CROW Flexible dolphins

Alfred Roubos / Port of Rotterdam Authority / TU Delft
Dirk-Jan Jspers Focks / Witteveen+Bos

Witteveen+Bos
Port of Rotterdam
kennisplatform CROW

Alfred Roubos

- Port Engineer (17.5 years) Port of Rotterdam Authority
- Lecturer PAO (2010)
- Researcher TU Delft (2016);
- Doctoral defence Oct. 2019.
- Member of several national & international committees (CEN, NEN, CROW, PIANC, BS)

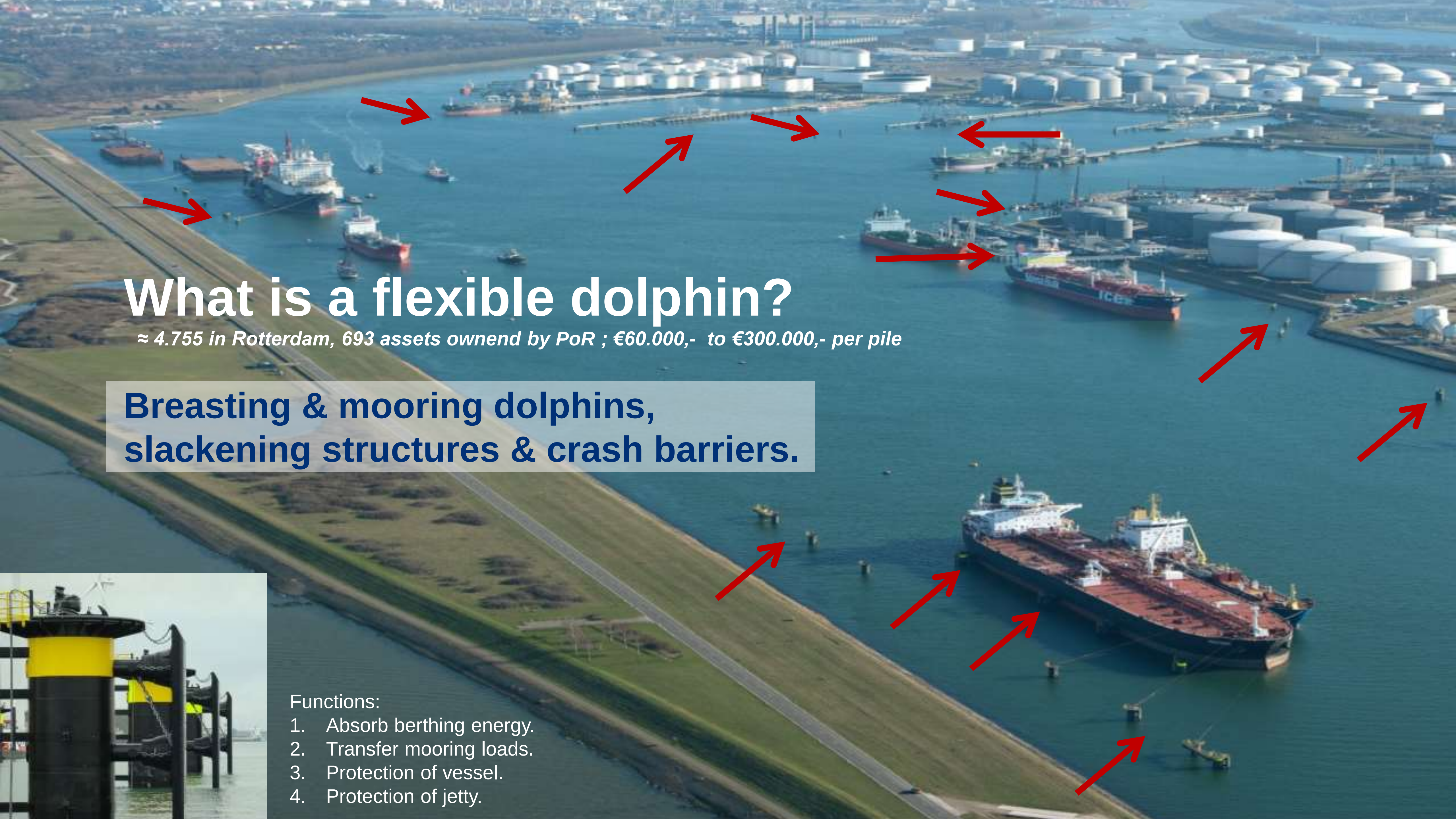
Main interests:

- Marine structures (e.g. quay walls, jetties and flexible dolphins)
- Dredging, revetments and bottom protections
- Innovations, research & full scale field tests

Content

1. Introduction & motivation
2. Upgrade CROW guideline
   - Berthing energy and mooring loads
   - Modelling flexible dolphins
   - Tests
   - Design approach
3. Impact of the new CROW guideline

Questions & discussion (10 min)



What is a flexible dolphin?

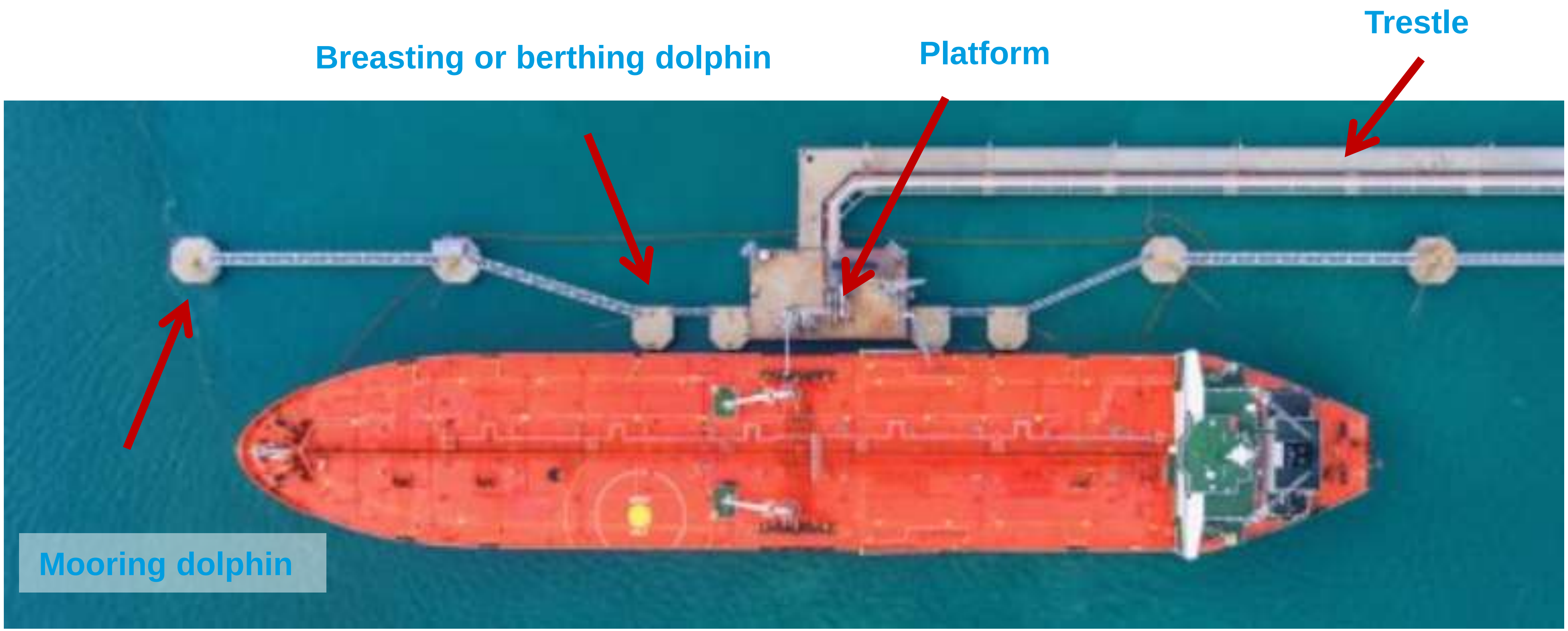
≈ 4.755 in Rotterdam, 693 assets ownend by PoR ; €60.000,- to €300.000,- per pile

**Breasting & mooring dolphins,
slackening structures & crash barriers.**

Functions:

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

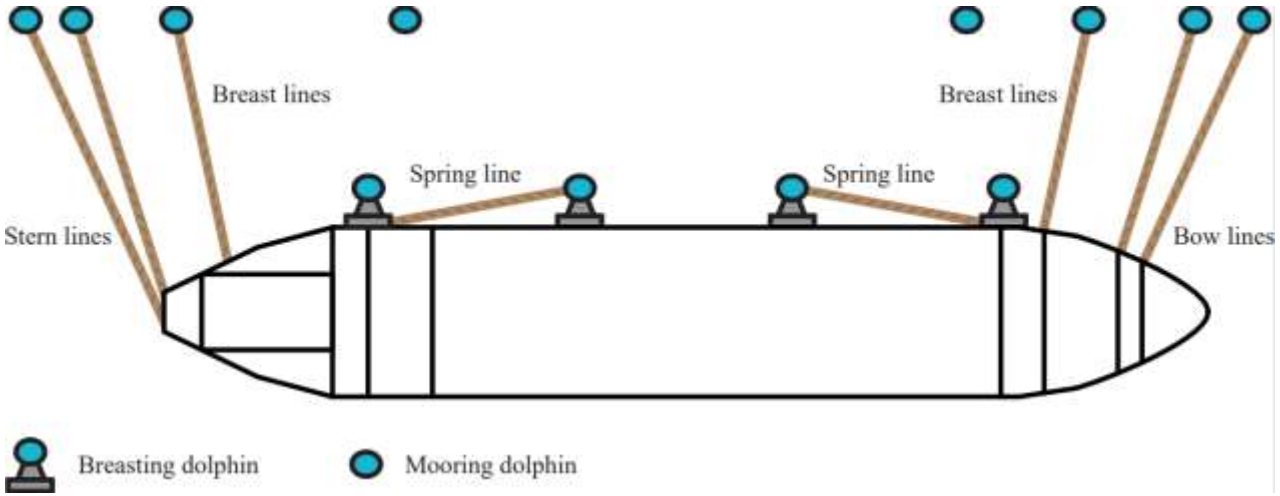
Typical layout jetty



What is a flexible dolphin?

- Horizontally loaded flexible dolphin.

Top view berth layout consisting of flexible dolphins



Breasting dolphins absorb berthing energy and mooring line forces.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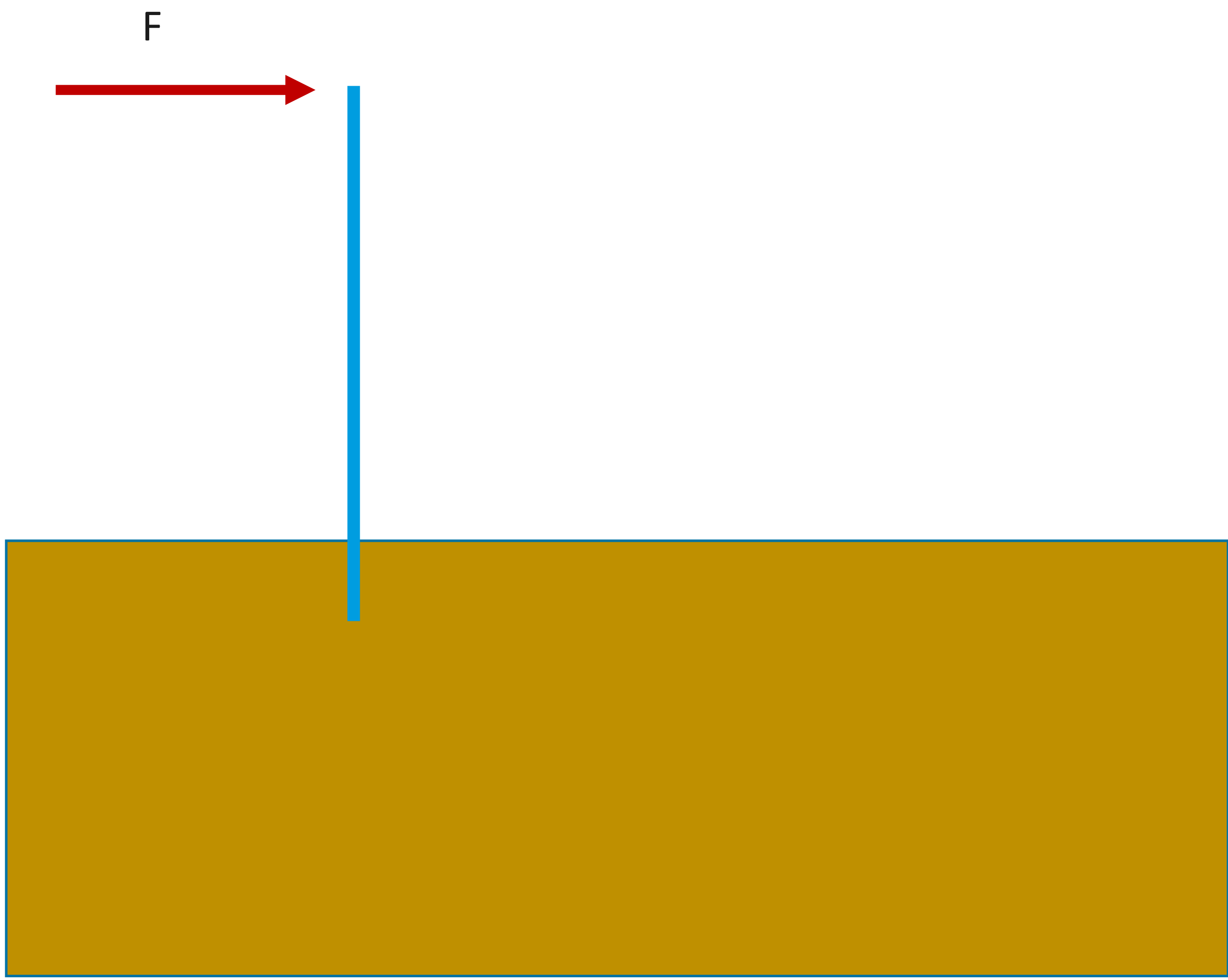
What is a flexible dolphin?

- Horizontally loaded flexible dolphin.



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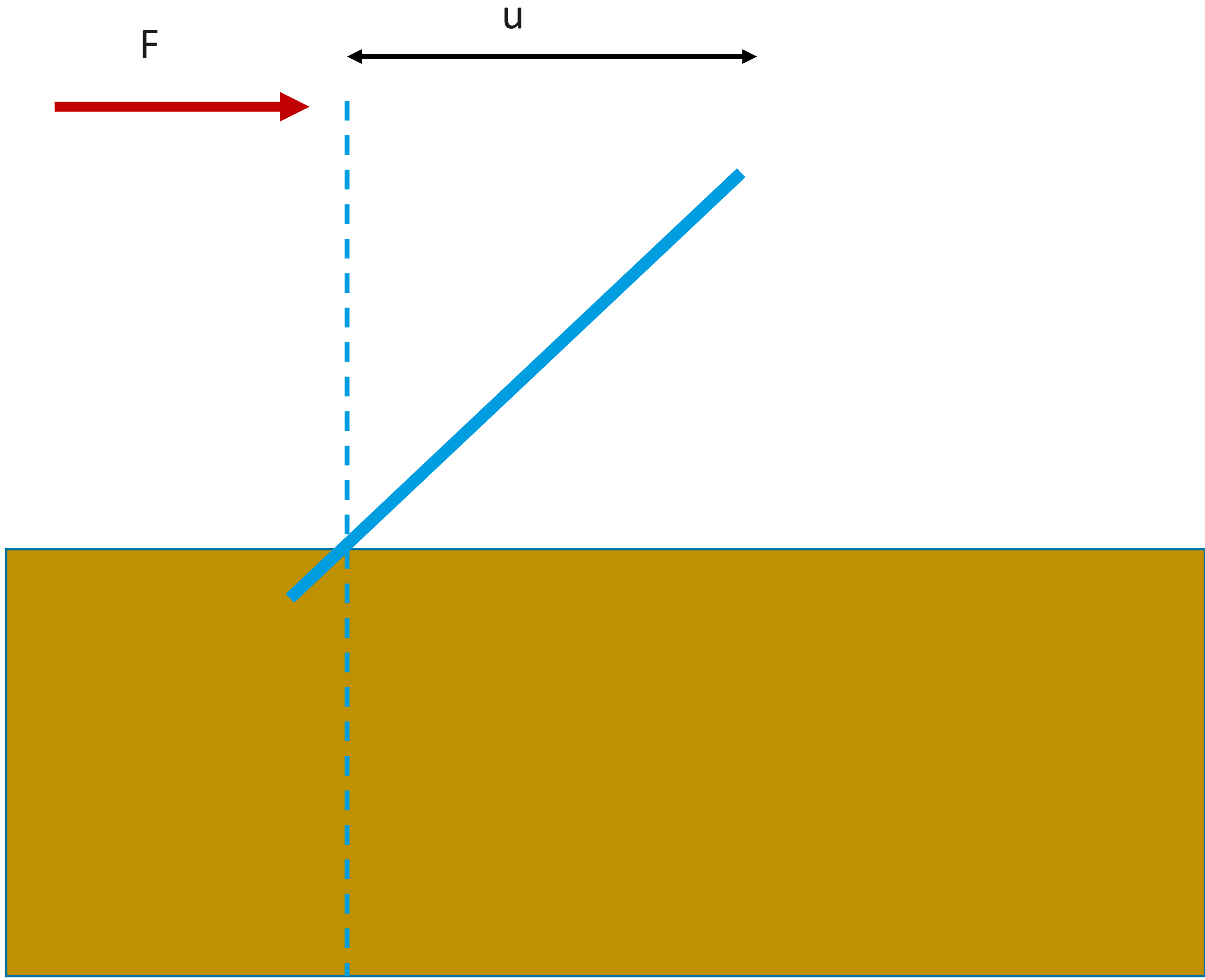

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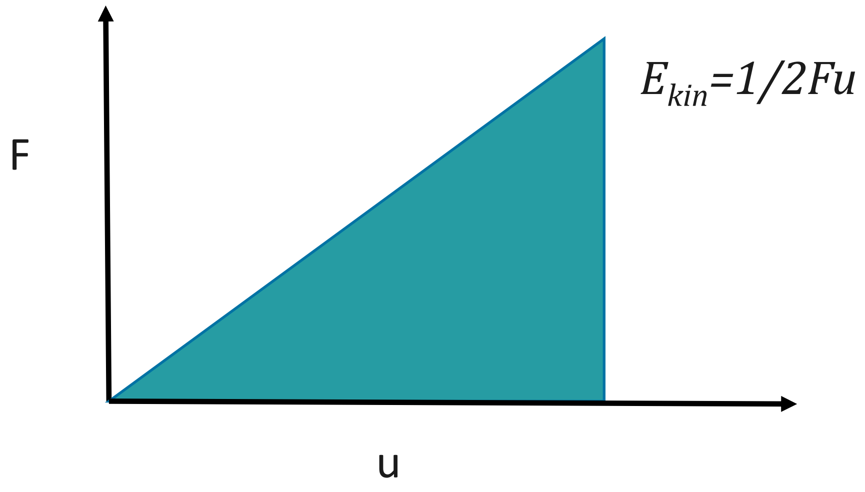
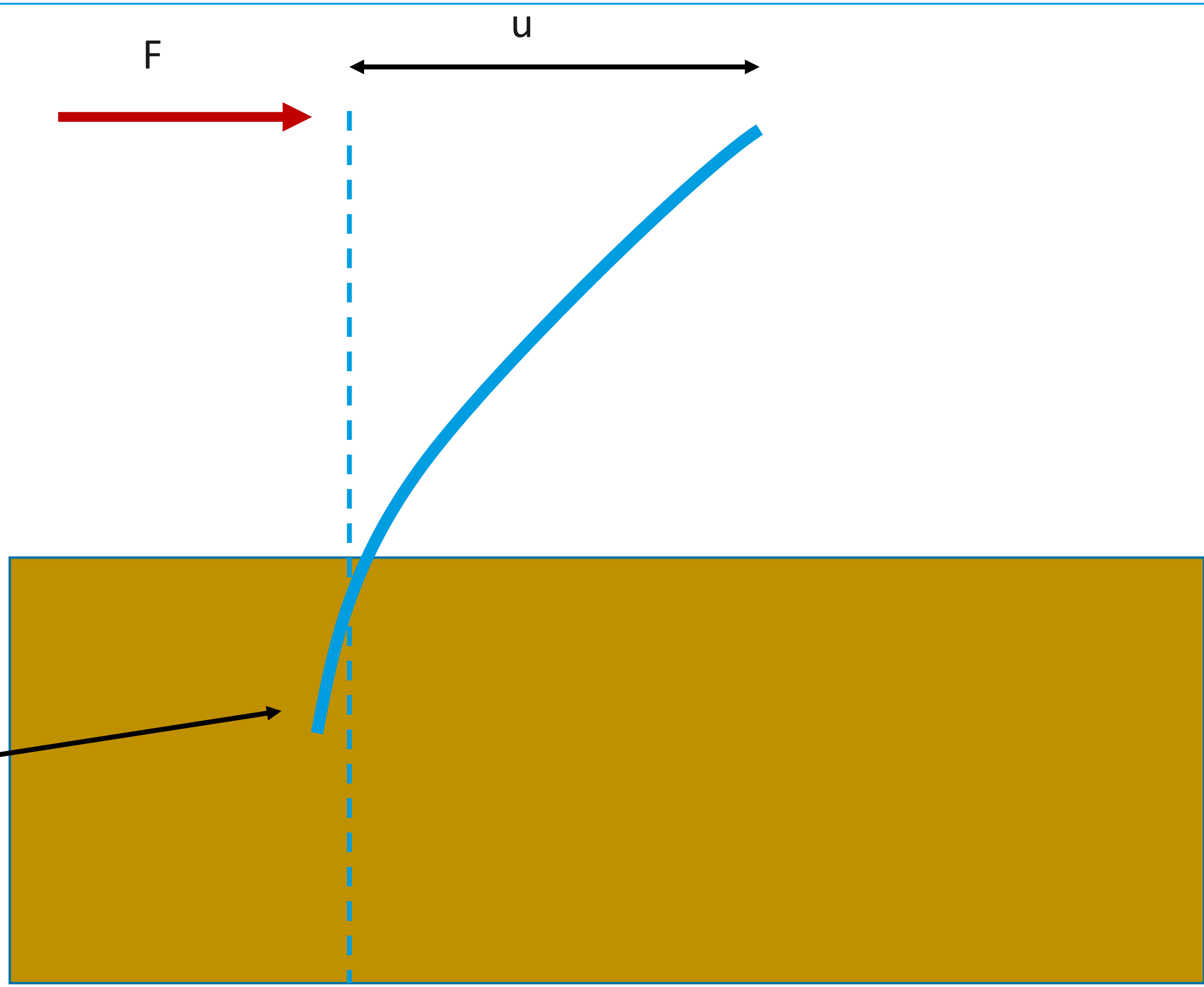


When a dolphin pile is too short, this results in (permanent) displacement of the pile toe and this displacement contributes to absorbing berthing energy.



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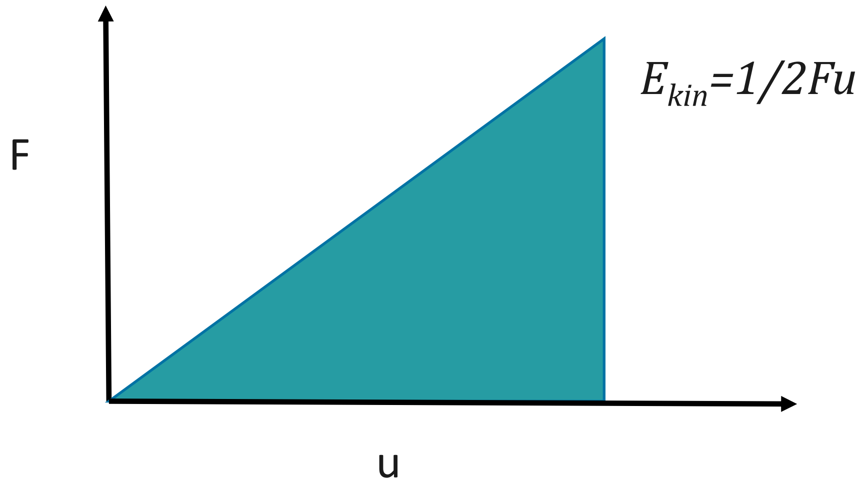
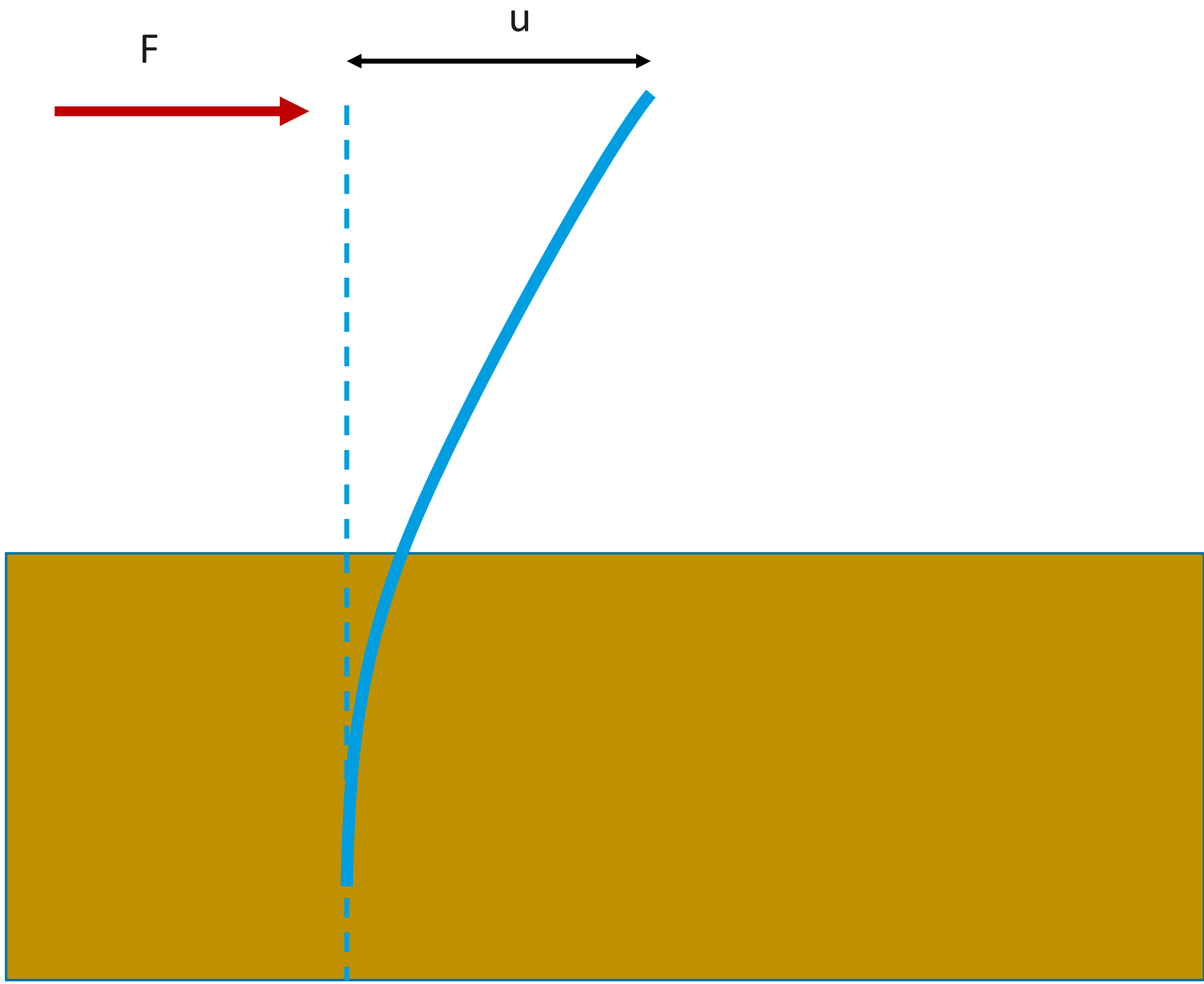
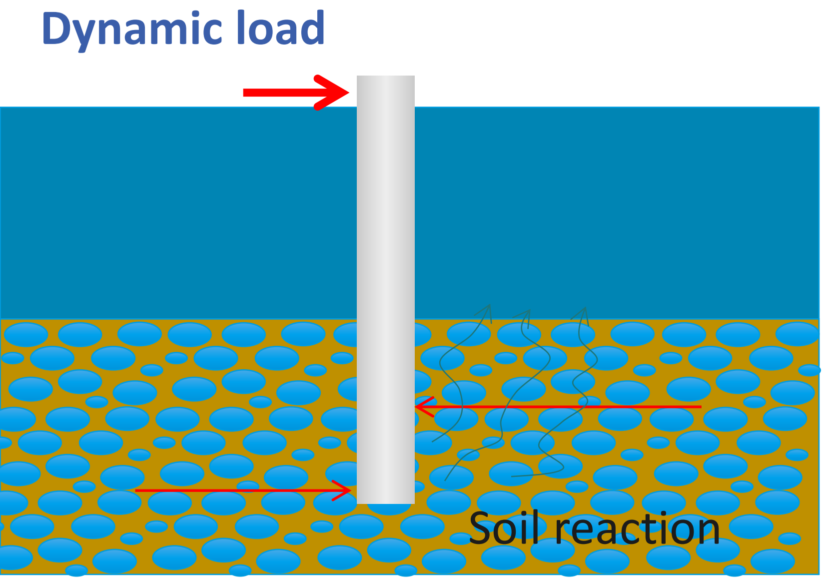
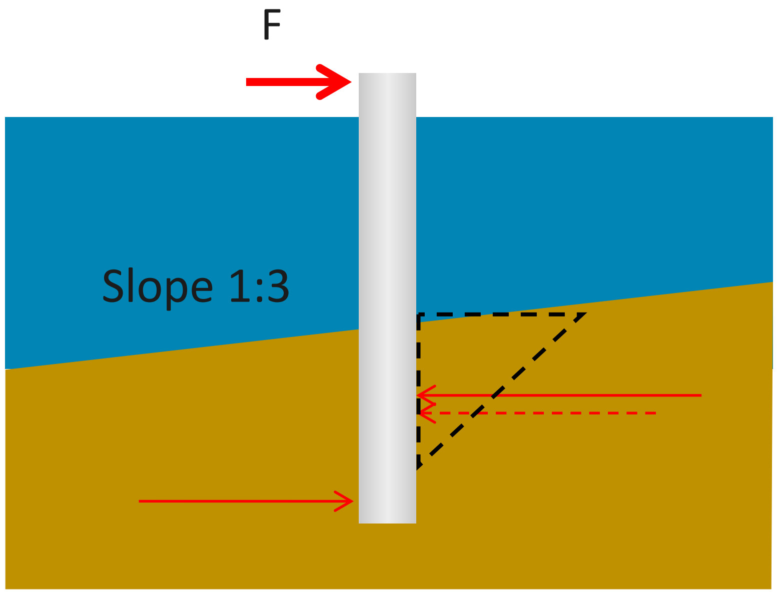


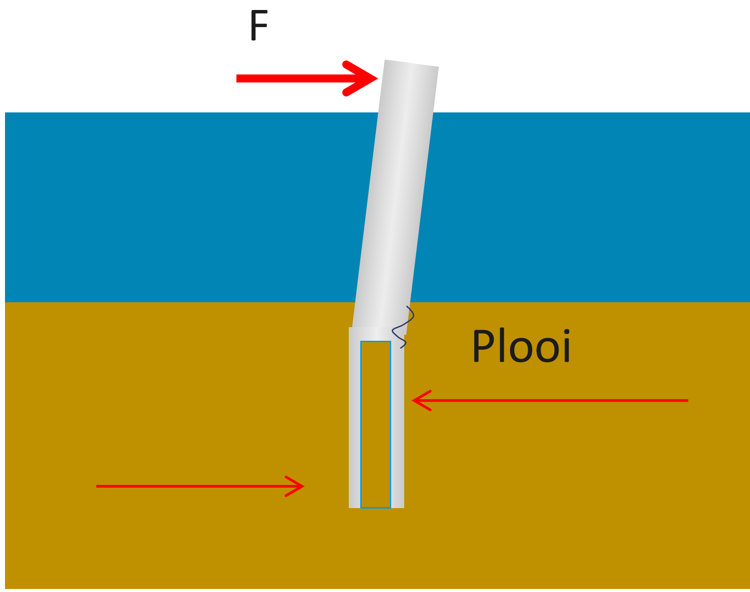


What is a flexible dolphin?

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

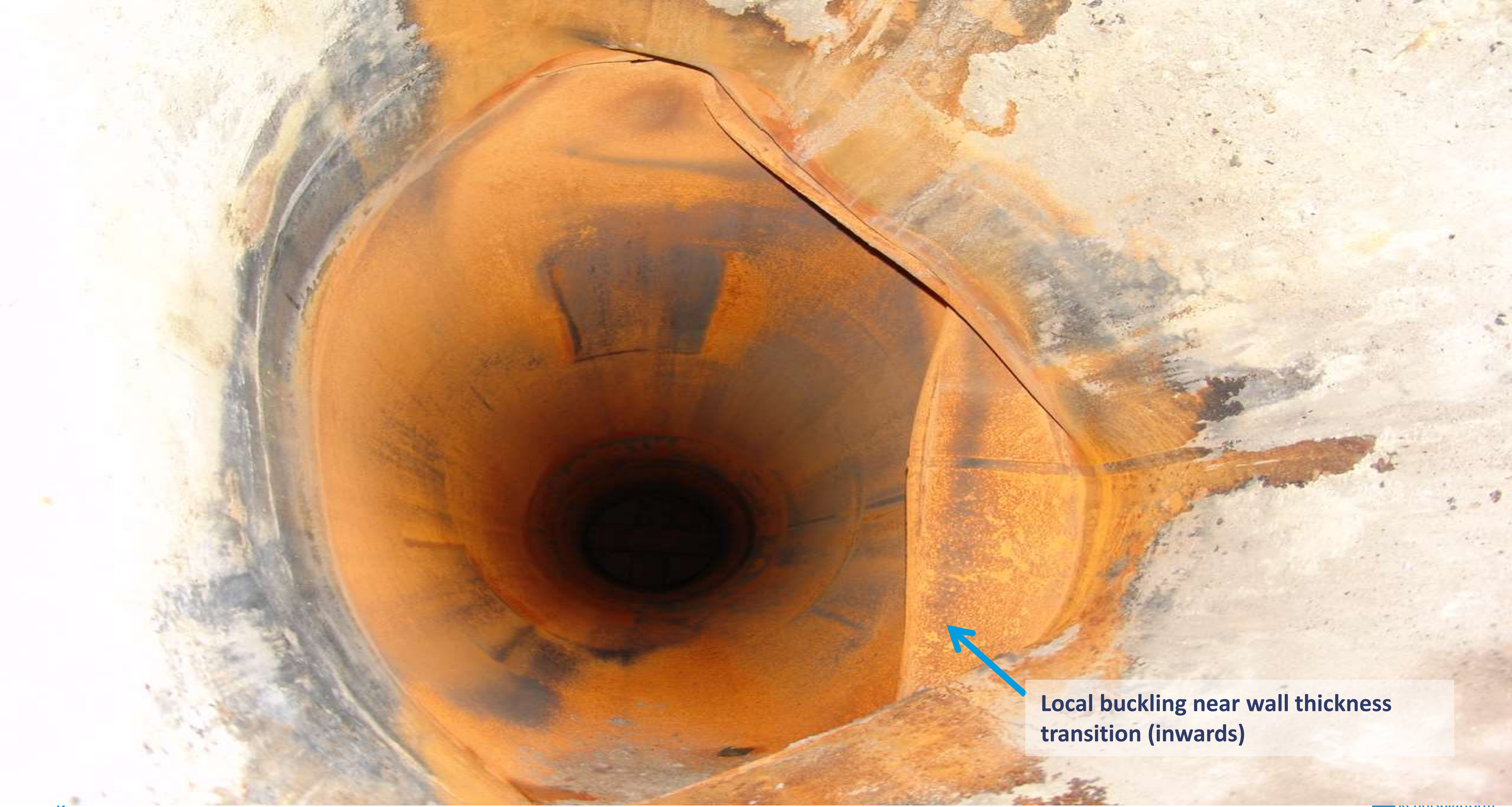




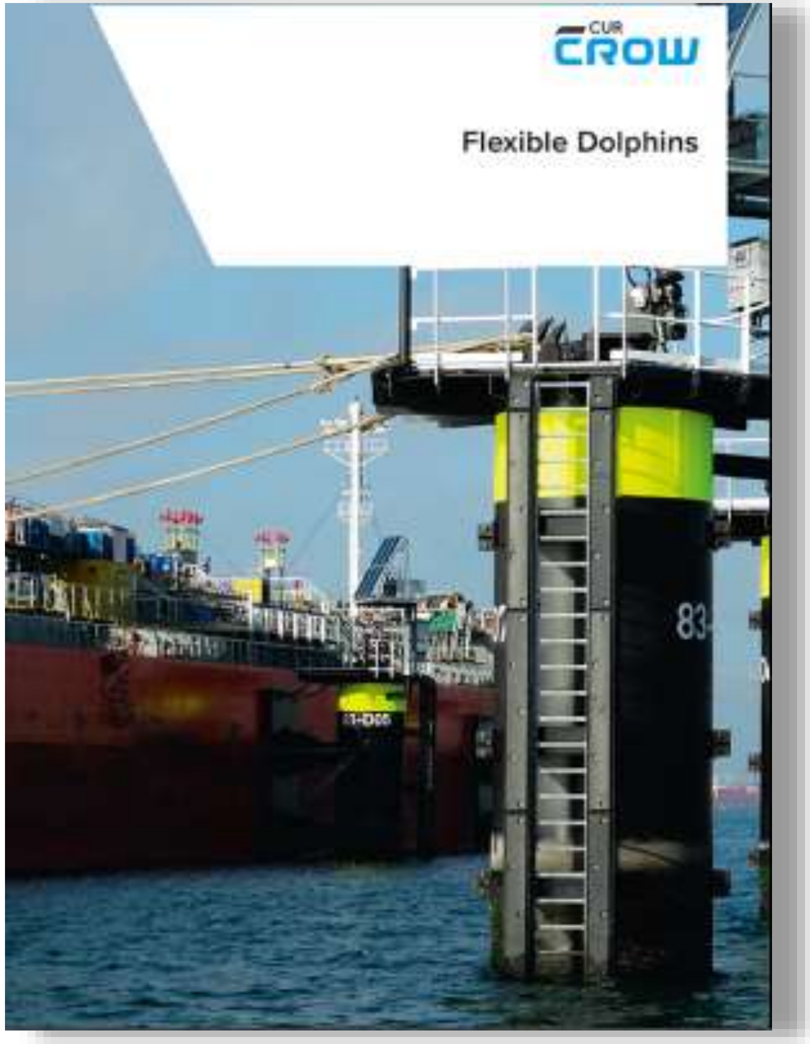


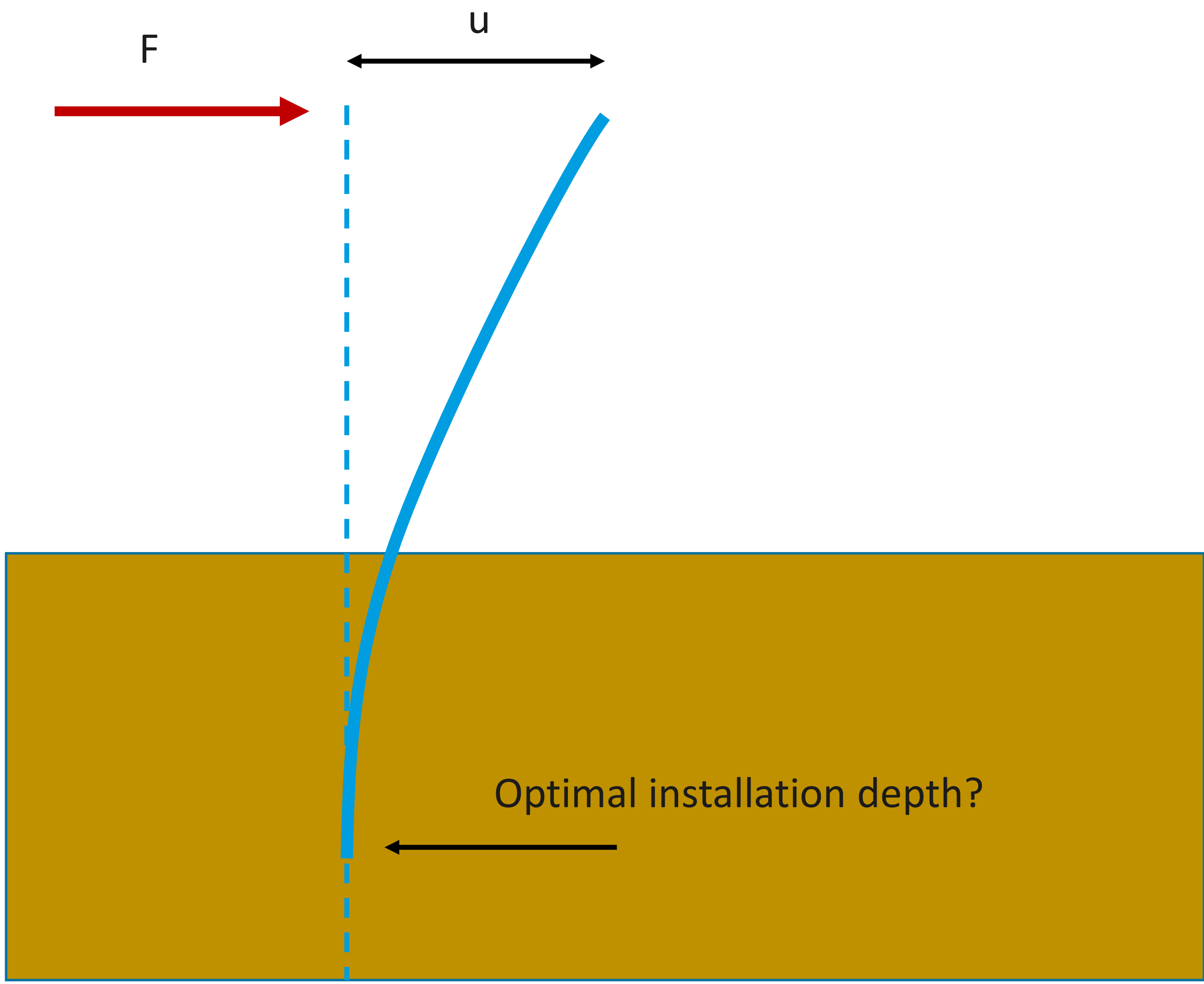

Local buckling empty tube (inwards)


Local buckling sand filled tube (outwards)


Local buckling near wall thickness
transition (inwards)


First CROW design guideline in 2017



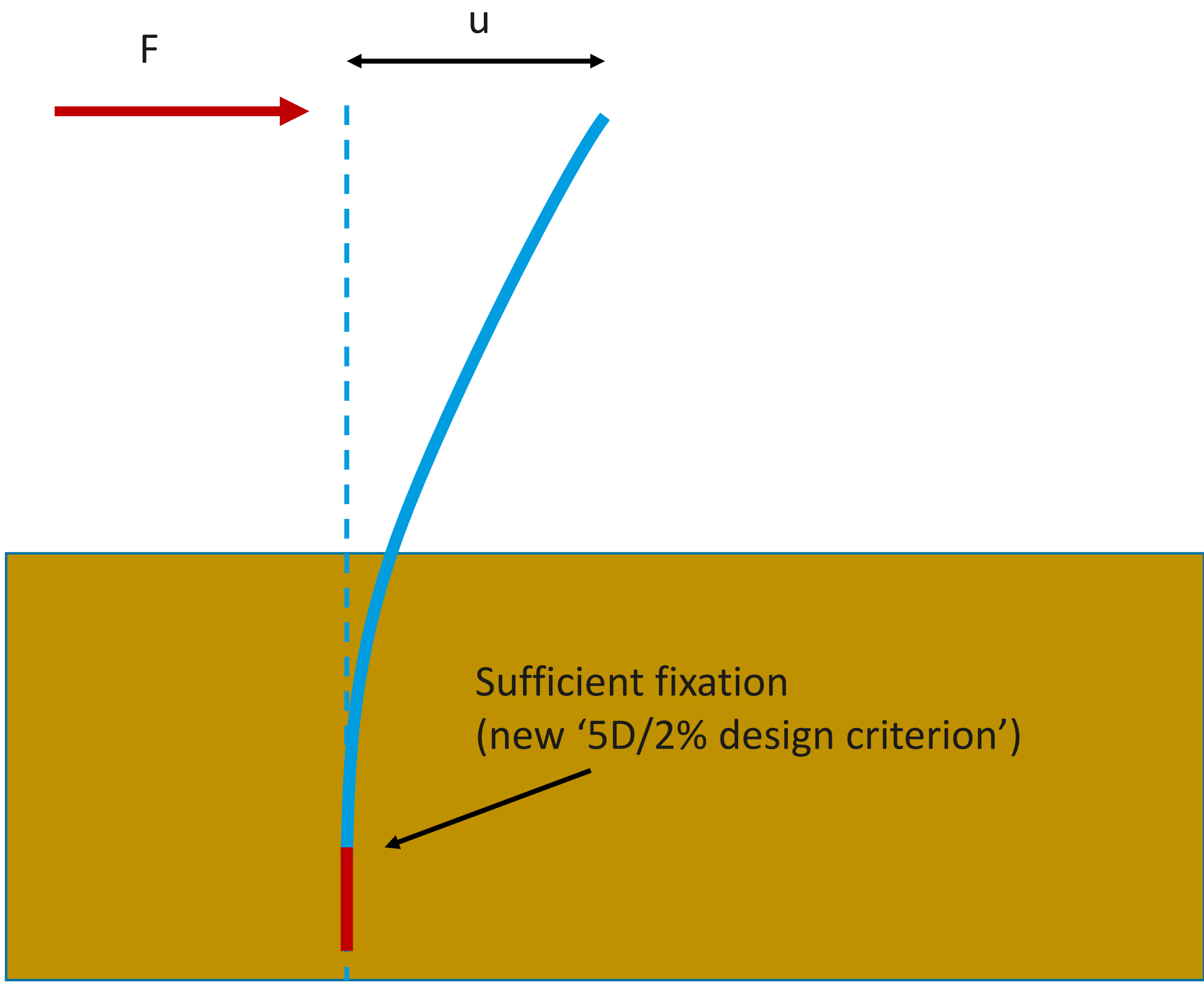


How to determine sufficient soil fixation?

- New method included in CROW 2017 design guideline : Displacement of the pile head should be lower than 2% compared to an infinite long pile, which is modelled as a 5D longer pile.

This criterion resulted in big discussions:

- Why 2% and not 5%?
- Consequence 10m longer piles
- In Rotterdam generally 2 - 6m longer piles.

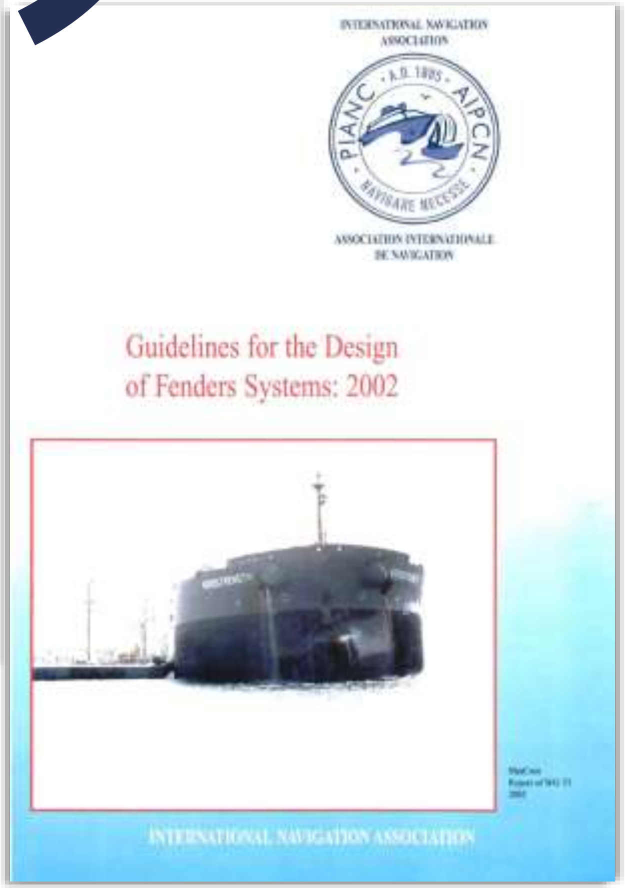


Revised CROW Flexible Dolphins in 2024

- Berhting energy and mooring loads
- Fixation and repetitive loads
- Local buckling
- Design approach
- Lessons learned (beyond scope of this presentation)

Berthing energy & mooring loads

- New guideline for fender design (PIANC WG211, 2024)



CROW 2017 (PIANC WG33): Global safety factor	CROW 2024 (PIANC WG211): Load and resistance factor
Determine normal energy $E_d = \frac{1}{2} M V_B^2 C_e C_m C_s C_c$ Determine abnormal energy $E_{ab} = C_{ab} E_d$ Capacity of selected fender $E_f = \frac{E_{RPD}}{F_{TOL} F_{ANG} F_{TEM} F_{VEL}}$ Limit state verification selected fender $E_f \geq E_{ab}$	Determine characteristic energy $E_{k,c} = \frac{1}{2} M_c V_{B,c}^2 C_{e,c} C_{m,c}$ Design energy: 8-step approach for γ_E $E_{k,d} = \gamma_E \, E_{k,c}$ Design capacity of selected fender $E_{f,c} = E_{base} \, C_{ang,c} \, C_{t,c} \, C_{v,c} \, C_{mult,c}$ $C_{mult} = \frac{E_{f,system}}{E_{base}} = \frac{\sum_{i=1}^{n_f} E_{f_i}}{E_{base}}$ $E_{f,d} = \frac{E_{f,c}}{\gamma_m}$ Limit state verification selected fender $E_{f,d} \geq E_{k,d}$

Berthing velocity

- **Reliability of berthing velocity dominates uncertainty in calculating berthing energy for 85% (Ueda et al., 2010)**

$$E_{kin} = {}^{1}/_{2}\, M v^{2}\, C_m C_s C_c C_E$$

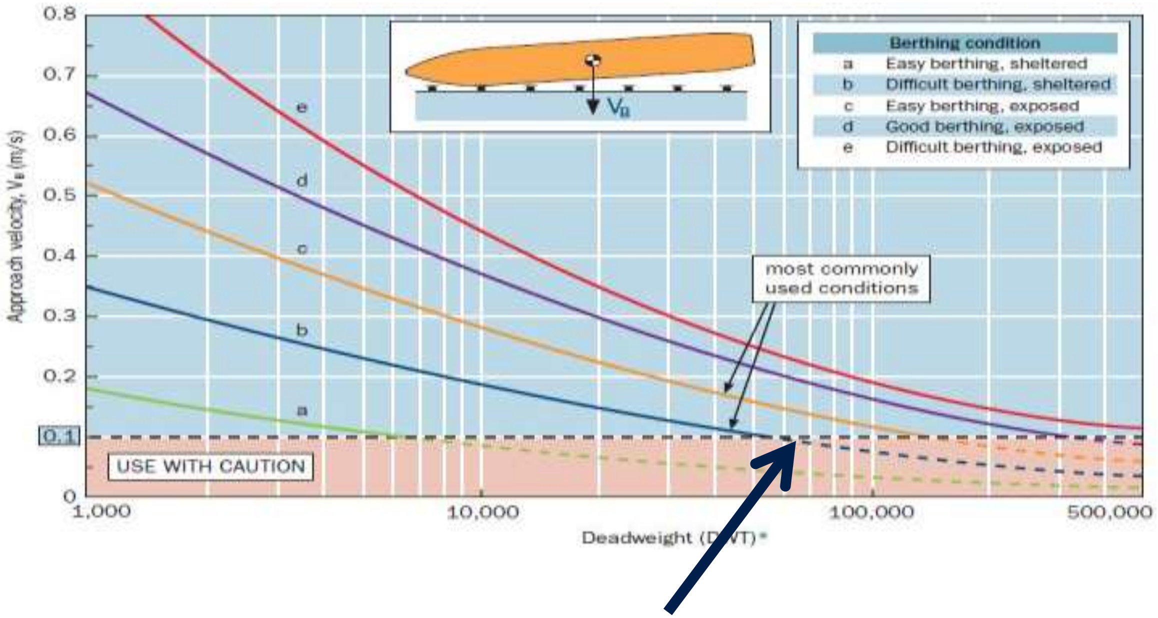
in which:

E_{kin}	Kinetic energy [kNm]
M	Mass of vessel/water displacement [tonnes]
v	Total translation velocity of centre of mass at time of first contact [m/s]
C_m	Virtual mass factor [-]
C_s	Ship flexibility factor [-]
C_c	Waterfront structure attenuation factor [-]
C_E	Eccentricity factor [-]

Berthing velocity

- PIANC 2002 (Guidelines for the Design of Fender Systems) is widely accepted in the industry.
- Berthing velocity curves and berthing angles are based on research conducted in 1972, (Brolsma et al, 1977)

Absorb ship’s berthing energy and reduce berthing impact force



Strong negative correlation

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Data collection PIANC WG145

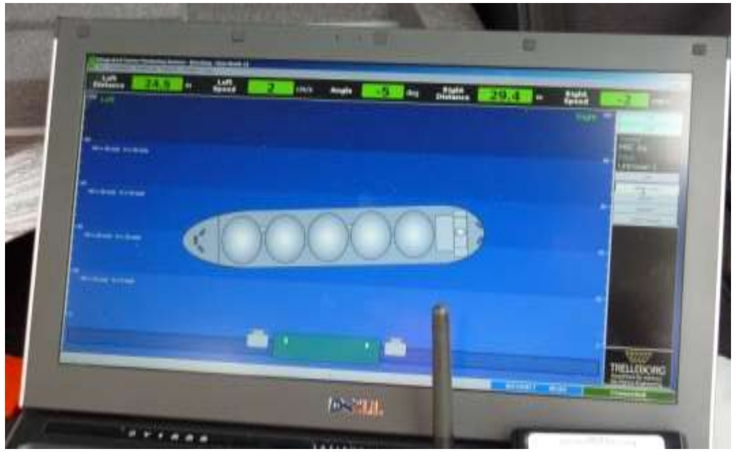
Methods used to collect data:

- Interviews/questionnaires
- Laser docking aid systems
- Portable Pilot Units (PPU)
- Smart dock portable workstation

Vessel Type	Number of ports	Number of collected data	Number of data for vessels > 30,000 DWT
Bulk	2	243	243
Container	8	1644	1068
LNG	1	70	70
Oil tanker	3	486	472
Total	14	2443	1853

Measurements Maasvlakte Rotterdam

Container berths   Tanker berths   Bulker berths



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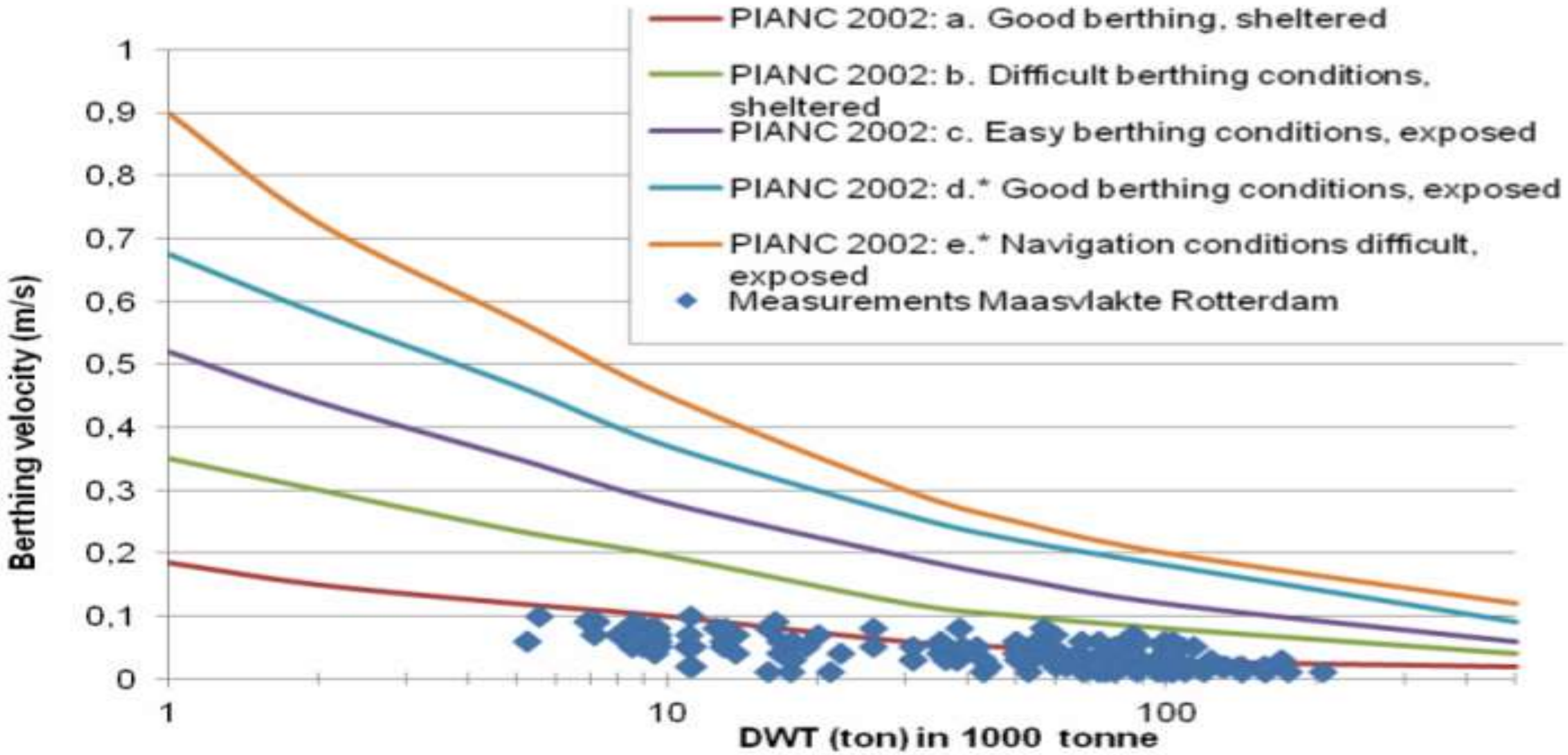
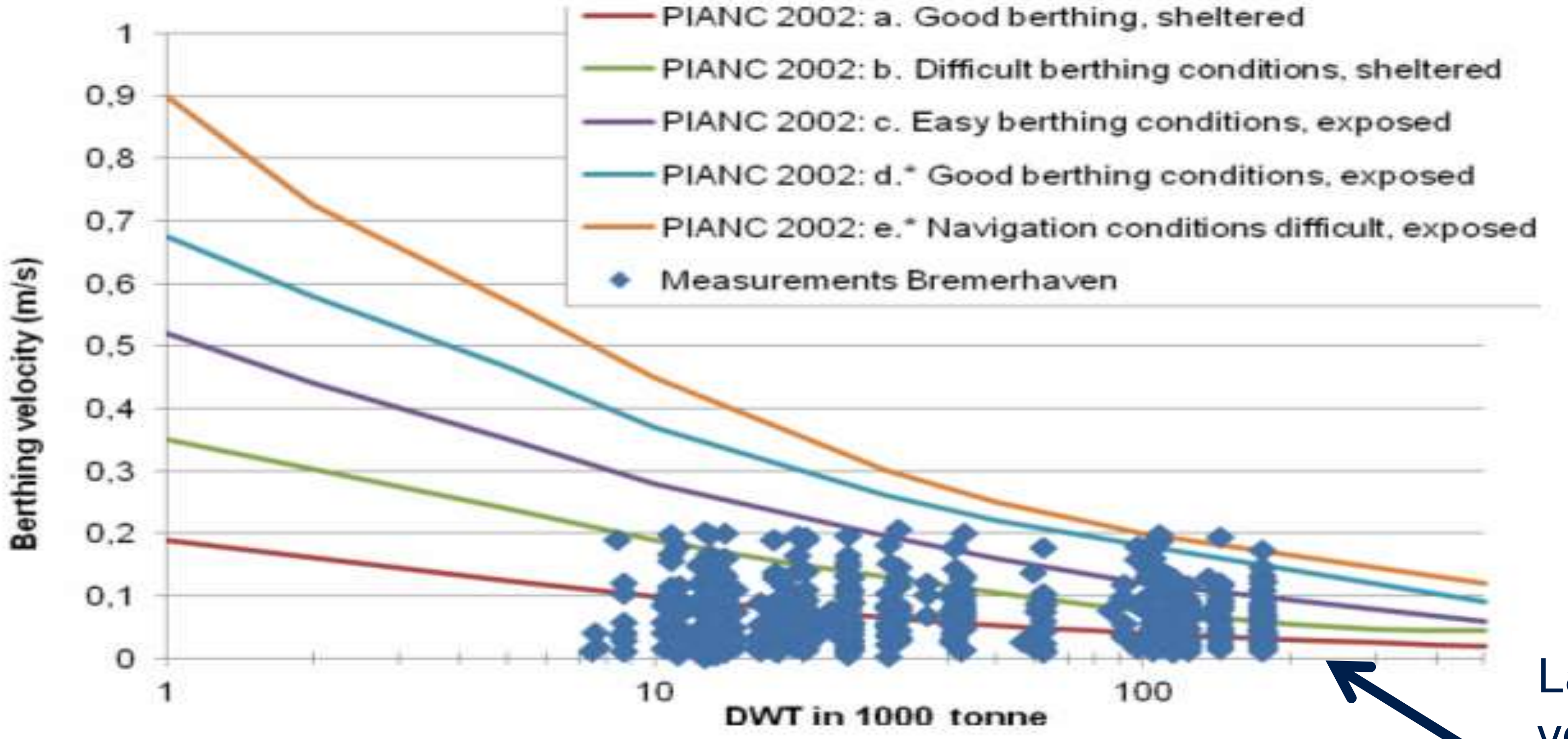
Measurements Rotterdam (Container vessels)



- Sheltered conditions
- Parallel landing
- Mean 3-4 cm/s
- Max 10 cm/s
- Low berthing angle
- 3 months of data

Measurements Bremerhaven (Container vessels)



- High tidal current
- Angular landing
- Mean 5-6 cm/s
- Max 20 cm/s (2013)
- Max 26 cm/s (2018)
- Very low berthing angle
- 8 years of data

Large variation in berthing velocity

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Recommendations in PIANC WG211 for velocities [cm/s]

- PIANC WG211 recommends to use site-specific information e.g.

a) berthing records/field observations,

b) insights from pilots/masters,

c) global company records,

d) speed limits,

e) operational limits,

f) past service performance.

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Navigation Condition:	Favourable	Moderate	Unfavourable
Type of Vessel[a]	V_{Bc} (m/s)		
Coaster	0.180[f]	0.300[e]	0.400[e]
Feeder, Handysize	0.150[b]	0.225[c]	0.300[d]
Handymax, Panamax	0.120[b]	0.200[c,g]	0.275[d]
Vehicle Carriers	0.120[e]	0.200[e]	0.275[e]
Post Panamax, Capesize (small), Aframax	0.100[b,e]	0.175[c]	0.275[d]
New Panamax, Capesize (large), Suezmax, ULCV, VLBC, VLCC, ULCC	0.100[b,e]	0.150[c,f]	0.250[d]
Cruise & Passenger Vessels	0.100[e]	0.150[e,f]	0.250[e]

a. Typical vessel dimensions: Coaster (5,000-15,000 DWT), Feeder, Handysize (15,000-42,000 DWT); Panamax, Handymax (42,000-85,000 DWT); Post Panamax, Capesize, Aframax (85,000-115,000 DWT); New Panamax, Capesize, Suezmax (115,000-170,000 DWT); ULCV, VLBC, VLCC, ULCC (>170,000 DWT). For vessels not listed in the table (e.g. LNG) use equivalent size. Although most gas tanker owners have their own global data set.
b. These recommended berthing velocities are largely based on field measurements in Rotterdam and Wilhelmshaven, (PIANC WG145, 2022), (Roubos, Gaal, Hein, Iversen, & Williams, 2022).
c. These recommended berthing velocities are largely based on the normal navigation conditions distinguished by PIANC WG 145 (PIANC WG145, 2022) and verified by WG 211 against new data sets from Poland, Korea, US and India.
d. These recommended berthing velocities are largely based on the measurements conducted in Bremerhaven, (PIANC WG145, 2022), (Roubos, Gaal, Hein, Iversen, & Williams, 2022).
e. These recommended berthing velocities are based on interviews with masters, pilots, harbour masters and experienced port engineers. The values are based on comparison with similar vessel sizes.
f. These recommended berthing velocities are based on EAU 2012 and ROM 2.0-11 (2012).
g. Some unpublished berthing records, of berths claiming to be moderate, include slightly higher velocities. BS6349 and WG 211 consider this value to be sufficient for the majority of berths.

- **In the absence of site-specific information** Table 5.3 of PIANC WG211 provides recommendations for characteristic berthing velocity.

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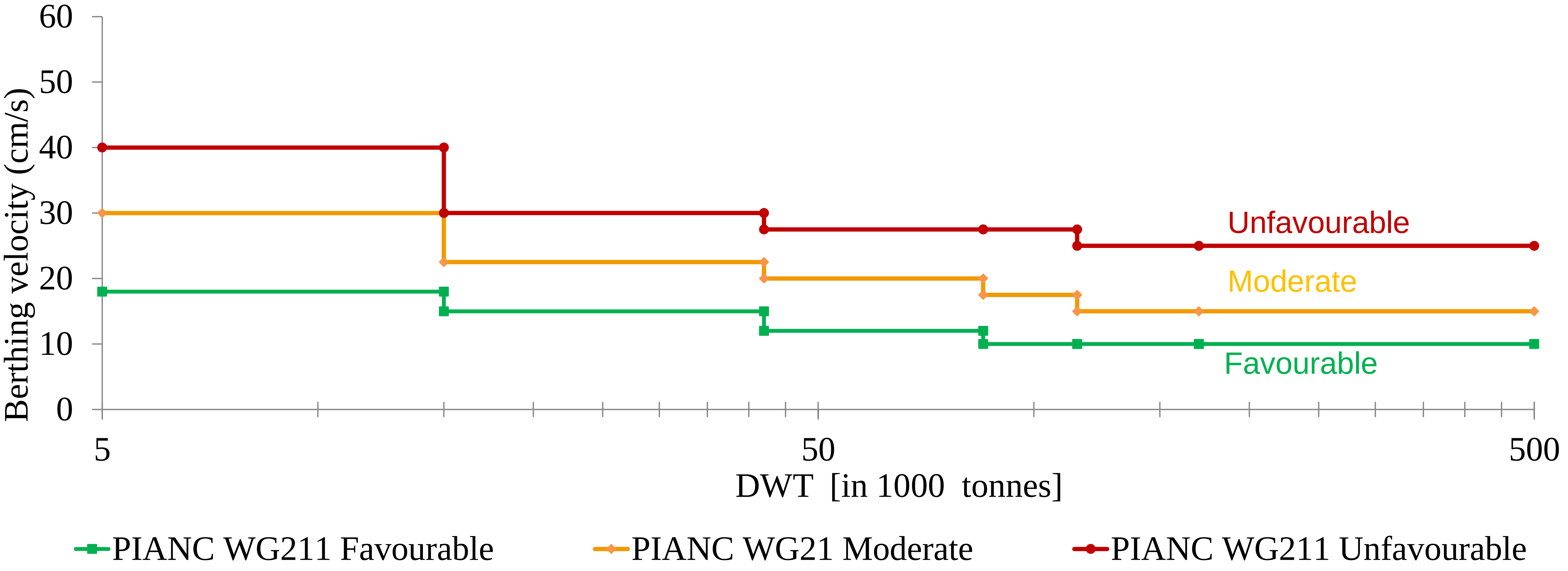
Visualisation Table 5-3 PIANC WG211



Dirk-Jan Jaspers Focks (Witteveen+Bos)

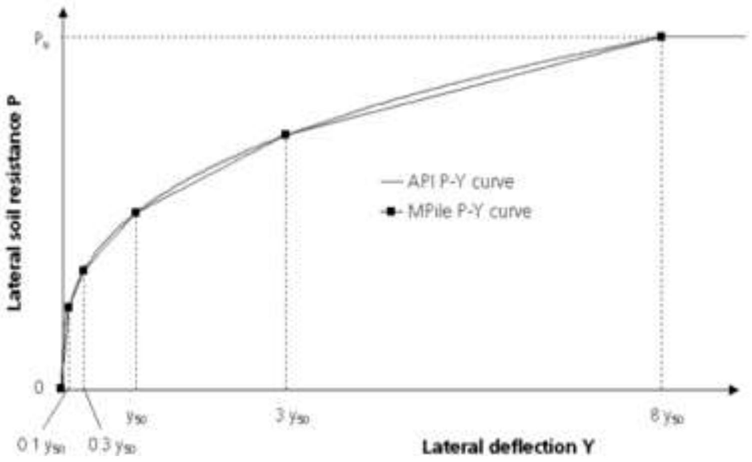
- Geotechnical Engineer (18 years) at Witteveen+Bos
- Involved in >100 designs of maritime structures
- Lecturer PAO (2010-present)
- Co-author of CUR/CROW publications: Handbook Quay Walls, Hydraulic Fill manual, Flexible Dolphins
- Member of several national committees (NEN, CUR and CROW)

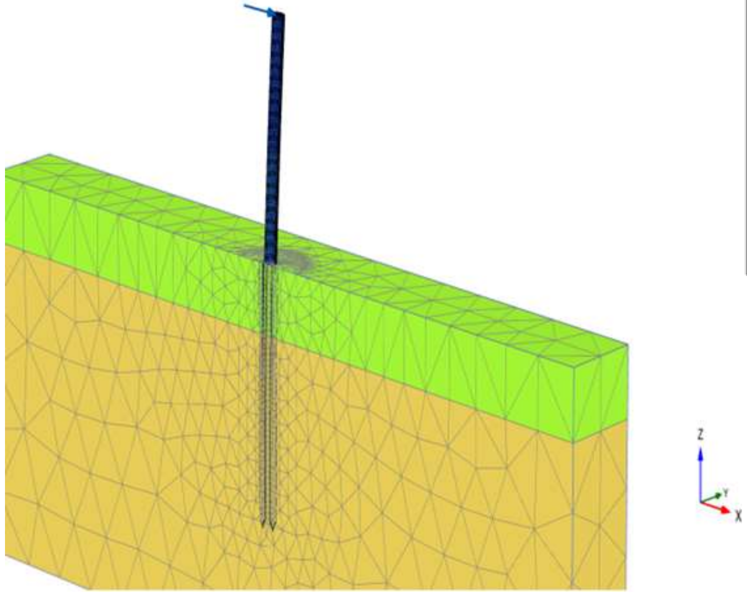
Modelling tools dolphins

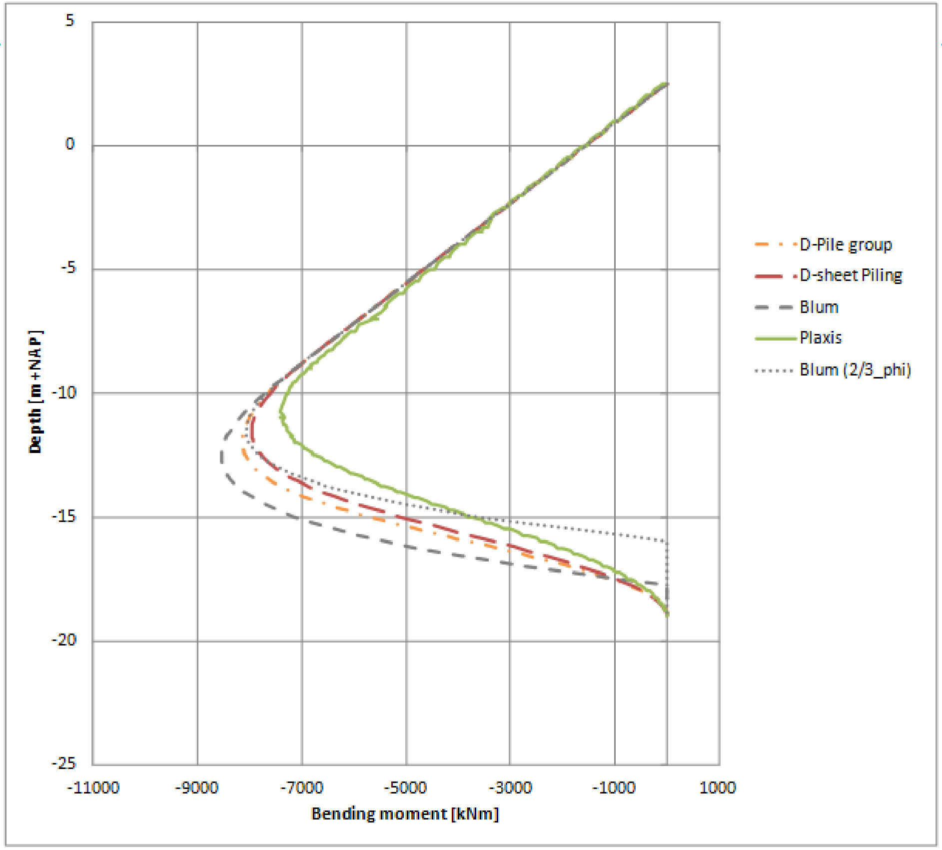
Various models available:

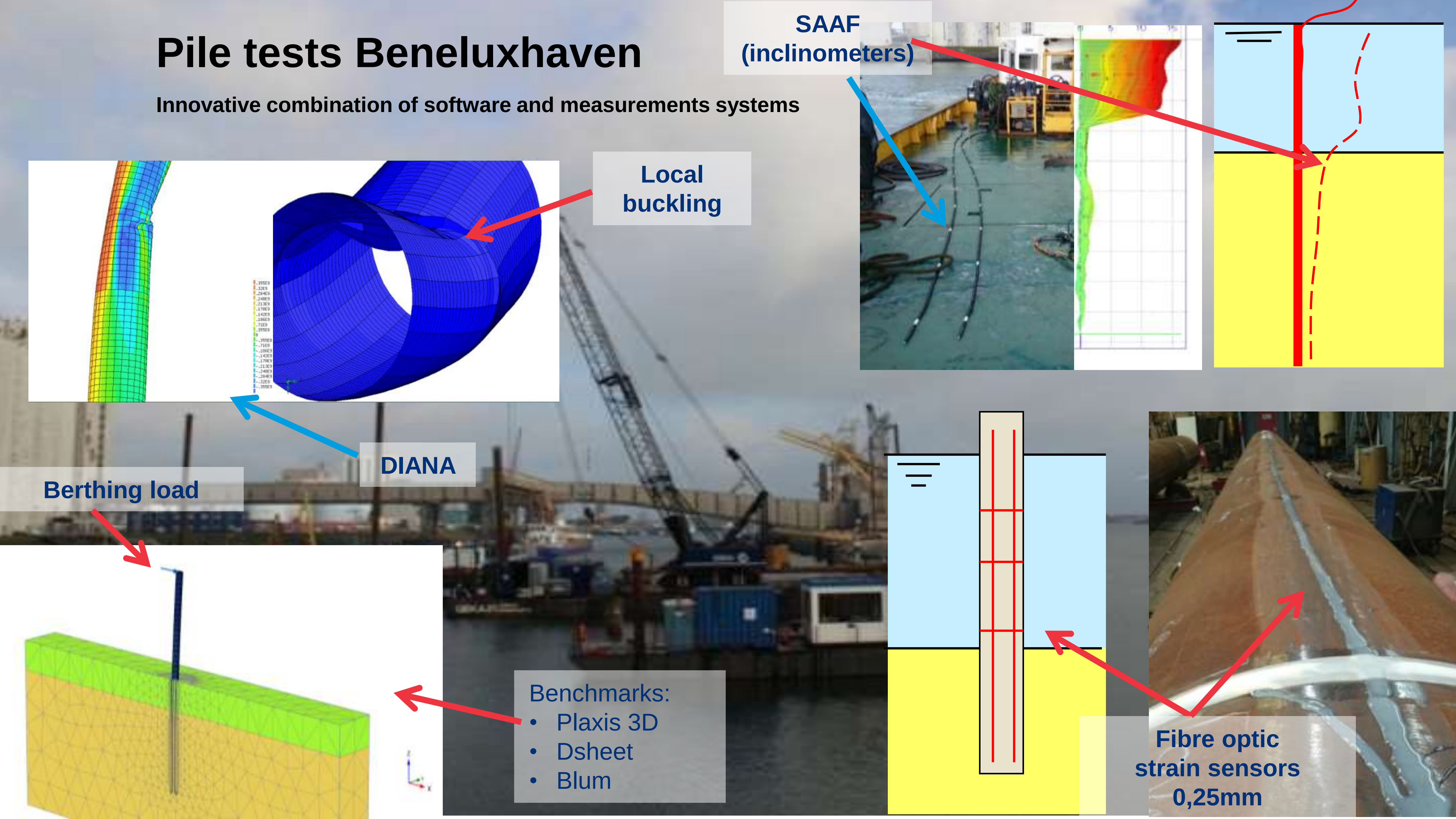
- Force-equilibrium
- Elasto-plastic spring-models
- Finite Element Method (FEM)

with significant differences in outcome



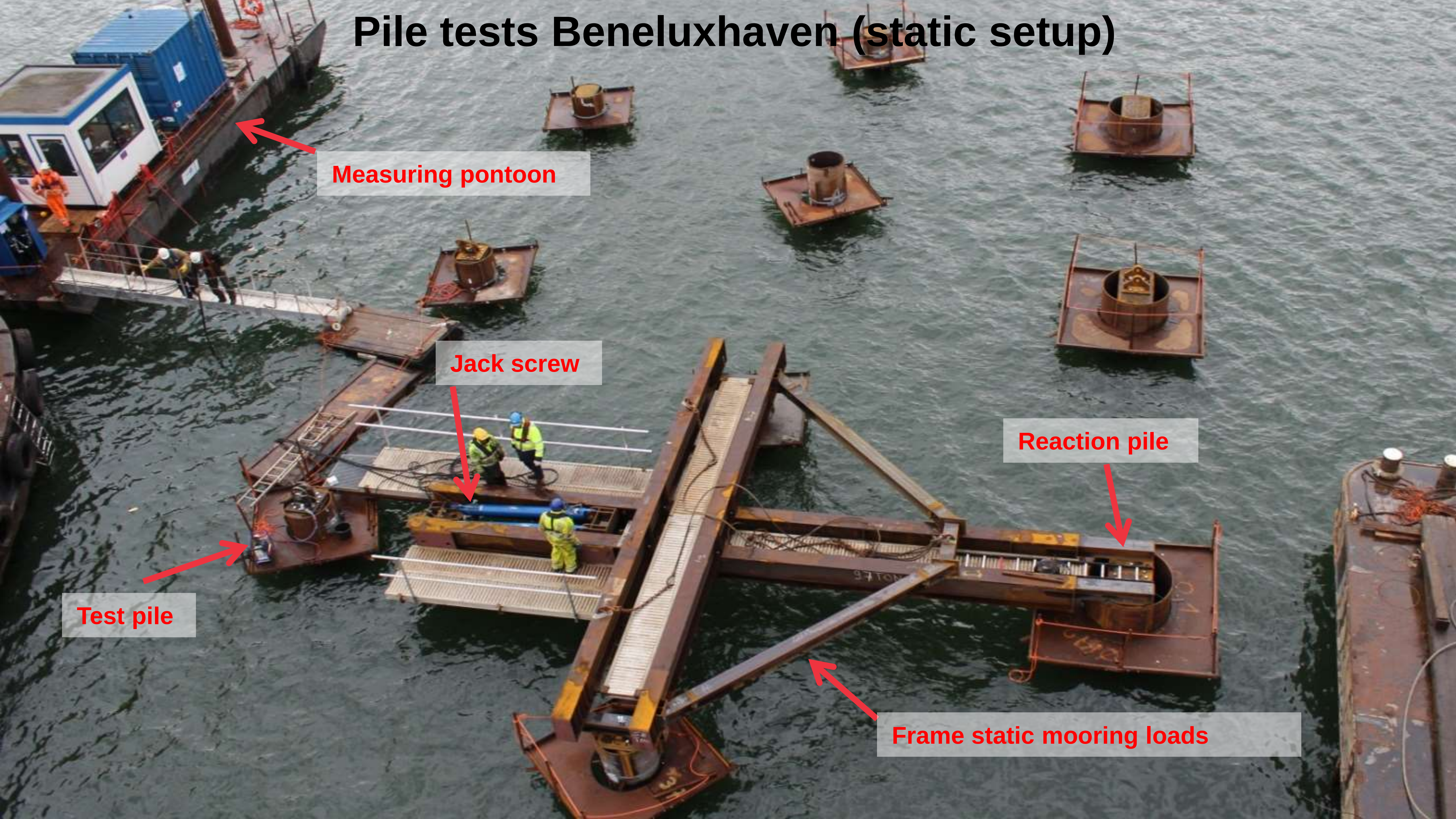




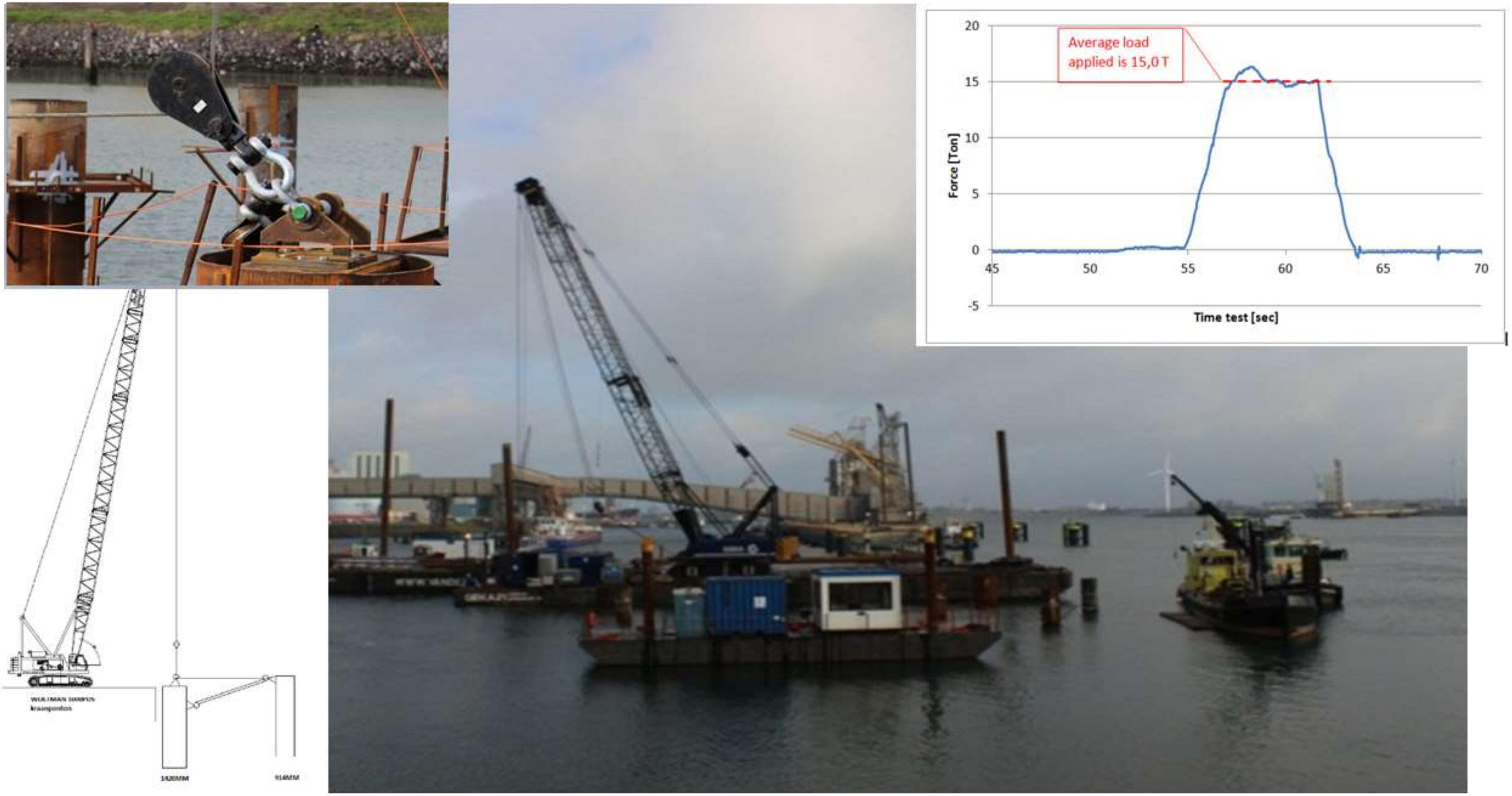


Pile tests Beneluxhaven
Innovative combination of software and measurements systems
SAAF
(inclinometers)
Local
buckling
DIANA
Berthing load
Benchmarks:
• Plaxis 3D
• Dsheet
• Blum
Fibre optic
strain sensors
0,25mm

Pile tests Beneluxhaven (static setup)



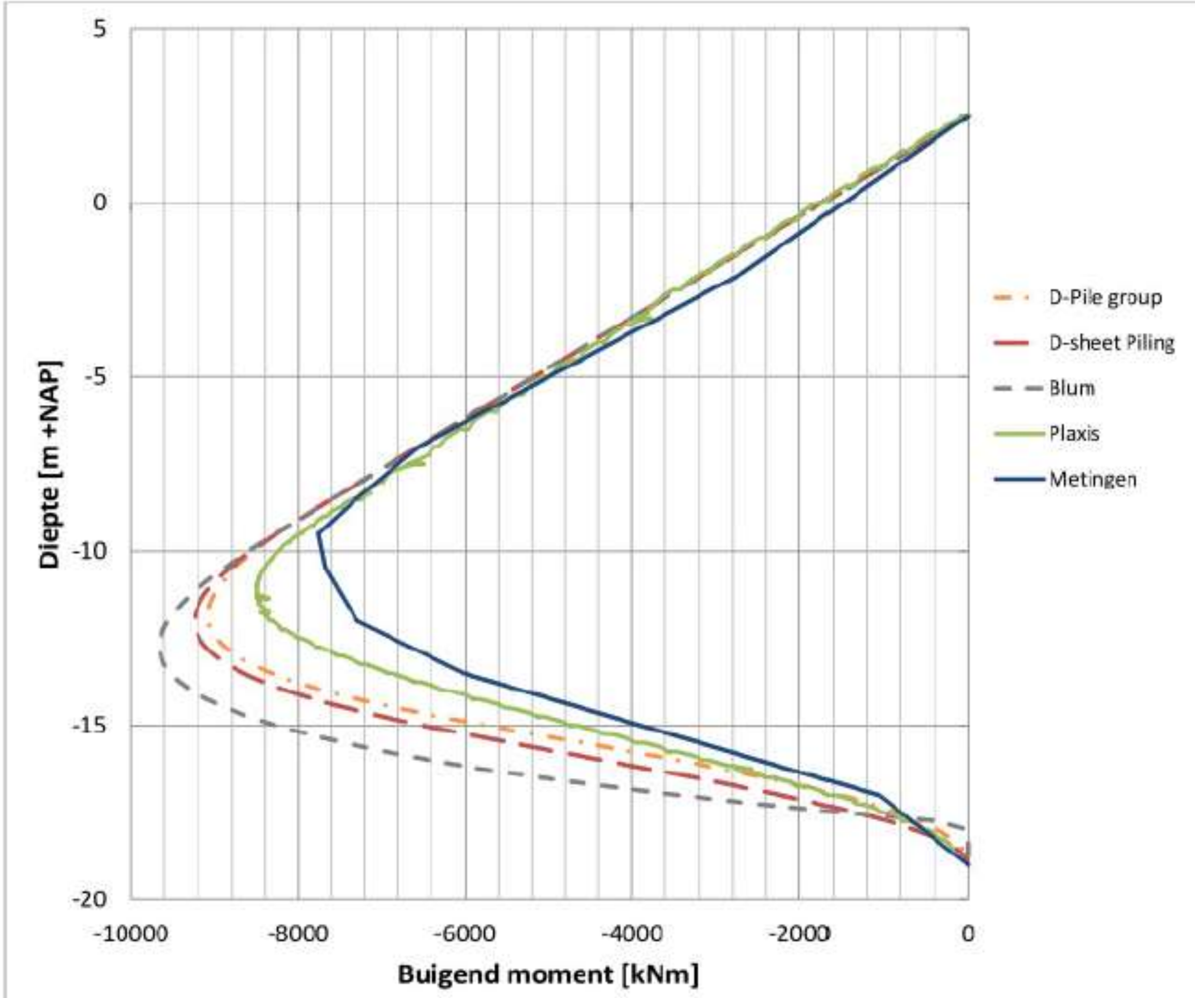
Pile tests Beneluxhaven (“dynamic” setup)



Pile tests Beneluxhaven: Results

Main takeaways:

- Significant differences in results
- Advanced models provided best results
- Most models are allowed, but some specific exceptions

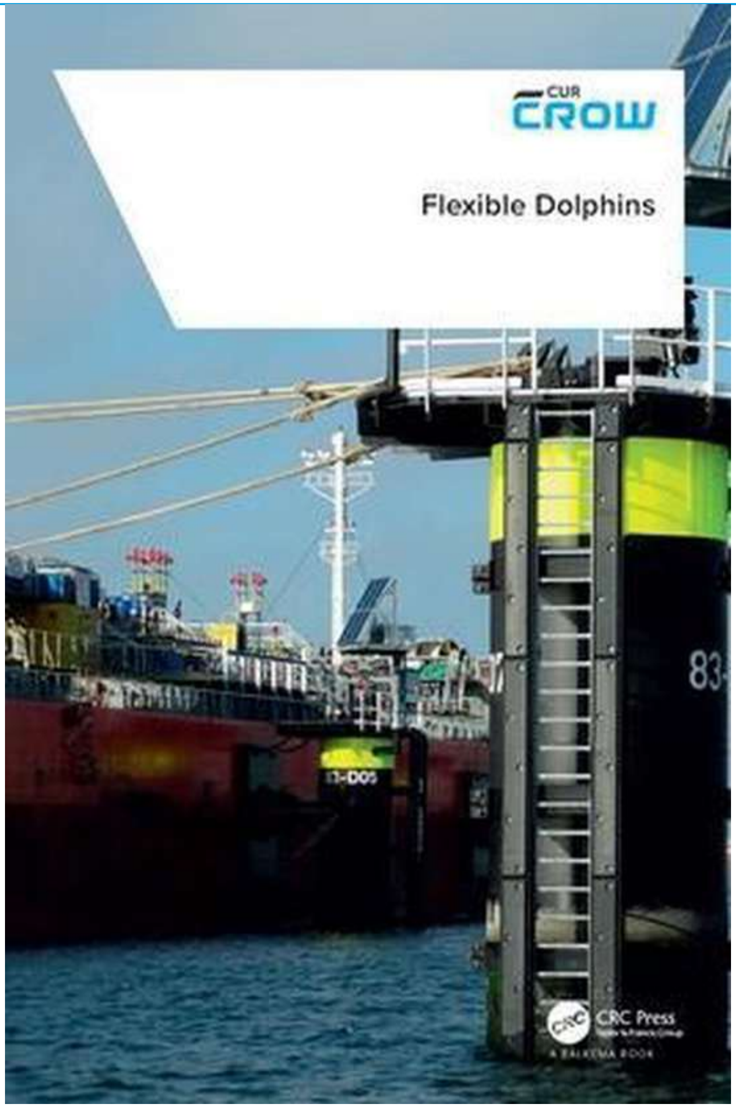


Tests in Beneluxhaven

Beneluxhaven (2015) tests formed the basis of:

- Selection on applicable design models
- Their limitations and advantages
- Local buckling criteria

Included in first edition Handbook Flexible Dolphins

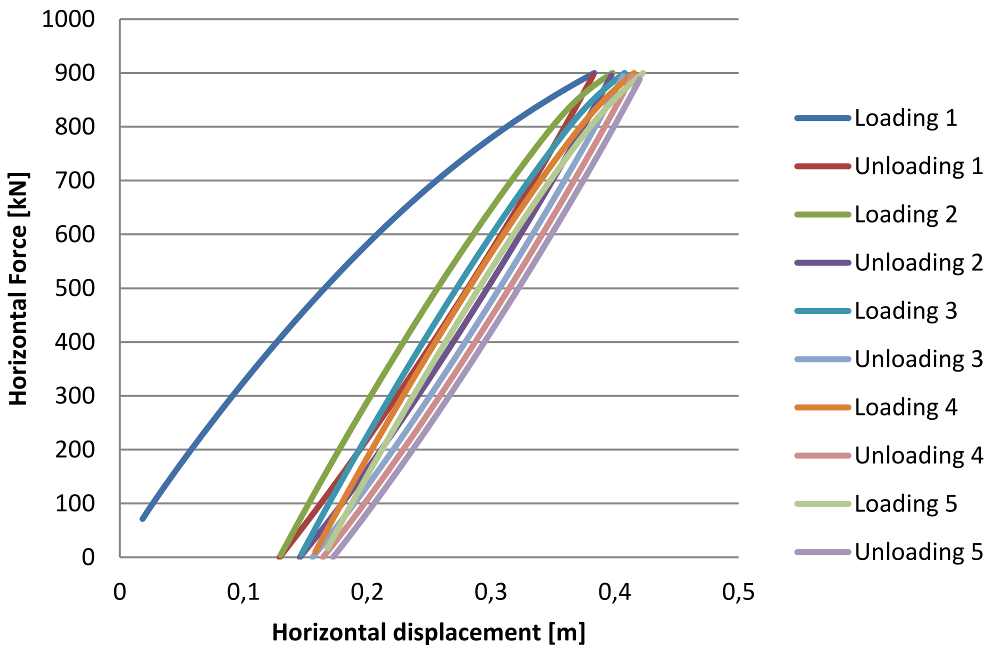


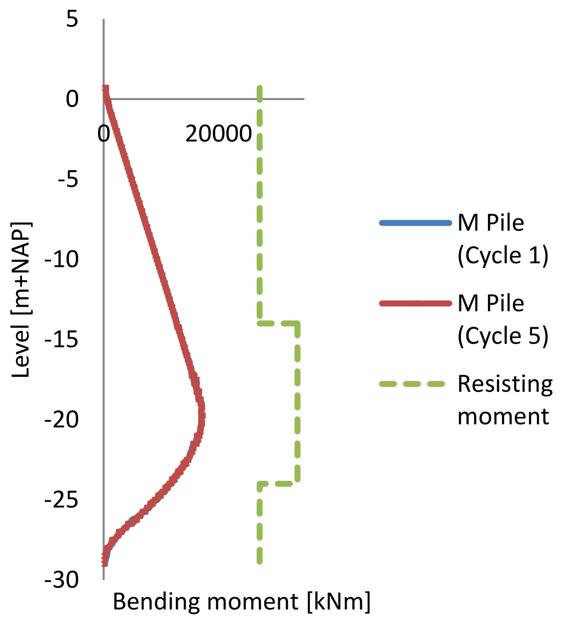
Tests in Beneluxhaven

But in Beneluxhaven:

- Repetitive loading was not tested
- Pile fixity (in relation to pile length) was not tested

Benchmarks in CROW showed effect of repetitive loading





Full scale tests Calandkanaal

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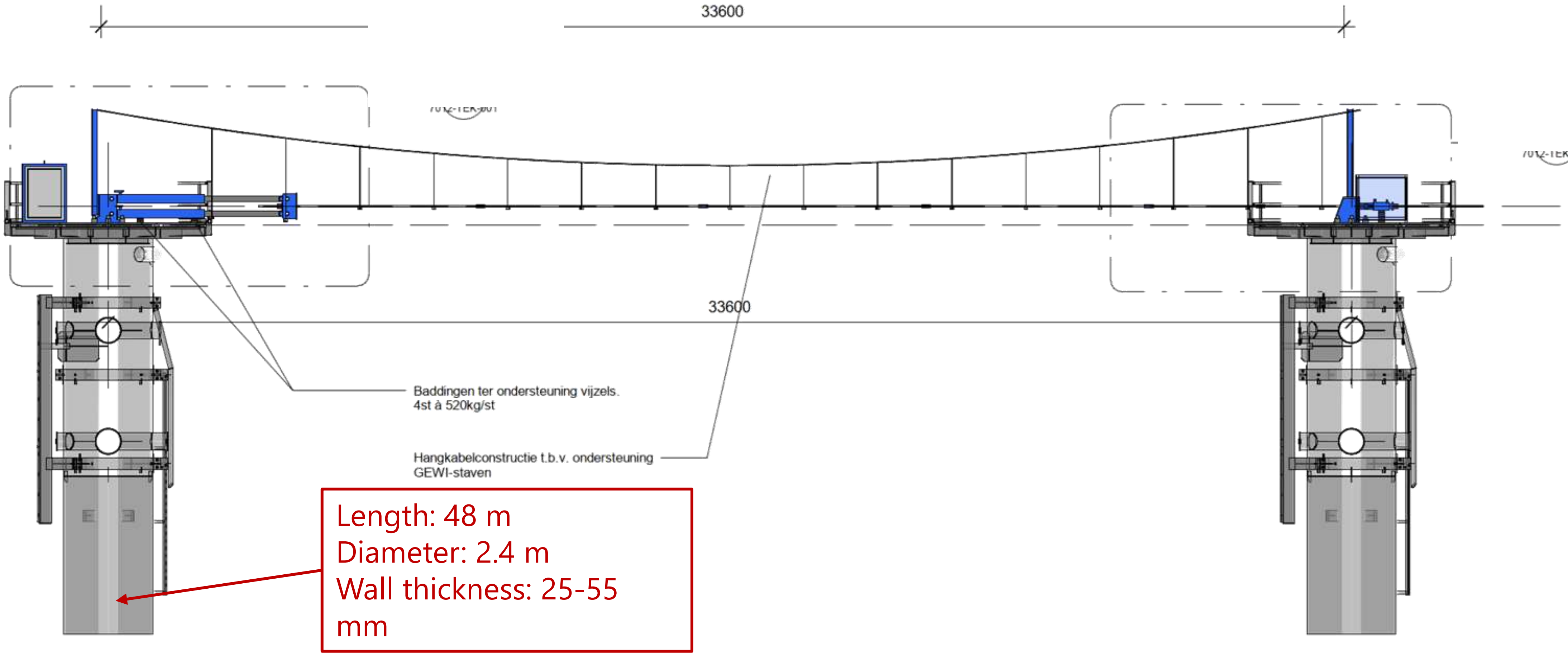
deKlerk WERKENDAM

deBoer
Civiele technieken deBoer bv

Iv-Infra

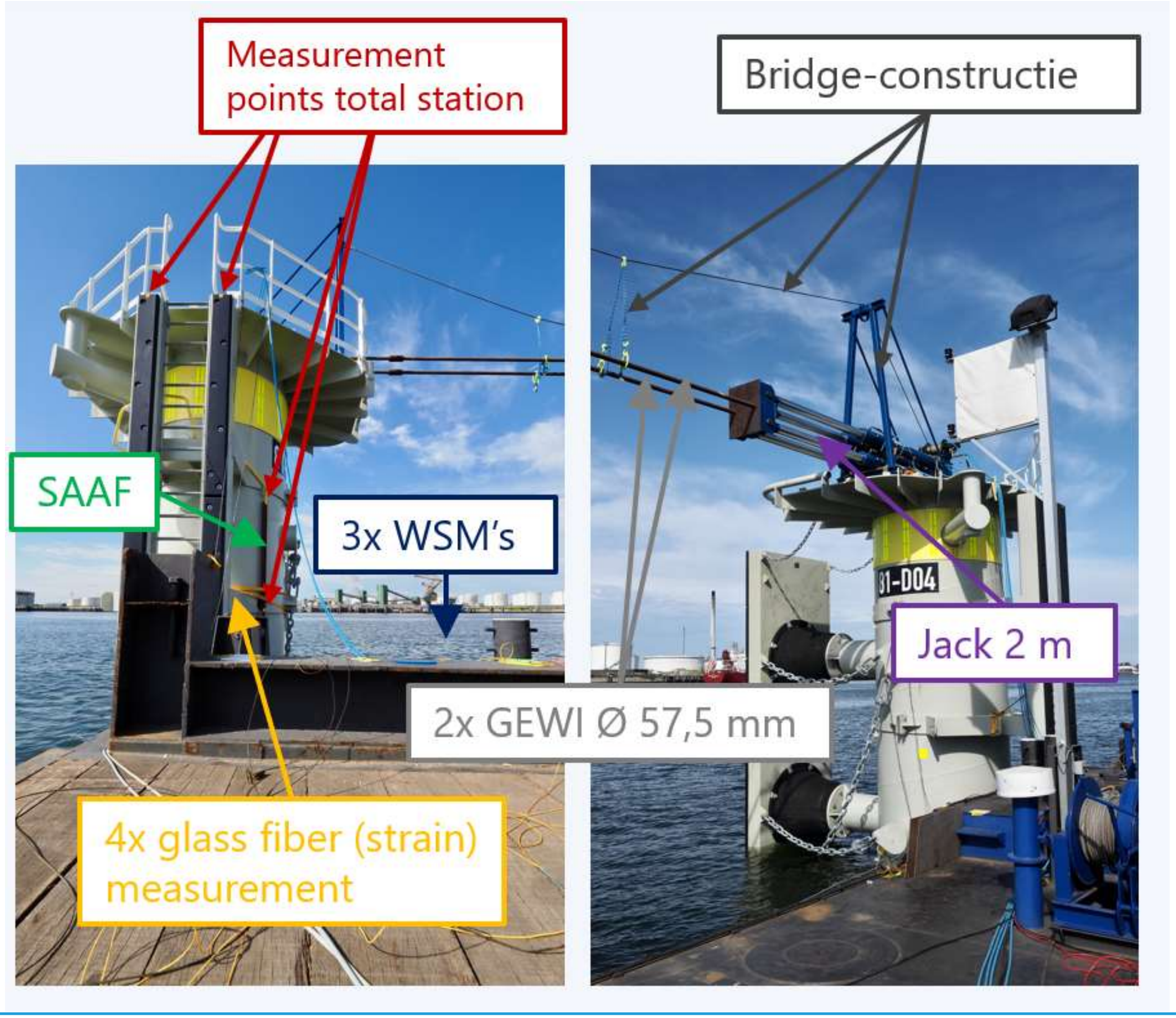
Gemeente Rotterdam

Full scale tests Calandkanaal



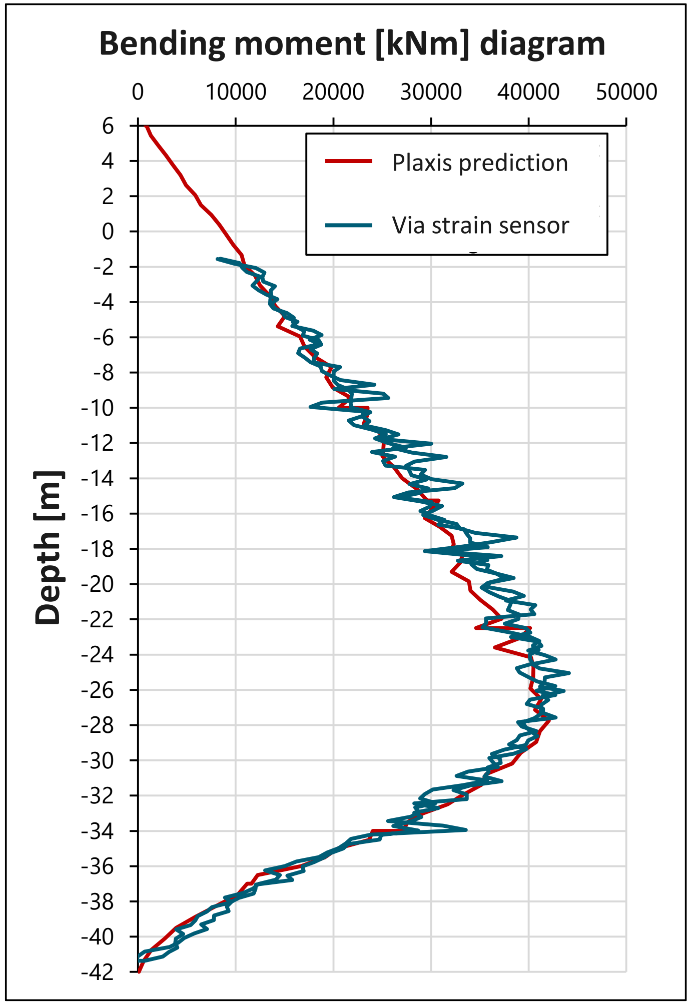
Full scale tests Calandkanaal

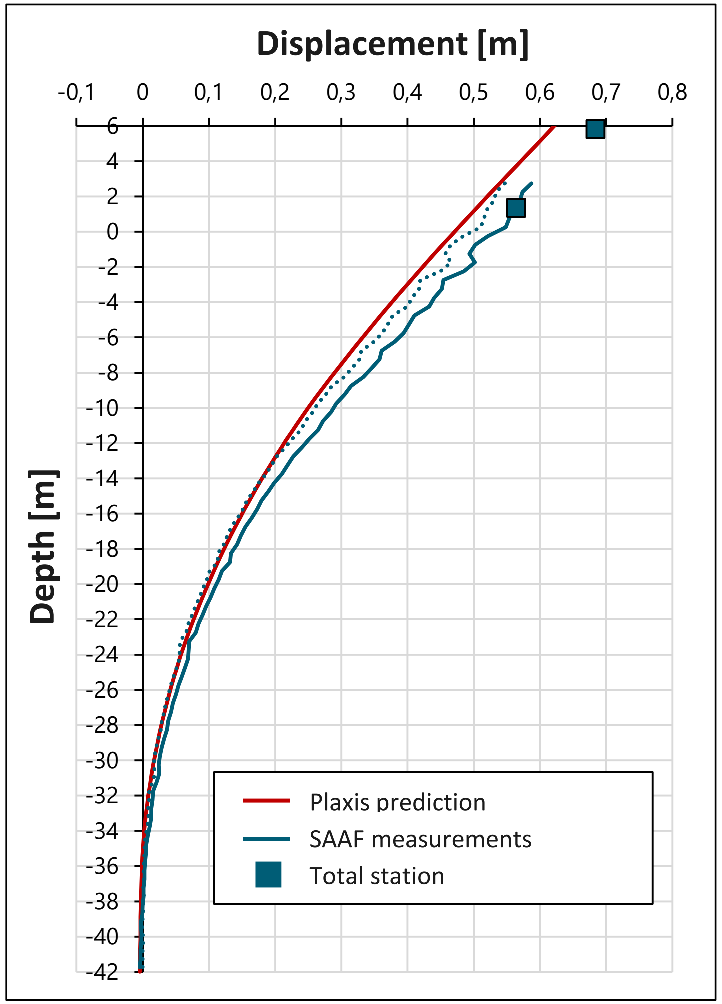
- Test load ≈ 1820 kN (90% of ULS load)
- Max deformation ≈ 1m.
- Sensors:
  - BOFDA fibre optics
  - SAAF
  - water pressure sensors
  - total station

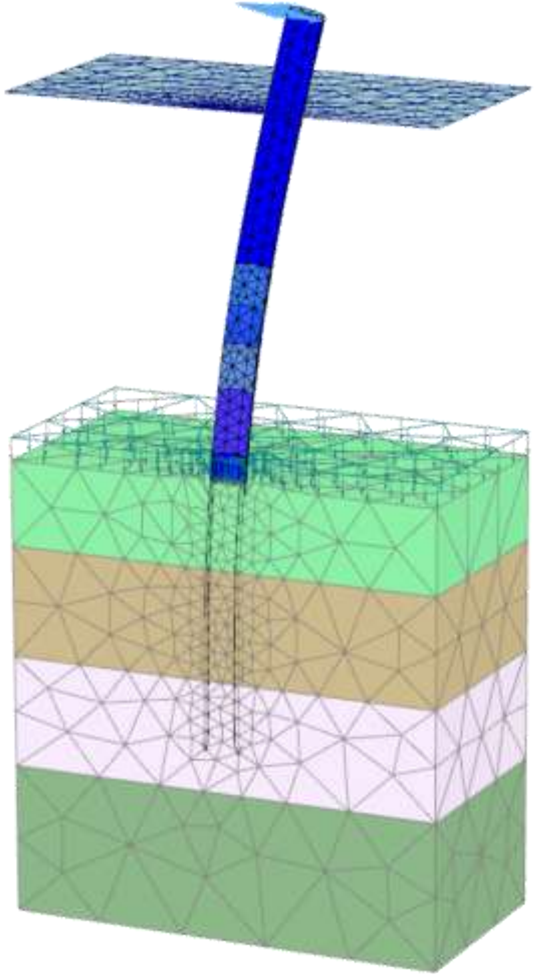


Full scale tests Calandkanaal: results

Repetitive loading : loading step 1

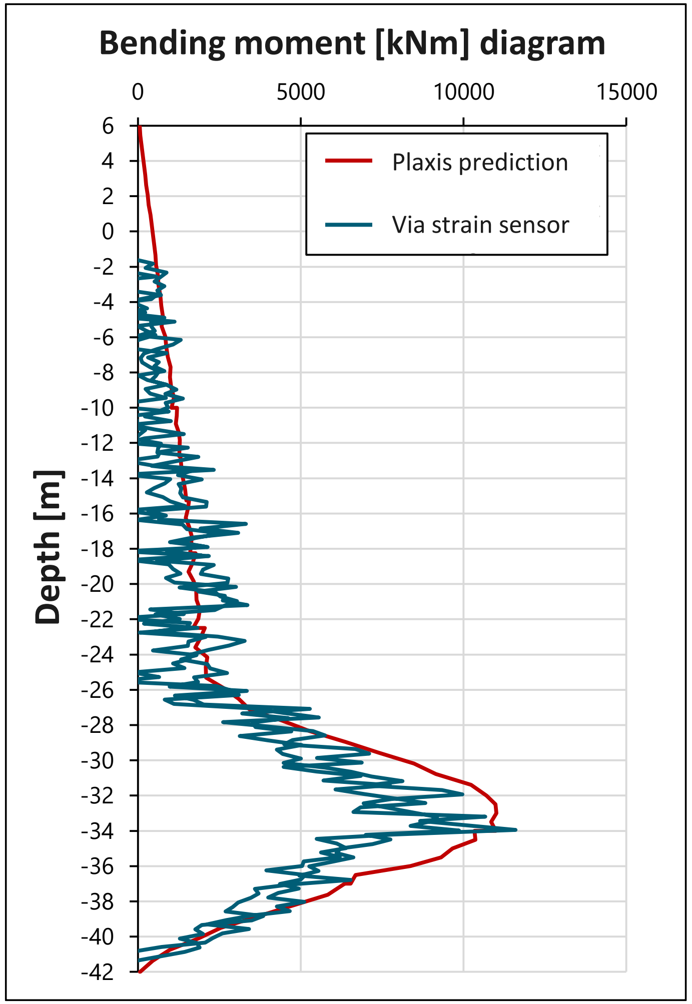


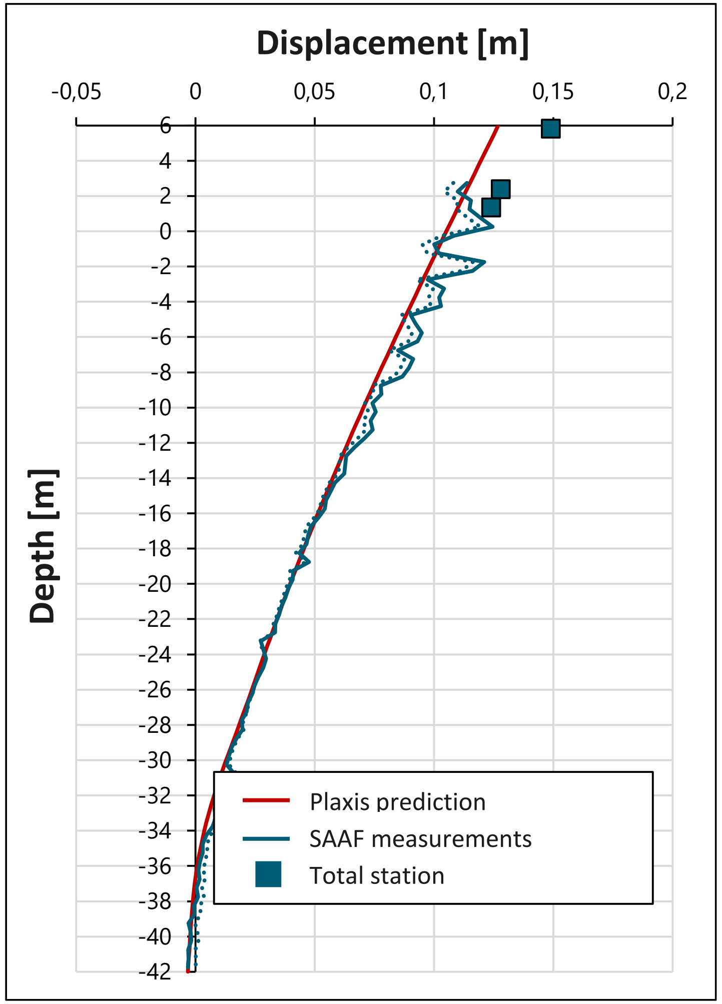


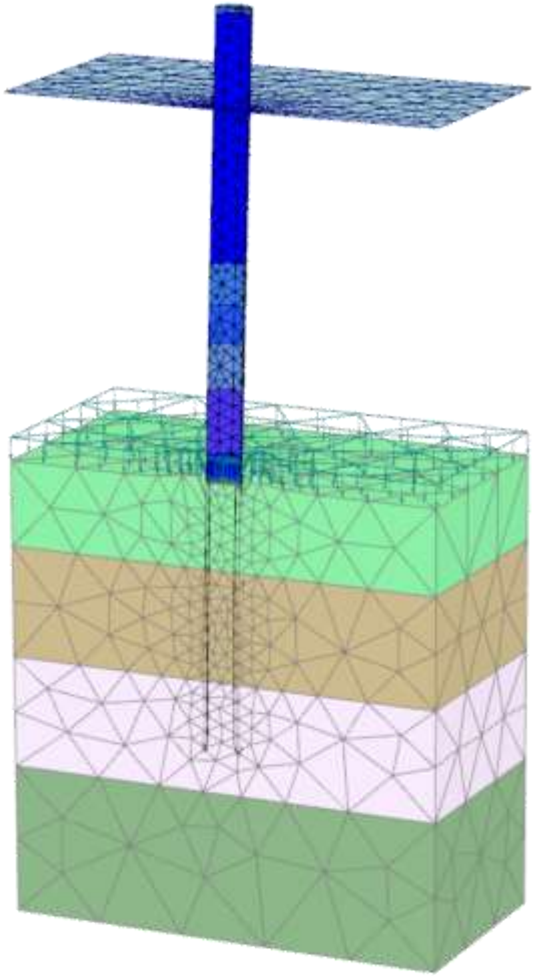


Full scale tests Calandkanaal: results

Repetitive loading : unloading



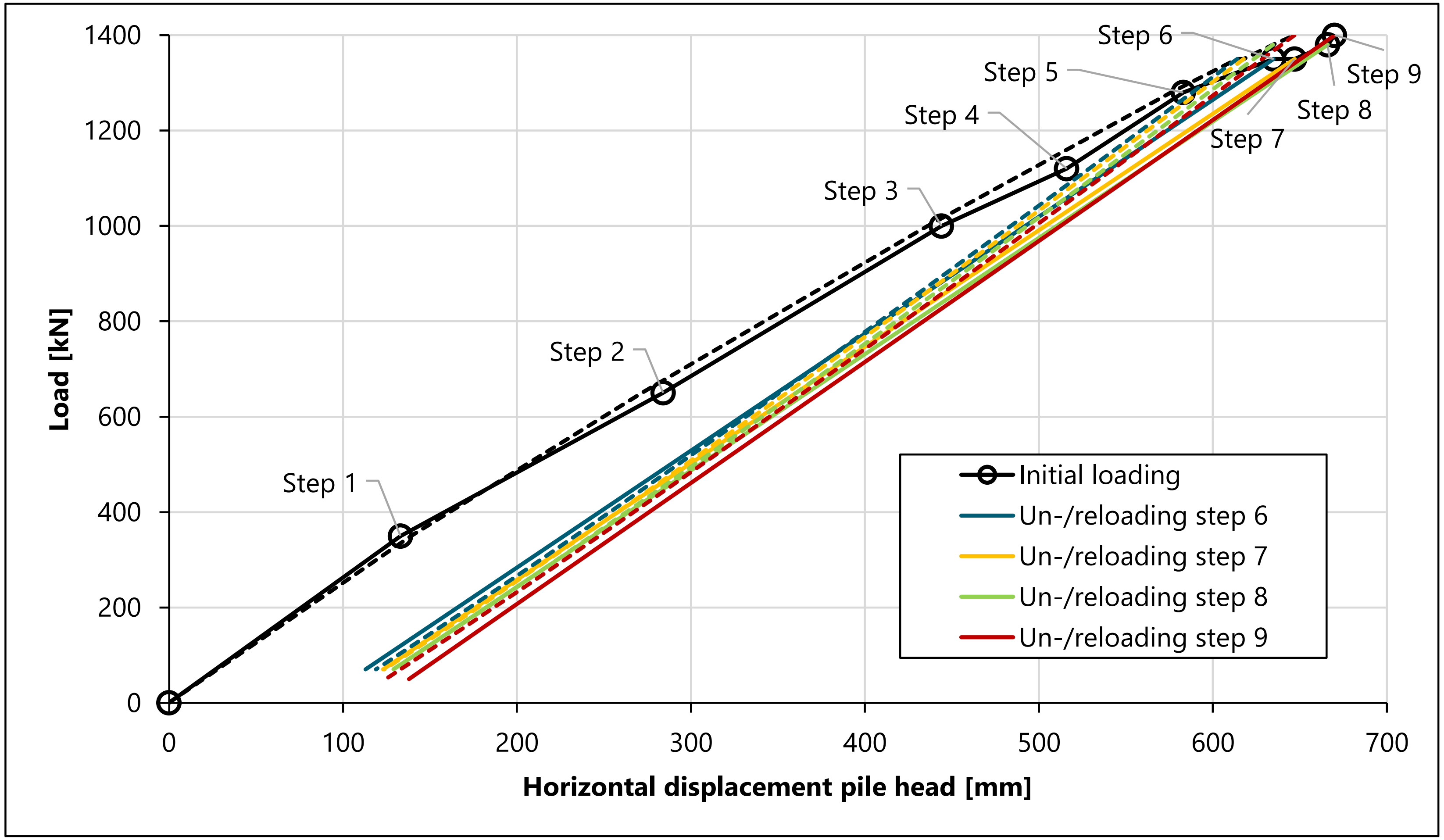




Full scale tests Calandkanaal: results

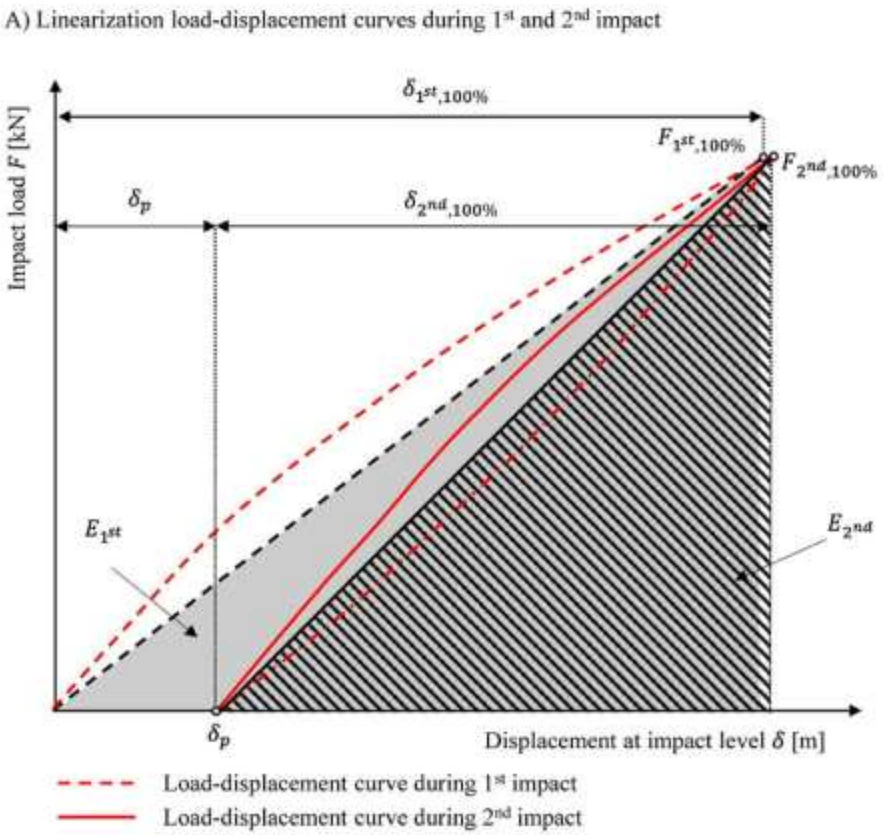
Repetitive loading : reloading

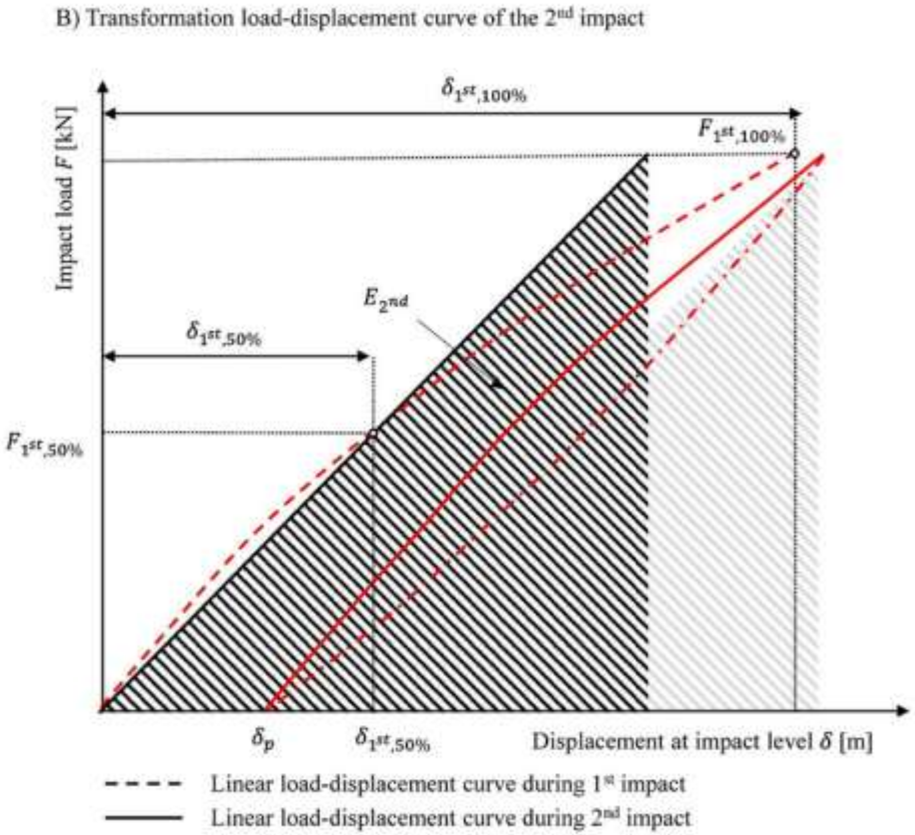
- Continuous: measurements
- Dashed: model (Plaxis 3D)



New design approach

- Repetitive loading behaviour needs to be included: use 2nd berthing impact in design

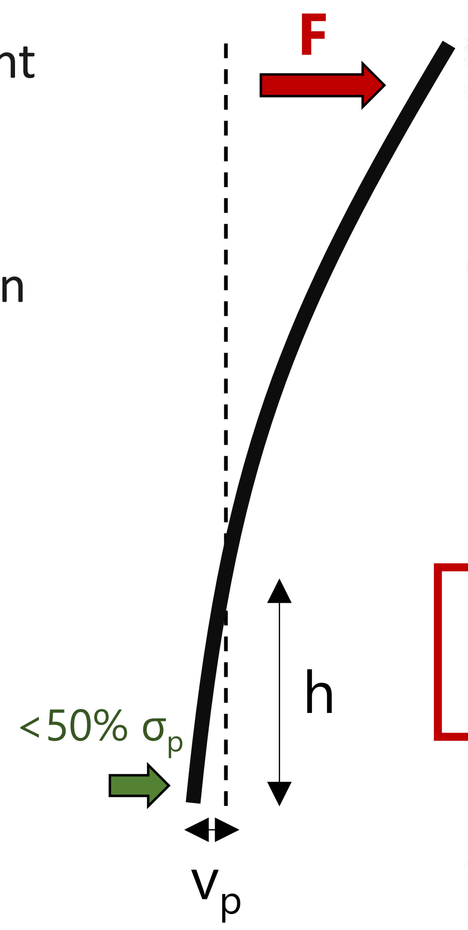




New design approach

Fixity criteria in first edition is too conservative

- New guidelines for soil fixation for different design methods (e.g. Blum, p-y cures and finite element models such as Plaxis)
- ULS geotechnical failure 100% mobilisation of passive soil wedge (ULS energy once in the service life)
- SLS fixity check: 50% mobilisation of passive soil wedge after 2nd berthing impact. Except:
  - Blum-method 33% mobilisation
  - 3D FEM: 50% or vp/h criterion NEN 9997-1 appendix C.3



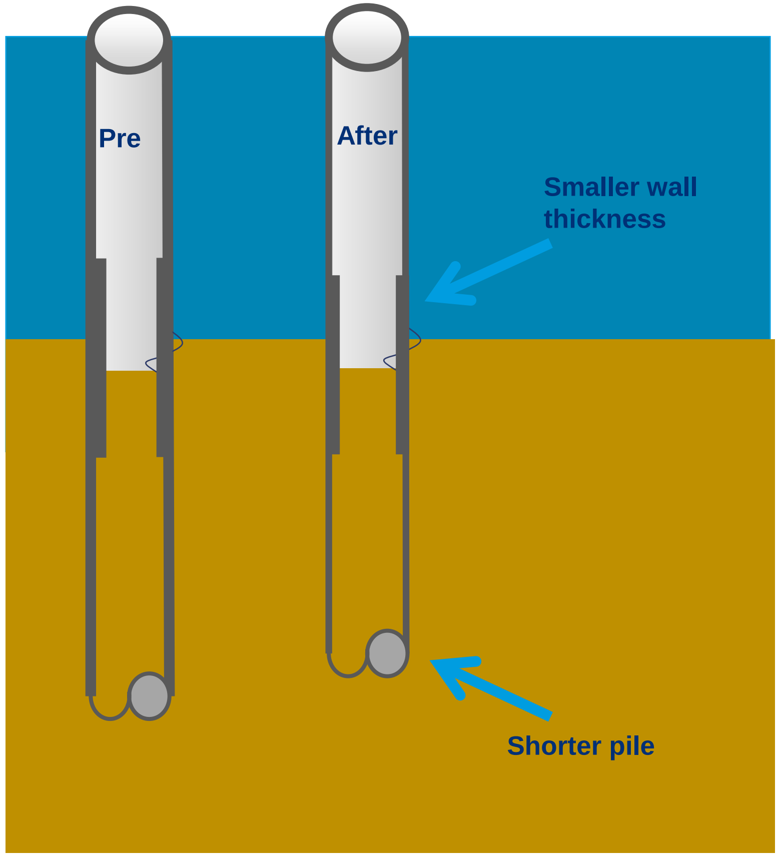
Tabel C.2 — Verhouding v_p / h en v / h voor 0,5σ_p voor niet-cohesieve grond

Soort wandbeweging	v_p / h (v / h voor 0,5σ_p) % los gepakte grond	v_p / h (v / h voor 0,5σ_p) % vast gepakte grond
a)	7 (1,5) tot 25 (4,0)	5 (1,1) tot 10 (2,0)
b)	5 (0,9) tot 10 (1,5)	3 (0,5) tot 6 (1,0)
c)	6 (1,0) tot 15 (1,5)	5 (0,5) tot 6 (1,3)

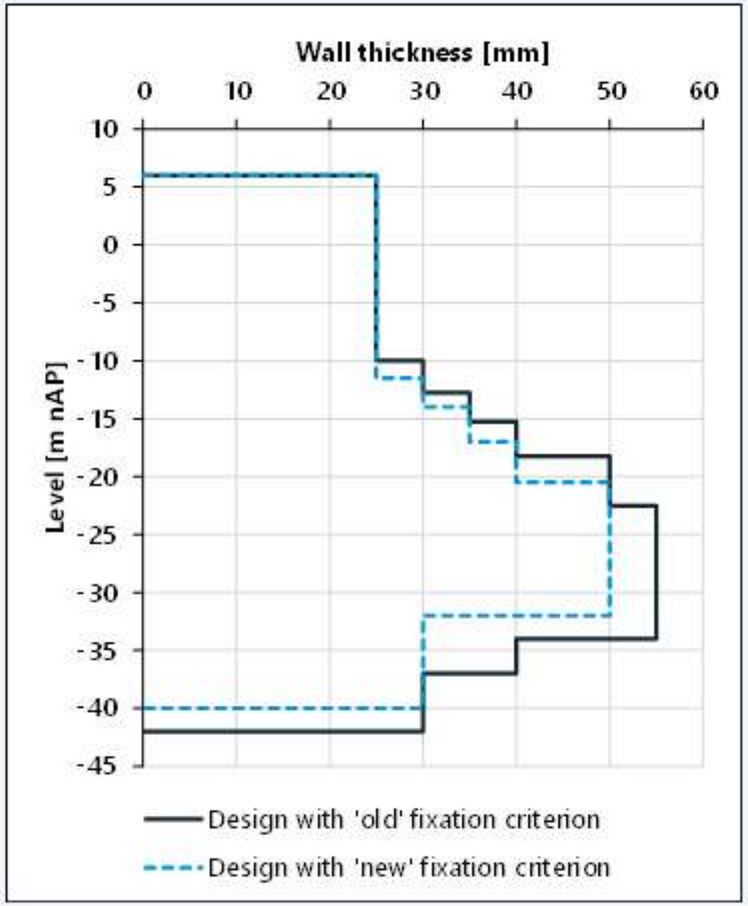
waarin:
v is de wandverplaatsing;
v_p is de wandverplaatsing om de passieve gronddruk te mobiliseren;
h is de hoogte van de wand;
σ_p is de volledig gemobiliseerde passieve grondweerstand.

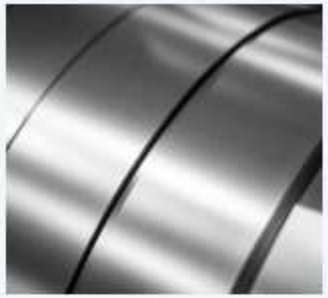
Impact update handbook

- Uniformisation
- Less discussions expected on models
- Optimisation: Shorter dolphin piles and smaller wall-thicknesses.



Impact update handbook





13.4 ton/pile (-12.4 %)

21700 EUR/pile

14.7-29.5 ton CO_2/pile

Want more information?

- CROW Handbook Flexible Dolphins available on “kennisbank”
- PAO course “Dolphins &Jetties”

- Publications:

Beneluxhaven:

- Van der Meer, Jaspers Focks, Roubos
- ISSMGE en Vakblad Geotechniek

Calandkanaal

- Sluis, Griffioen, Roubos
- ECSMGE en Vakblad Geotechniek


GEO water

PAALPROEF CALANDKANAAL
INZICHT IN HET LAST-VERPLAATSINGSGEDRAG
VAN EEN AFMEERPAAL


Proceedings of the XVIII ECSMGE 2024

ECSMGE 24

Evaluation full-scale mooring pile load test Rotterdam

Évaluation de l'essai de chargement de pieux d'amarrage grandeur nature Rotterdam

J.J.M. Sluis
Witteveen+Bos, Utrecht, The Netherlands

H.J. Lengkeek
Witteveen+Bos, Deventer, The Netherlands

A.A. Roubos
Port of Rotterdam, Rotterdam, The Netherlands

1 INTRODUCTION

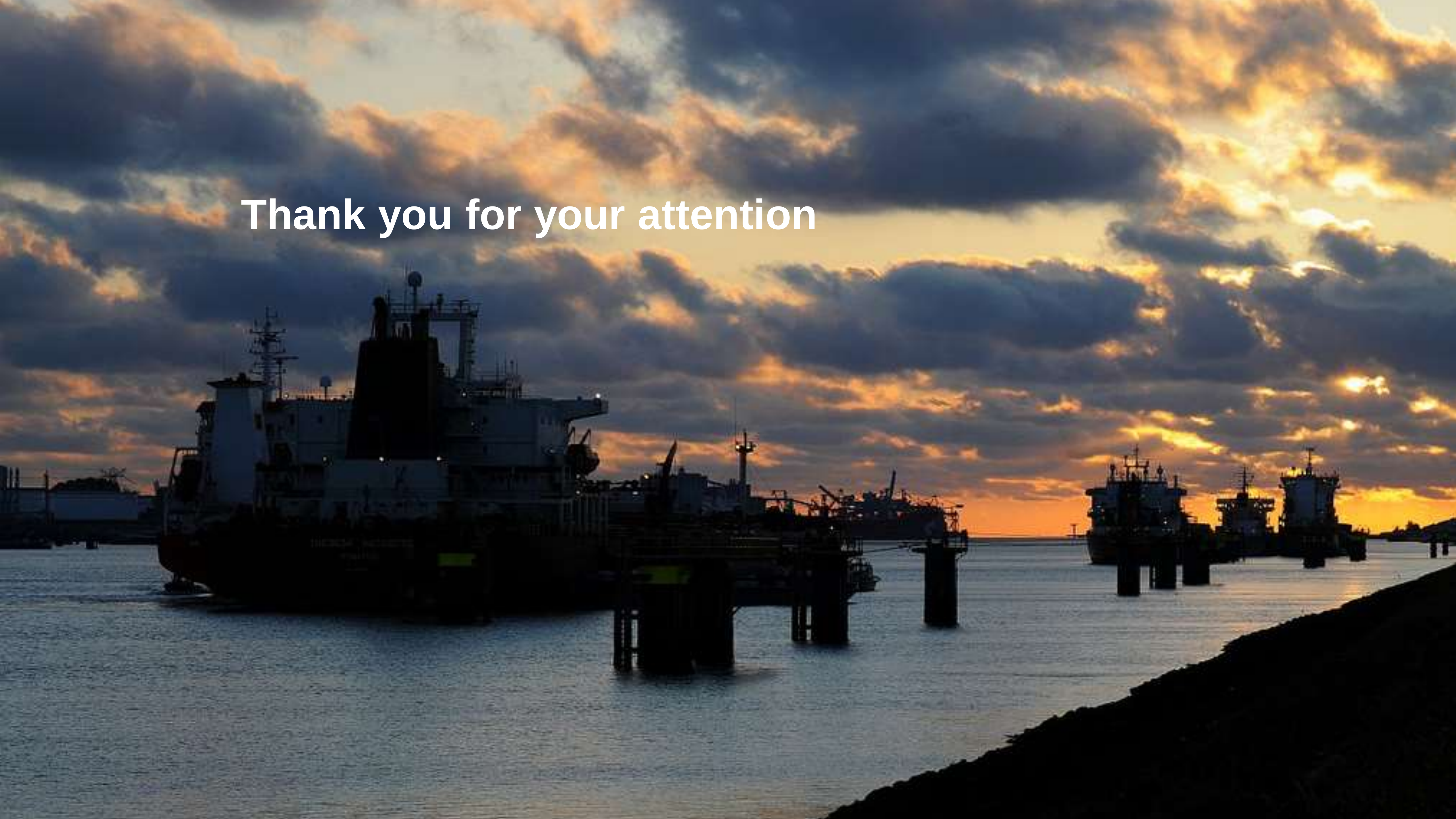
2 PILE DESIGN AND TEST SETUP

2.1 Pile design

Thank you for your attention!

dirk-jan.jaspers.focks@witteveenbos.com
aa.roubos@portofrotterdam.com


Thank you for your attention

Bedankt voor je aandacht

kennisplatform CROW

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0318 69 53 00

LinkedIn

CROW nieuwsbrieven

Delphina

- Dolphin refers to delphina (Greek):

⇒ Delph (hollow), delve (dig into the world)

⇒ Dolphins are also installed deeply into the soil.

- Delphin (Latin) => Dalben (German) => Delven (NL)
- Duc dáble (French) & Dukdalf (NL) refer to the duke of Alba.

Less plausible

- Shadow of canons installed on marine structures looked like a dolphin

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