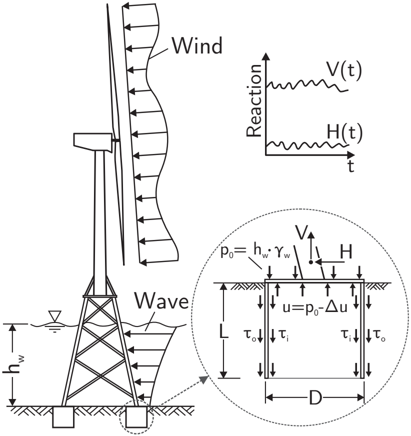
Behaviour of suction buckets under monotonic and cyclic tensile loading in sand

Dipl.-Ing. Patrick Gütz

Institute for Geotechnical Engineering

14th FZK-Colloquium, 21st March 2019

1. Introduction
   - Suction bucket foundations for offshore wind
   - Pros and cons
2. Physical model tests
   - Testing facility
   - Monotonic tests
   - Cyclic tests
3. Numerical simulation
   - Finite element model
   - Monotonic tests
   - Cyclic tests
   - Transient loading
4. Concluding remarks
   - Conclusion and outlook



Task

Enlarging demand for renewable energy requires appropriate foundations for OWT

→ Multipods supported by 3 or 4 suction bucket foundations

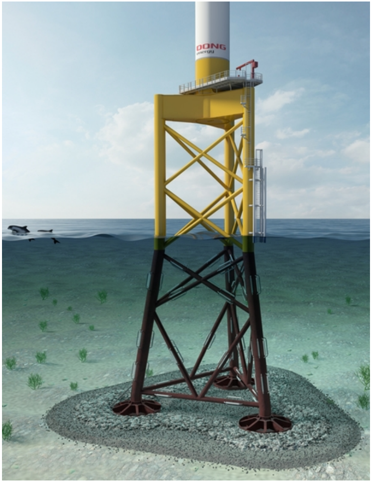
Current state

Tensile forces to be omitted or limited to the drained capacity

Target

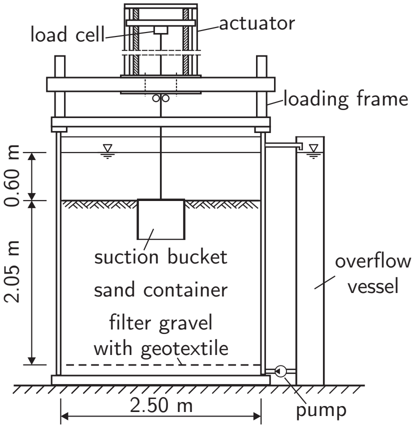
Determination of the partially drained tensile bearing behaviour

Pros and cons



- \+ High partially drained tensile resistance
- \+ No pile hammer required (costs)
- \+ Silent installation
- \+ Economically beneficial
- \+ Floatable structure
- \+ Decommissioning is feasible

- \- Complicated fabrication
- \- Critical suction during installation (avoid erosion and buckling)
- \- Drained tensile resistance is low
- \- Potential for heave and pore pressure accumulation



Constant heave rate

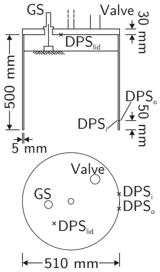
- (Partially) drained monotonic response

Constant force

- Time-dependent heave

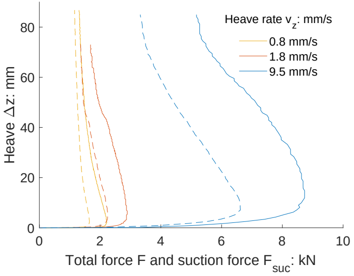
Cyclic force

- Pore pressure and heave accumulation



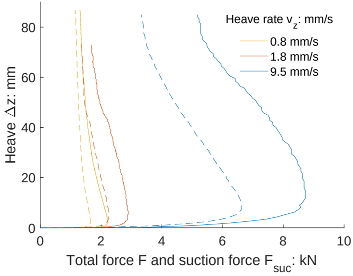
Tests with $L/D = 500mm/510mm$
Higher heave rates induce:

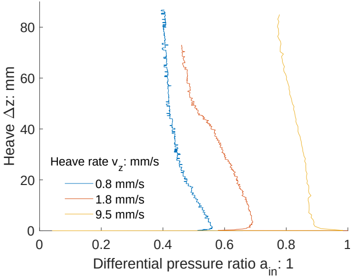
- Higher tensile resistance (mainly due to suction force)



Tests with $L/D = 500mm/510mm$
Higher heave rates induce:

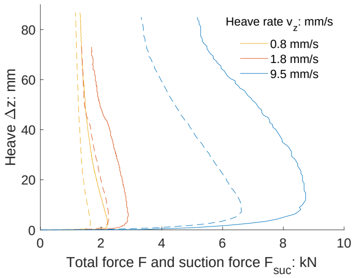
- Higher tensile resistance (mainly due to suction force)
- More undrained behaviour (less dissipation inside the suction bucket)

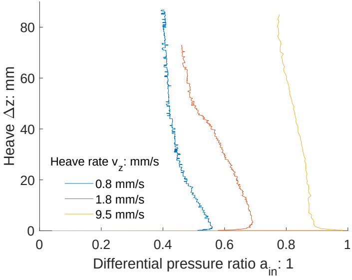


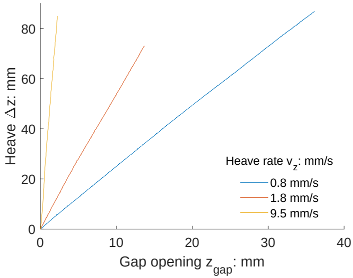


Tests with $L/D = 500mm/510mm$
Higher heave rates induce:

- Higher tensile resistance (mainly due to suction force)
- More undrained behaviour (less dissipation inside the suction bucket)
- Less gap opening

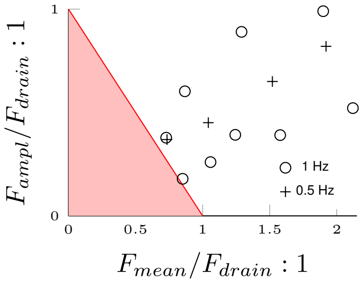






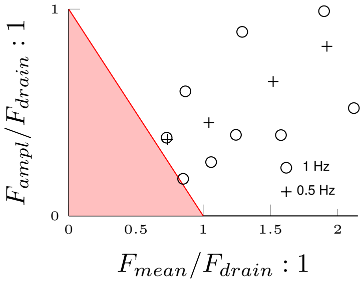
Heave accumulation

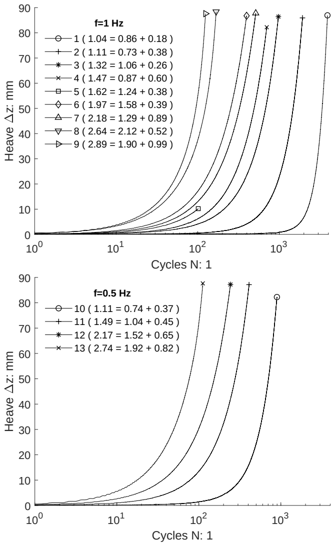
- Cyclic loads exceeding the drained capacity
- Normalised loads (divided by drained resistance)
- Two load frequencies



Heave accumulation

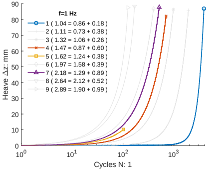
- Cyclic loads exceeding the drained capacity
- Normalised loads (divided by drained resistance)
- Two load frequencies





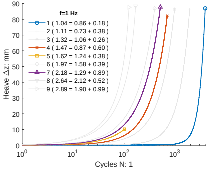
Low load level

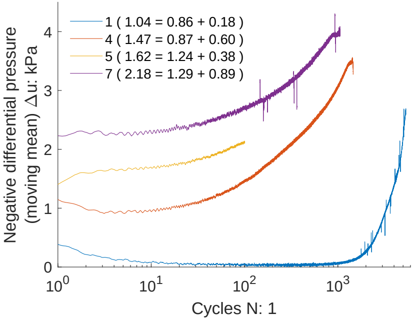
- Minor heave for numerous cycles followed by significant heave accumulation



Low load level

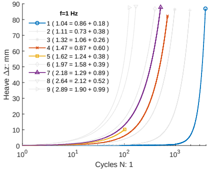
- Minor heave for numerous cycles followed by significant heave accumulation
- Accumulation of negative differential pressure

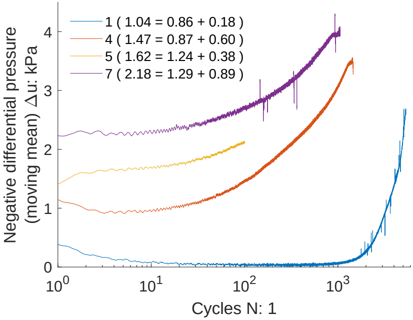


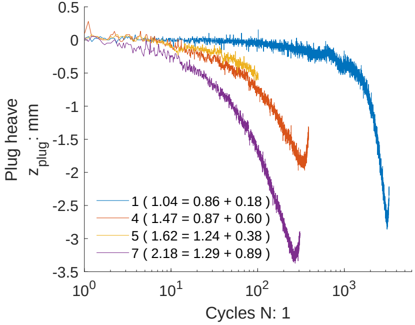


Low load level

- Minor heave for numerous cycles followed by significant heave accumulation
- Accumulation of negative differential pressure
- Initial settlement of plug and subsequent heave

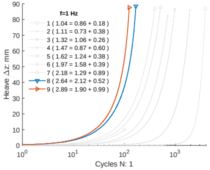






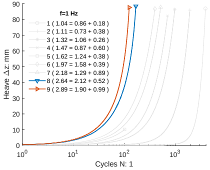
High load level

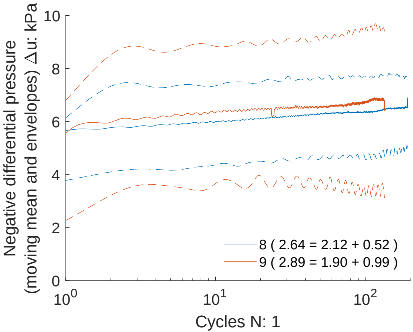
- More distinct heave accumulation



High load level

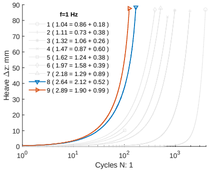
- More distinct heave accumulation
- Significant negative differential pressure with wider span for higher amplitudes

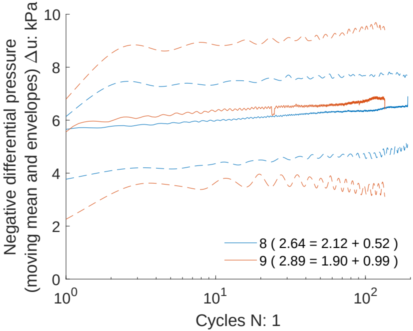


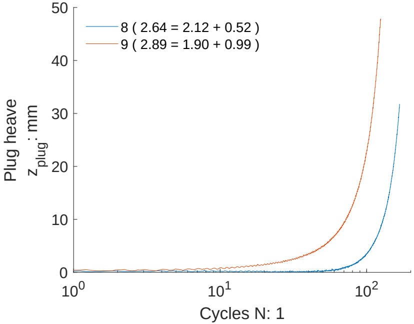


High load level

- More distinct heave accumulation
- Significant negative differential pressure with wider span for higher amplitudes
- No settlement of soil plug, but relevant heave

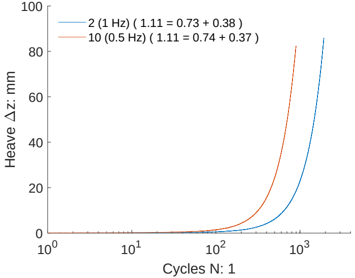






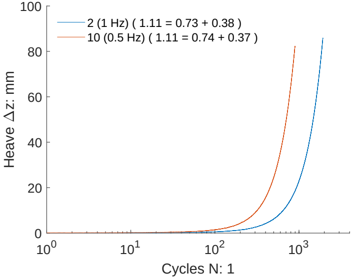
Effect of load frequency

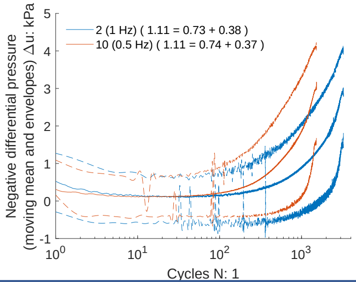
- Higher heave accumulation for lower frequency



Effect of load frequency

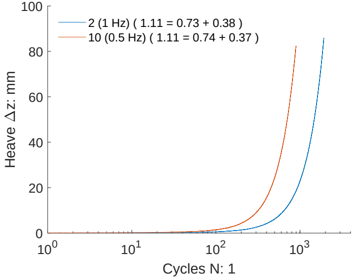
- Higher heave accumulation for lower frequency
- Negative differential pressure accumulates faster for lower frequency

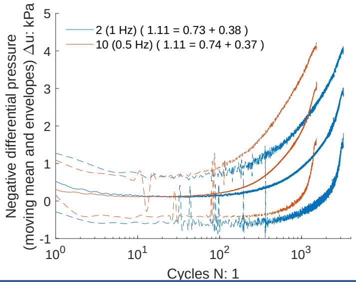


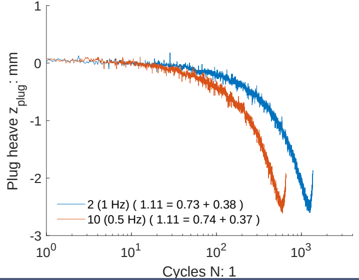


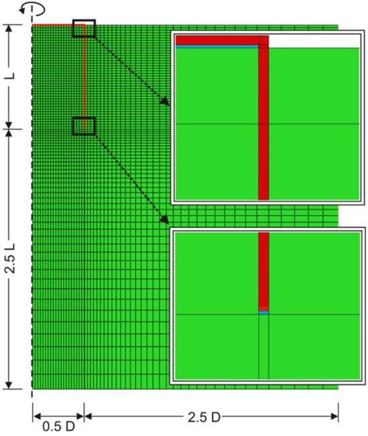
Effect of load frequency

- Higher heave accumulation for lower frequency
- Negative differential pressure accumulates faster for lower frequency
- Plug heave commences as significant heave takes place









Features

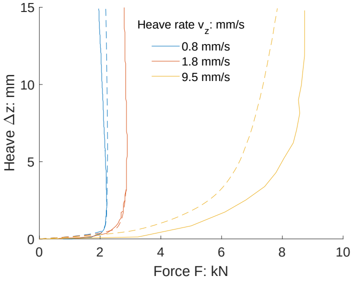
- Hydro-Mechanically coupled analysis in ABAQUS/2017
- Water elements
- Static and cyclic loading
- Second-order elements (CAX8P)

Soil properties

- Stress-dependent stiffness
- Elasto-plastic soil behaviour (Mohr-Coulomb plasticity model) with non-associated flow rule
- Permeability depends on void ratio
- Calibrated in laboratory tests

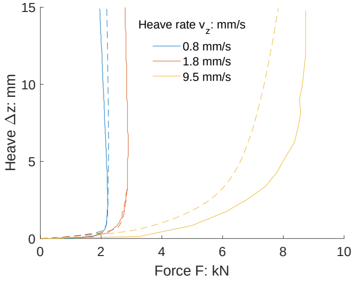
Simulation of model tests with $L/D = 500mm/510mm$

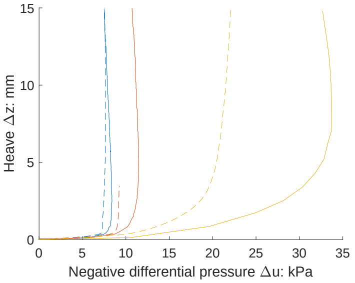
- Forces are well represented



Simulation of model tests with $L/D = 500mm/510mm$

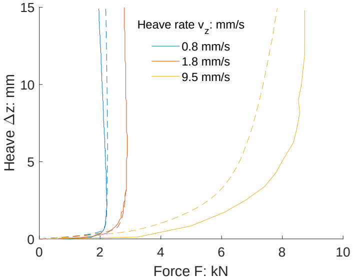
- Forces are well represented
- Negative differential pressure is somewhat underestimated

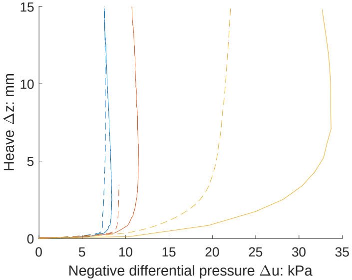


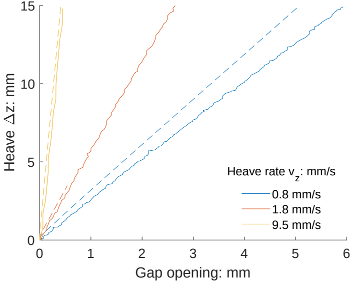


Simulation of model tests with $L/D = 500mm/510mm$

- Forces are well represented
- Negative differential pressure is somewhat underestimated
- Plug heave deviates slightly for lower heave rates

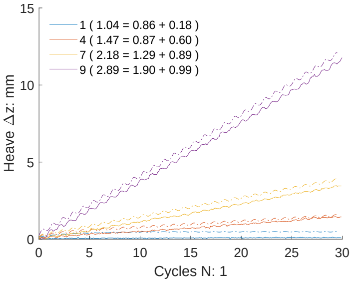






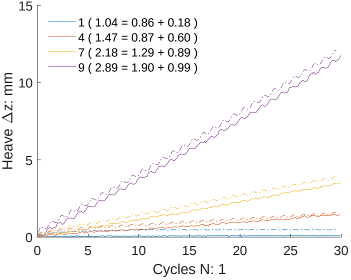
Successful simulation of model tests with $L/D = 500mm/510mm$ regarding

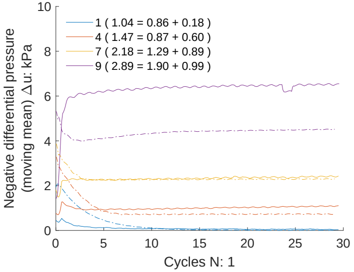
- Heave accumulation rate



Successful simulation of model tests with $L/D = 500mm/510mm$ regarding

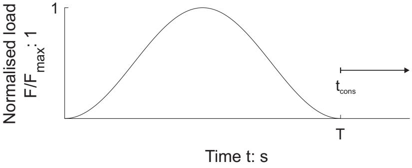
- Heave accumulation rate
- Negative differential pressure





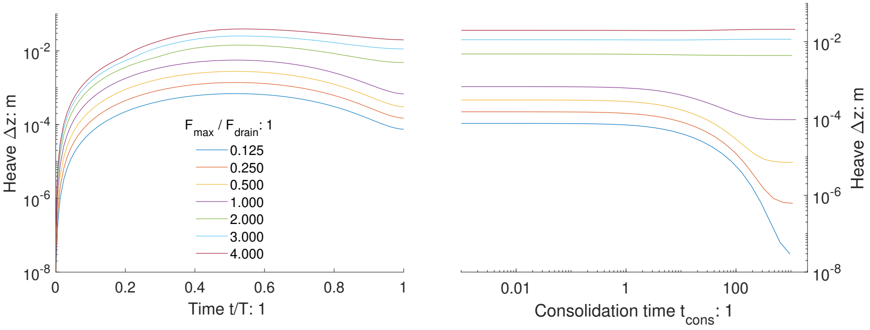
Concept

- Self weight of the OWT induces compressive loads on the foundations
- Environmental loads (wind and waves) may invoke tensile loads
- The occurrence of frequent tensile loads is unlikely
  - → Singular sinusoidal tensile loads with subsequent consolidation
  - → Simulation with $L/D = 10m/10m$
  - → Multiple normalised load magnitudes $0.125 \leq F_{max}/F_{drain} \leq 4$
  - → Evaluation of heave and negative differential pressure



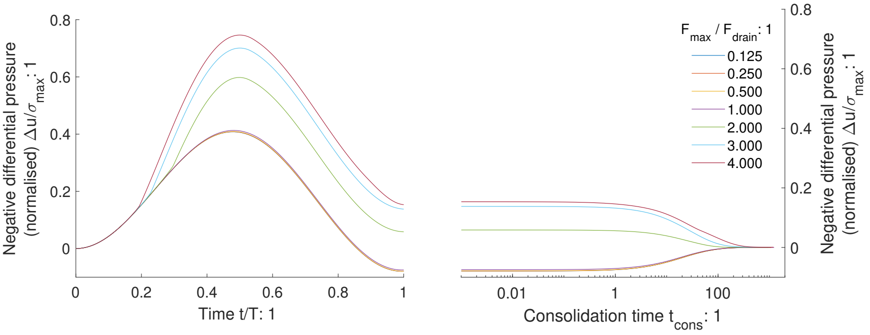
Heave

- Heave depends on the load magnitude
  - → $F_{max}/F_{drain} \leq 1$: linearly affected by F_{max} during loading
  - → $F_{max}/F_{drain} > 1$: increases over-proportionally with F_{max}
- Consolidation
  - → $F_{max}/F_{drain} < 3$: Settlement
  - → $F_{max}/F_{drain} < 1$: Negligible residual heave (less than $0.01mm$)



Negative differential pressure

- Suction force depends on F_{max}
  - $\rightarrow$ $F_{max}/F_{drain} \leq 1$: 40% of the load is sustained by the suction force
  - $\rightarrow$ $F_{max}/F_{drain} > 1$: Nonlinear increase of suction force
- Dissipation during consolidation
  - $\rightarrow$ $F_{max}/F_{drain} < 2$: Positive differential pressure after loading
  - $\rightarrow$ $F_{max}/F_{drain} \geq 2$: Longer duration t_{cons} for higher loads



Main conclusions

- Great potential regarding the partially drained tensile resistance
- Cyclic tensile response depends on loading
  - → Significant number of cycles can be withstood
  - → Accumulation of negative differential pressure along with heave
- Simulation of model tests with FE is feasible
- Successfully verified FE model for transient loading

Main conclusions

- Great potential regarding the partially drained tensile resistance
- Cyclic tensile response depends on loading
  - → Significant number of cycles can be withstood
  - → Accumulation of negative differential pressure along with heave
- Simulation of model tests with FE is feasible
- Successfully verified FE model for transient loading

Perspective

- Further model tests
  - → Investigation of model scale
  - → Verification and validation of FE model
- Comprehensive FE parametric study
  - → Confirm scale effects and extrapolate to prototype scale
  - → Holistic evaluation of transient tensile loading
  - → Provide database for calibration of an analytical approach

Thank you for your attention.

Funded by
Deutsche
Forschungsgemeinschaft
German Research Foundation