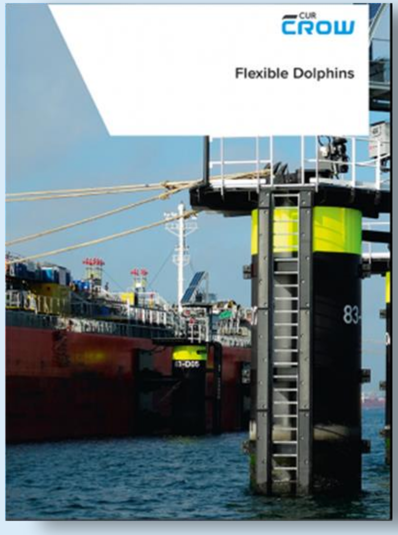
Test setup (static)

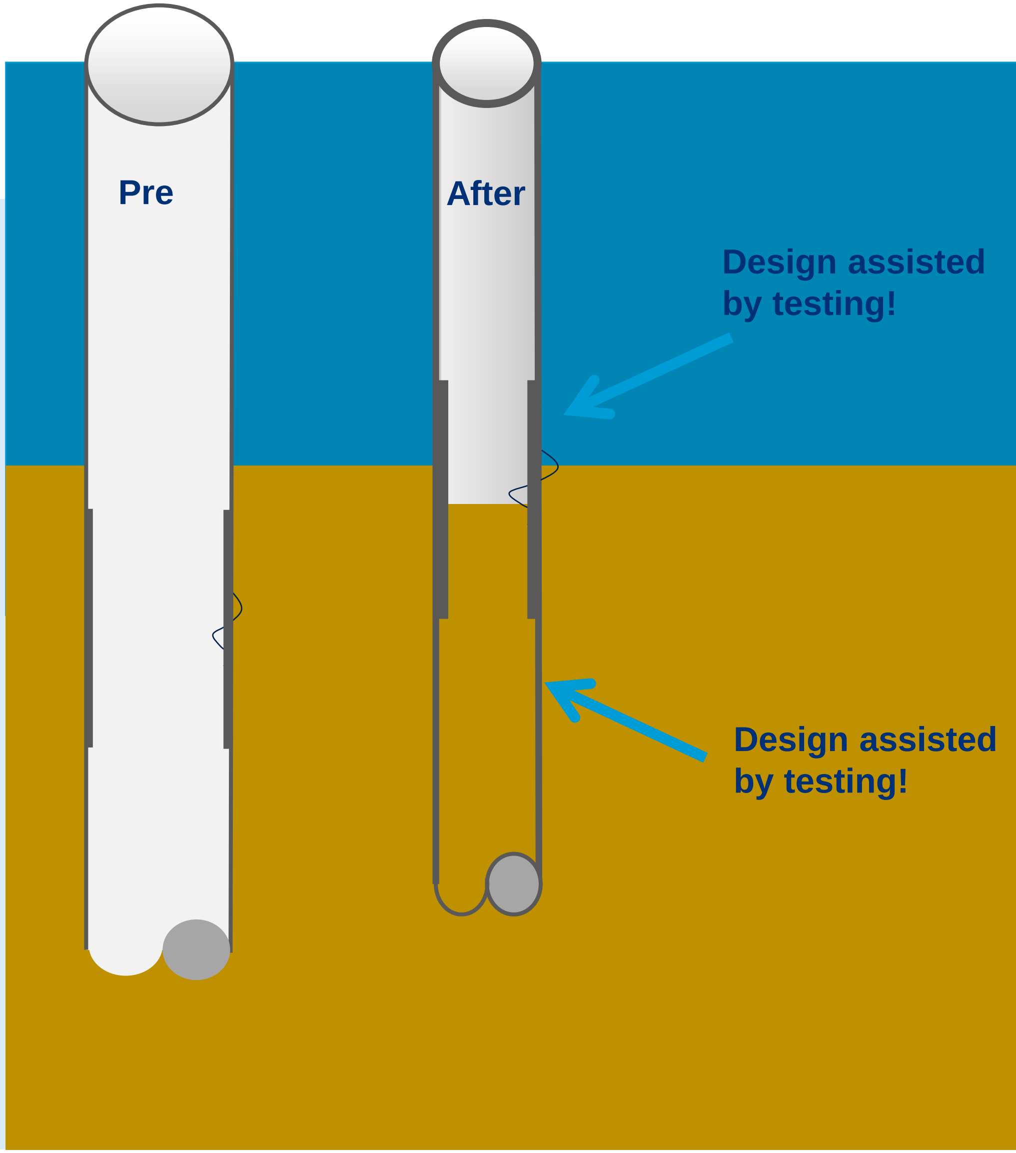


Test 1: Conclusion

- Factor 2 difference with Eurocode.
- Safer design using less steel.
- Smaller diameter, large wall thickness
- Optimisation of UXO investigation.

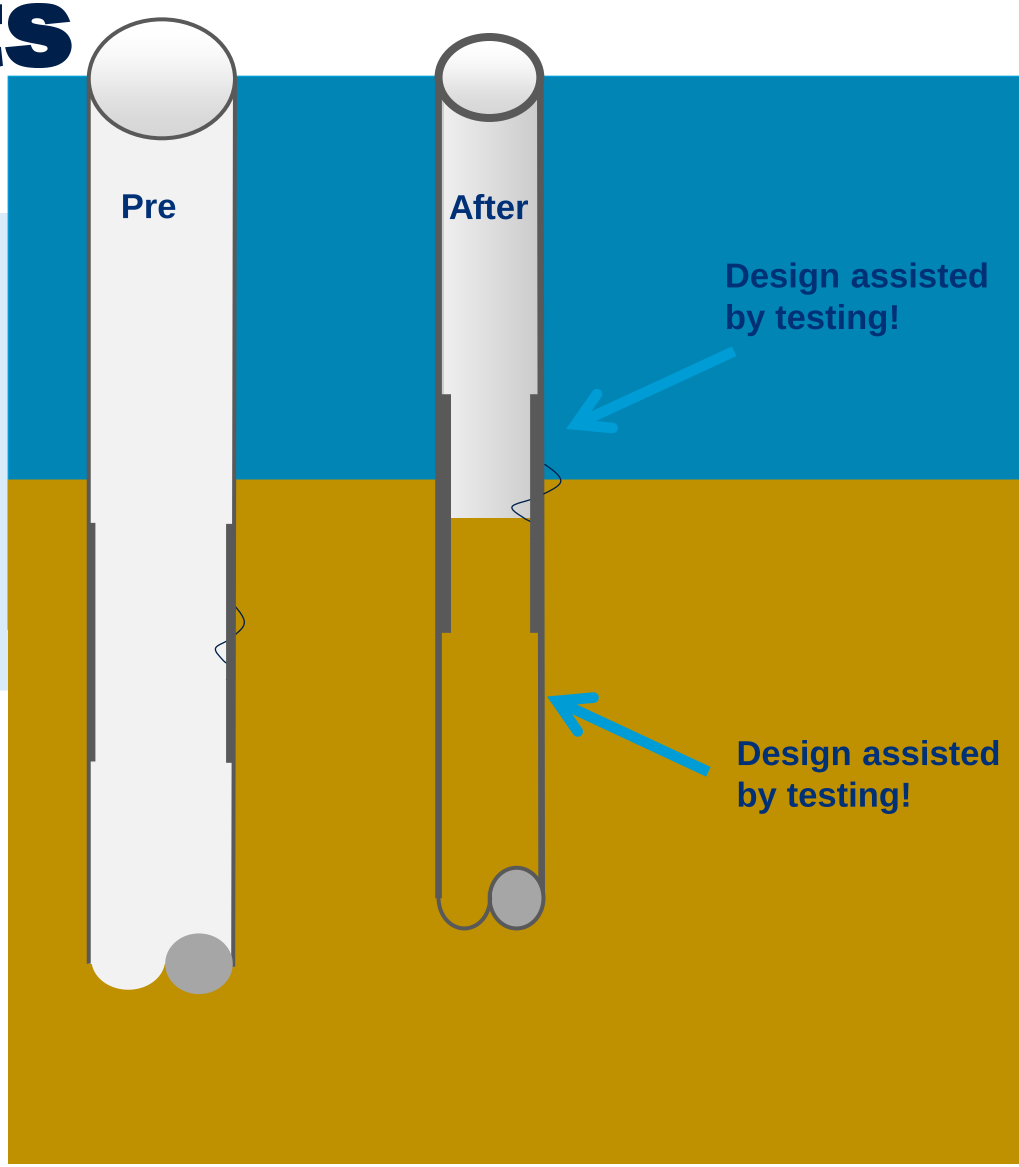
⇒ New CROW design guideline





Test 1: Financial results

- Project 1: Flexible Dolphins (40#) ≈ € 4.500.000,-
  (15% construction costs)
- Project 2: Jetty Aframax tankers ≈ € 800.000,-
  (5% construction costs)
- Reduction UXO investigation ≈ € 1.500.000,-



Test 2: Pile test Waalhaven (2017)

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

Since update Eurocode 7 (NEN9997-1)

- 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 CO_2 footprint.

- No foundation pile failures are known in Rotterdam
- Much higher risk of damage during installation

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Test 2: Pile test Waalhaven (2017)

Scope

- 4# precast concrete piles 450x450
- Test load: 9,000 kN

Results

- Failure load: 6,500 kN
- 25% less foundation piles.

Benefits

- 5% reduction of project costs

Test costs €450k

Total reduction €550k

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Onderzoekt • Ontwikkelt • Informeert

Witteveen + Bos

DIMCO

Infra Marine Contractors

TU Delft

Royal HaskoningDHV

Enhancing Society Together

Port of Rotterdam

Test 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

Test 3: Full scale failure test MV piles

Technical results

- 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?

=> Research is on going.

MSc thesis:
Geotechnical bearing capacity MV piles
Frederike Westerbeke

TUDelft MariTeam Gemeente Rotterdam Royal HaskoningDHV Enhancing Society Together Port of Rotterdam

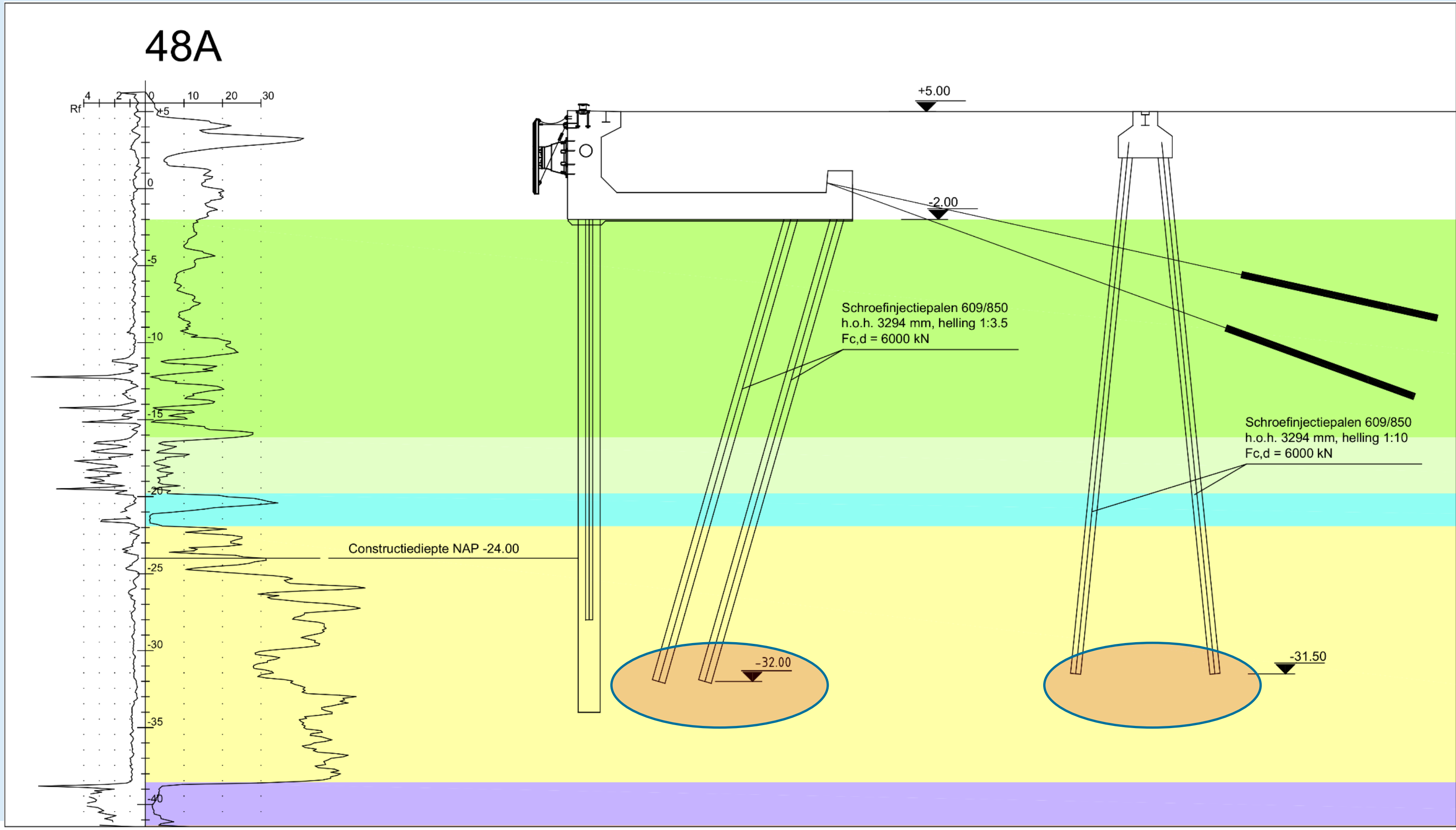
Test 4: Foundation pile tests Amaliahaven (2020)

Quay wall Amaliahaven

- 2.4 km
- Design depth NAP-24m
- Number of SI piles 2400

SI-piles

- 609/850
- Inst. depth NAP-32m
- Length 30m



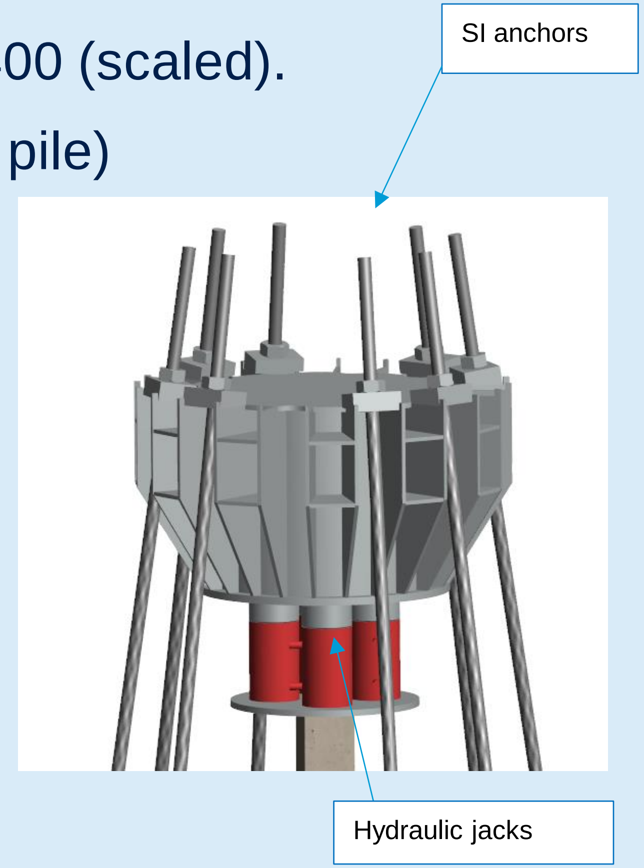
Test 4: Foundation pile tests Amaliahaven (2020)

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** !!!



Test 4: Foundation pile tests Amaliahaven (2020)

Inventory existing foundation piles of quay walls at Maasvlakte

- 7750 precast piles (value €18m) => Old NEN6743 (60%); Opstal van Dalen (30%);
- 4600 vibro piles (value €20m) => Old NEN6743 (5%); Opstal & van Dalen (95%).
- 975 SI piles (value €8m). => New NEN9997-1 (100%)

New quay wall projects at Maasvlakte (2020/2021)

⇒ SIF phase 2: 102 vibro piles and 10 SI-piles

⇒ Amaliahaven: 2400 SI piles (alternatives e.g. vibro piles allowed).

Test 4: Precast concrete piles; Results

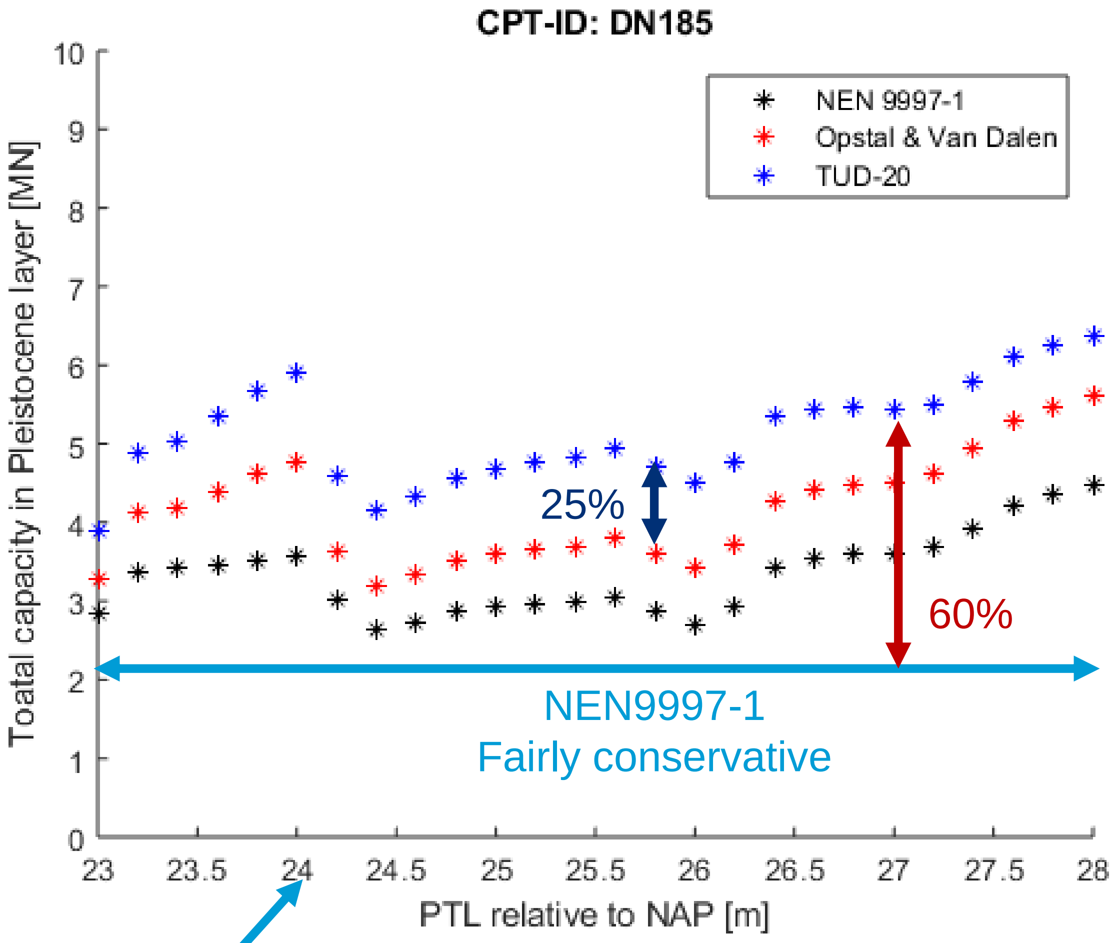
Example: Precast piles 450x450 in Maasvlakte conditions

Method TUD 2020

- Higher α_p and limiting value of 30MPa & UWA method for α_s

Bearing capacity method TUD 2020

- 60% increase compared to NEN9997-1.
- 30% increase compared to old NEN 6743.
- 25% increase compared to Opstal & van Dalen (1995).



This graph show the difference in bearing capacity for various pile lengths

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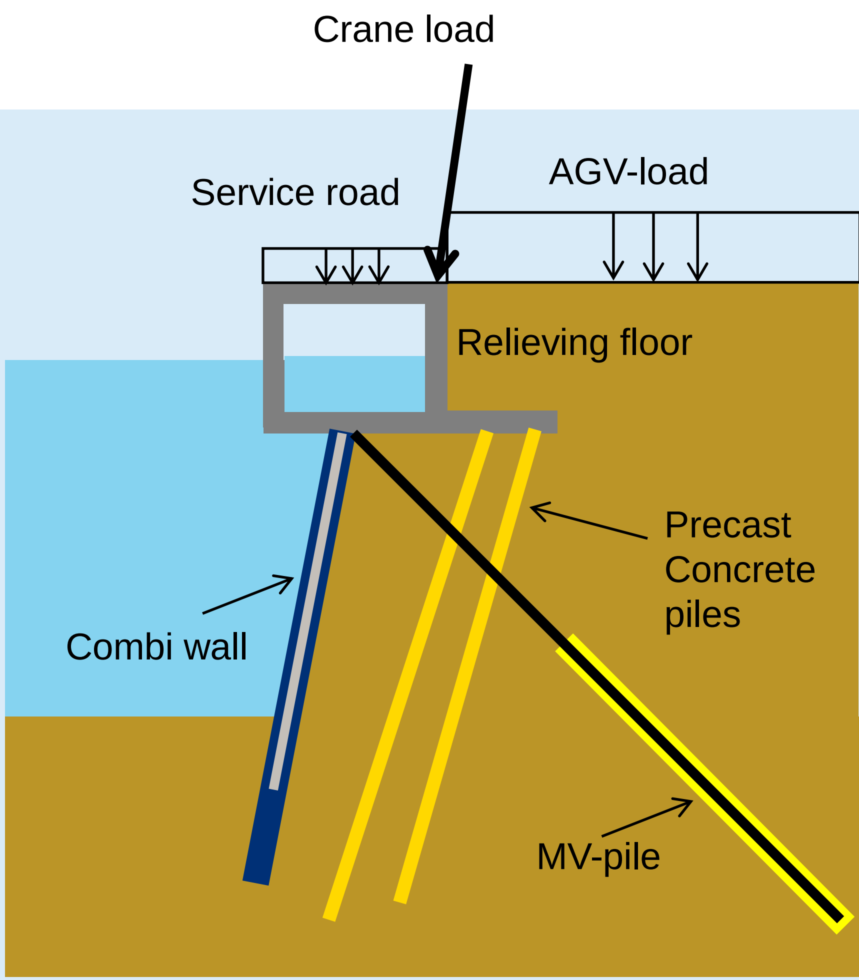
Test 4: Precast concrete piles; Benefits

Deepening existing quay wall ECT (1.6km)

- Compared to original design (based on Opstal & van Dalen) there is 25% extra capacity.
- The costs for realizing 25% extra bearing capacity for this existing quay wall are

  ≈ €4-5 million*.

⇒ Bigger crane and/or additional nautical depth



*In the event of a new quay wall the cost reduction is €0.65 million.

Test 4: Vibro piles (cast in situ); Results

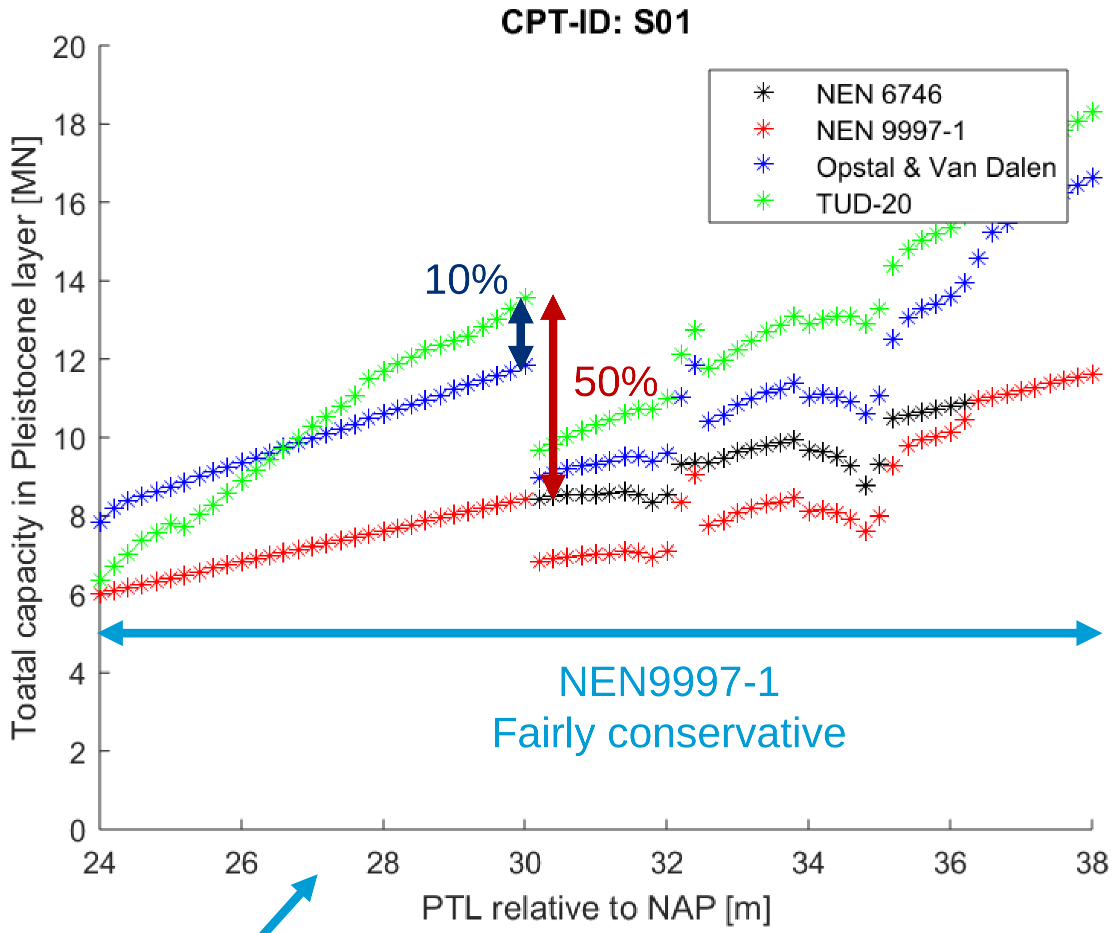
Example: Vibro piles 610/680 in Maasvlakte conditions

Method TUD-2020

- Lower α_p and limiting value of 20MPa & lower α_s but no limiting values.

Bearing capacity TUD-2020

- 50% increase compared to NEN9997-1.
- 10% increase compared to Opstal & van Dalen (1995).



This graph show the difference in bearing capacity for various pile lengths

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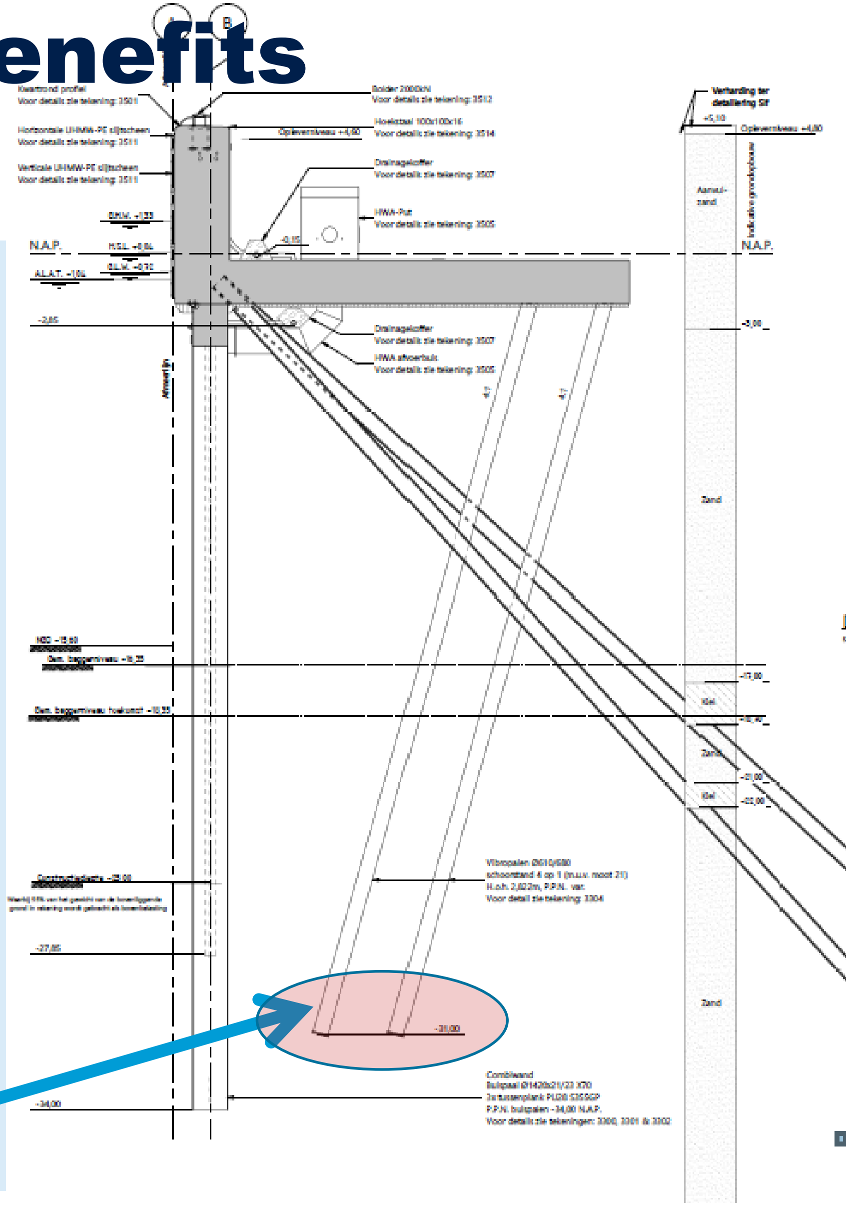
Test 4: Vibro piles (cast in situ); Benefits

Example 102 foundation piles SIF phase 2

- Application of vibro in stead of SI piles => cost reduction ≈ €0.35 million (factor 1.75 lower cost per pile).
- CO_2 reduction ≈ 2 kton

Method TUD 2020 is not yet considered. Design is based on NEN9991-1 (limiting value of 15MPa).

- Piles can be approximately 3-4m shorter => cost reduction ≈ €50k.
- Less installation risks.



Vibro Piles

Port of Rotterdam

Test 4: Screw injection piles (SI); Results

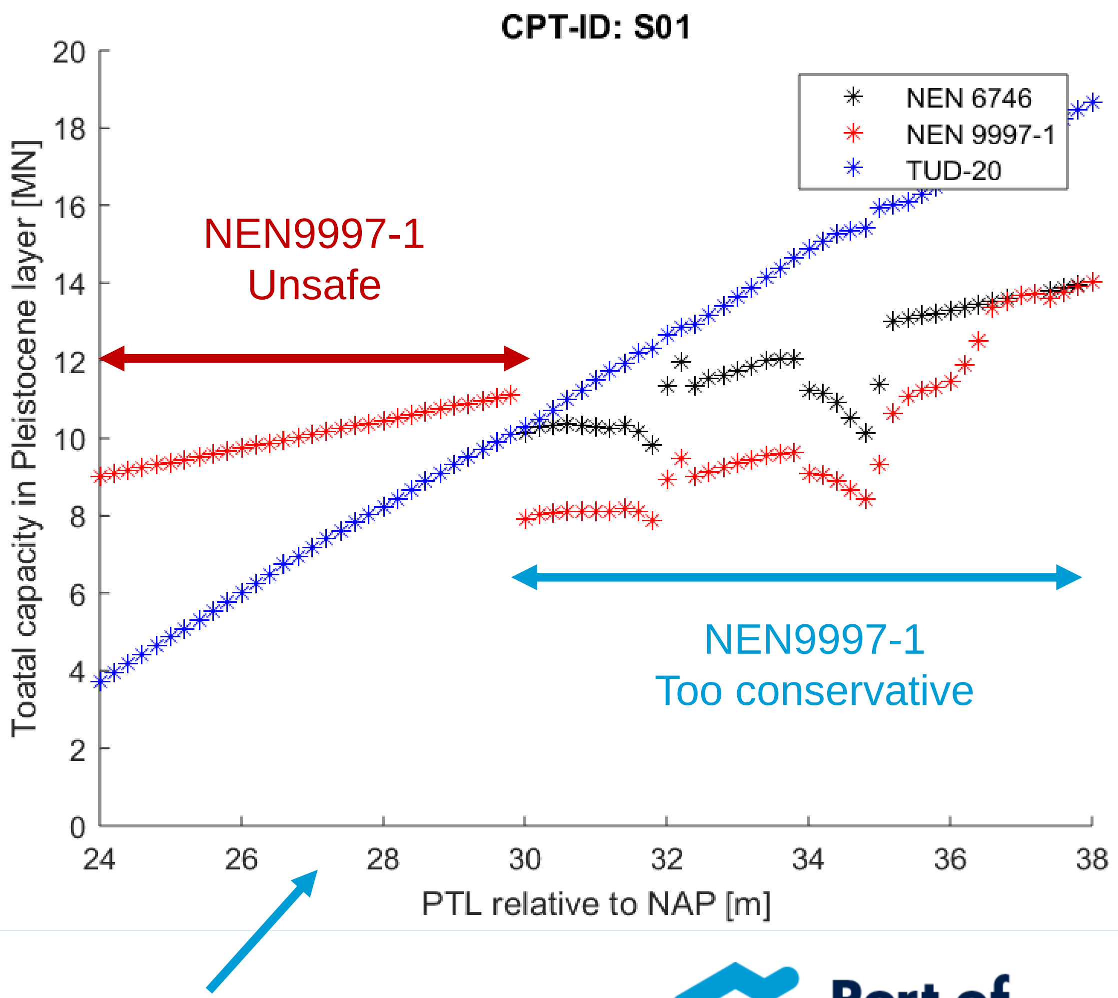
Example: SI-piles 610/850 in Maasvlakte conditions

Recommendations TUD-2020

- Lower α_p + limiting value 4MPa & higher α_s but no limiting value shaft resistance

Bearing capacity

- Pile test shows that the recommendations in NEN9997-1 are not (always) safe. The length of the piles will be too short
- In Maasvlakte conditions it is likely that piles may become too long, introducing high installation risks.



This graph show the difference in bearing capacity for various pile lengths

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Test 4: Screw injection piles (SI); Results

Example: SI-piles 610/850 in Maasvlakte conditions

Example: Quay wall Amaliahaven (2400 piles)

- Design update resulted in less SI-piles (≈ 4km reduction of total length).
- Cost reduction ≈ €1.6 million.
- CO_2 reduction ≈ 1325 ton
- Significant risk reduction and shorter installation time.

⇒ Alternative design solutions were allowed during the tender stage.

Test 4: SI piles were replaced by vibro piles!

Current situation at the Amaliahaven quay-wall project

Example: Quay wall Amaliahaven (2400 piles)

- Contractor replaced the SI piles by vibro piles.
- Cost reduction ≈ €10 million.
- CO_2 reduction ≈ 8kton

⇒ Return on investment!

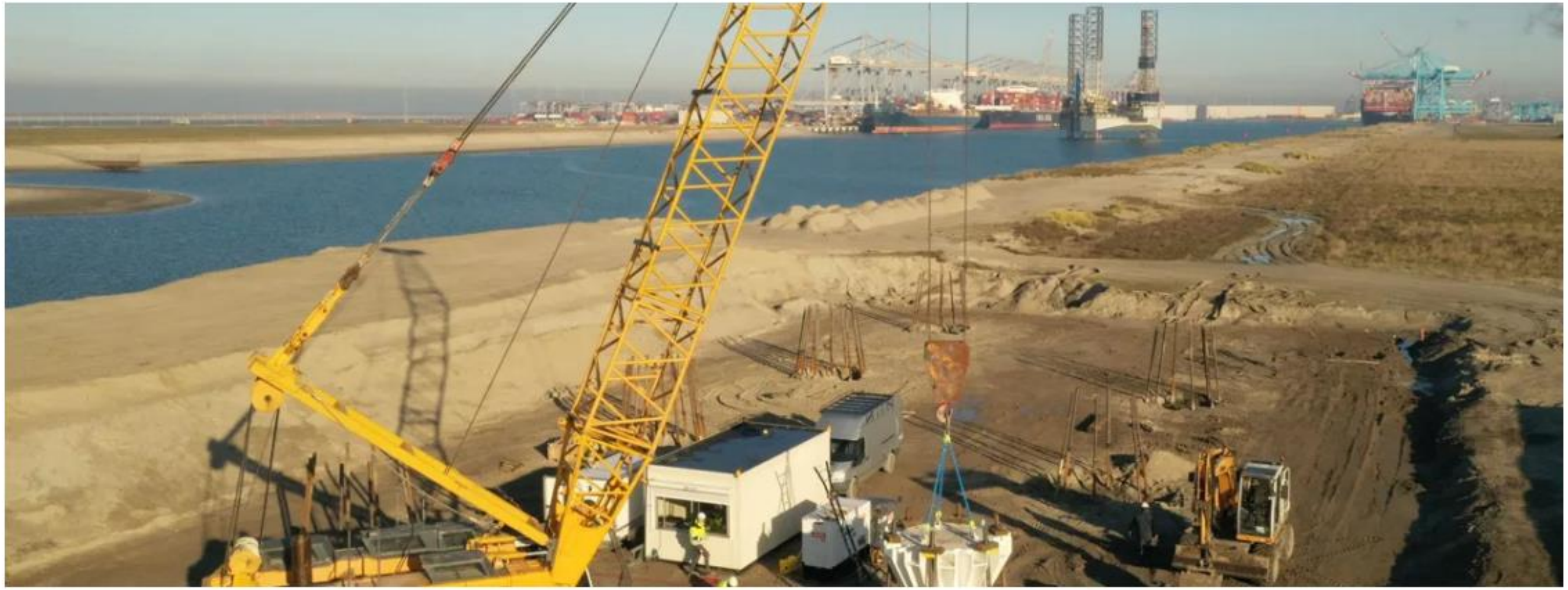
⇒ This is the 1st test that is included in the Dutch national pile test data base.

NVAF nen wtcb.be deKlerk WERKENDAM TUDelft MariTeam Port of Rotterdam

Test 4: Eerste zelfverklaring voor proefbelastingen

23 apr. 2021 E-mail of deel deze pagina

Om de draagkracht van palen beter te kunnen bepalen, vinden er steeds meer proefbelastingen plaats. NPR 7201 geeft regels voor de uitvoering, de uitwerking en de interpretatie van proefbelastingen op axiaal belaste funderingspalen. Met deze proeven kunnen de maximum draagkracht op druk en trek, paalklassefactoren, het last-zakkingsgedrag of last-rijzingsgedrag van de palen worden bepaald.



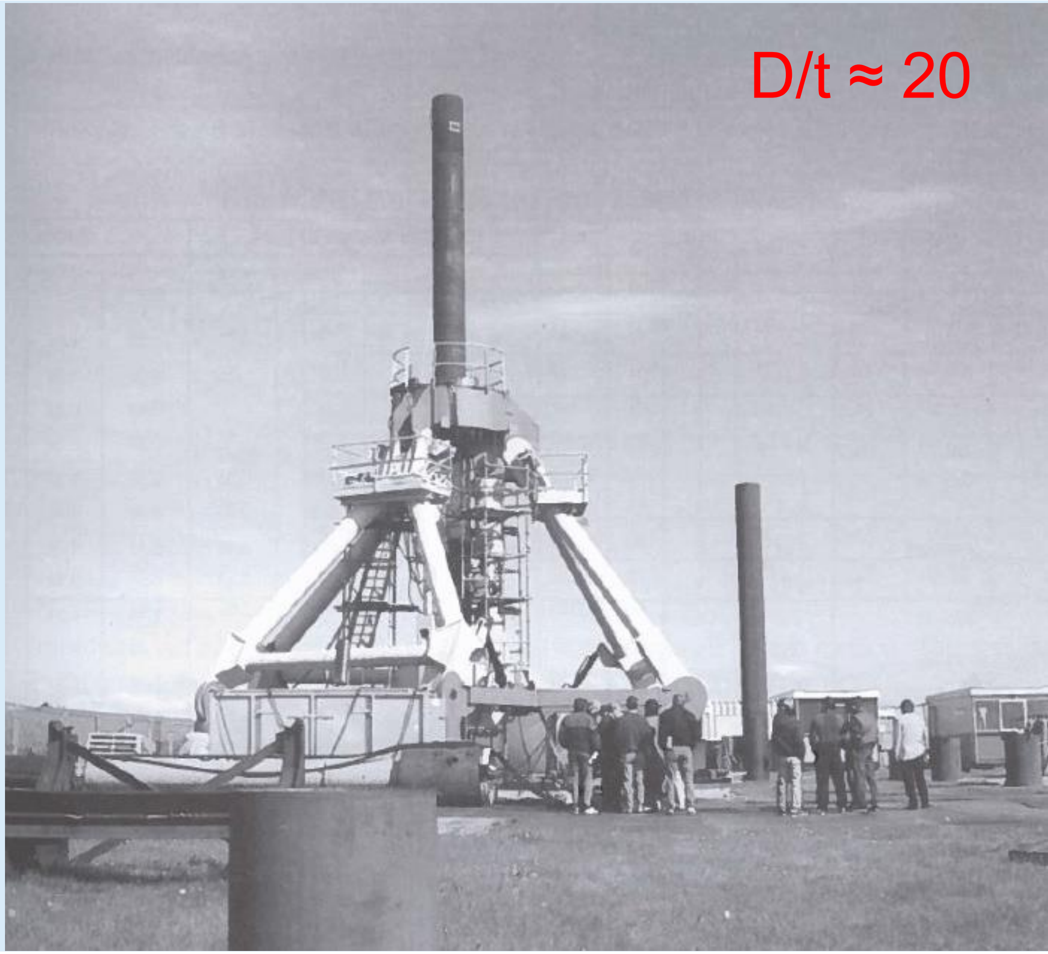
Next steps => Test 5

- Port of Rotterdam is willing to share all data!
- National research program ‘grondkerende constructies’ (e.g. joint industry projects)
- Reduce the uncertainty of the soil-structure interaction in order to bridge the gap between theory and practice.

New piles load test:

- Test 5: Full scale field test open ended steel tubular piles (5 piles; ø1220; D/t of 60, 80 and 100).
- Stress Wave conference Sept 20-23 in Rotterdam, demonstration day at Maasvlakte.

Euripides project: Eemshaven Ø762-36mm (’95 – ’97)



Thank you for your attention!

Egbert van der Wal & Alfred Roubos, Port of Rotterdam

21 October 2021, The Hague, Netherlands

Typical CO_2 footprint quay wall

- CO_2 footprint deep sea quay wall 50ton (excl. fuel for dredging)
- Target reduction in 2030 ≈ 10 kton.
- 52% of footprint is concrete.
- 48% of footprint is steel.