Offshore renewables: Is centrifuge modelling the right tool?

Western Geotechnical Centrifuge Opening Symposium

Prof. Christophe Gaudin

The University of Western Australia

Oceans Graduate School

2 May 2019

Outline

- The National Geotechnical Centrifuge Facility
- Offshore renewable energy: new challenges?
- Suction caisson: installation
- Suction caisson: VHM capacity
- Pile under multidirectional loading

The National Geotechnical Centrifuge Facility

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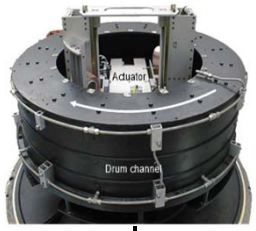
NGCF

The National Geotechnical Centrifuge Facility



ARC SRC: COFS

1989

1998

2005

State CoE

Lloyds Register CoE

ARC CoE: CGSE

ARC ITRF: OFF

WERC

2007

2010

2011

2012

2015

2016

2017

2018

2020

Creation of the NGCF

Specialised proprietary facility

Multi-disciplinary open platform

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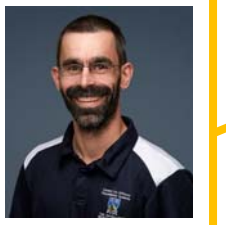
Centrifuge Operation

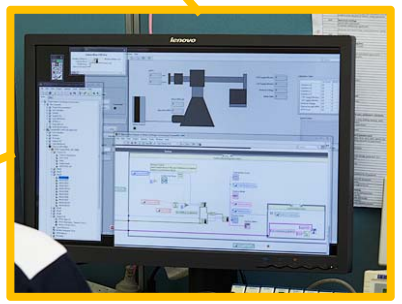

M. Palacios


K. Leong

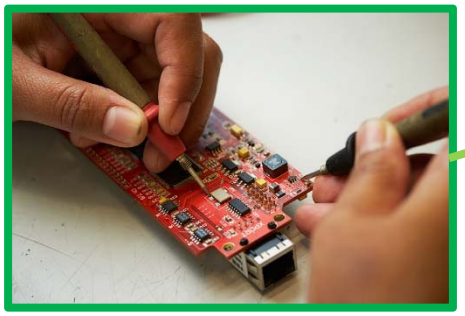

A. Stubbs

Software development


M. Turner



Mechatronics Electronics




J. Breen


G. Wager


K. Seint


A. Van Dam

Mechanical Engineering


D. Jones

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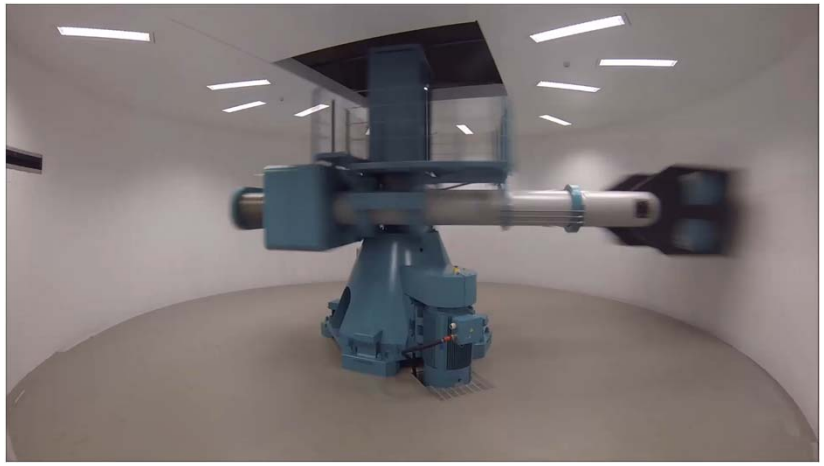

General

- 240 g-tonne beam centrifuge
- 5 m radius
- 130 g max acceleration
- 1.2×1.2×1.2 m, 2,400 kg payload

Specific

- 2 AC 110 kW induction motors
- Automatic balancing system

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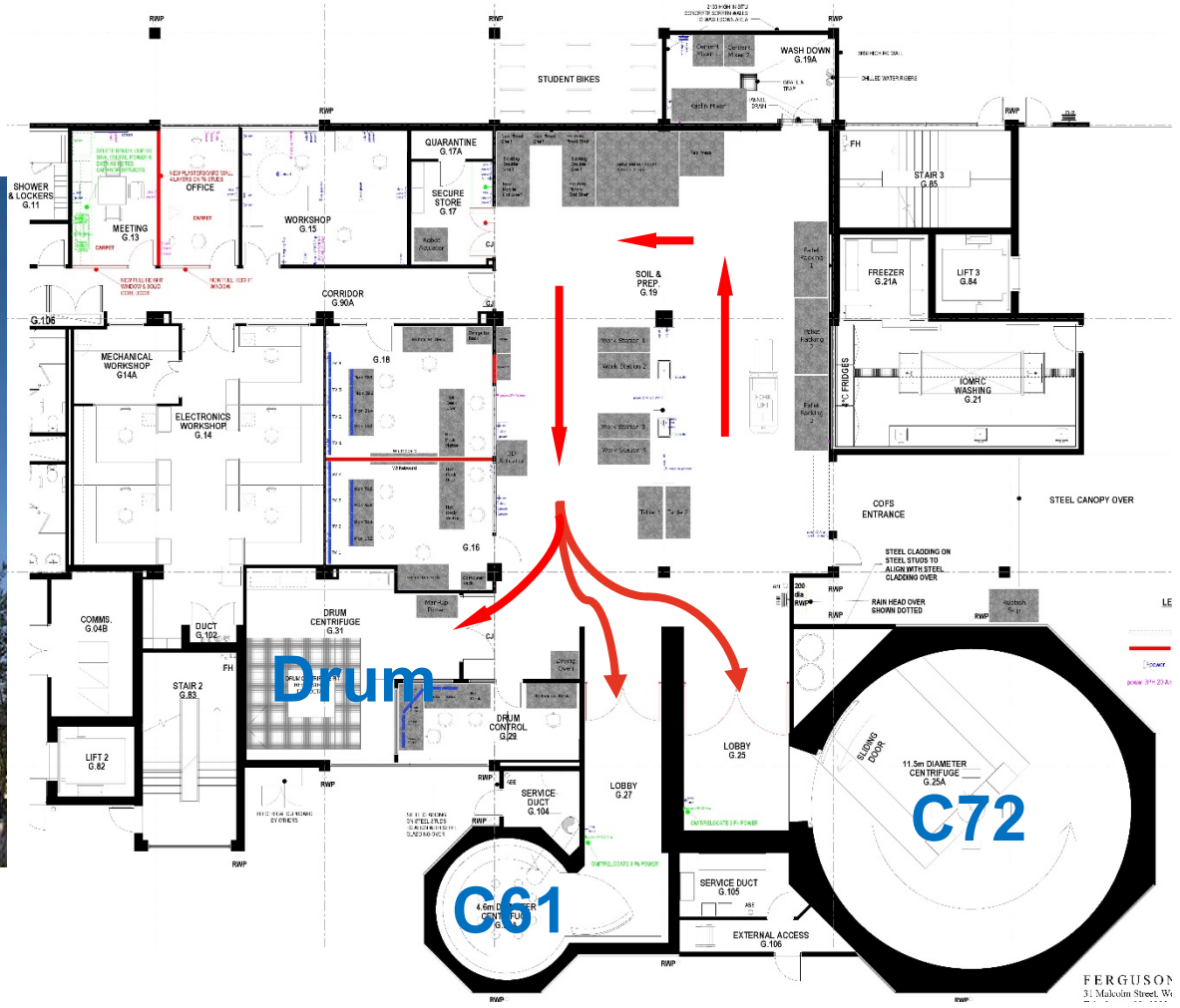
- **Building integration and laboratory layout**



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- **Control command room organisation**

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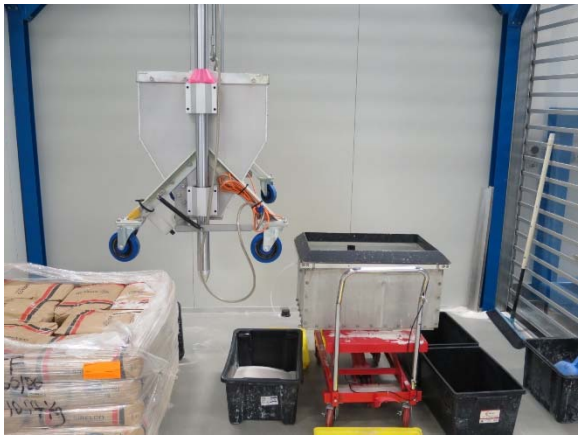
- **Internal development and upgrades**

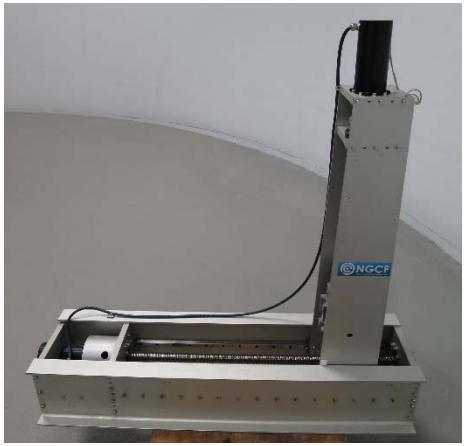
  Sample preparation and characterisation

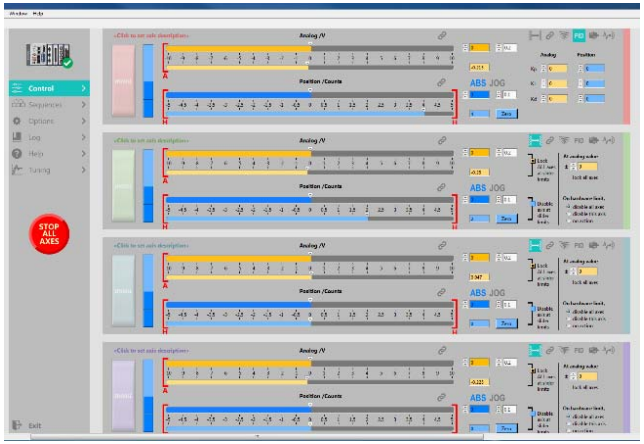
  - Sand rainer
  - Electrical consolidation press

  On-board equipment

  - 2D actuator
  - Control software







The transition to offshore renewables

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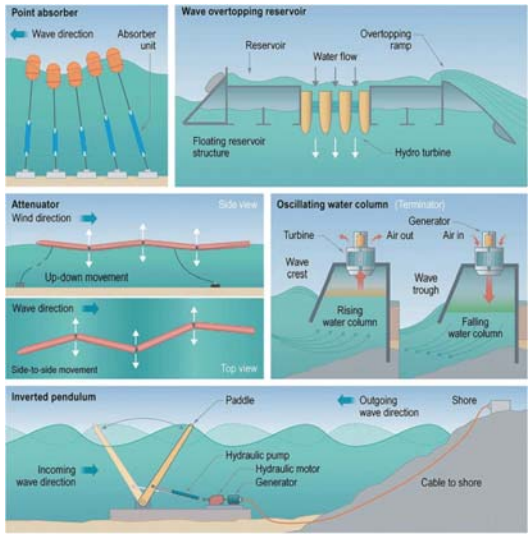
Offshore renewable energy

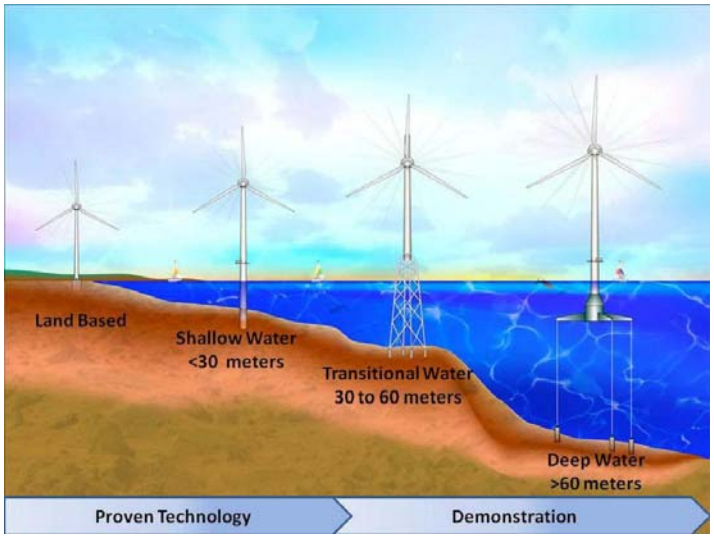
WAVE

WIND

TIDAL



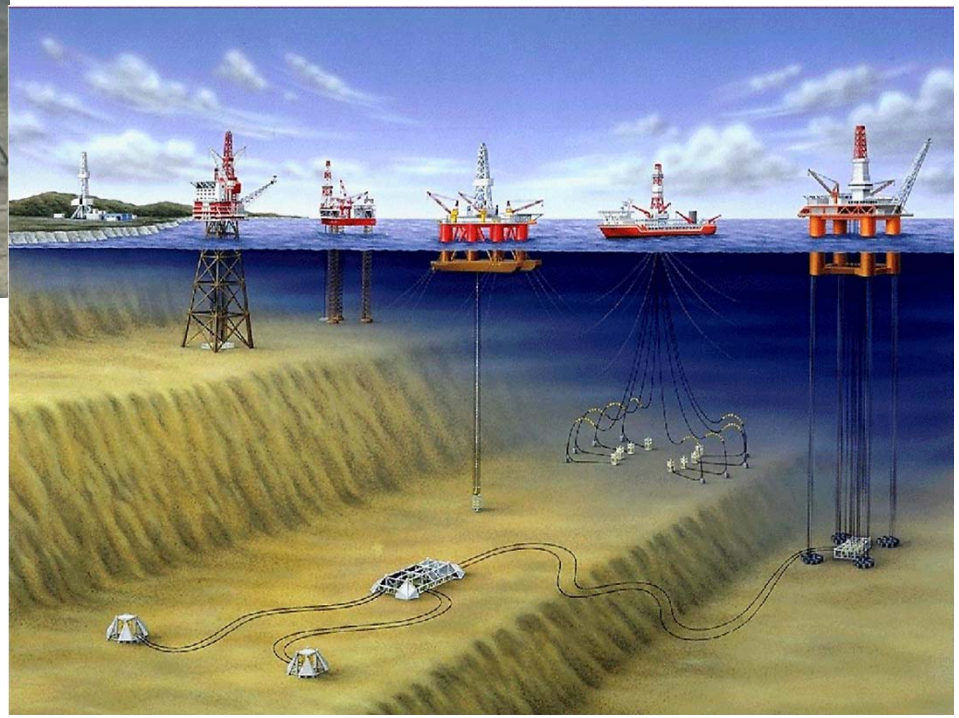
Development projects



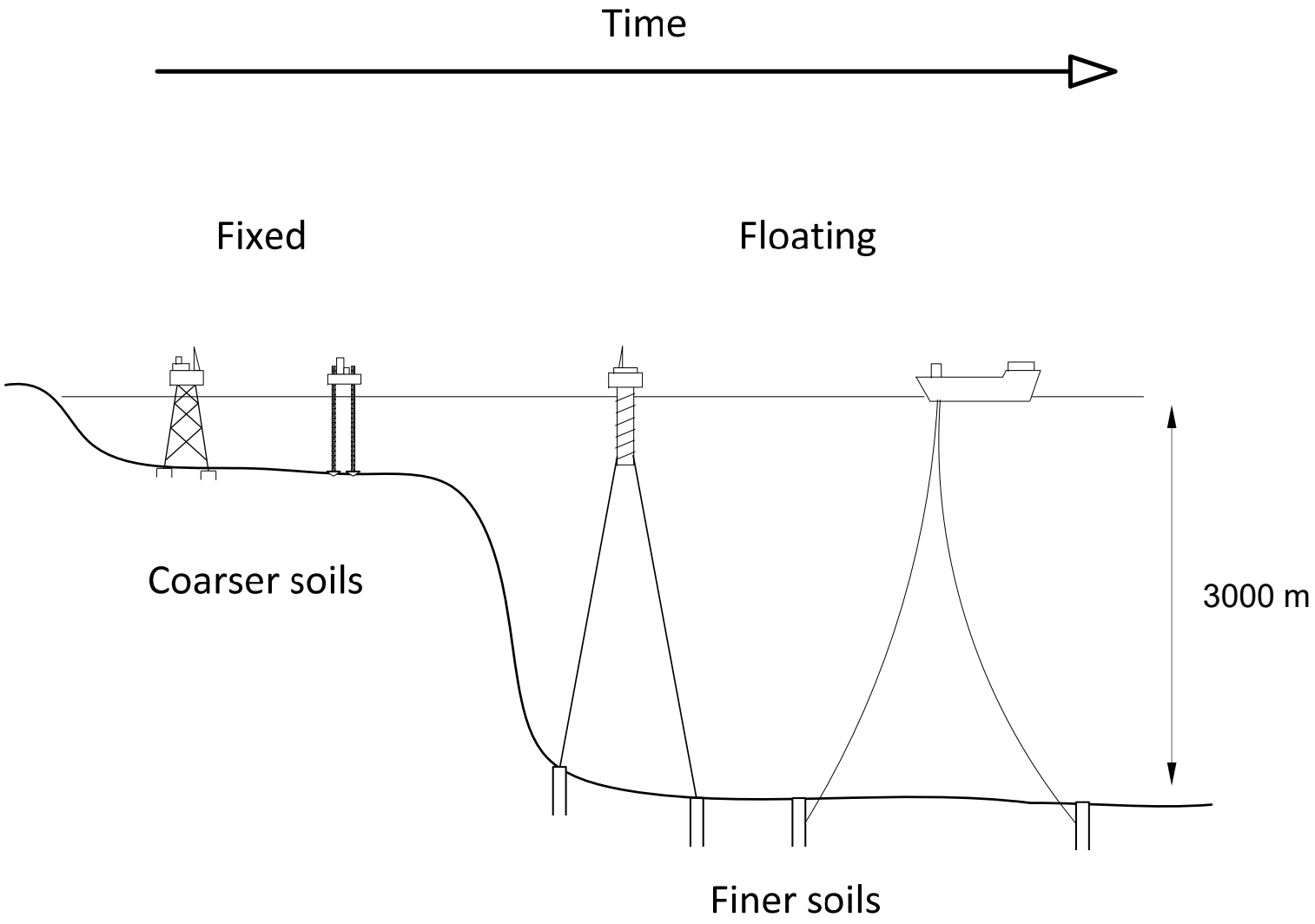
Commercial projects

Development projects

Challenges

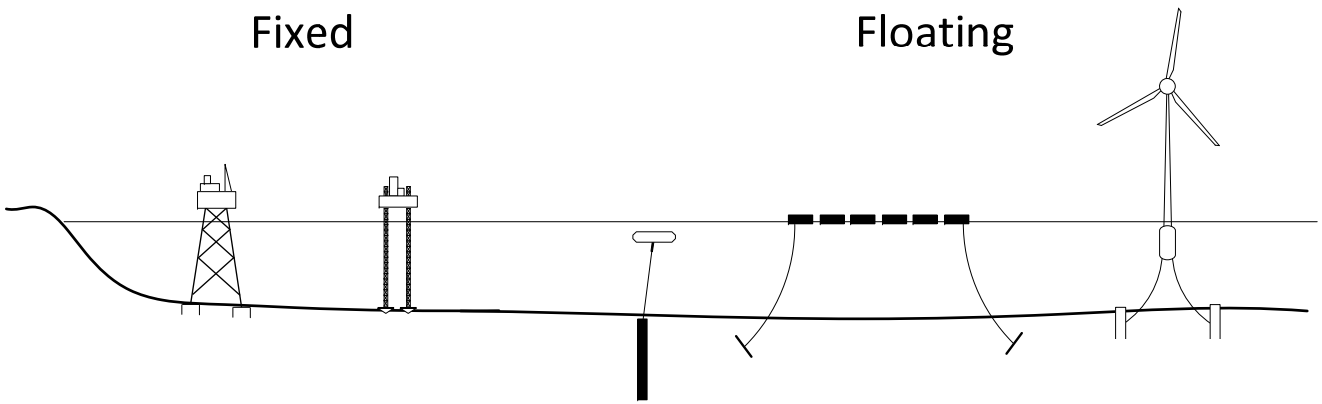


Knowledge transfer?

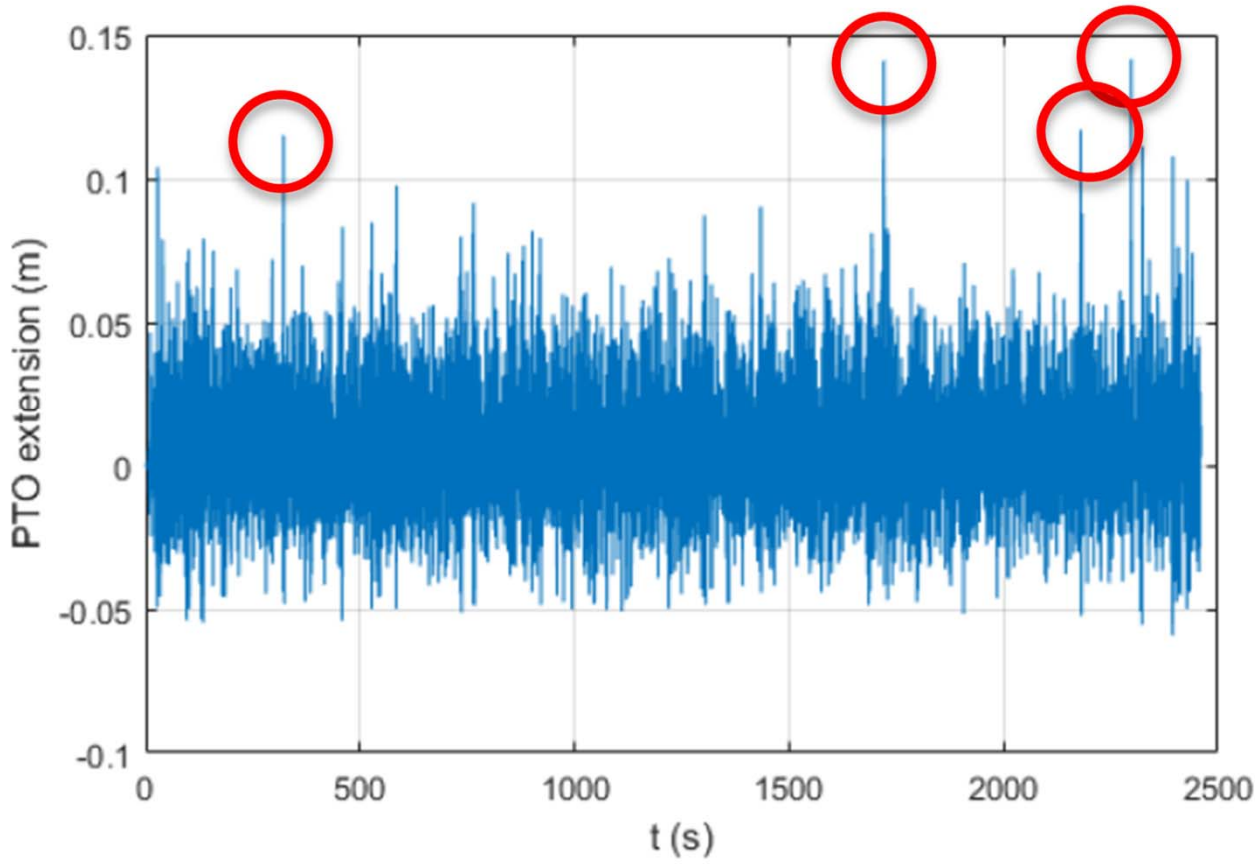


Knowledge transfer?

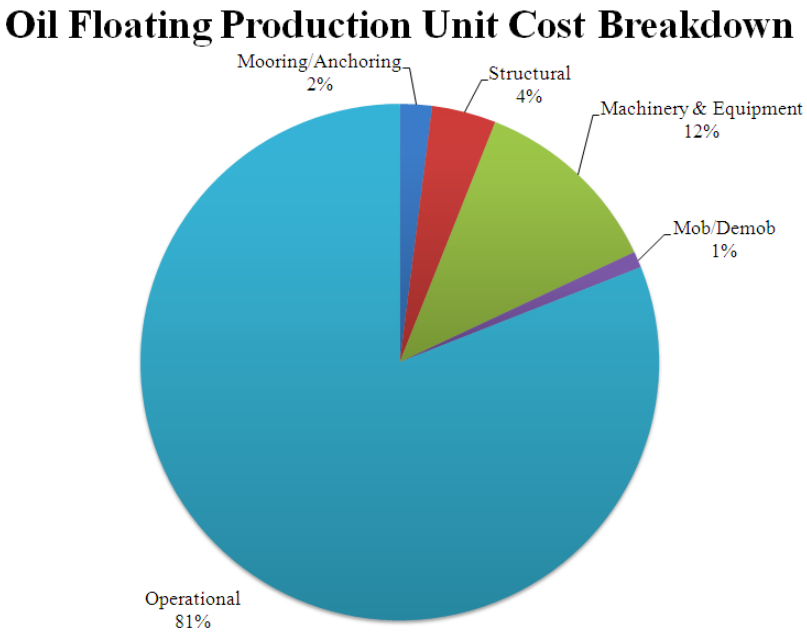
Back in time ?

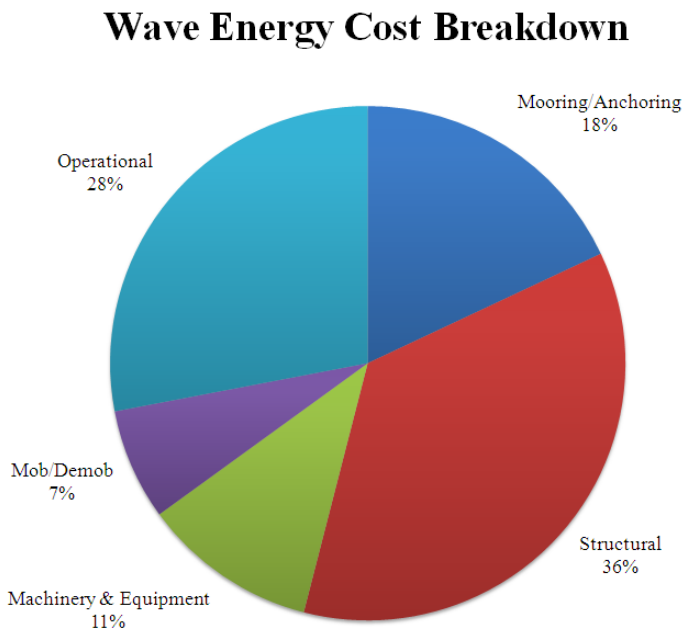


Avoiding/surviving extreme loads



Economical constrains





Research landscape

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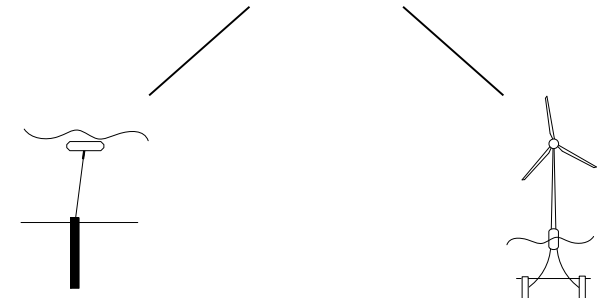
WAVE

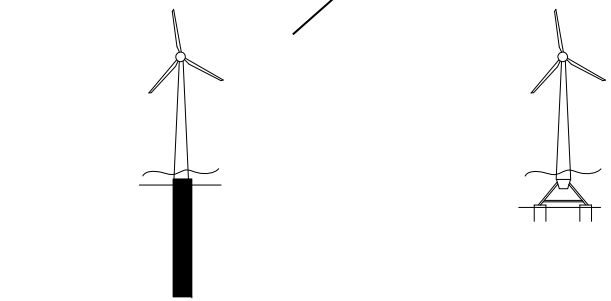
WIND

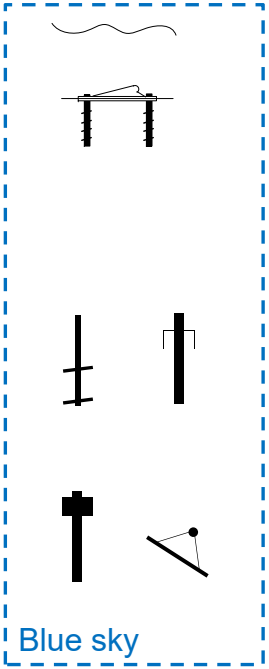
TIDAL

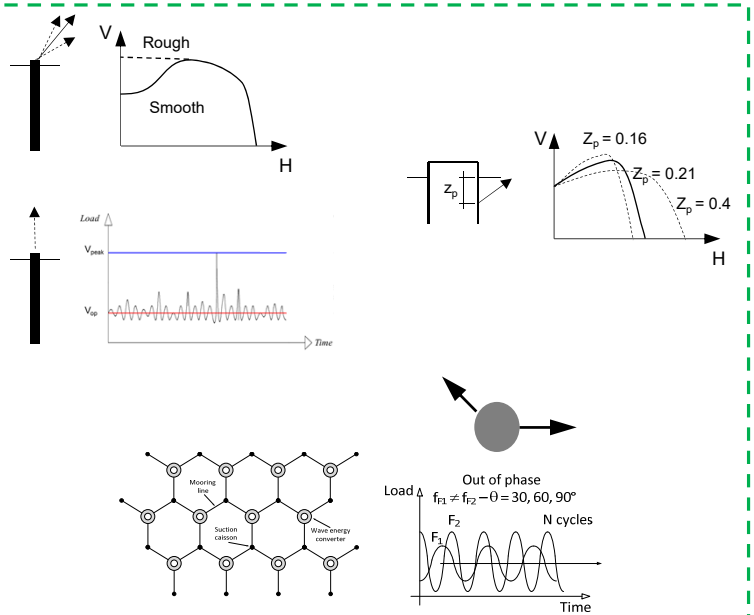
Floating

Fixed

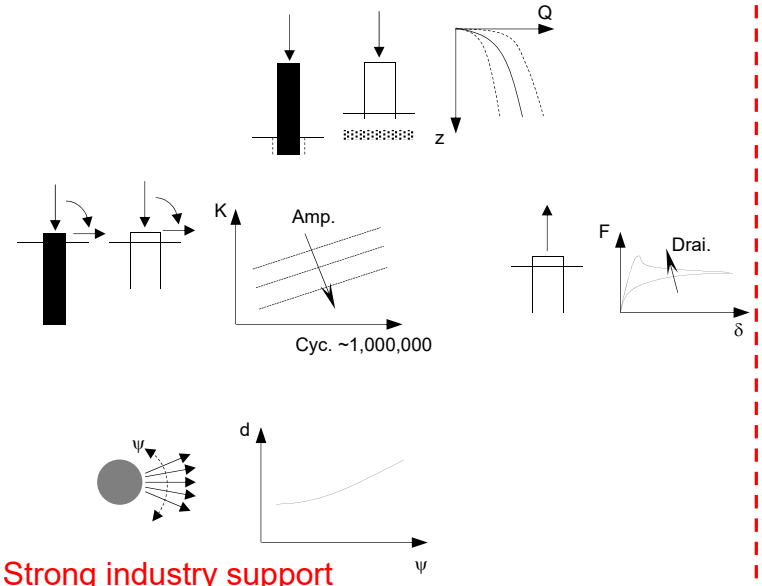








Developer support



Strong industry support

Blue sky

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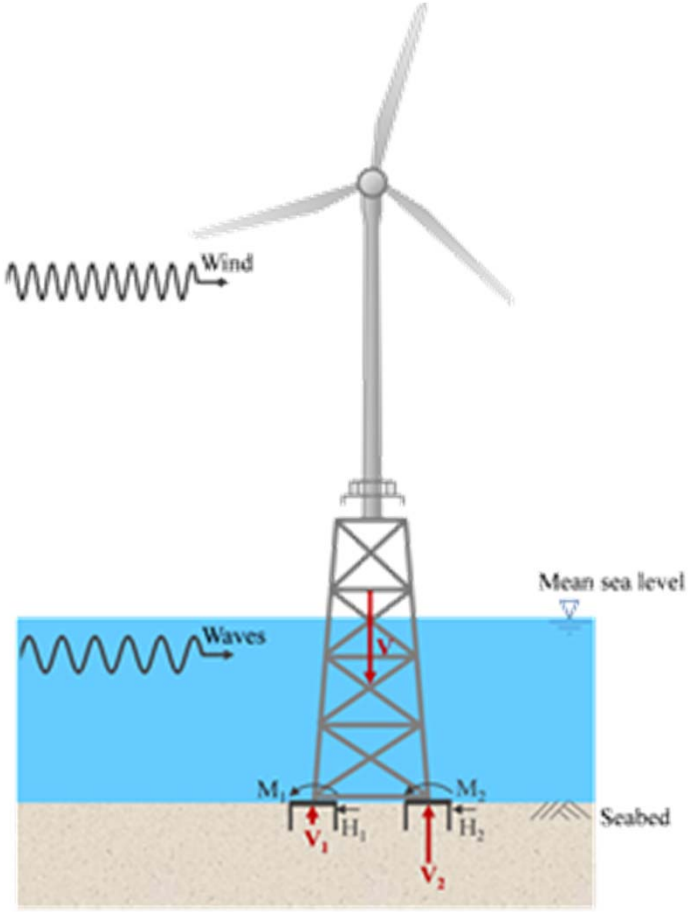
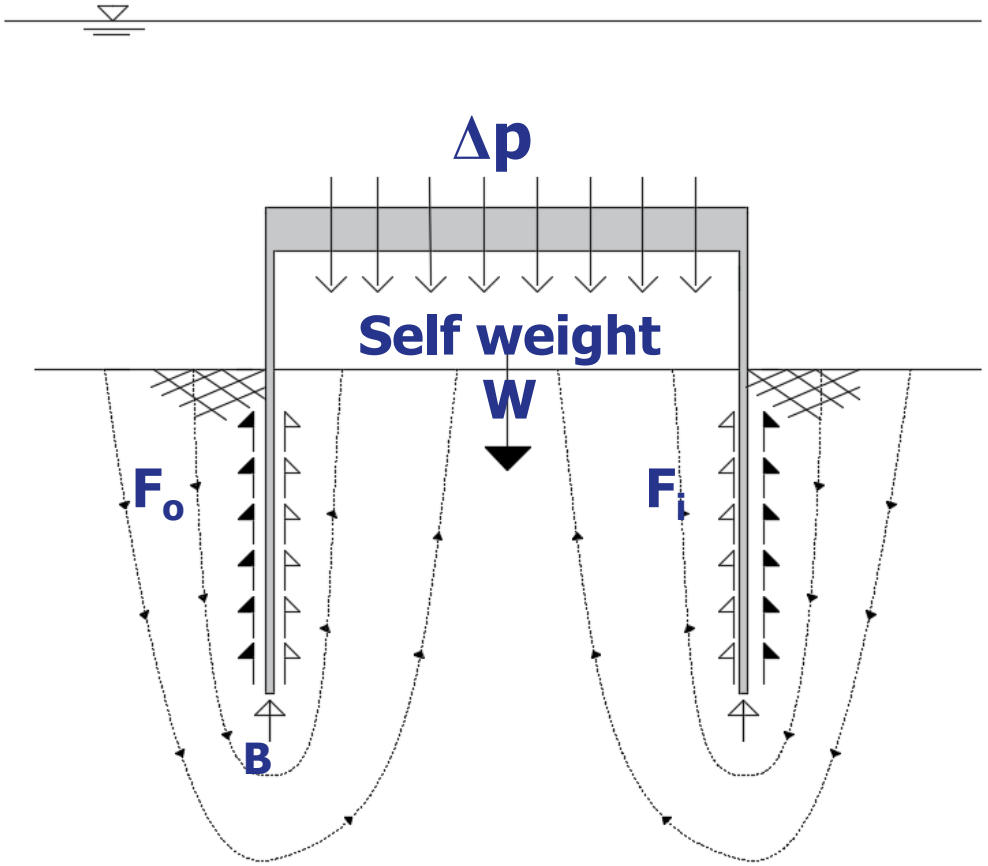
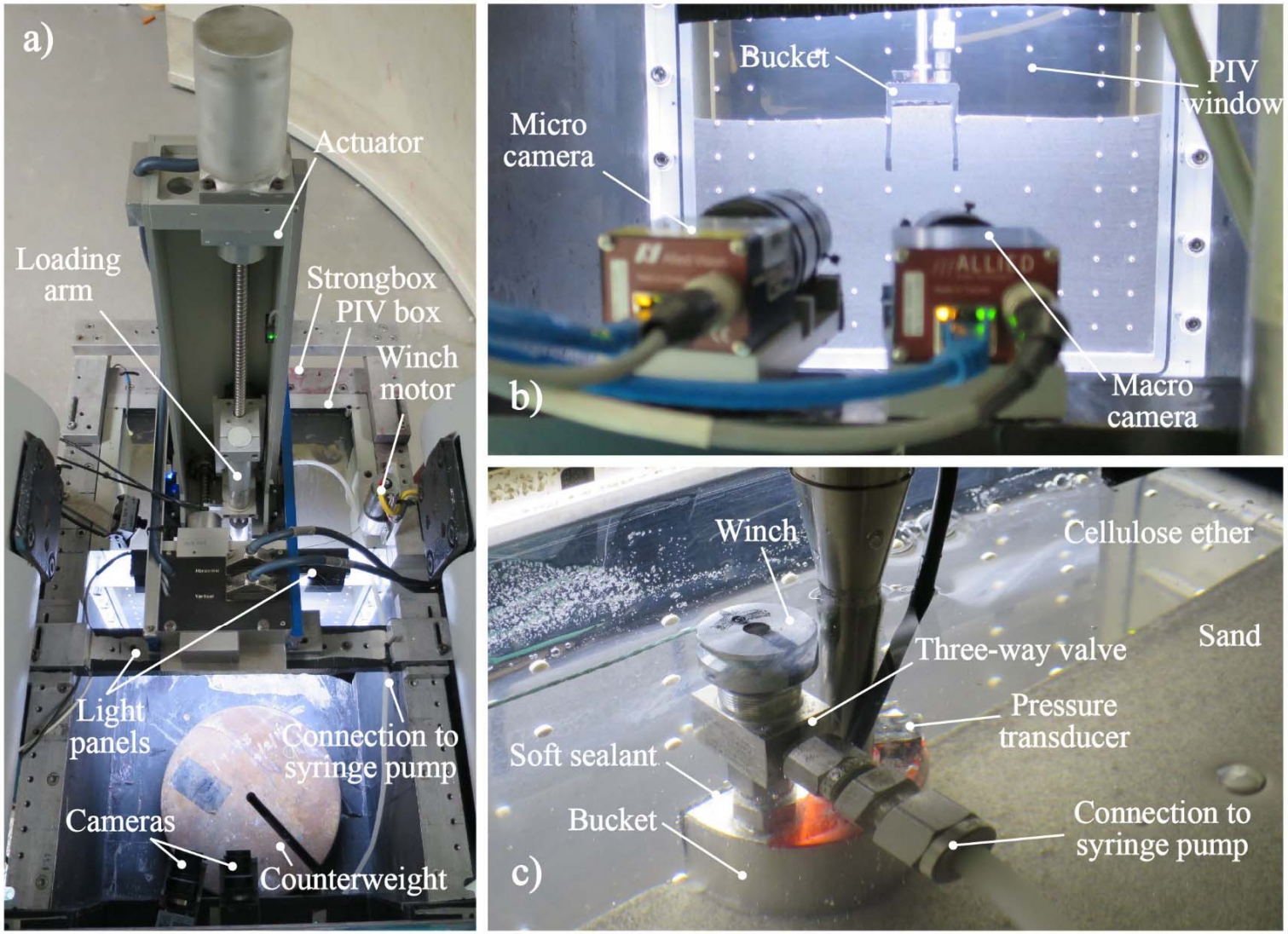
Suction caisson installation

Suction caisson





Experimental set up



Installation

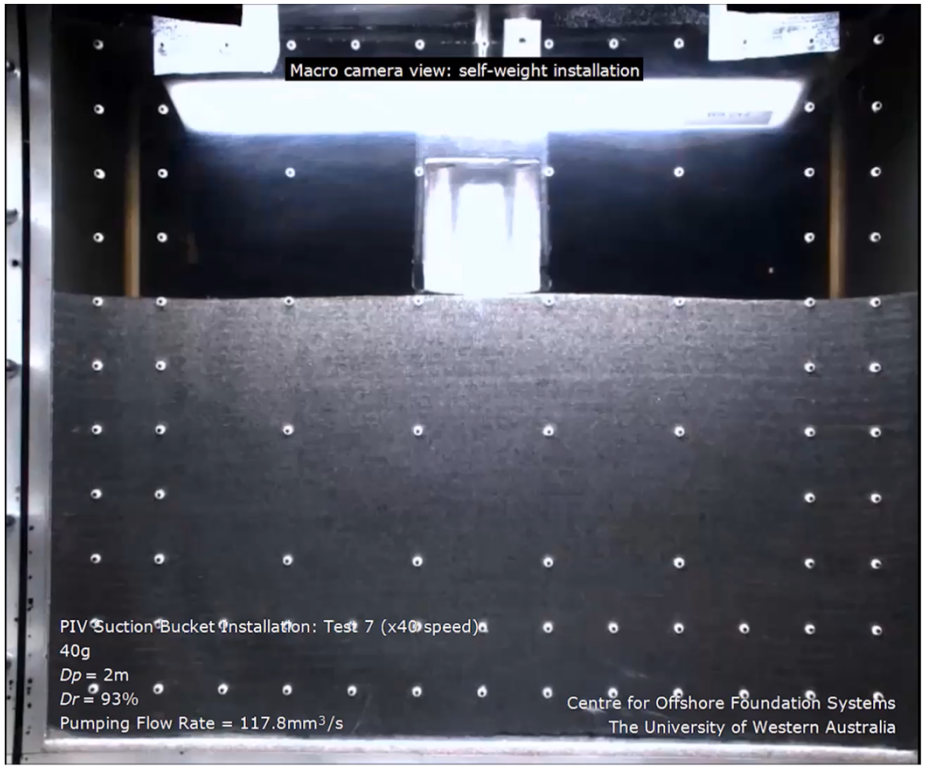
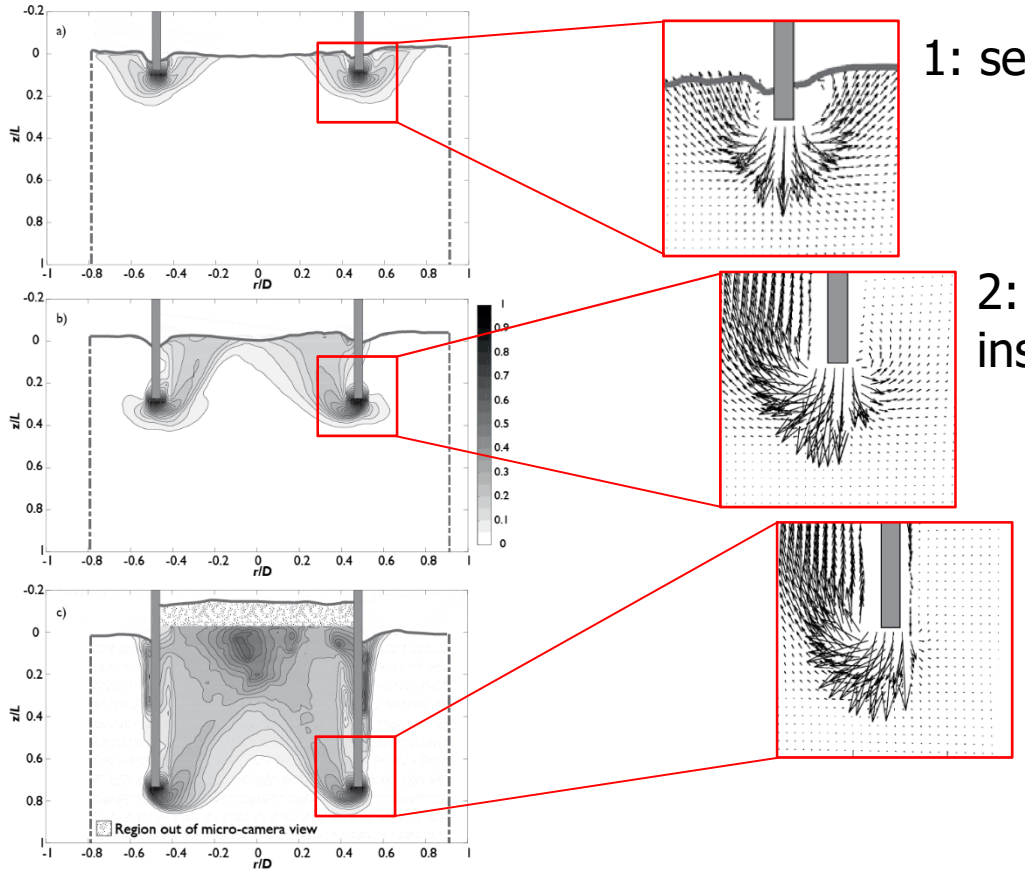


Image analysis

z/L = 0.075

z/L = 0.28

z/L = 0.74



1: self-weight installation

2: suction-assisted installation

3: suction-assisted installation

Ragni, R., Bienen, B., Stanier, S.A., O'Loughlin, C. and Cassidy, M.J. (2019). Observations during suction bucket installation in sand. *IJPMG*

Image analysis

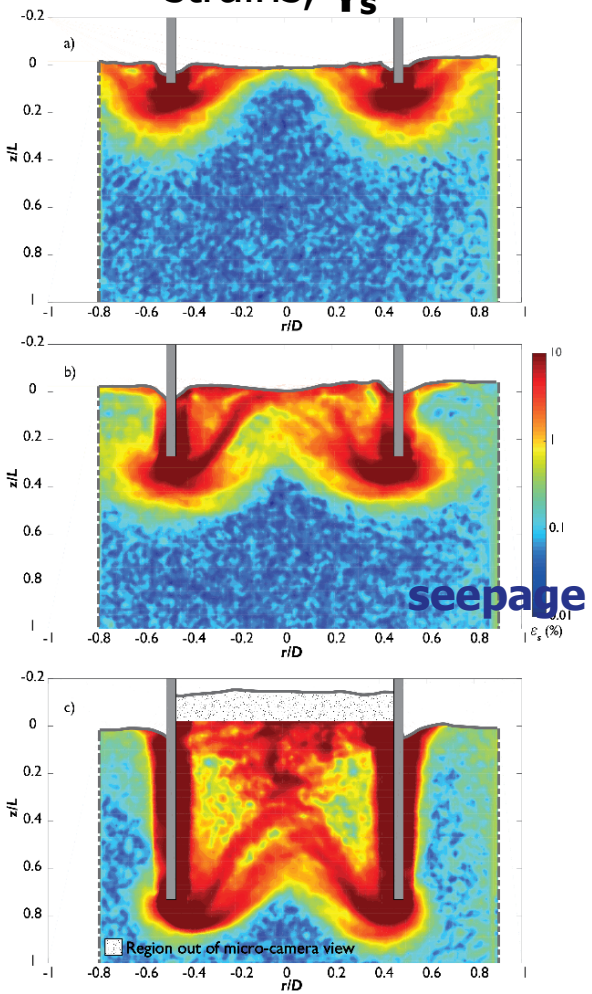
Shear strains, γ_s

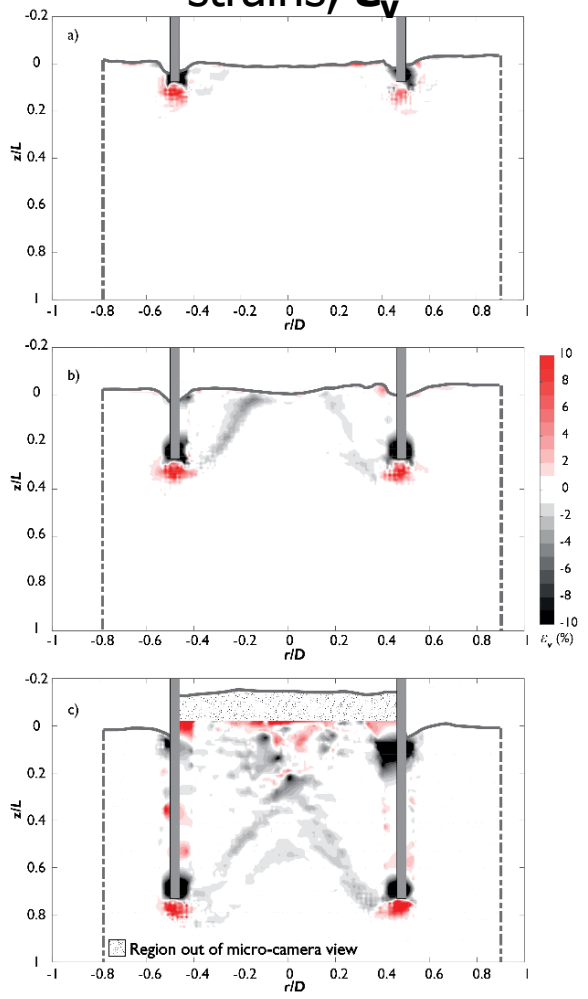
Volumetric strains, ε_v

z/L = 0.075 (self-weight installation)

z/L = 0.28 (suction-assisted installation)

z/L = 0.74 (self-weight installation)





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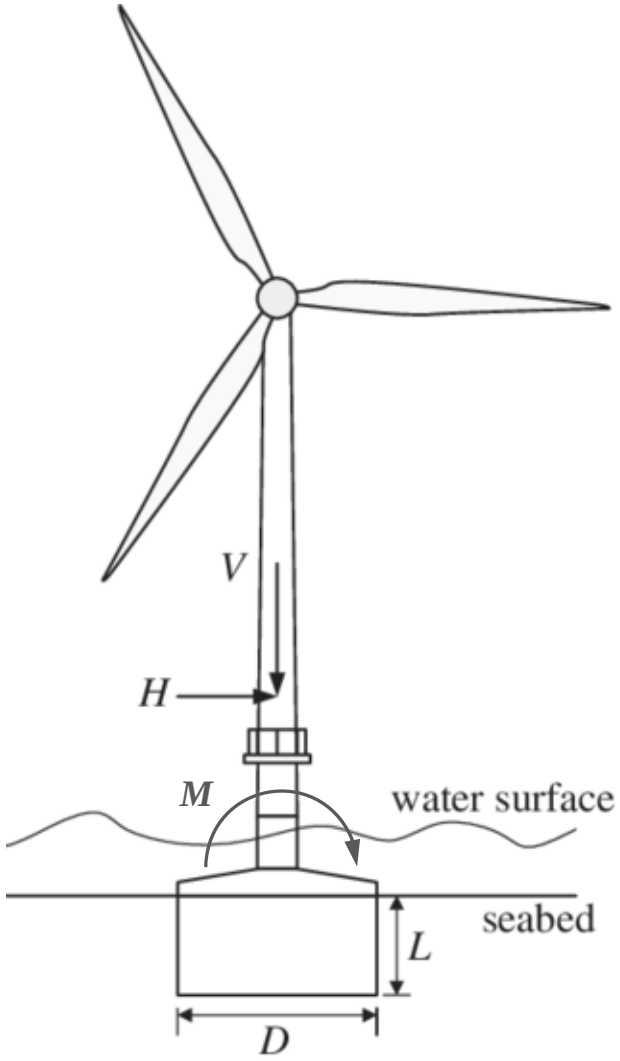
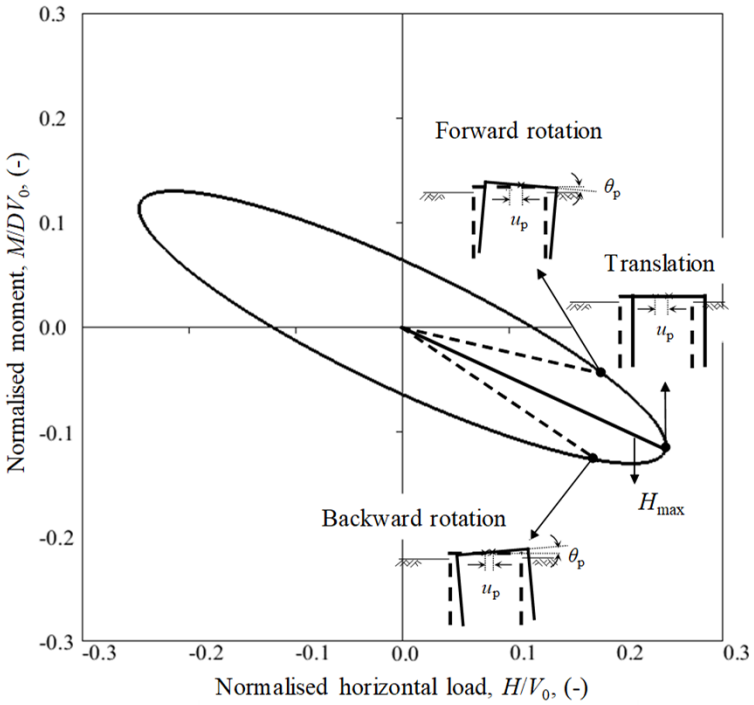
Caisson under combined loading

Caisson under combined loading

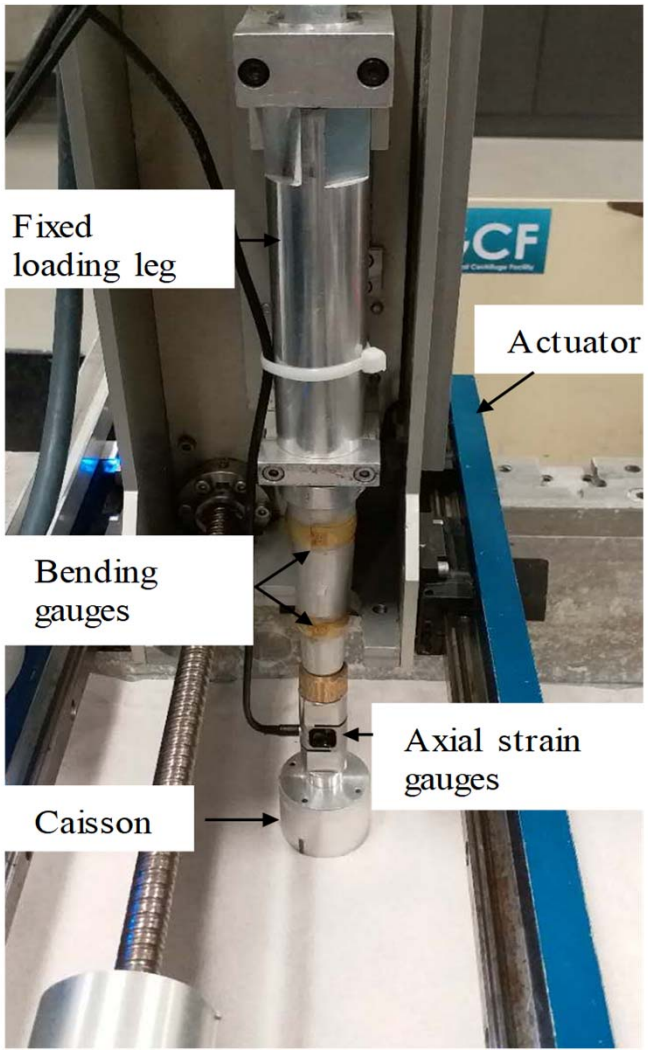


Drained response

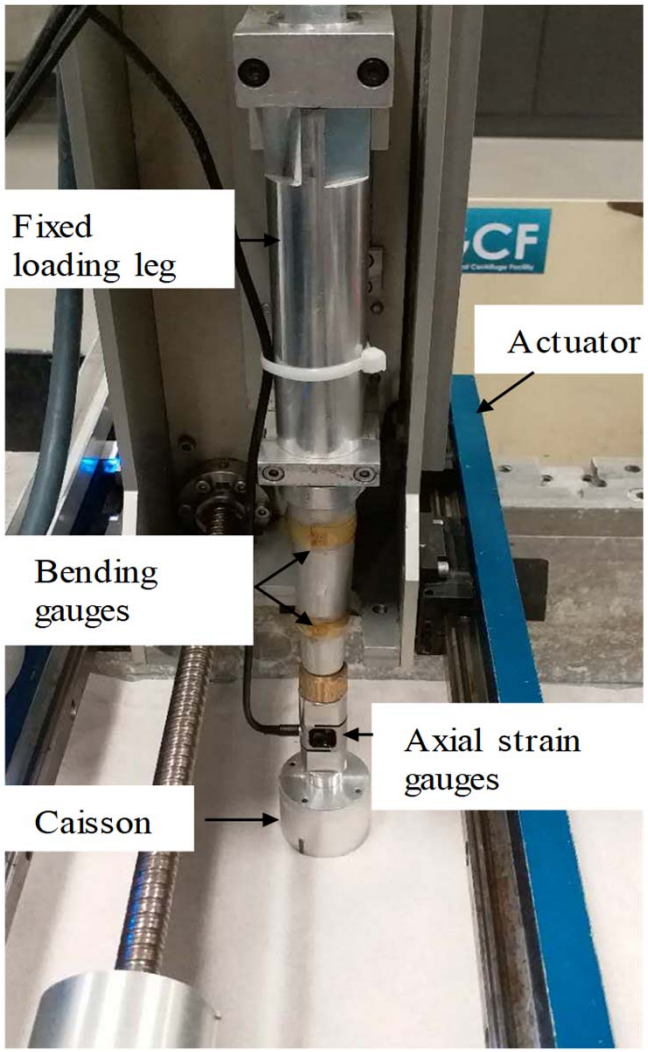


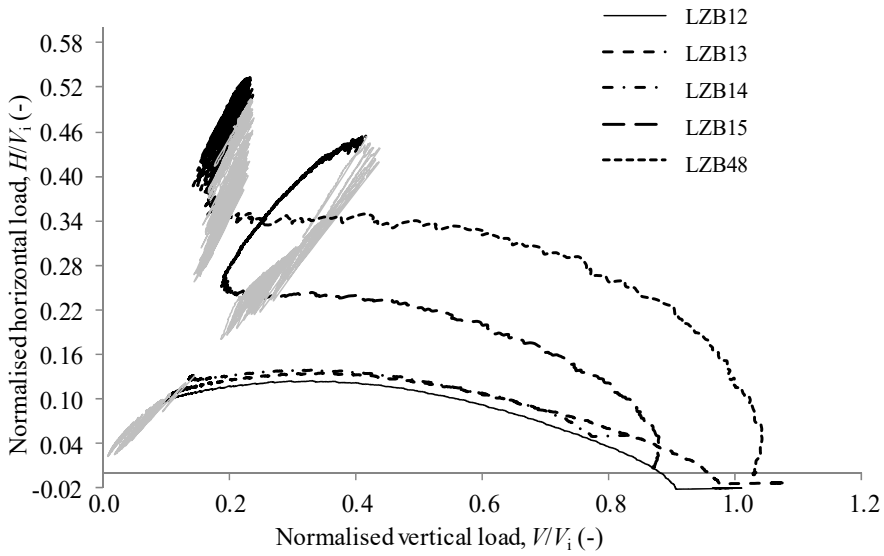
Identical for low V/H?

Experimental setup

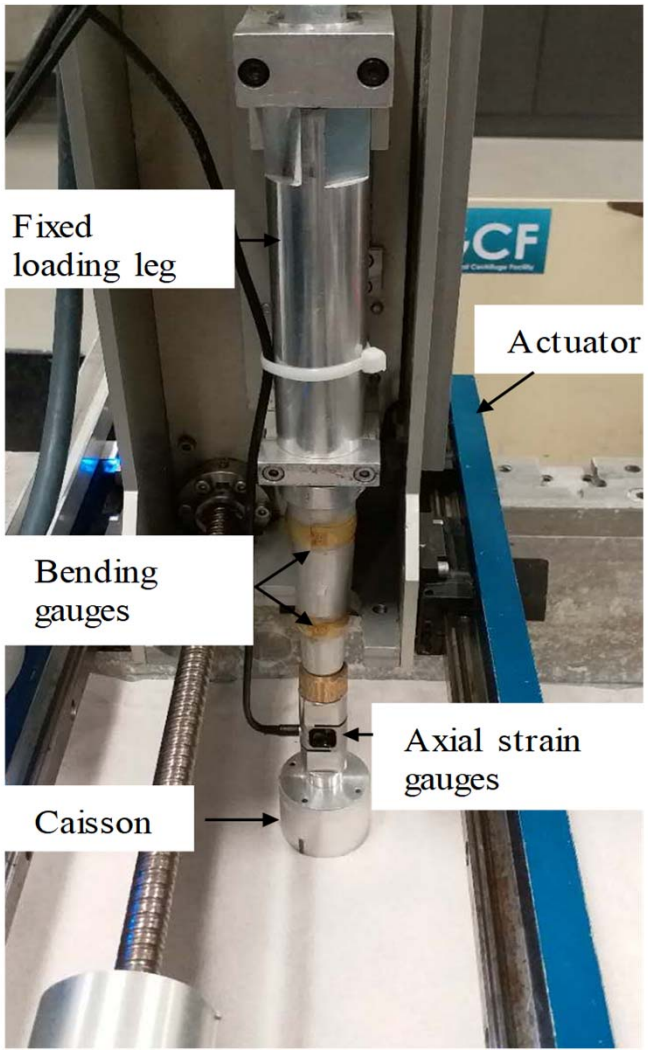


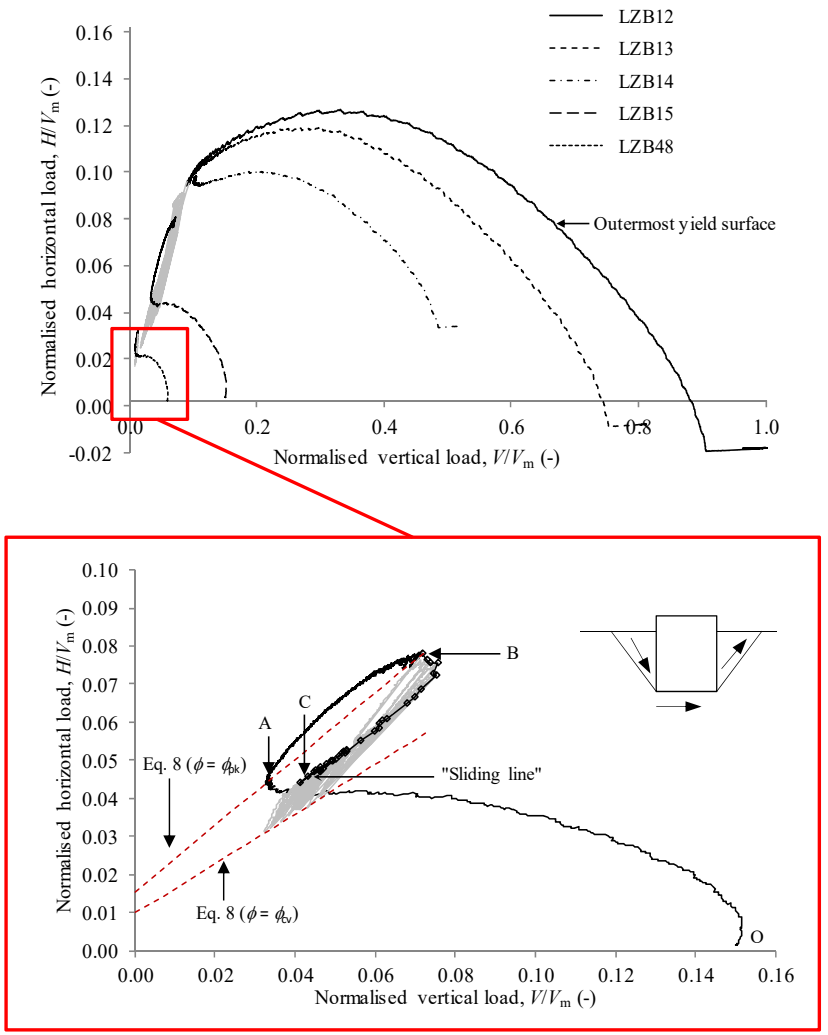
Swipe tests


Fixed loading leg
Actuator
Bending gauges
Axial strain gauges
Caisson


LZB12
LZB13
LZB14
LZB15
LZB48
Normalised horizontal load, H/V_i (-)
0.58
0.52
0.46
0.40
0.34
0.28
0.22
0.16
0.10
0.04
-0.02
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Normalised vertical load, V/V_i (-)

Swipe tests


Fixed loading leg
Actuator
Bending gauges
Axial strain gauges
Caisson


LZB12
LZB13
LZB14
LZB15
LZB48
Outermost yield surface
Normalised horizontal load, H/V_m (-)
Normalised vertical load, V/V_m (-)
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
0.0
0.2
0.4
0.6
0.8
1.0
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
A
B
C
O
Eq. 8 ($\phi = \phi_{pk}$)
Eq. 8 ($\phi = \phi_{cv}$)
"Sliding line"

Yield envelope

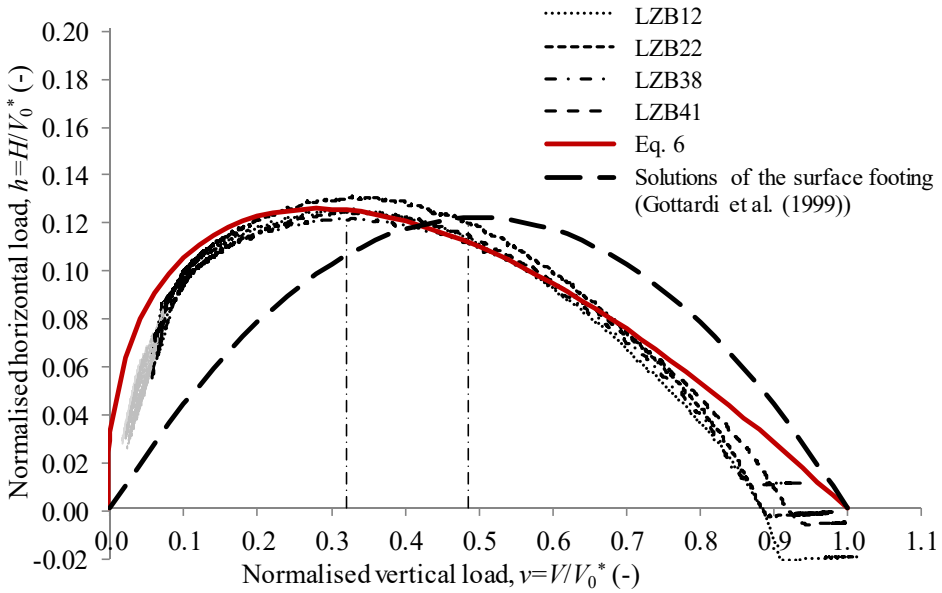
$$V_0^* = V_0(\Delta_p) = V_0(w_p + C_1|u_p|)$$

Horizontal plastic displacements

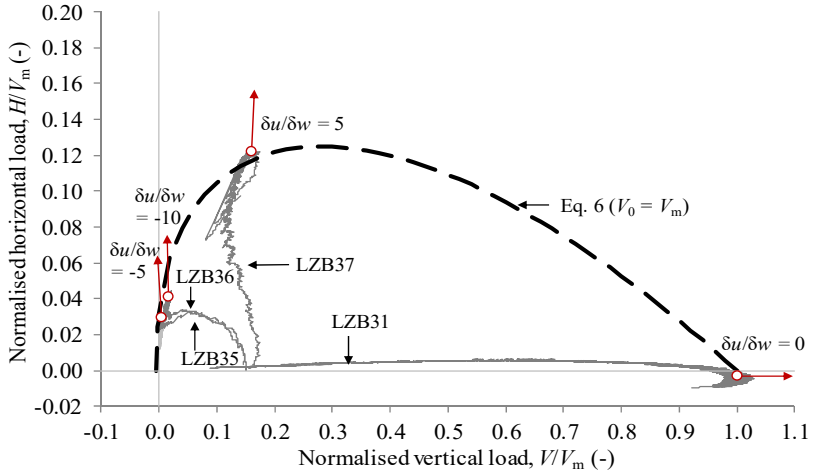
New yield envelope formulation

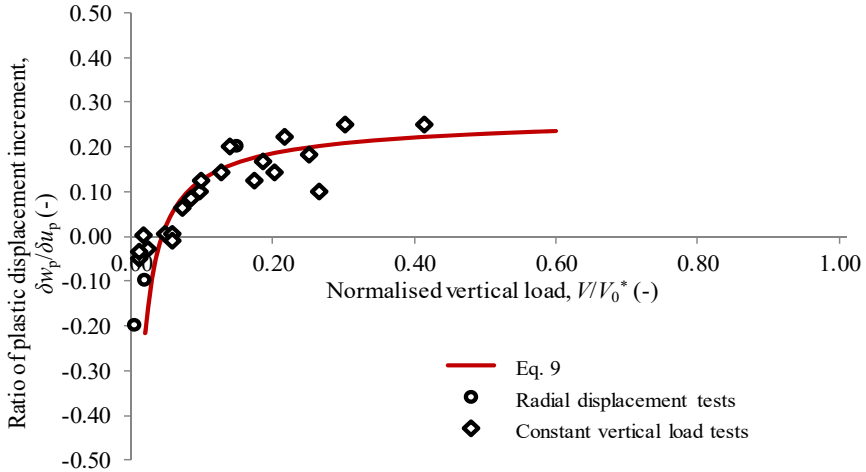
$$\boldsymbol{F} = \left(\frac{h}{h_0}\right)^2 - {\beta_{12}}^2 (v + t_0)^{2\beta_1} (1 - v)^{2\beta_2} = 0$$

$h = H/ V_0^*$, $v = V/ V_0^*$,



Flow rule



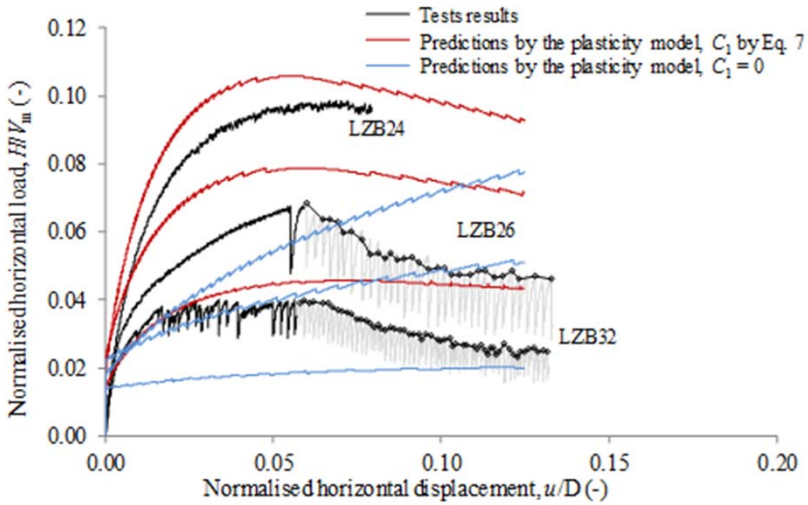


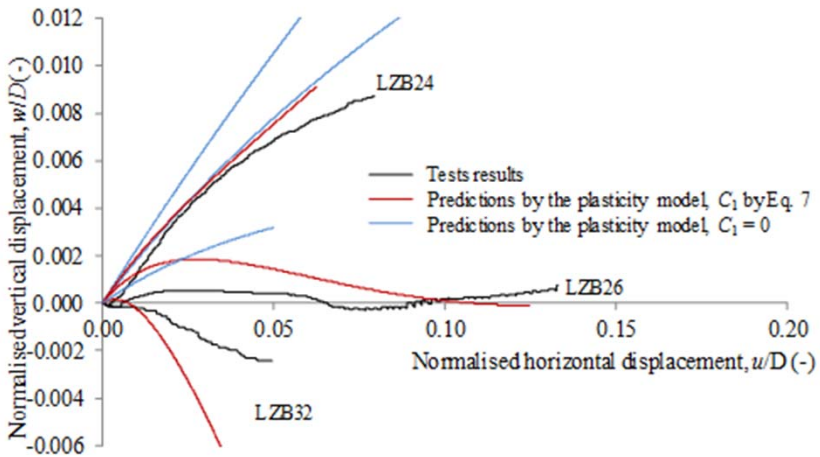
New flow rule

$$\frac{\delta w_p}{\delta u_p} = -b_1\left[b_2\left(1-\frac{V}{V_0^*}\right)\left(\frac{V}{V_0^*}+t_0\right)^{b_2-1}-\left(\frac{V}{V_0^*}+t_0\right)^{b_2}\right]$$

Plasticity model

Improved plasticity model





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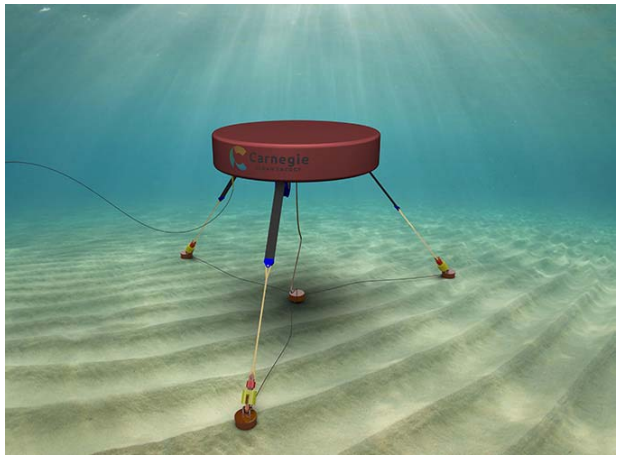
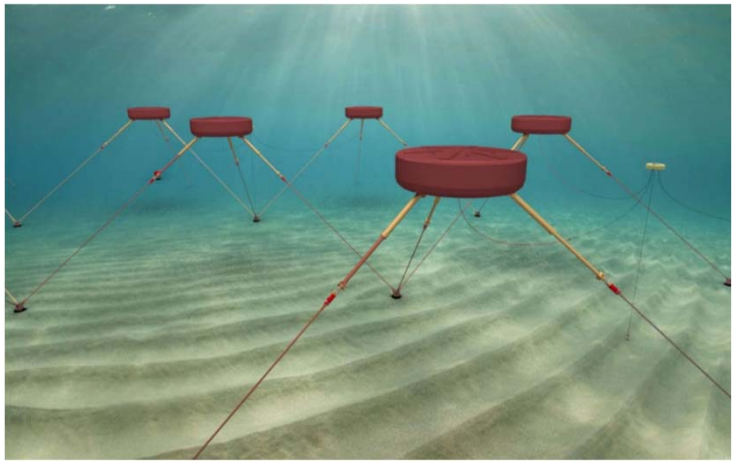
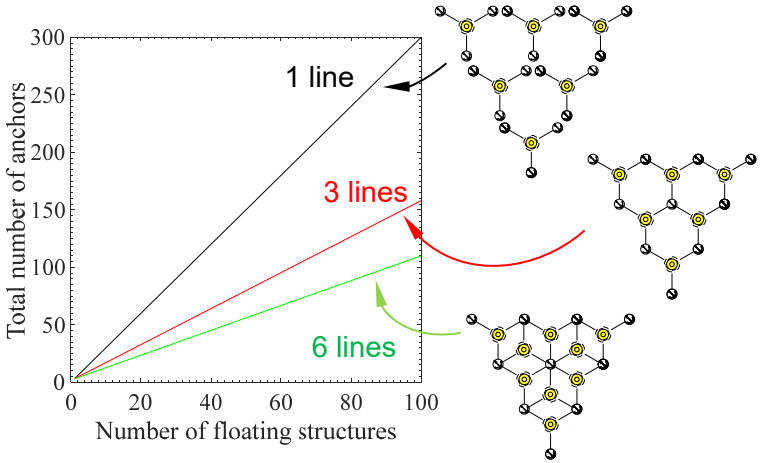
Multidirectional loading

Anchor sharing concept

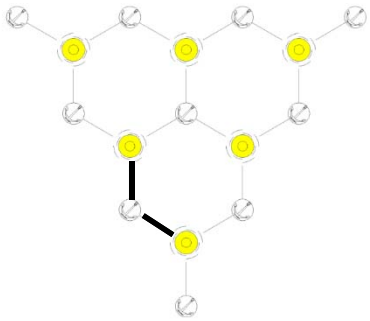
- Moving to array of WECS requires innovative anchoring systems
- Foundation sharing promising but challenging to design

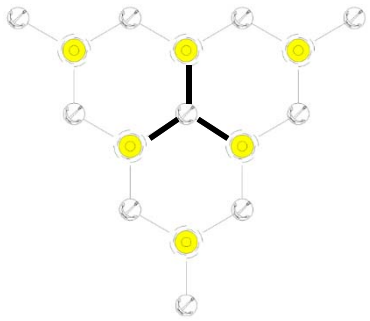




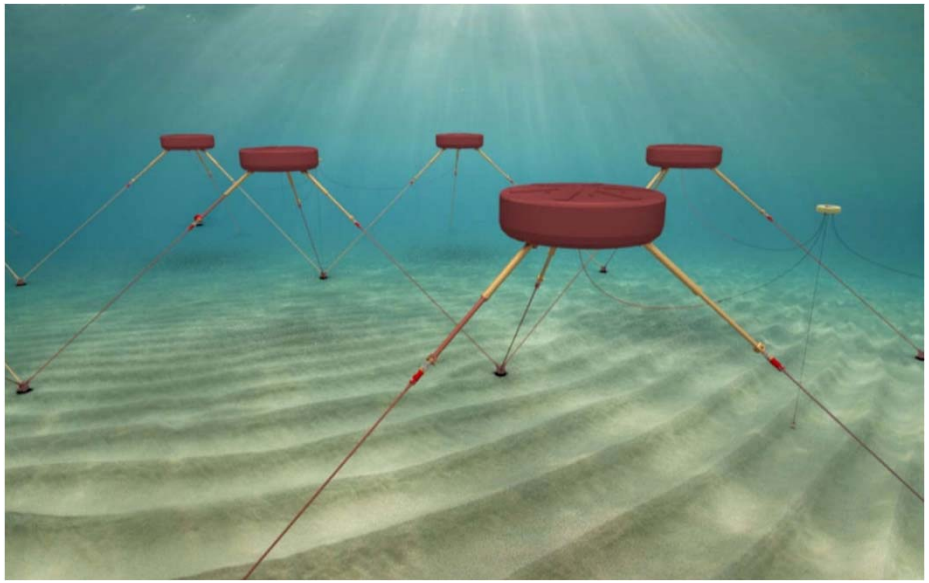


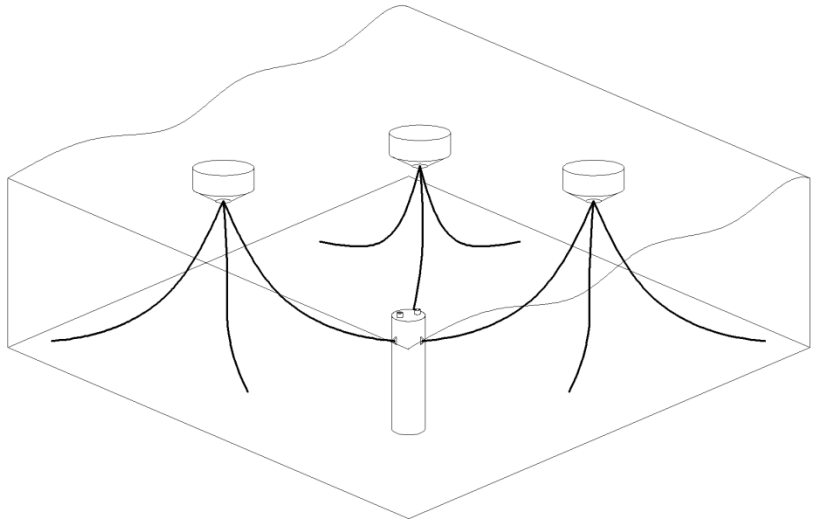
Wave

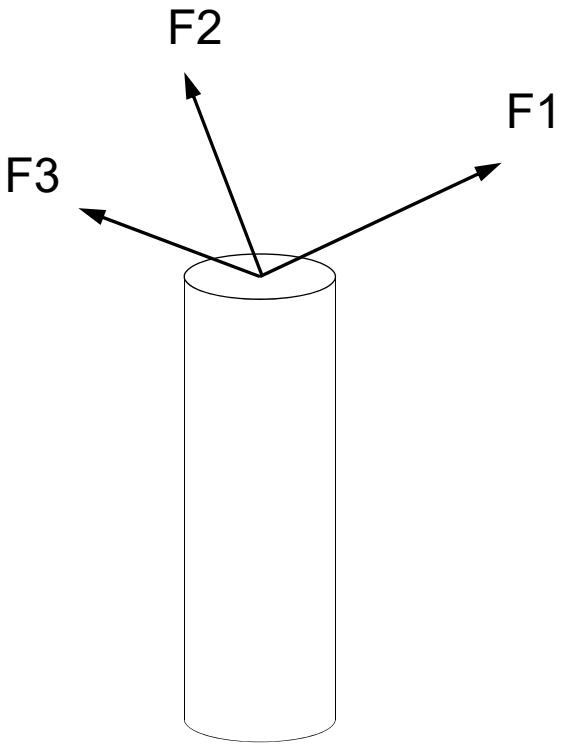




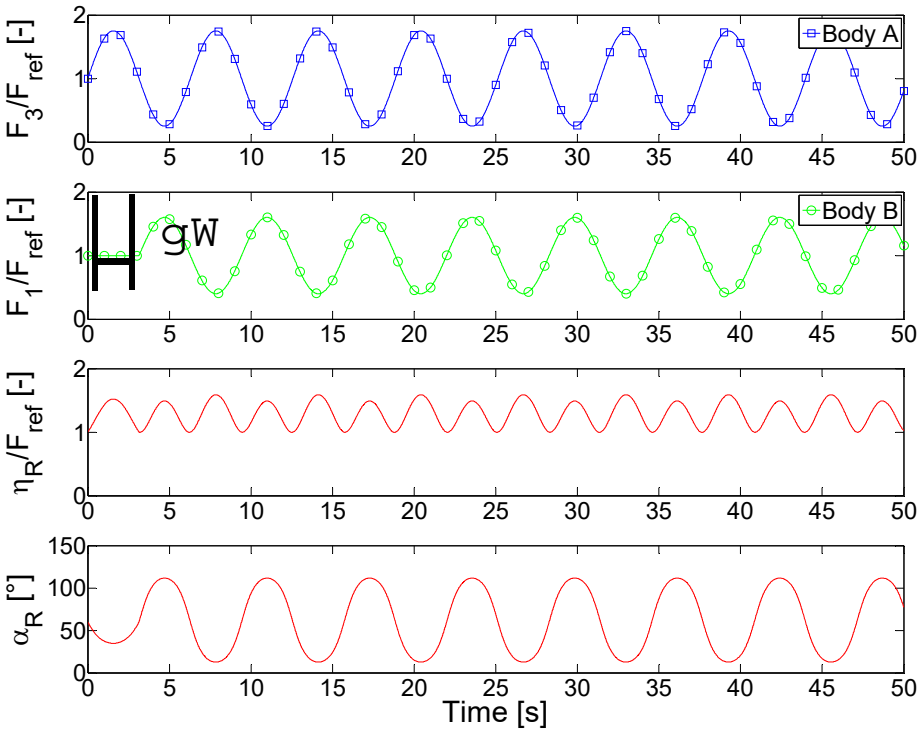
Multidirectional loading configuration

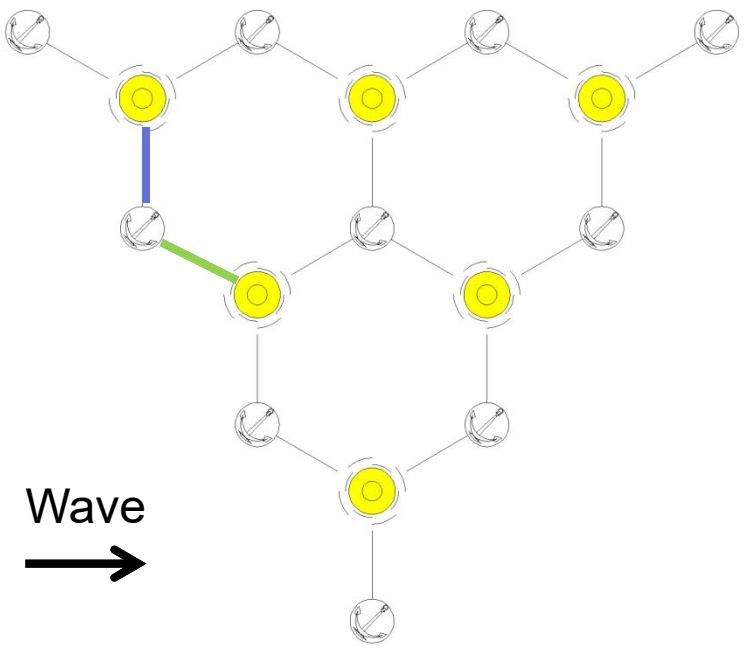






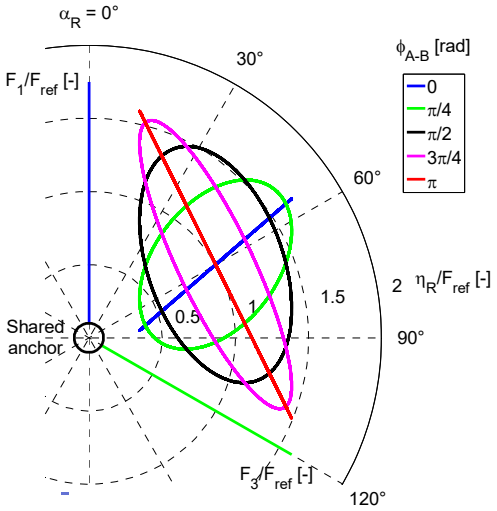
Load regime characterisation

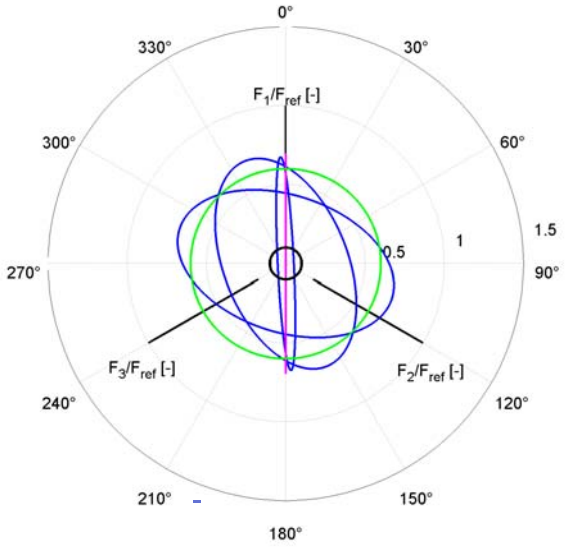




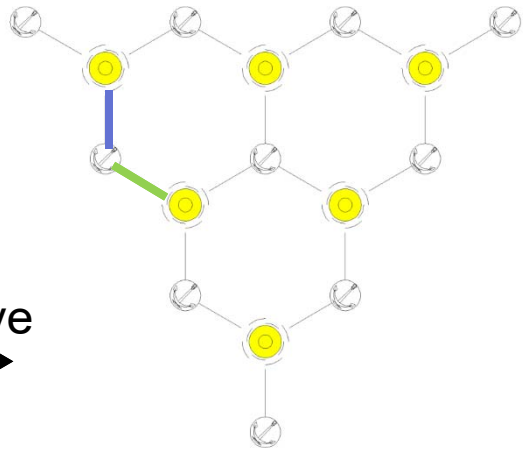
Wave period = 7.3 s
Phase angle = π rad (brought by longer wave periods)
Mooring loads are out-of-phase
Important variation of the loading direction

Load regime characterisation

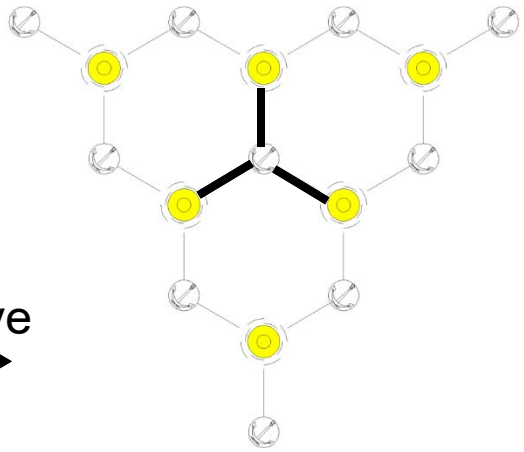




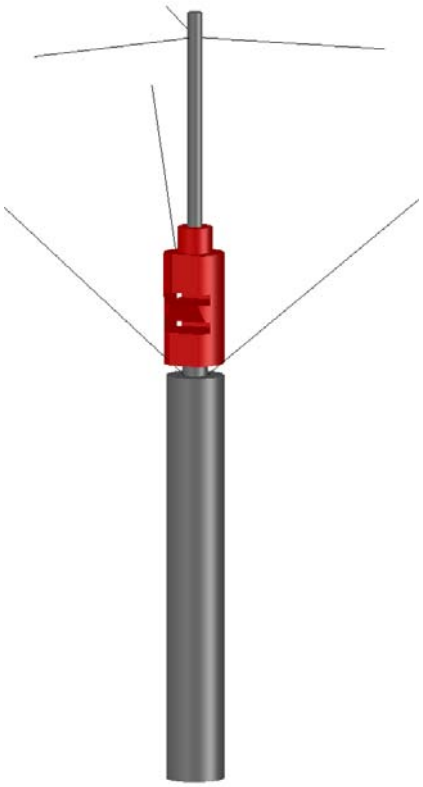
Wave →

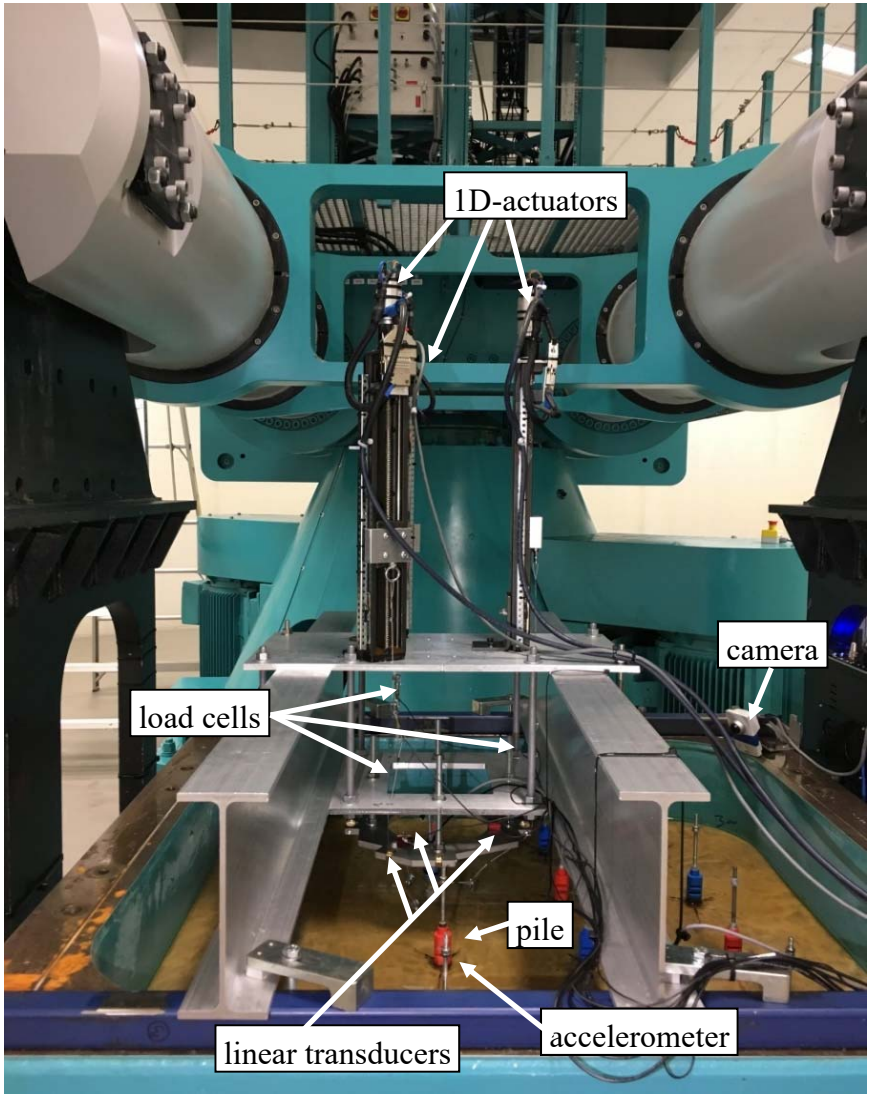


Wave →

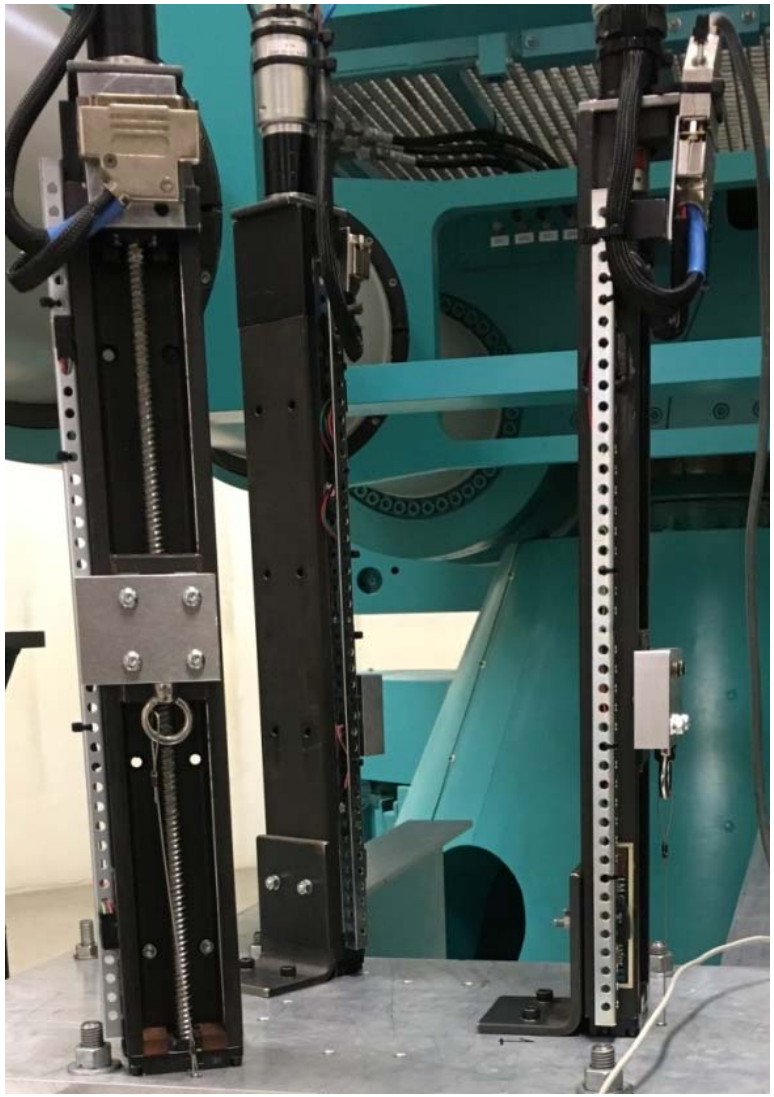


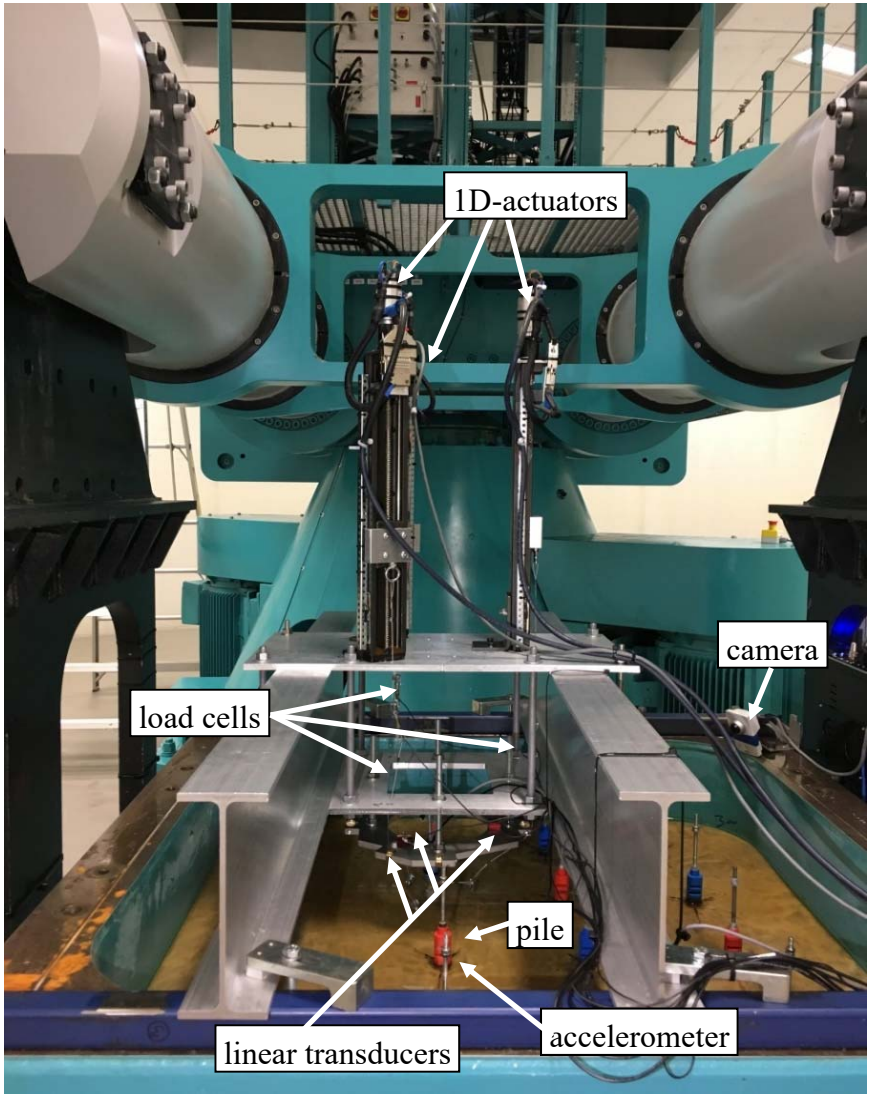
Experimental setup



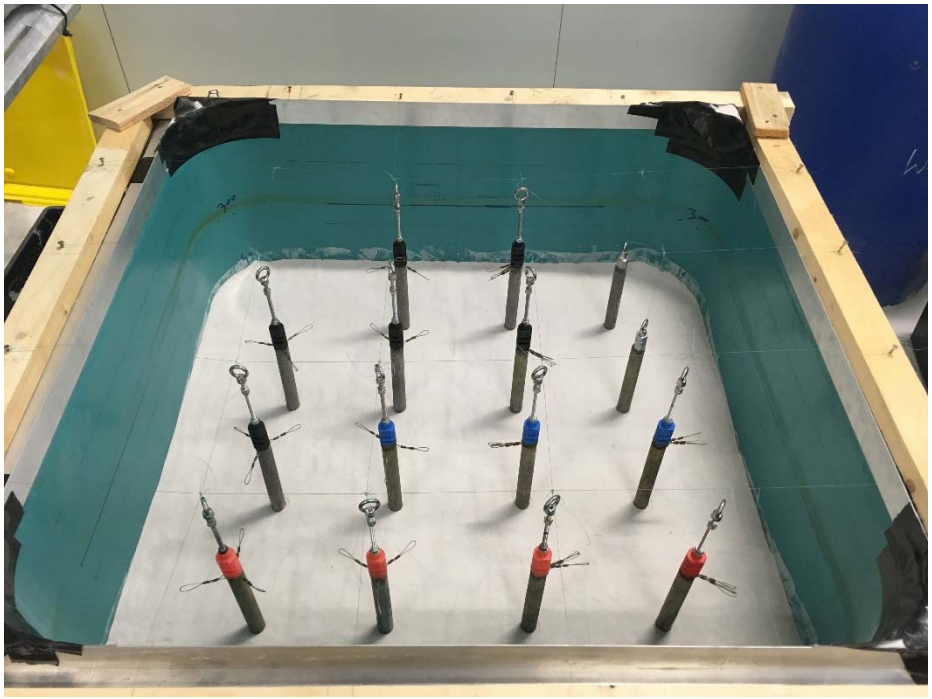


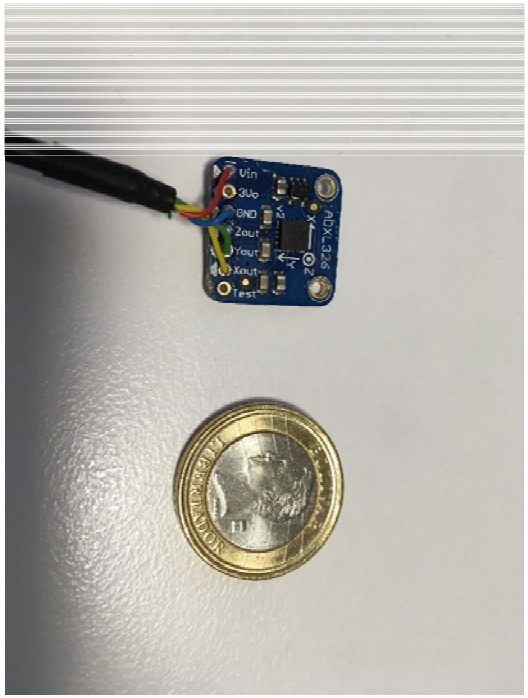
Experimental setup





Experimental setup



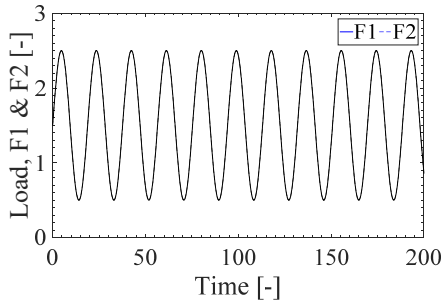


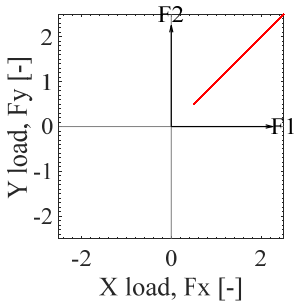
Rough piles embedded in medium dense sand

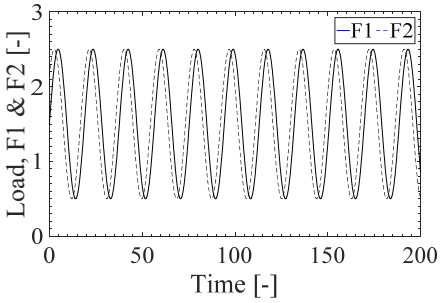
Load inclination: 40º in the vertical plan
60, 90,120, 180º in the horizontal plan

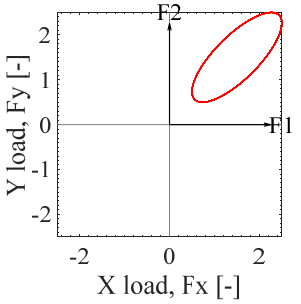
Pile motion monitored in the 6 degrees of freedom through combination of accelerometers and displacement transducers

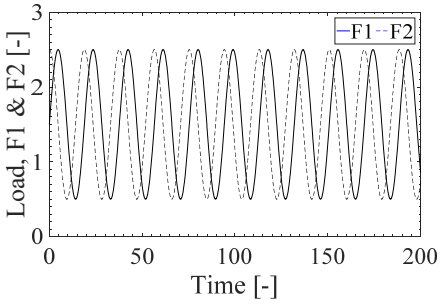
Experimental programme

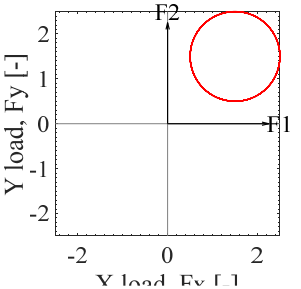


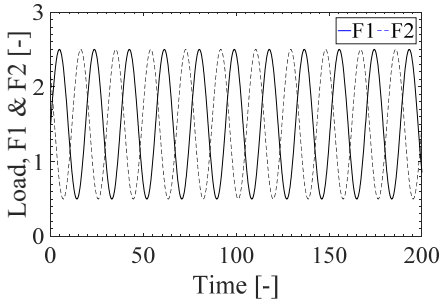


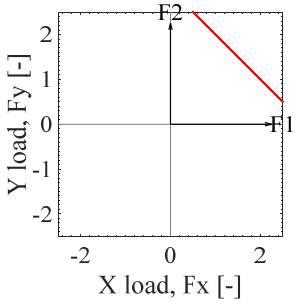












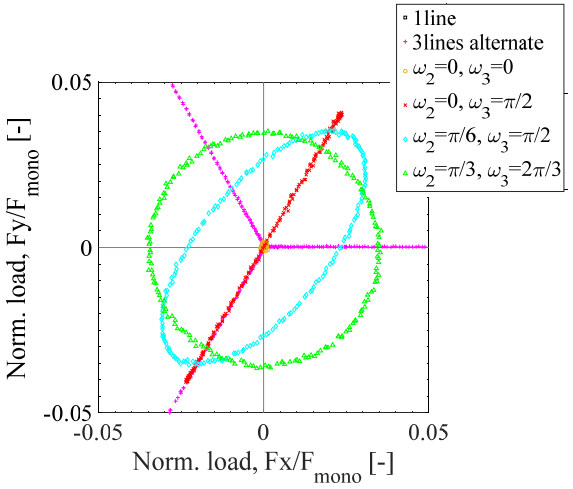
- 2 and 3 mooring lines
- 60, 90, 120 and 180º loading direction
- Alternate and phased loading
- Increasing load levels (25%, 50 and 75% of F_{mono})
- Nbr of cycles

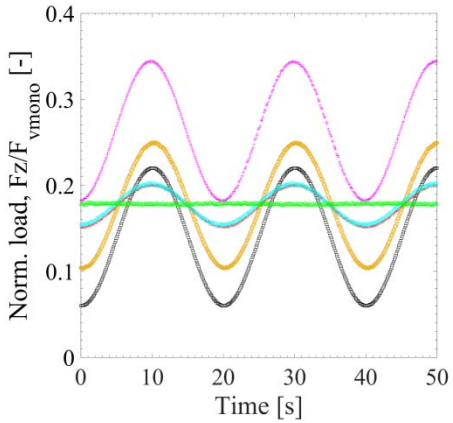
Results snapshots

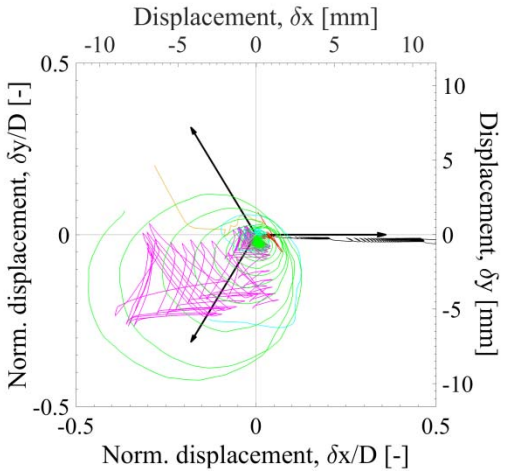
3 mooring lines - 120º - Alternate loading

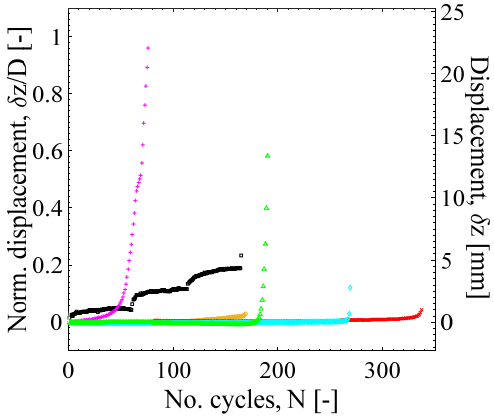
Results snapshots

3-line cyclic multidirectional loading

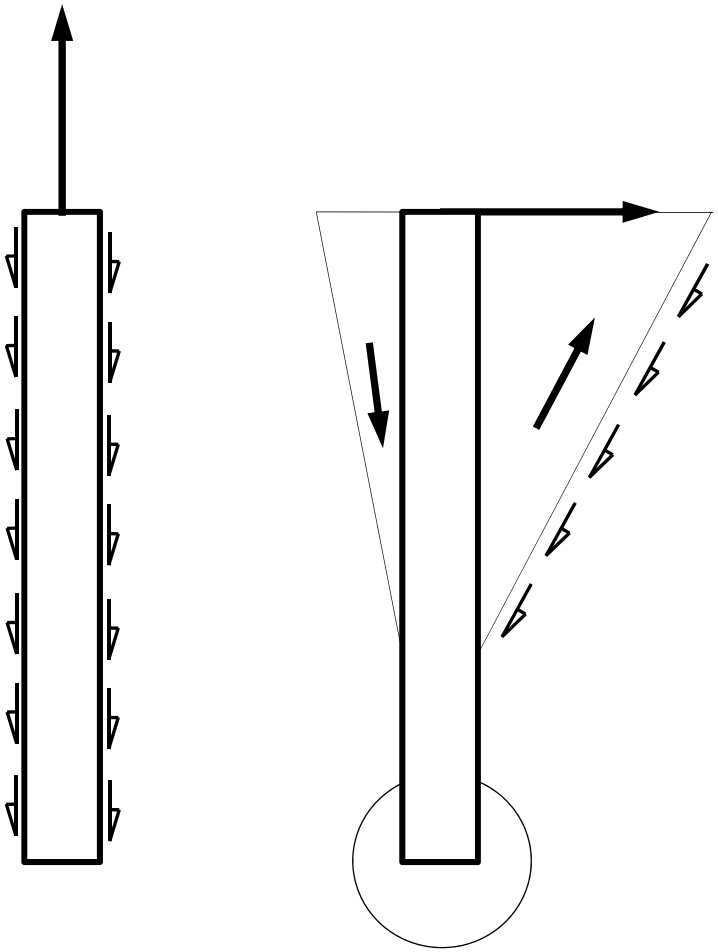


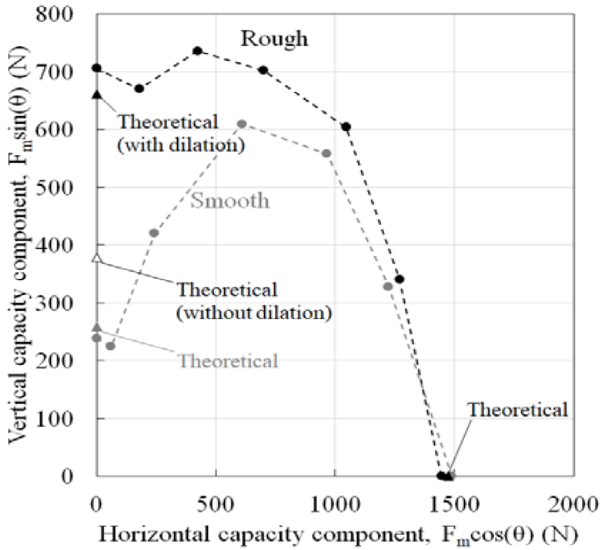


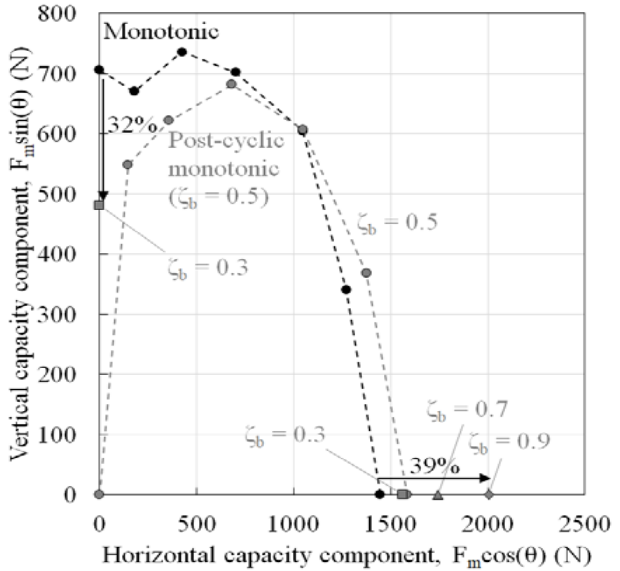




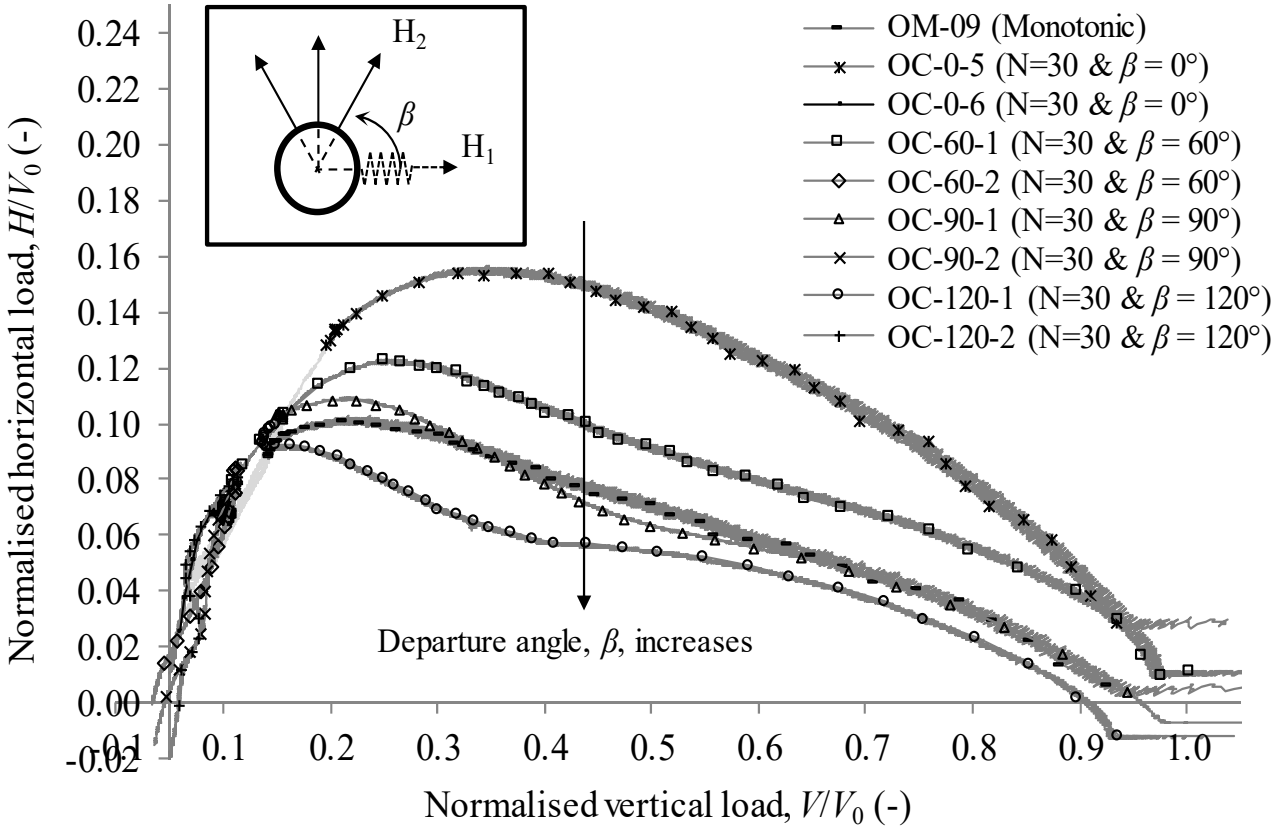
Pile under inclined cyclic loading







Caisson under multidirectional loading



Conclusions

THE UNIVERSITY OF WESTERN AUSTRALIA

- **Offshore renewable is diverse and will play an important role in the energy mix**
- **New boundary value problems raise new scientific challenges**
- **Centrifuge modelling will provide insights and answers**
- **New modelling techniques are required**