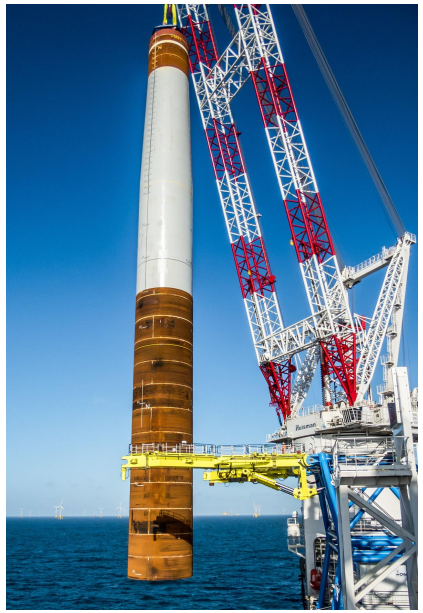
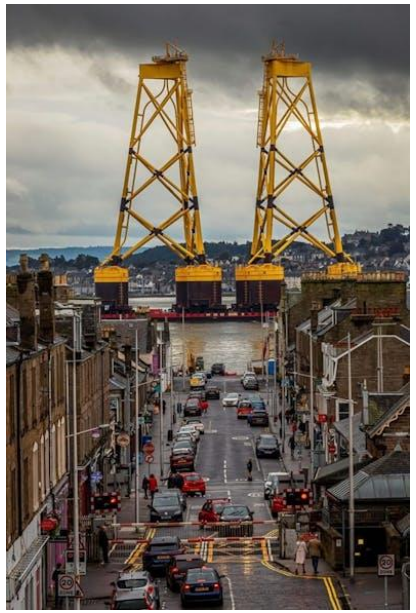
Geotechnical research to unlock safe, cost-efficient foundations to underpin offshore wind in Australia

Prof. Fraser Bransby, Prof. Christophe Gaudin, Prof. Phil Watson, Prof. Conleth O'Loughlin, Prof. Britta Bienen, Prof. Shazzad Hossain & Prof. Mark Randolph

Centre for Offshore Foundation Systems ('COFS')
The University of Western Australia





Today's talk will:

Show that foundations are a key part of (future Australian) offshore wind infrastructure and are important because of:

- Cost
- Installation risk
- Noise during installation

Show how we reduce each of these through research.

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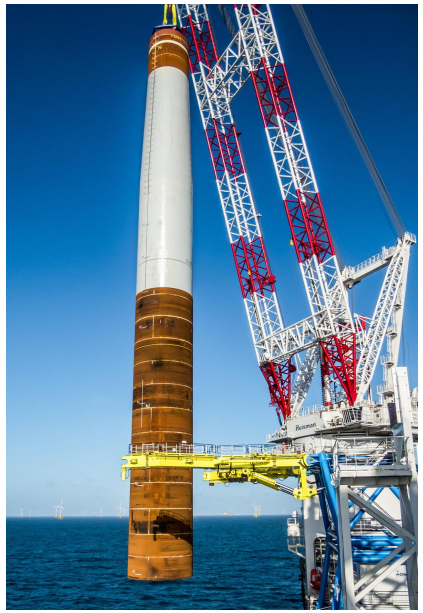

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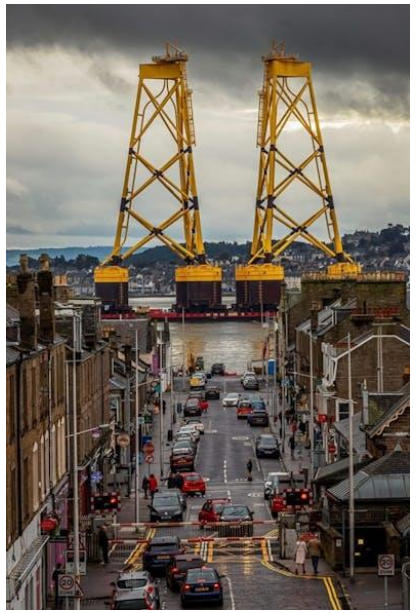

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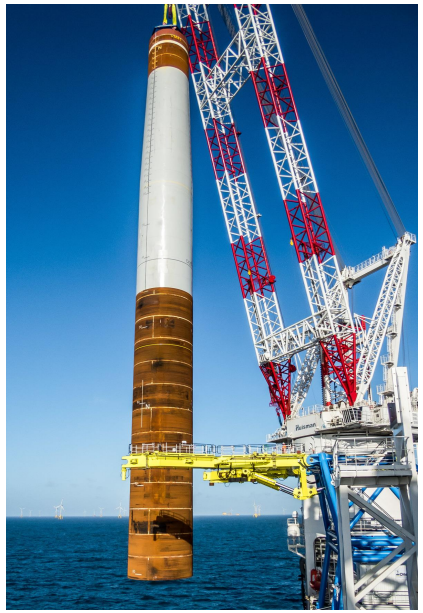

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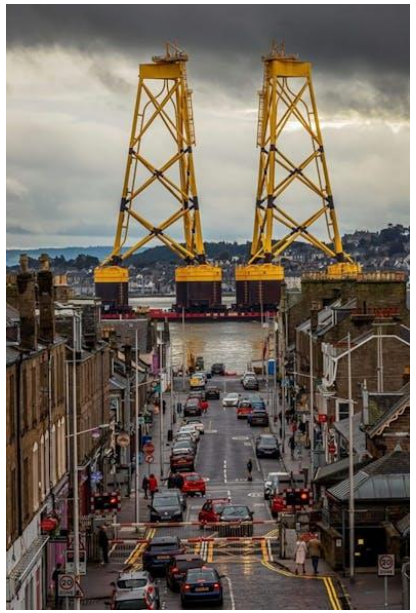

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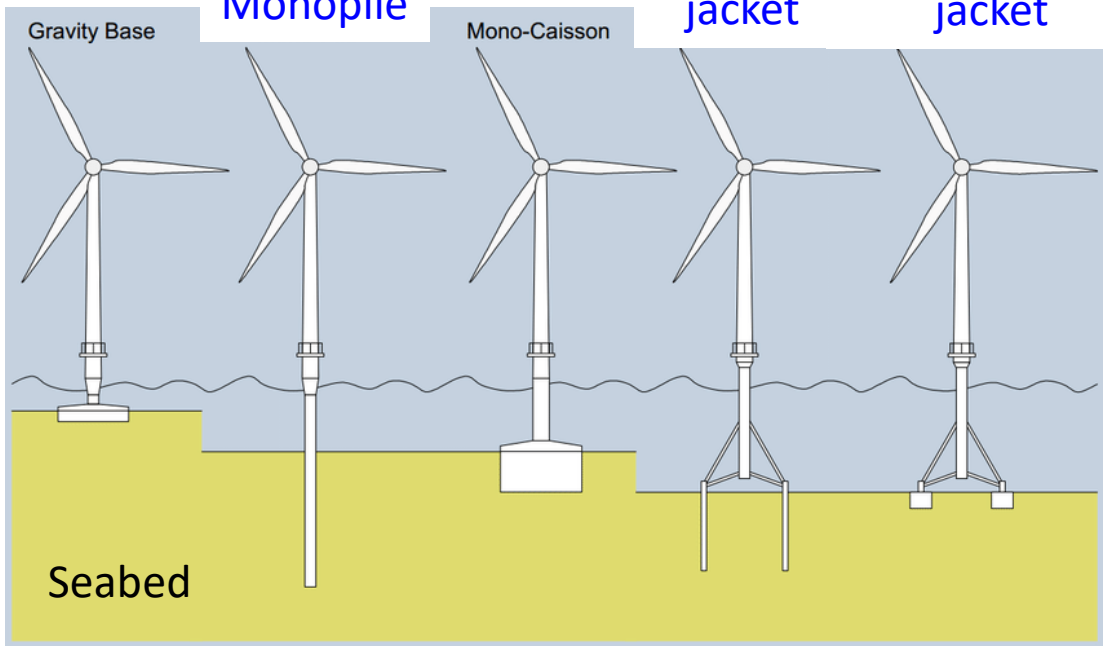
Different types of foundation systems

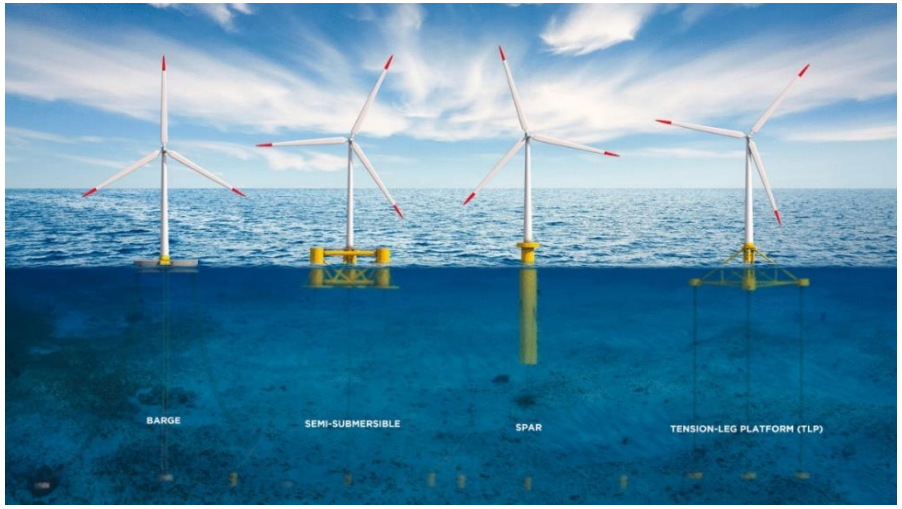
Wind: Bottom-fixed

Monopiles, suction bucket jackets, piled jackets etc.



Covered (briefly) today

Floating wind



Anchored to the seabed

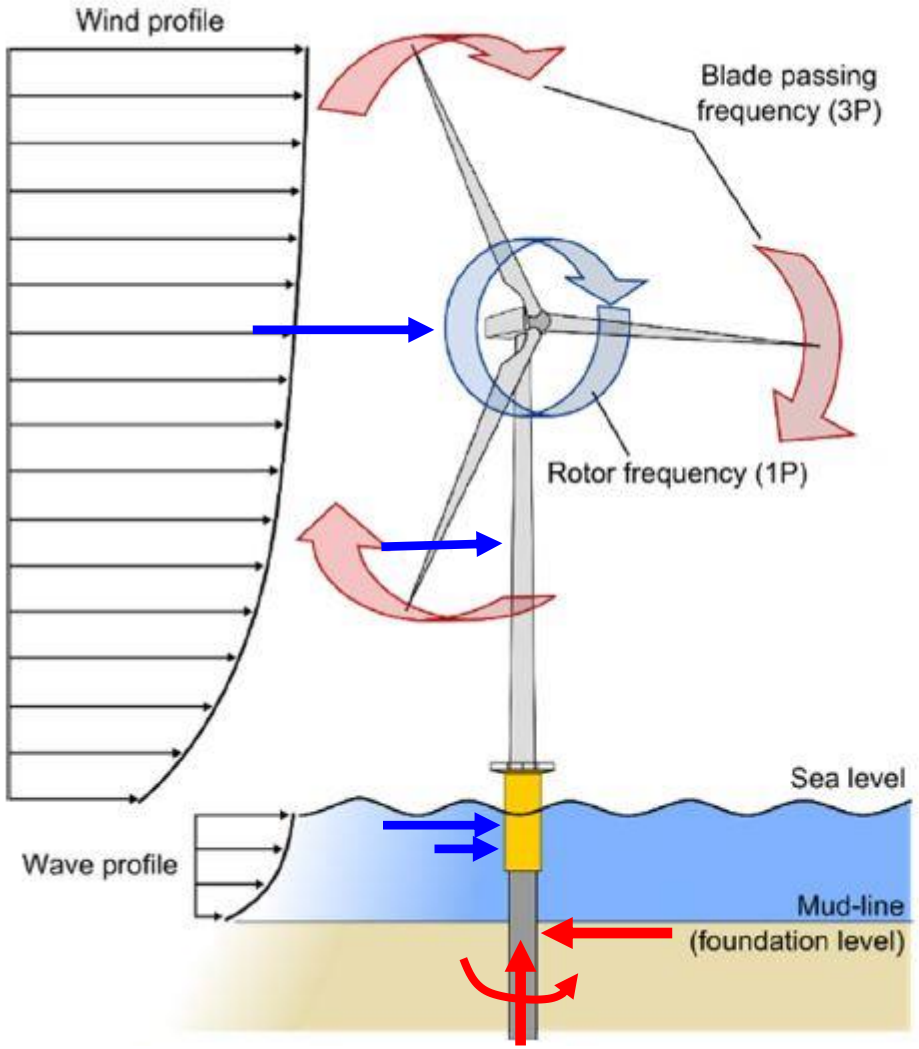
Need mooring system and anchor design

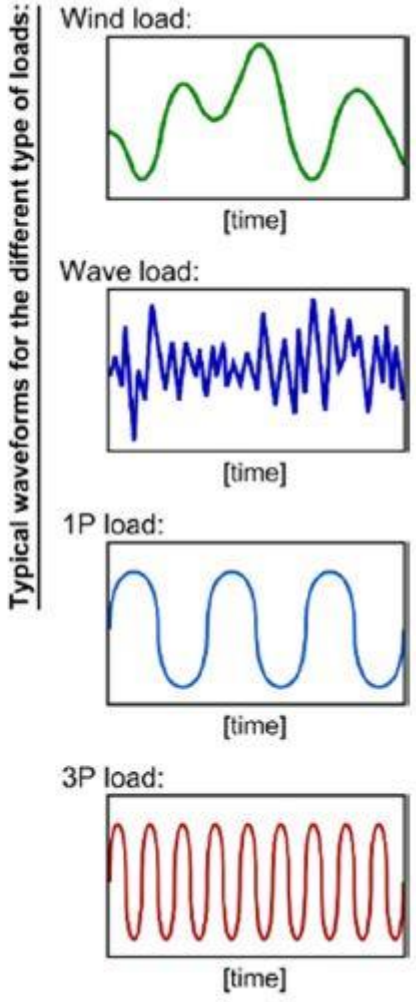
Covered by COFS but not the topic today

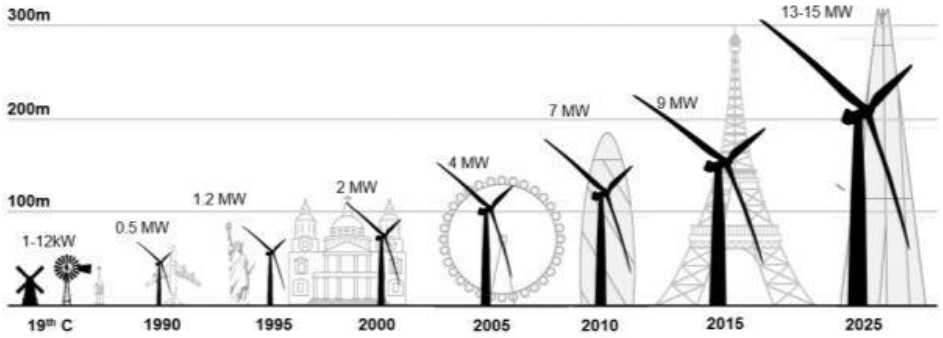
Wave energy

What is the foundation for? (Loadings)

→ Foundation designed to support the turbine for all likely loading conditions







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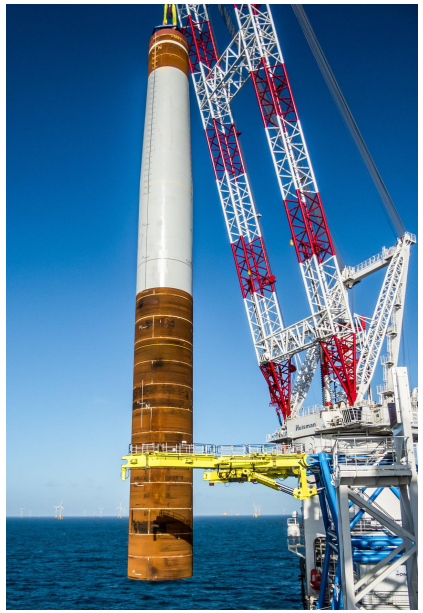

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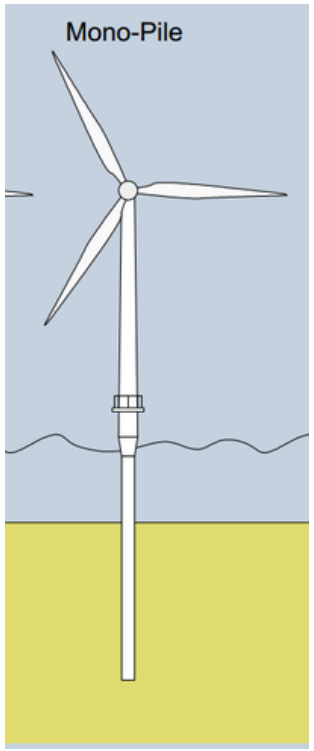
Monopiles



Most common type globally is the driven monopile

Source: DEME, SeaMade

Pile installation

Most common type globally is the driven monopile

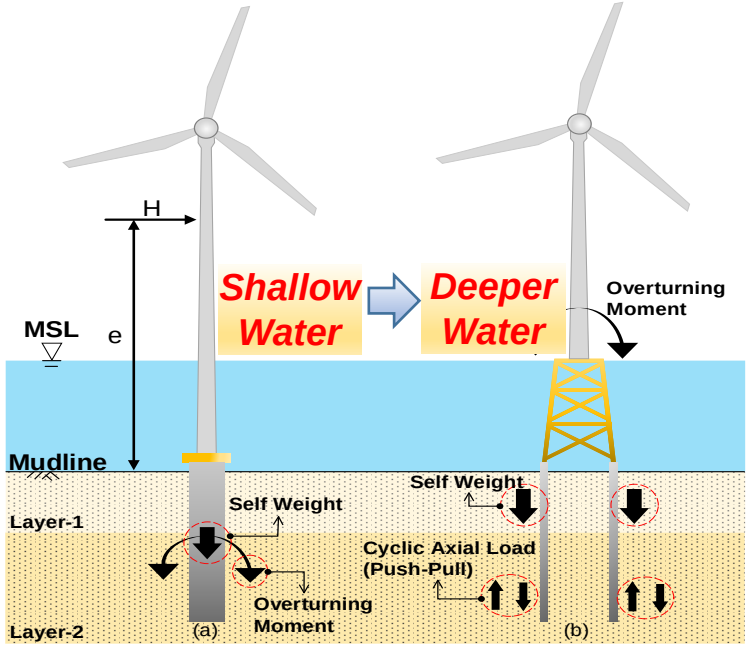


Fig. (a) Monopile, (b) Piled jacket structure

Kamrul Ahsan (PhD student)

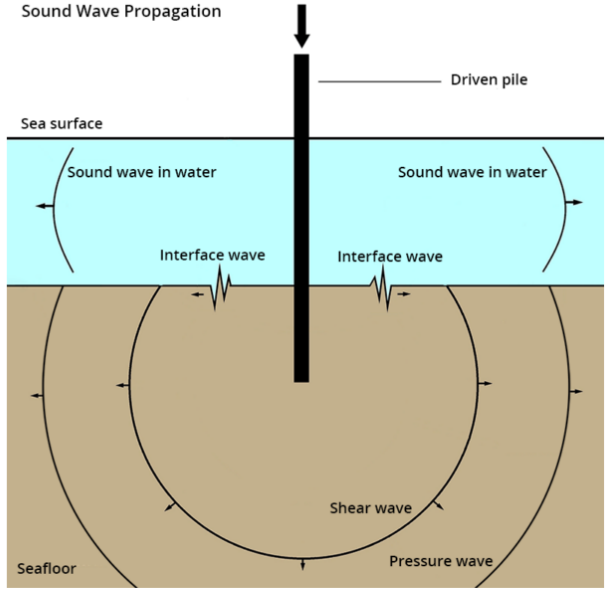


Diagram of sound waves generated by pile driving. Sound waves in water generated by pile driving can come directly from the pile in water, from seismic waves in the seafloor as the seismic waves reach the sediment water interface, and from interface waves that move away from the pile along the water-seafloor interface. Image modified from Dr. Anthony D. Hawkins.

https://dosits.org/animals/effects-of-sound/anthropogenic-sources/pile-driving/

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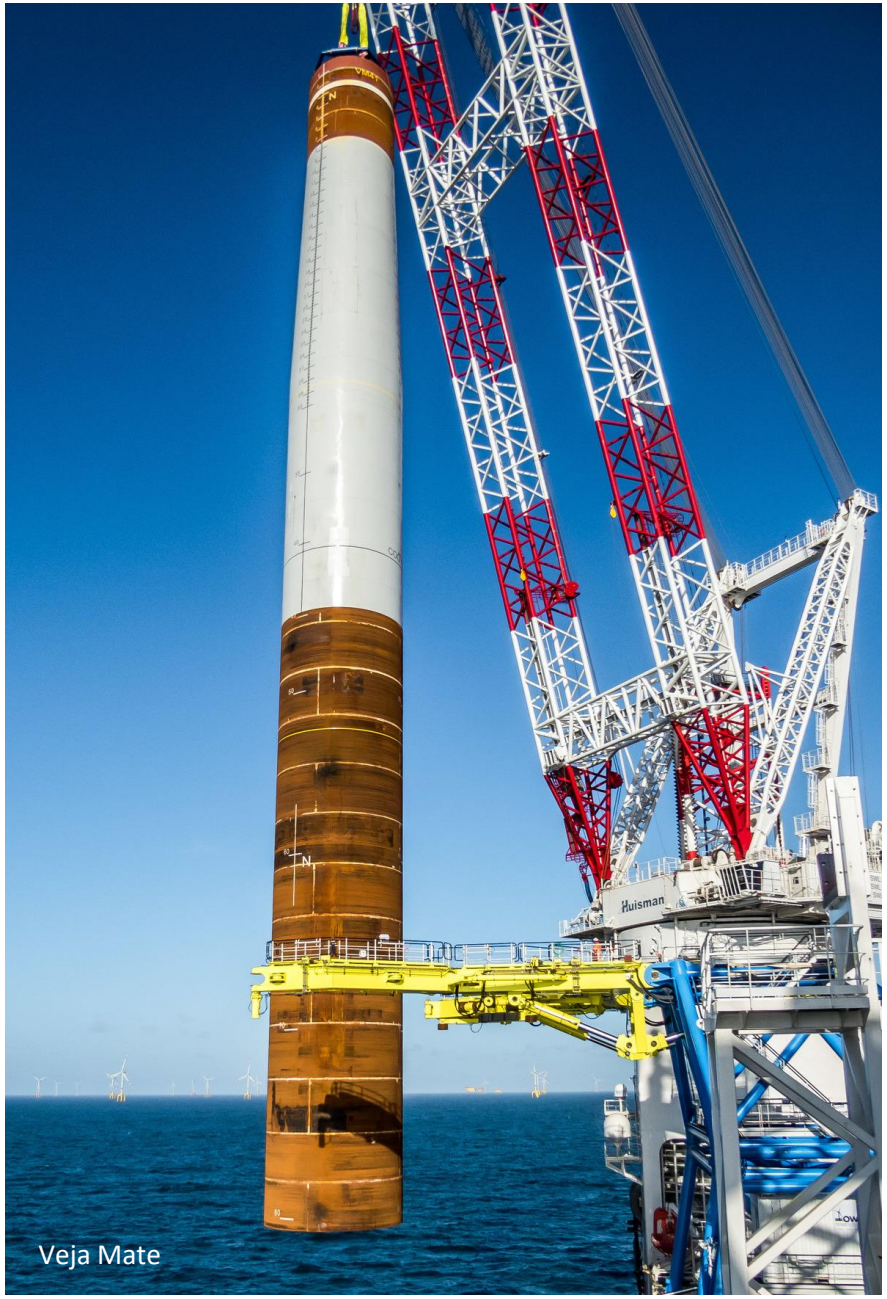
Source: Ørsted

Pile installation

Source: DEME

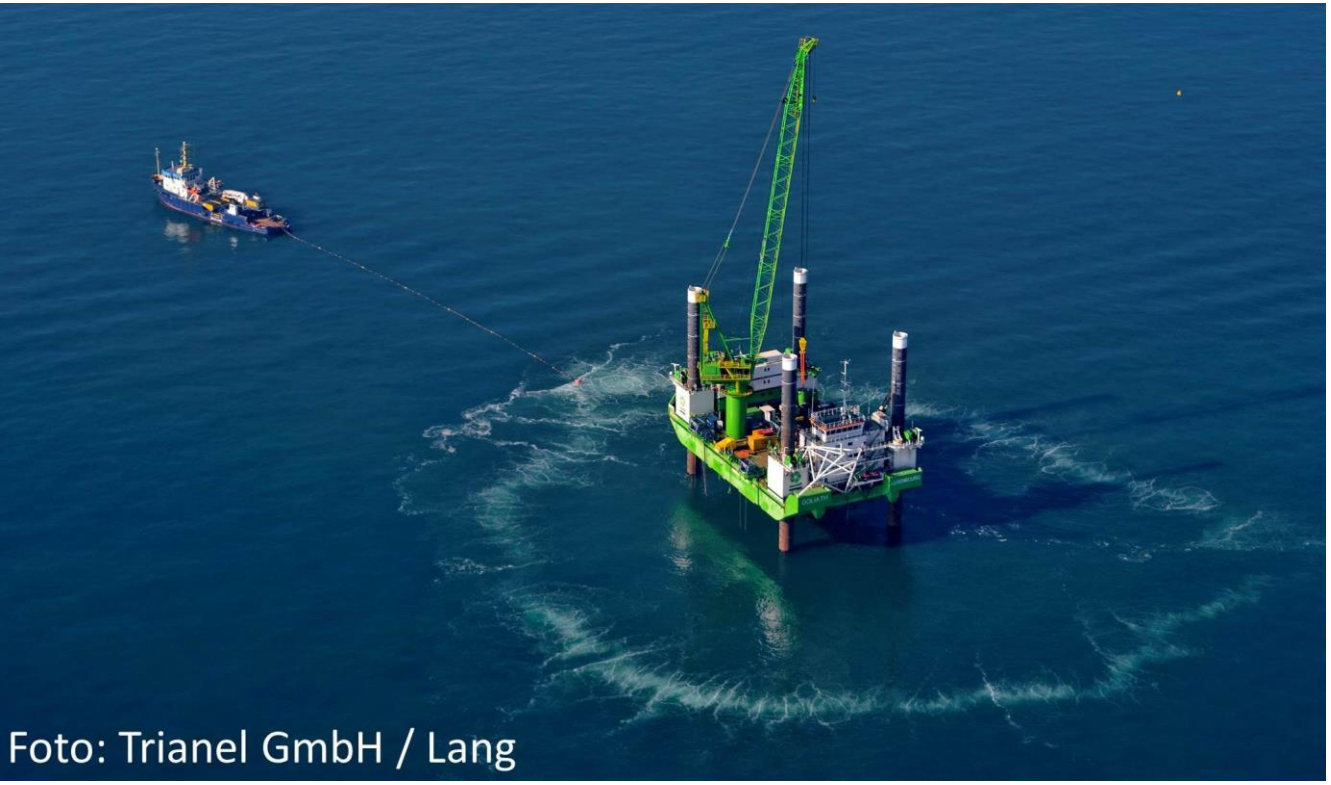

Source: DEME



Veja Mate

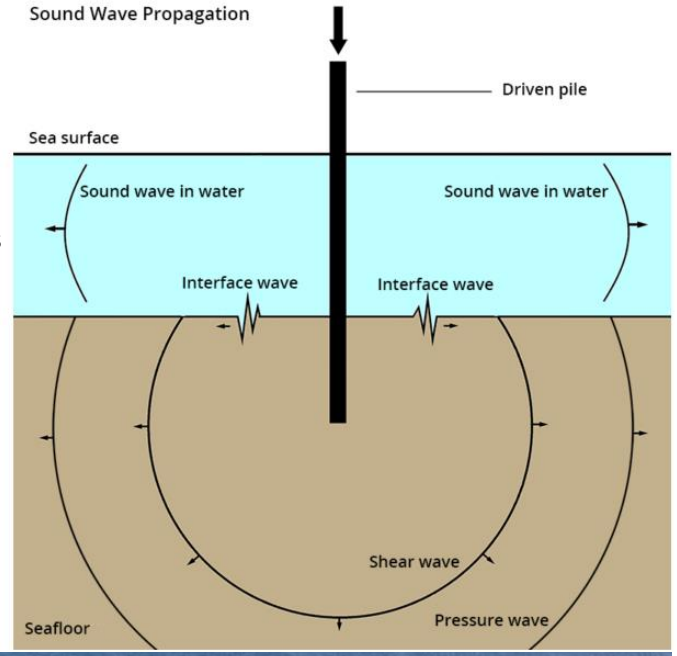
Problem 1: Acoustic emissions from pile driving

Examples of bubble curtains



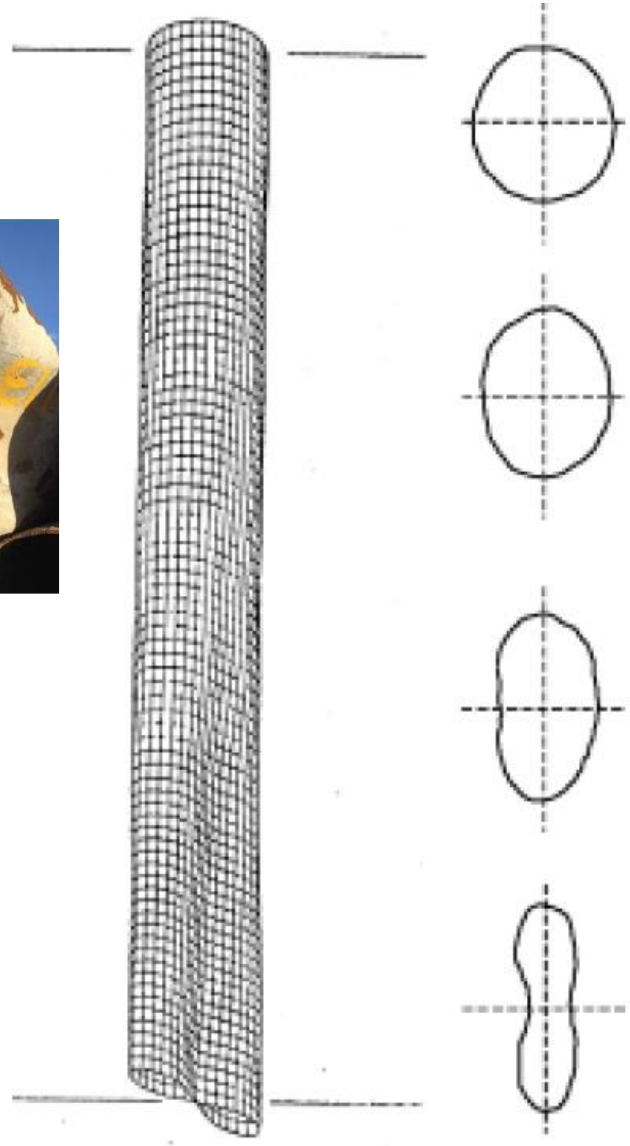
Expensive
Reduce, not remove noise

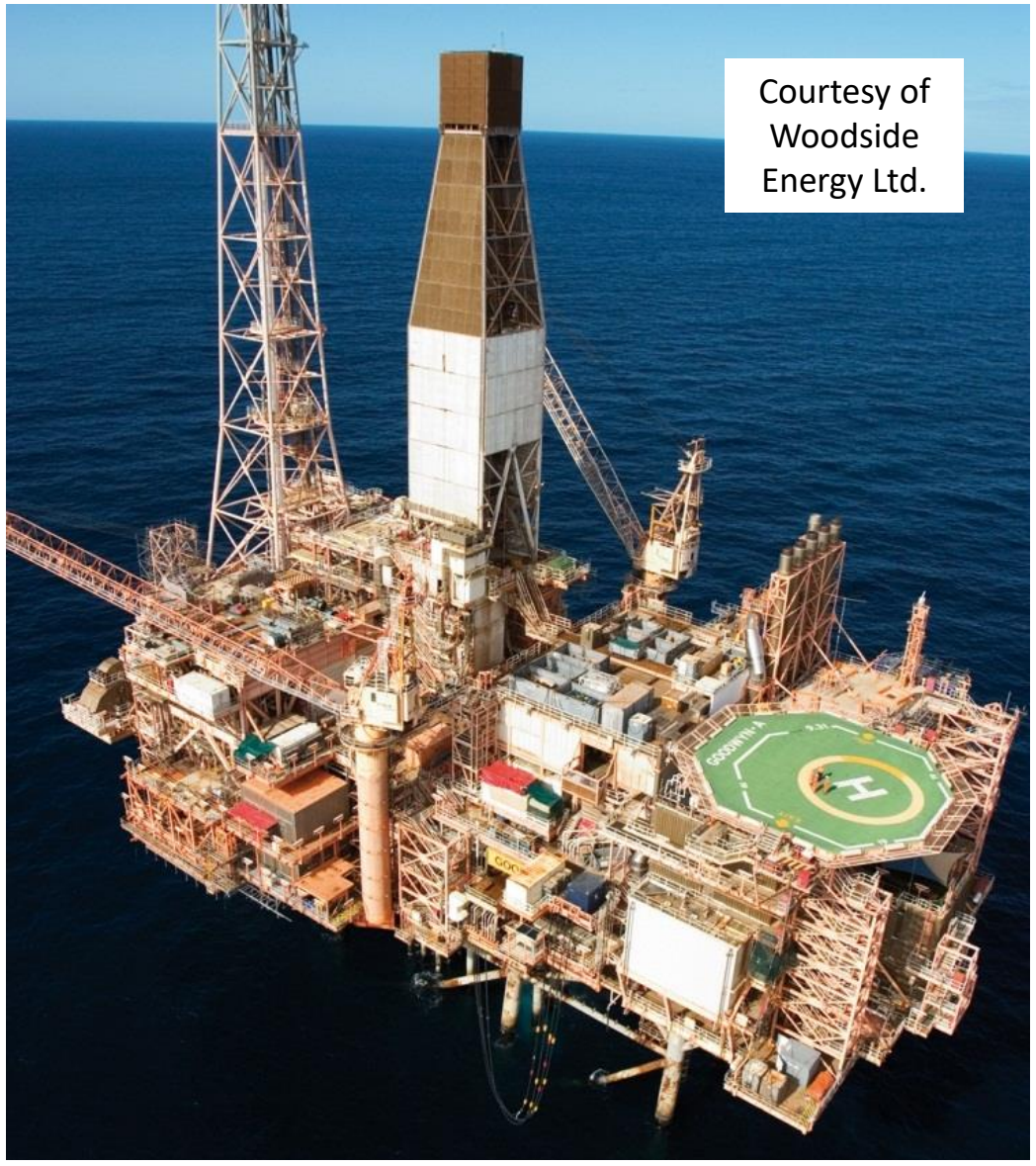
https://dosits.org/animals/effects-of-sound/anthropogenic-sources/pile-driving/



Problem 2: Pile damage (and refusal)

Goodwyn A





Courtesy of Woodside Energy Ltd.

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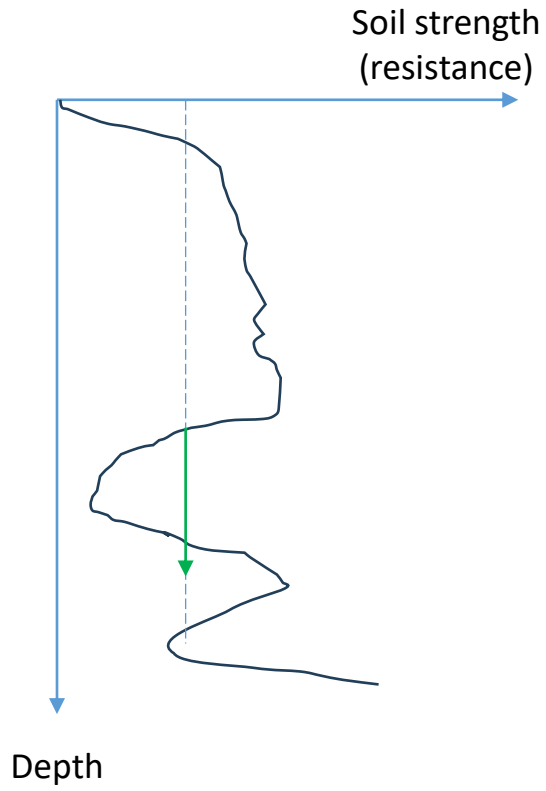
Problem 3: Free-fall



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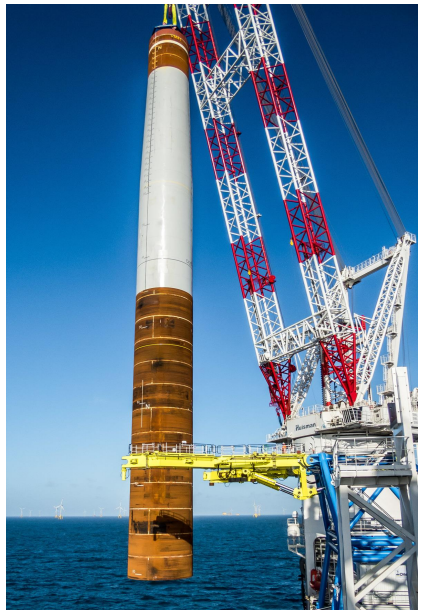

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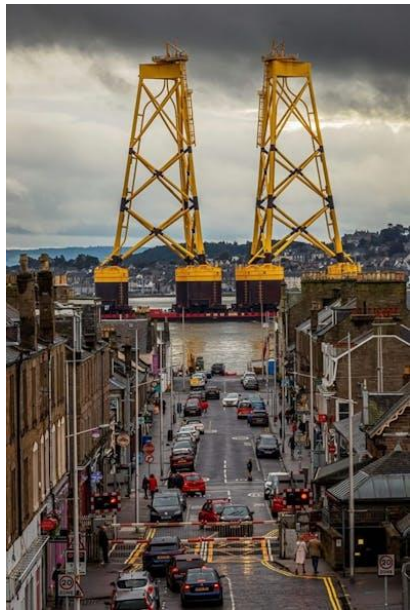

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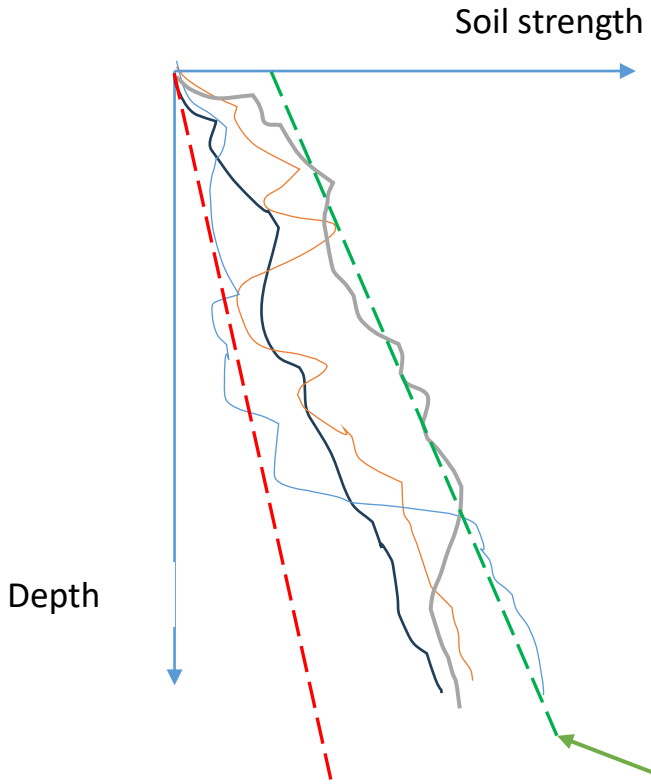
Cause 1: seabed uncertainty/variability



Make sure you can install for the strongest likely seabed

Base the foundation size on the smallest likely strength – so it doesn't fall over. Weaker = larger

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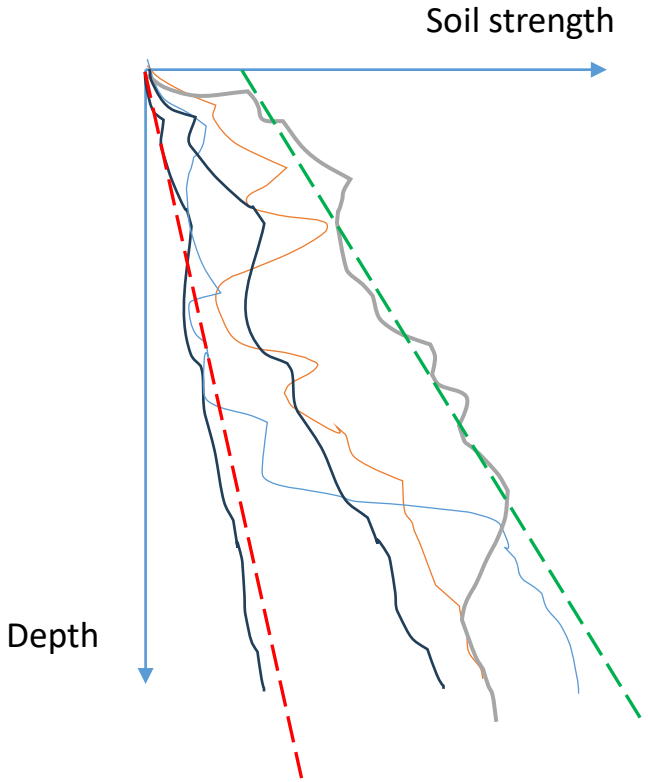
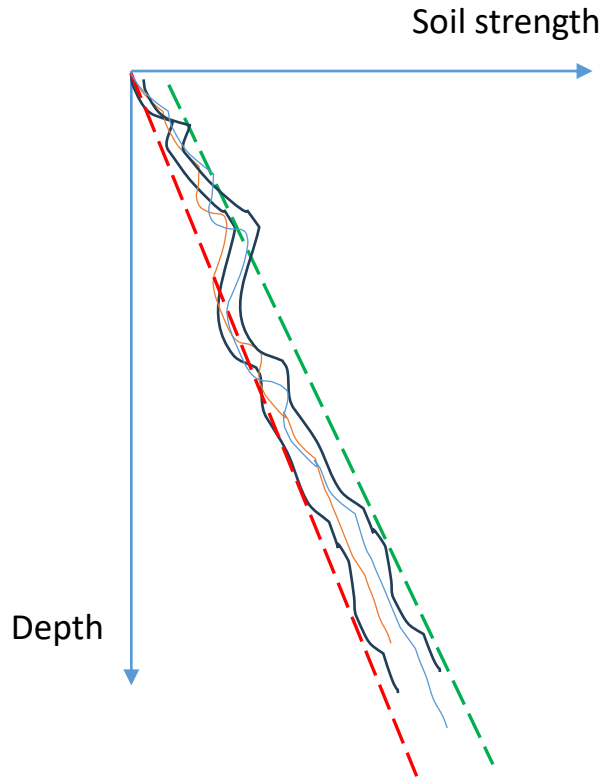
Seabed properties: seabed uncertainty/variability



More certainty?



Wide range of strengths →

Difficult / expensive (foundation big AND difficult to install)

Narrower range of strengths → Easier / cheaper

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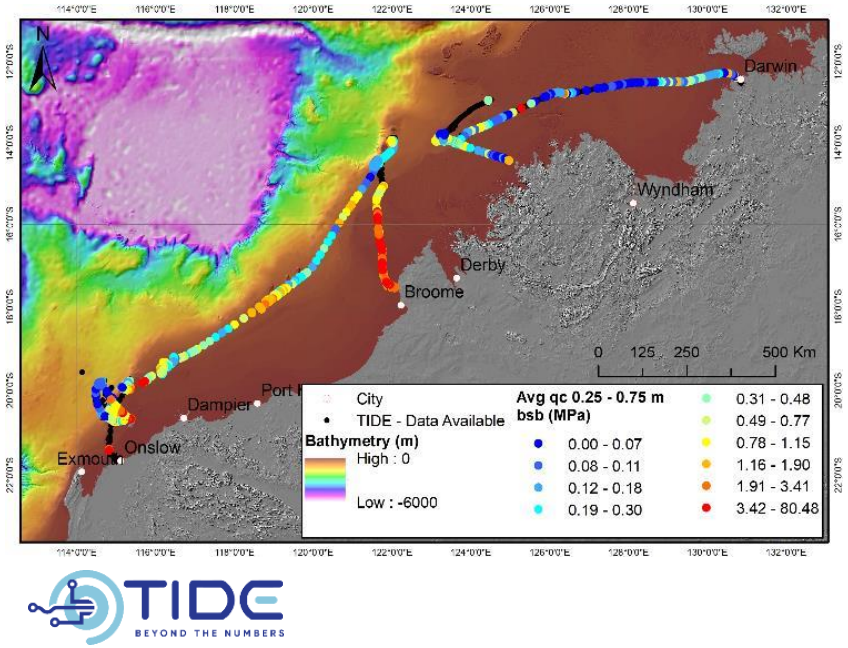
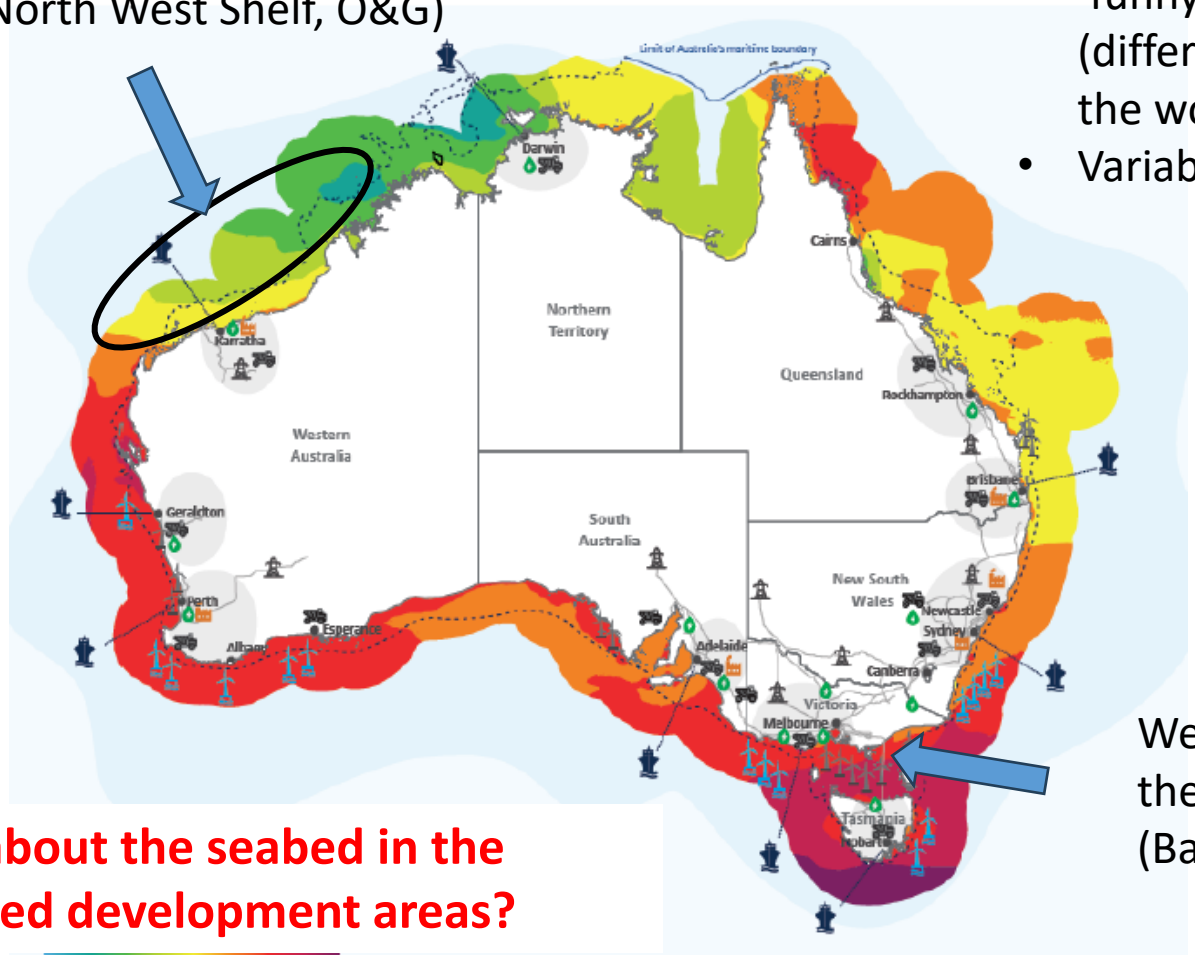
The Australian seabed



We know a lot about the seabed here (North West Shelf, O&G)



Carbonate soils:

- 'funny' properties (different to elsewhere in the world)
- Variable cementation

We know a lot about the seabed here (Bass Strait, O&G)

What about the seabed in the proposed development areas?

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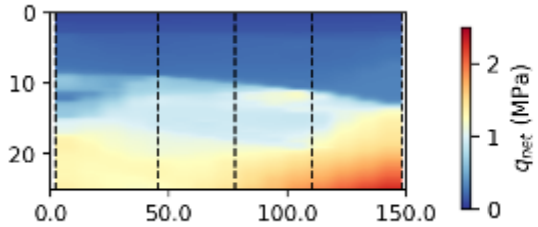
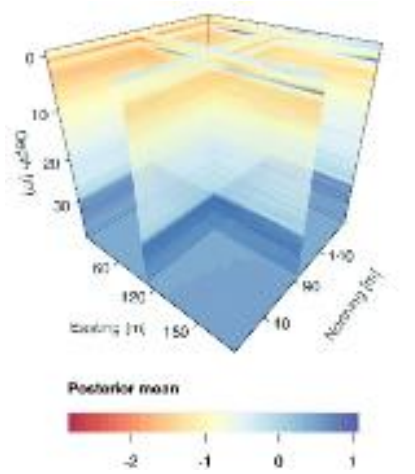
→ Reduce risk by conducting research to understand the seabed better

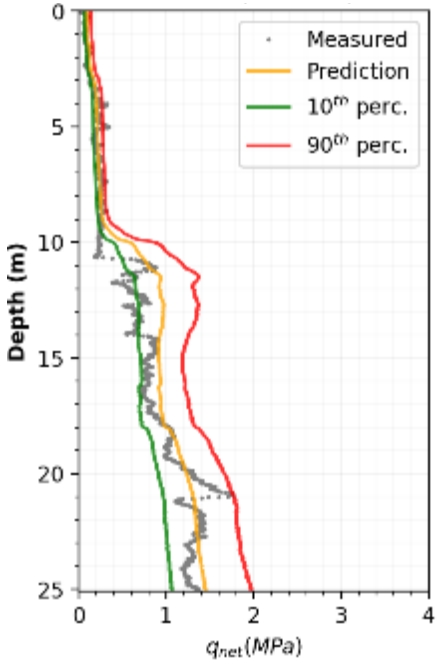
- Geological settings / analogues
- Better use of geophysics
- Better in situ testing methods
- Better use of field data (statistics)
- Better integration of all data

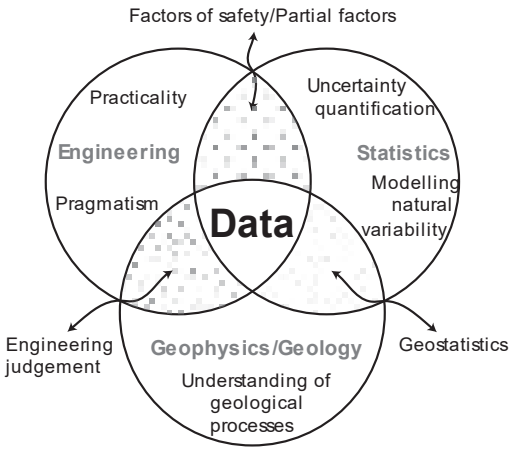
[No time for details today!]

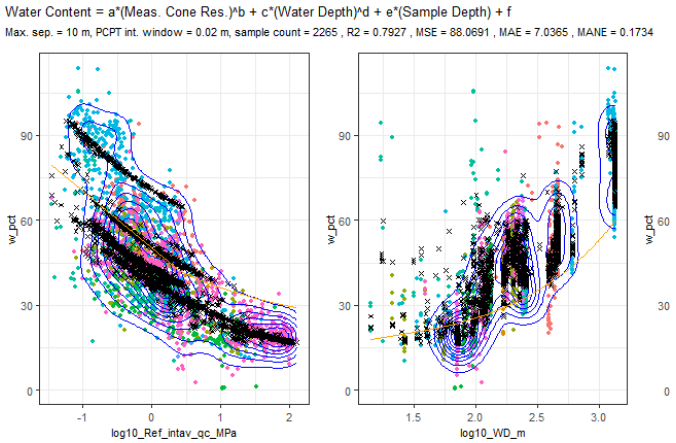
Bayesian NN

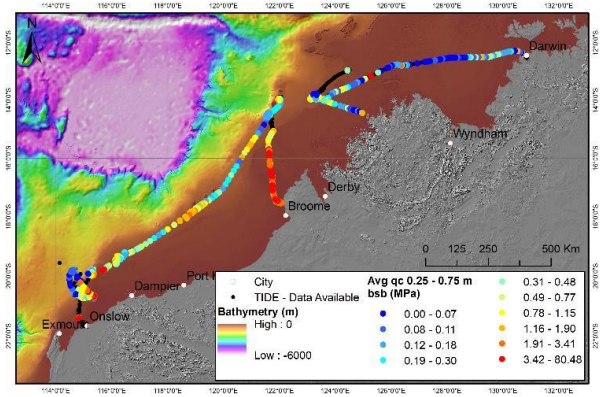












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Field testing - Piles in cemented carbonates: installation and uplift capacity

- Kamrul Ahsan (PhD) + Fugro & Shell

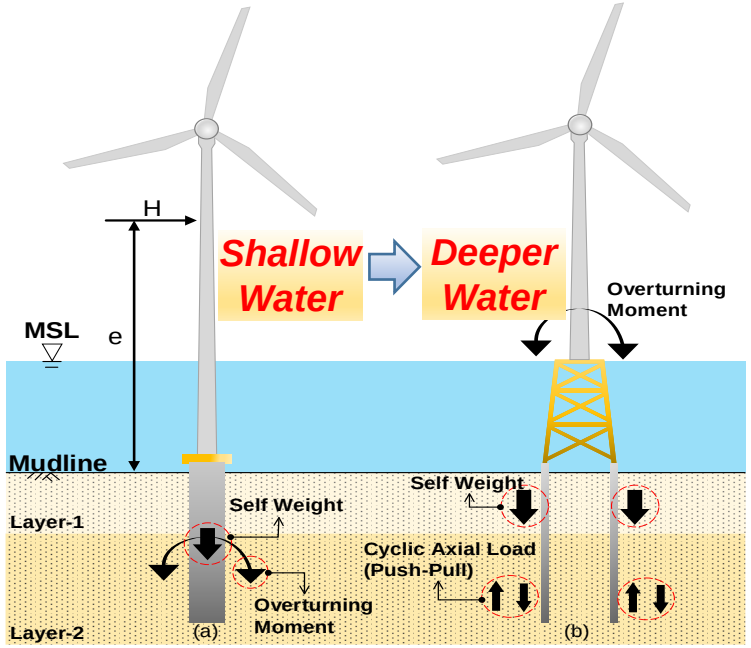


Fig. (a) Monopile, (b) Piled jacket structure

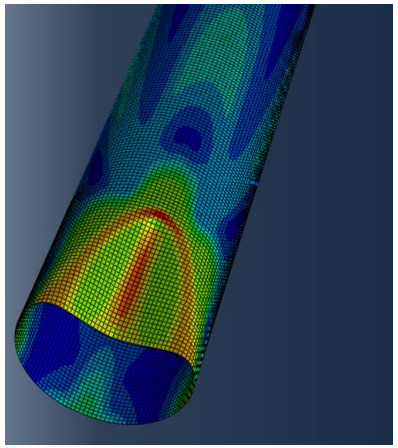
Uplift testing

Installation

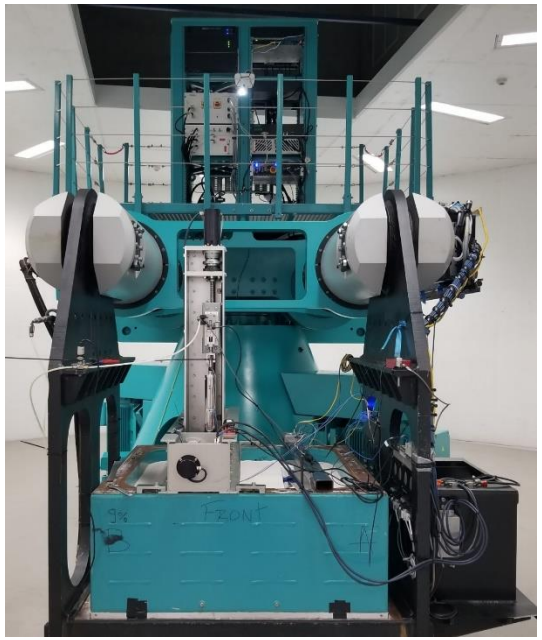
Ground conditions (cemented carbonate)

Pile damage during driving

Computer (FE) Analysis

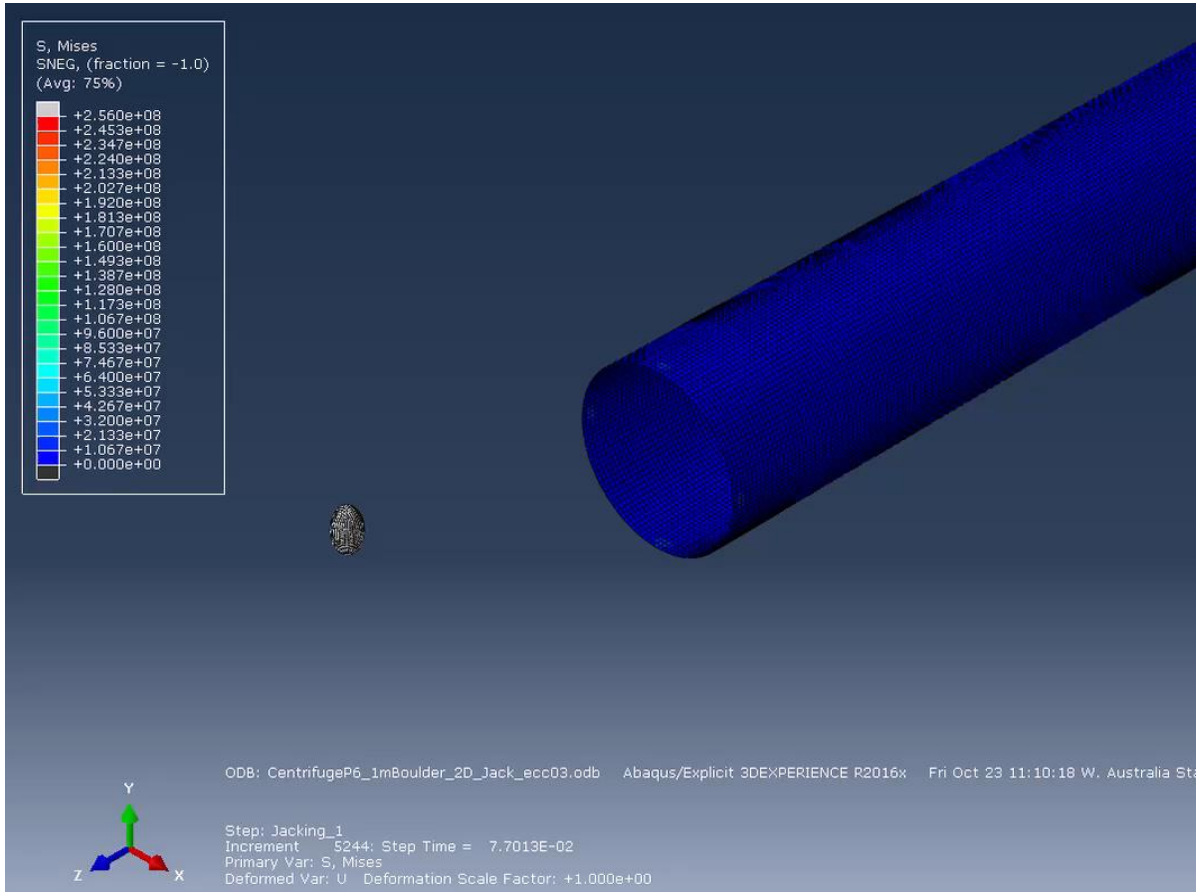


Pile driving in a centrifuge

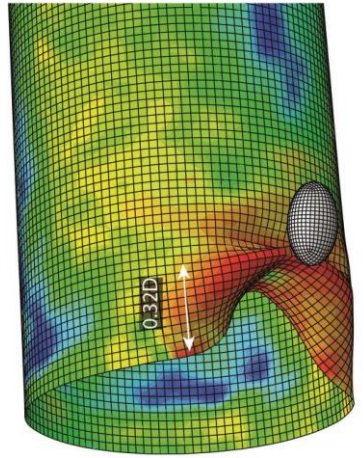


Juliano Nietiedt
(now post-doc)

Monopile-boulder interaction

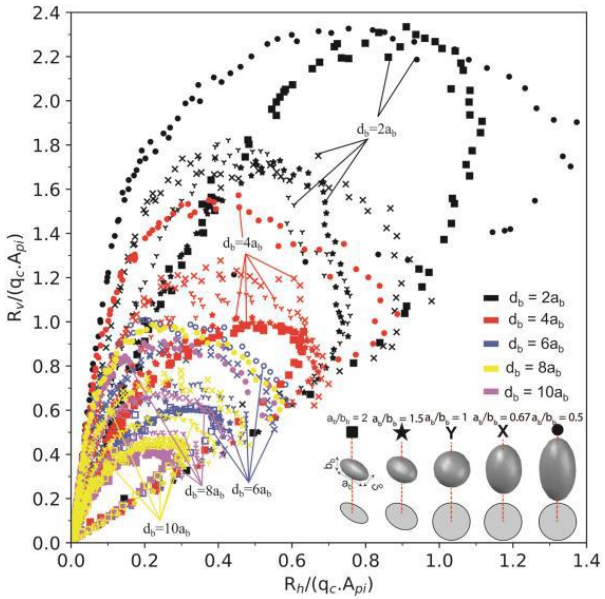


Abaqus



Centrifuge experiment

Juliano Nietiedt
(now post-doc)



Nietiedt, Randolph, Doherty, Gaudin. (2022). Numerical assessment of tip damage during pile installation in boulder rich soils. *Géotechnique*.

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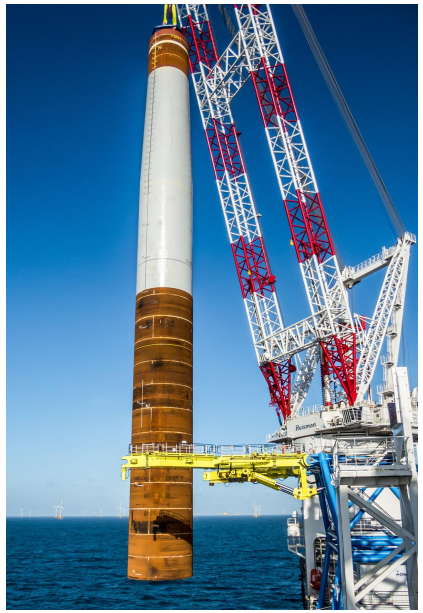

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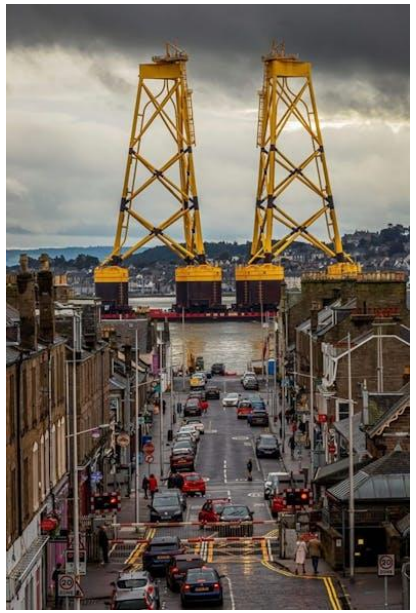

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How do we reduce installation noise?

Answer (a): Install our monopiles quietly

Vibro-driven monopiles

Julia Hein Mazutti and Pourya Esfeh (PhD students)

Reduced noise, Fast installation, no free-fall risk

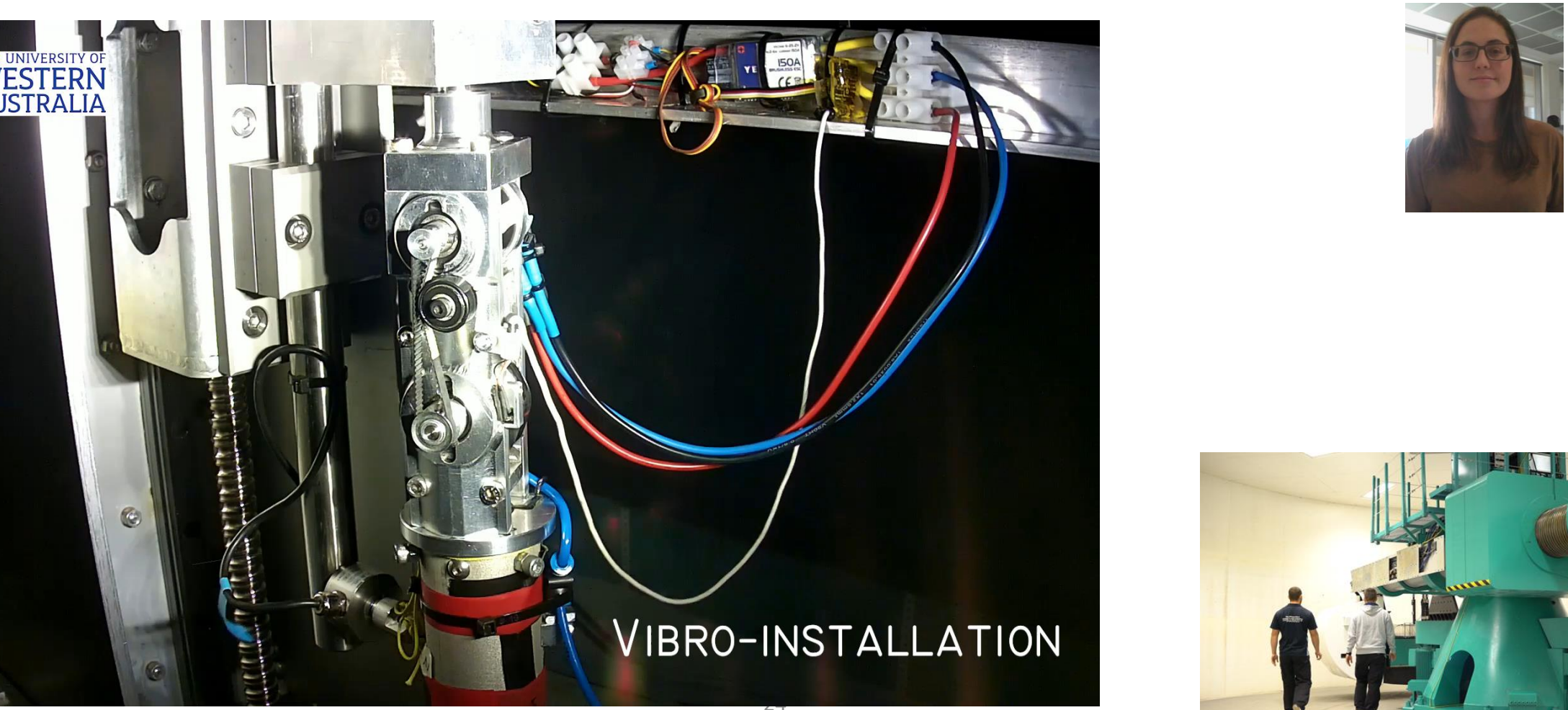
Vibro-pile installation at Riffgat OWT; (RHS) pile head with vibro-driver (Cape Holland)

Fraser.bransby@uwa.edu.au; cofs@uwa.edu.au

Vibro-installation & loading of monopiles

Can we understand installation better by using experiments?

Júlia Hein Mazutti
(PhD student)

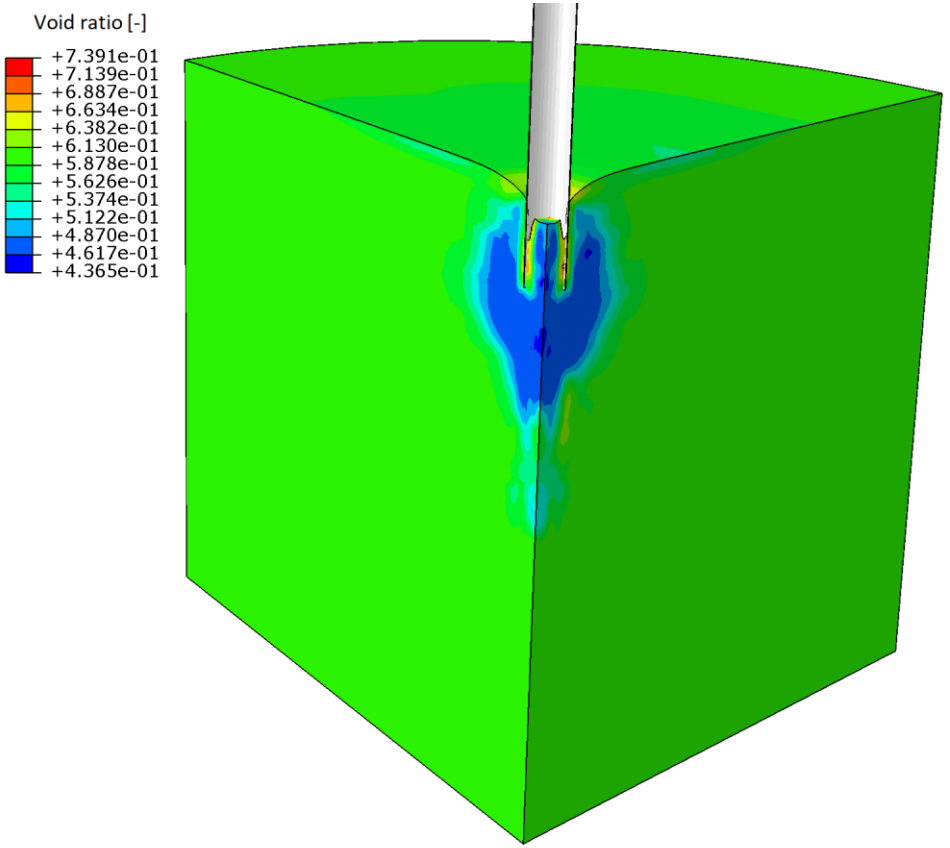


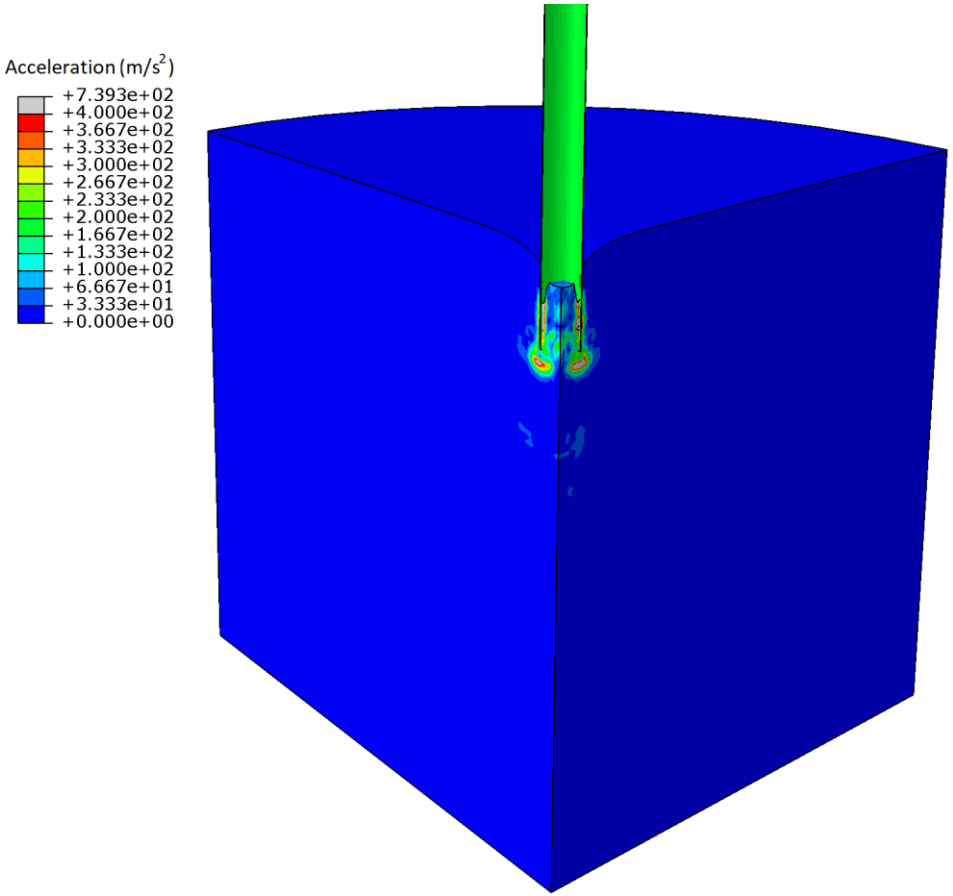
Vibro-installation & loading of monopiles

Can we understand installation better by using computer analyses?

Pourya Kazemi Esfeh (PhD student)

Vibro-driven monopiles





Abaqus CEL
(Hypoplastic soil)

How do we reduce installation noise?

Answer (b): Use a different foundation type

e.g. Suction bucket jackets

Versatile, low acoustic emissions foundation concept

Borkum Riffgrund I

Aberdeen Bay

Seagreen

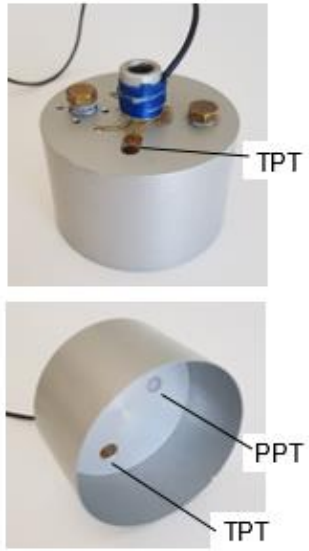
Fujian Changle Waihai

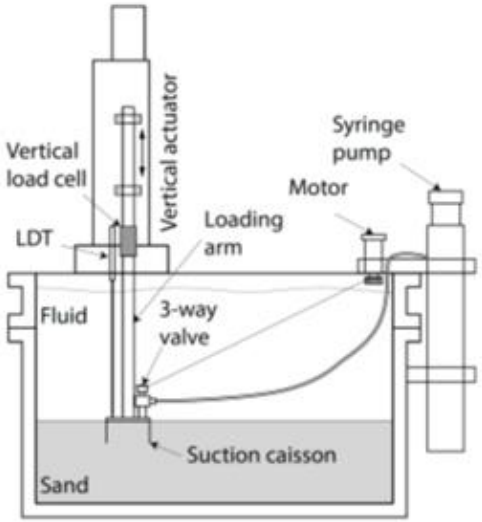
Borkum Riffgrund II

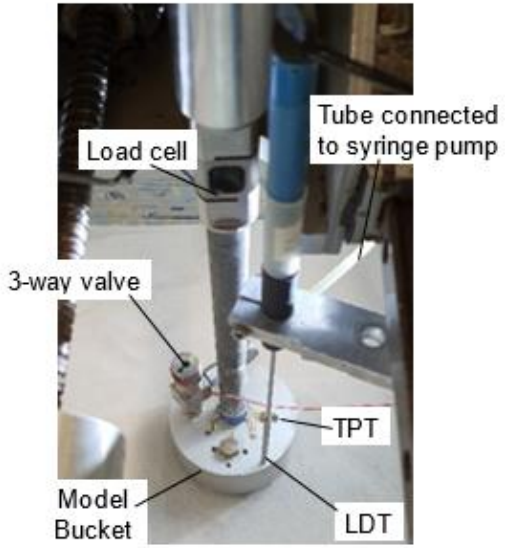
Centrifuge modelling of suction bucket foundations for offshore wind turbines.

Clients: BSEE, Fugro, Seagreen, Ørsted etc.

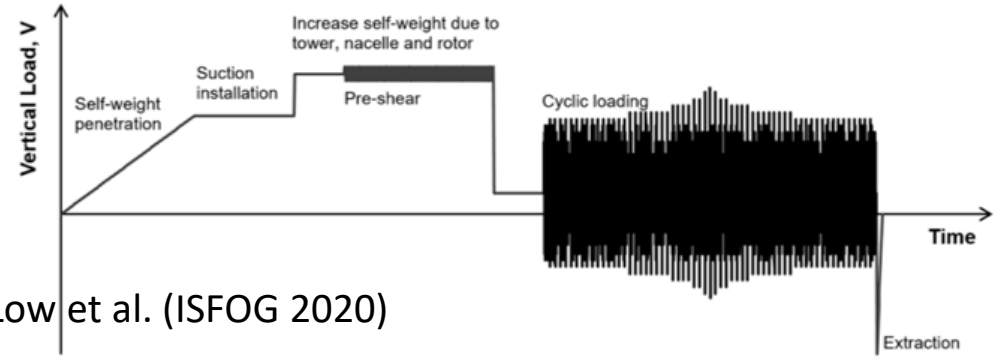
Centrifuge tests







1. Installation & Pre-shear	2. Cyclic Loading	3. Extraction

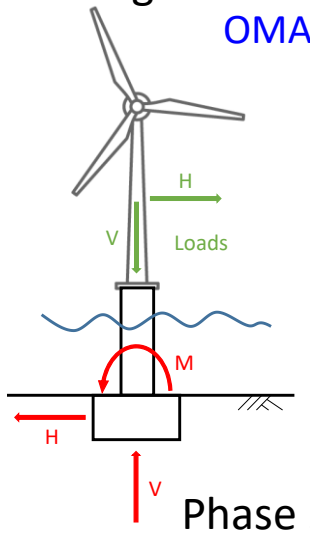


Low et al. (ISFOG 2020)

Fig. 4: Testing procedure

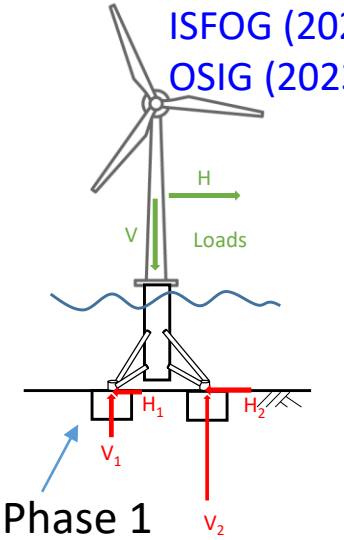
80 mm diameter bucket (8 m at full-scale)

Single bucket
OMAE (2021)

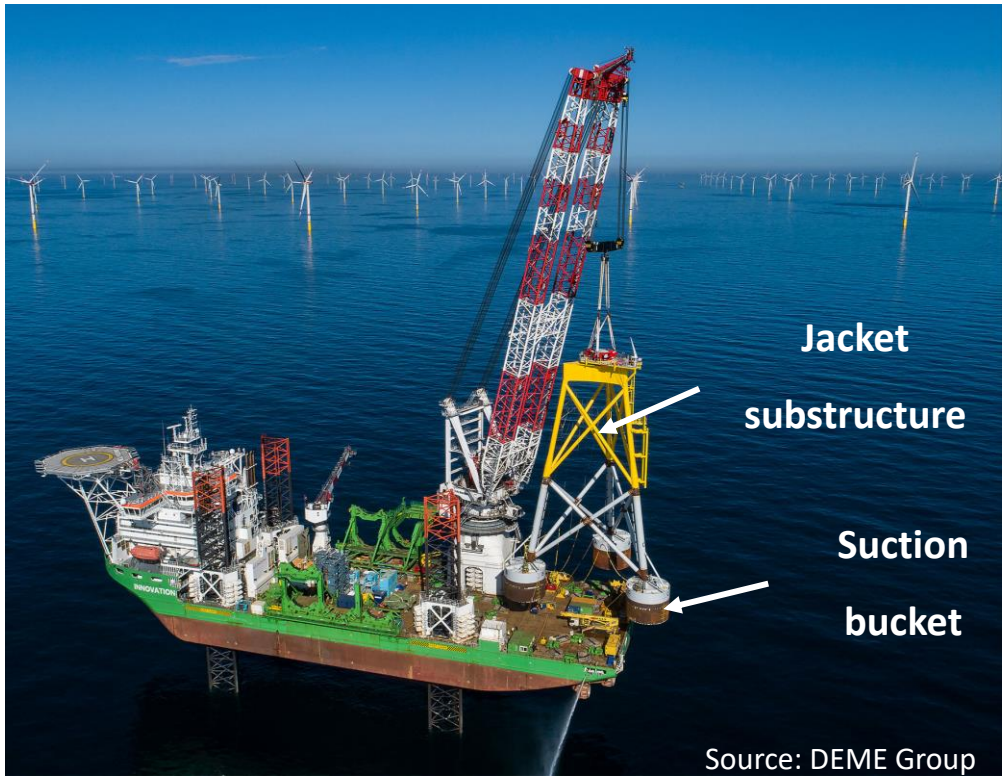


Phase 2

Multi-bucket
ISFOG (2020), OSIG (2023)



Phase 1



Suction buckets

Innovative installation strategies

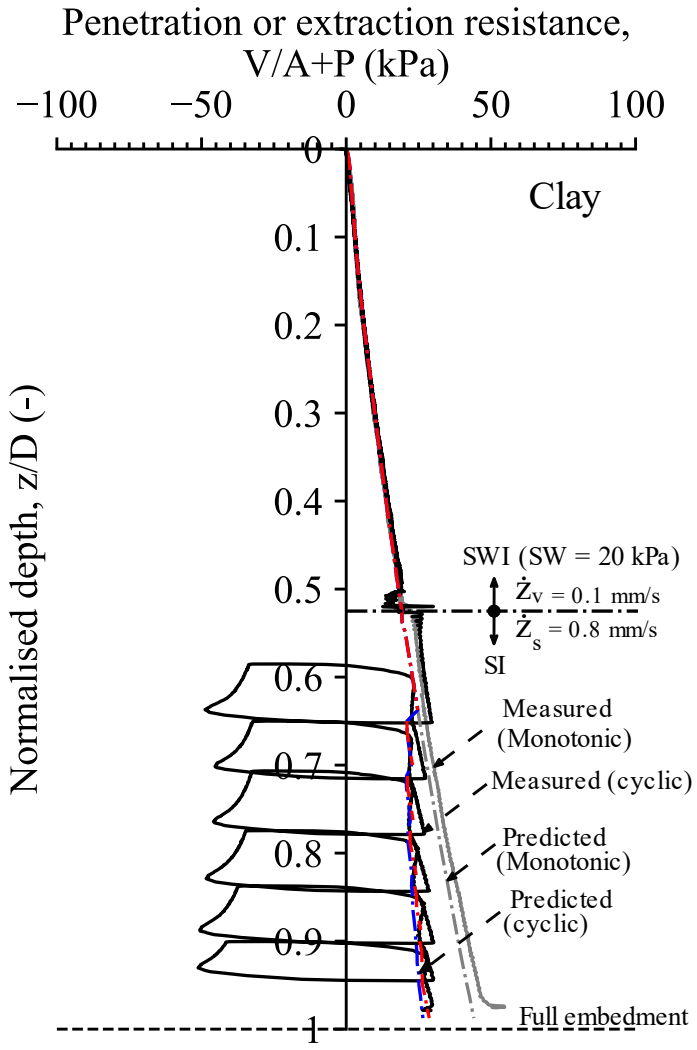
Challenges:

- Cavitation limit
- Buckling limit

Strategies:

- Pressure cycling

Pressure cycling

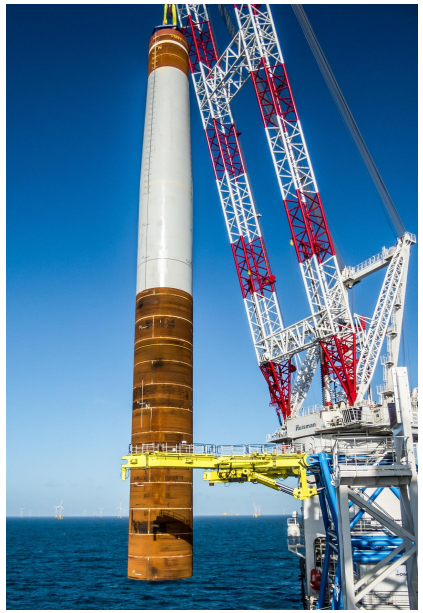


Senthen Mani (just finished PhD)

Britta, Conleth

Geotechnical research to unlock safe, cost-efficient foundations to underpin offshore wind in Australia

Prof. Fraser Bransby
Director, Centre for Offshore Foundation Systems ('COFS')
The University of Western Australia



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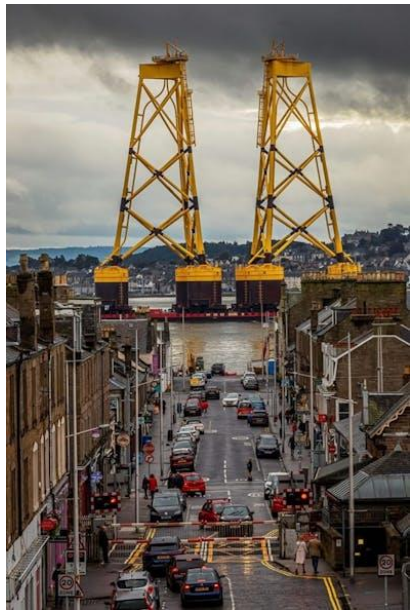
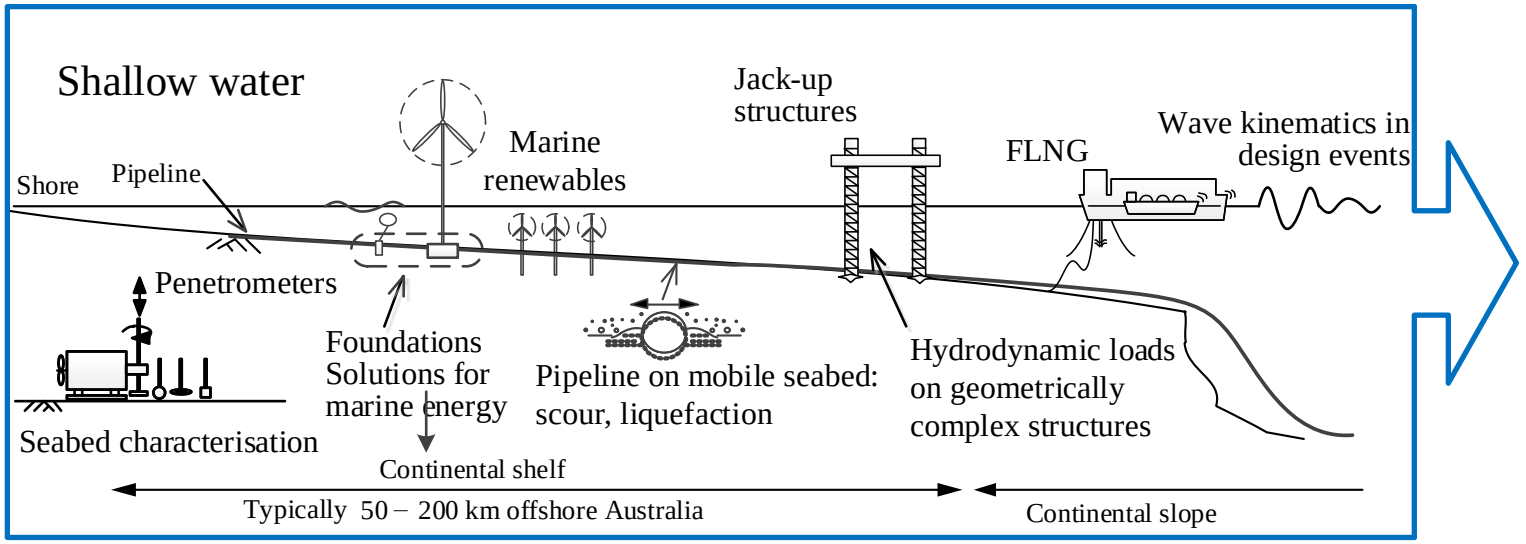


Fraser.bransby@uwa.edu.au; cofs@uwa.edu.au

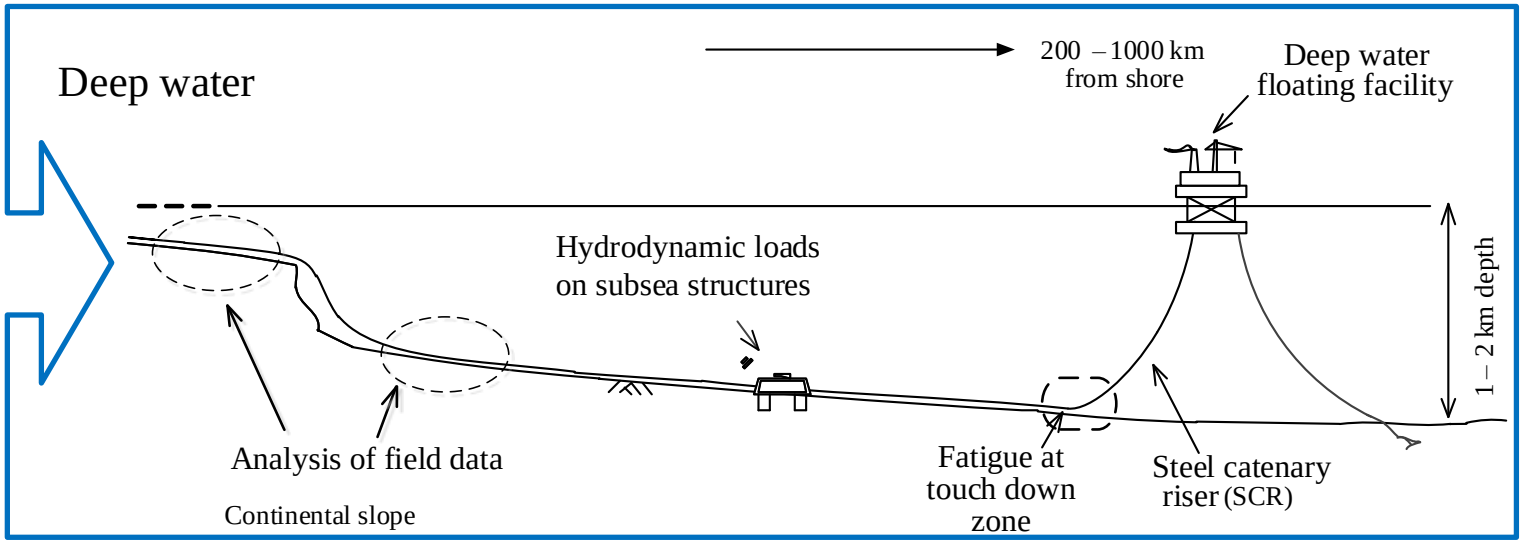
COFS History

Formed 26 years ago; Originally supported the (local) oil and gas industry

Wide range of topics now studied (*covered in the rest of the slides!*)



- **Foundations**
- **Anchoring systems**
- **Pipe/Cable systems**
- **Site characterisation**
- **Element response**



Oil and Gas: ≈ 25%
Renewables: ≈ 75%

+ Industrial engagement for >25 years

UWA had the largest number of papers from any one organisation in the last year's OSIG conference.

- 22 papers with COFS authors in OSIG 2023;
- ≈20 in ISFOG 2020(2).

Who we are

- Approximately 40 members

Academics:

Prof. Mark Randolph
Prof. Fraser Bransby (Director COFS; Fugro Chair)
Prof. Christophe Gaudin (Director, Oceans Institute)
Prof. Phil Watson (Shell Chair)
Prof. Conleth O'Loughlin (Centrifuge manager)
Prof. Britta Bienen
Prof. Shazzad Hossain

+ colleagues in Civil and Mining Engineering
Prof. Barry Lehane
Prof. Yuxia Hu
A/Prof. James Doherty
Prof. Andy Fourie
Dr. Dave Reid

6 post-doctoral researchers:
Mike O'Neill, Zhechen Hou, Juliano Nietiedt, Colm O'Beirne, Ulysse Lebrec, Vikram Singh

20-25 PhD students

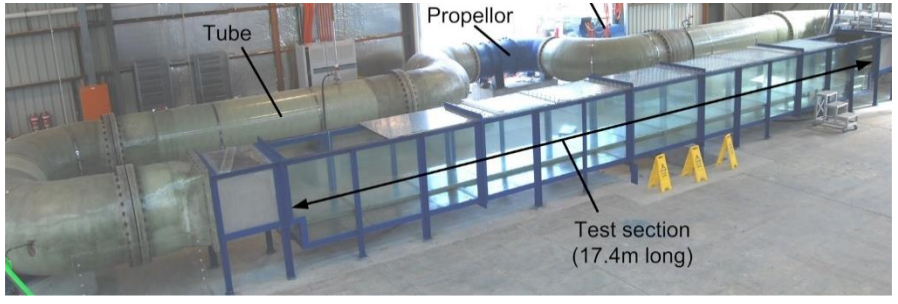
9 technicians associated with the centrifuge centre

10+ visitors per year (staying from weeks to a year)

Katherine Kwa (Southampton, UK) giving a seminar

Research tools

- Geotechnical centrifuges: http://www.ngcf.edu.au/
  - 3.6 m diameter beam
  - 10 m diameter beam
  - 1.2 m diameter drum
- Coastal and offshore engineering lab https://www.uwa.edu.au/facilities/coel
  - O-tubes (MOT, SOT, LOT)
  - 50 m wave flume
- 'Riverlab'
- Advanced soil testing laboratory
- Leading edge numerical modelling
- Field testing (sand – Shenton Park, clay - Bayswater, carbonate rock - Pinjar)



Geotechnical research to unlock safe, cost-efficient foundations to underpin offshore wind in Australia

6. Overall message

Foundations are a key part of offshore wind infrastructure (up to 40% of cost and significant risk)

- Fabrication, transport and installation is expensive.
- Installation involves risk (refusal, free-fall etc.) because of complexity of the seabed conditions (geology + limited investigation)
- Installation (of piles) involves noise (marine habitat).

Can reduce risk by:

(a) Better investigating/understanding seabed conditions (from geology to site characterisation) – so no surprises!
(b) By better understanding installation
(c) By making things smaller (better design and better site characterisation).

Can reduce noise by:

(a) Expensive mitigation (e.g. bubble curtains).
(b) Installing piles in different ways (e.g. vibrodriving)
(c) Replacing piles with other foundation types (e.g. SBJ)

We are researching all of these (and lots more).

Fraser.bransby@uwa.edu.au; cofs@uwa.edu.au