TC209 Offshore Geotechnics

Geotechnics for Offshore Wind

Setting the scene – Phil Watson

A developer's perspective of geotechnics for offshore wind – Elisabeth Palix

An overview of ‘new’ challenges facing offshore wind – Zack Westgate

Geotechnical research to support offshore wind – Christelle Abadie

Close – Phil Watson
Research to support offshore wind

Motivation and Objectives

Offshore wind expansion:

› Reduce costs
› Extend service life
› Bring further offshore
› Design for larger turbines
› Adapt for new world locations

An average offshore wind turbine of 3.6 MW can power more than 3,312 average EU households

For comparison: An average onshore wind turbine with a capacity of 2.5–3 MW can supply 1,500 average EU households with electricity

New Offshore Wind Installations 2011-2021 & predicted installations for 2026 and 2031 (GW)
Research to support offshore wind

Motivation and Objectives

Roles of R&D:
› Permit the development of new and improved design methods
› Enable the development of new foundation systems
› Verify foundation design through testing and numerical modelling

Challenges:
› Testing is difficult with large-scale field tests offshore nearly impossible
› Numerical modelling is computationally expensive and requires thorough validation against experimental database

Offshore wind expansion:
› Reduce costs
› Extend service life
› Bring further offshore
› Design for larger turbines
› Adapt for new world locations

Dr Christelle Abadie – Research Fellow
christelle.abadie@univ-eiffel.fr

ISSMGE Interactive Technical Talk:
TC209 – Geotechnics for Offshore Wind

28 February 2024
Research to support offshore wind
First Stages of the Research

- Understand the behaviour of large diameter monopiles under lateral loading
- Move away from traditional p-y curves and propose new and robust design methods to predict foundation capacity and small strain stiffness:
  » permit integration with structural design software
  » accurately predict turbine natural frequency
- Establish the first models to account for long-term cyclic loading

Establish Monopile Design Method
≈ early 2000s - 2017
Enable commercial viability of offshore wind in Northern Europe waters

Offshore wind expansion:
› Reduce costs
› Extend service life
› Bring further offshore
› Design for larger turbines
› Adapt for new world locations

Dr Christelle Abadie – Research Fellow
christelle.abadie@univ-eiffel.fr

ISSMGE Interactive Technical Talk:
TC209 - Geotechnics for Offshore Wind
28 February 2024
Understand the behaviour of large diameter monopiles under lateral loading

Move away from traditional $p-y$ curves and propose new and robust design methods to predict foundation capacity and small strain stiffness:
- permit integration with structural design software
- accurately predict turbine natural frequency

Establish the first models to account for long-term cyclic loading
Research to support offshore wind
Progress on bottom-fixed foundations

➢ Subsidy-free offshore wind (bottom-fixed)

Establish Monopile Design Method

Monopile Design Optimisation

Gravity, Jacket Piles & Caissons

≈ early 2000s - 2017
Enable commercial viability of offshore wind in Northern Europe waters

≈ 2010s – Today
Improve design robustness and installation methods

≈ 2010s - Today
Provide a wider foundation mix to adapt to large range of offshore environments
Research to support offshore wind
Improving monopile design

Subsidy-free offshore wind (bottom-fixed)

Establish Monopile Design Method
Monopile Design Optimisation

≈ early 2000s - 2017
Enable commercial viability of offshore wind in Northern Europe waters

≈ 2010s – Today
Improve design robustness and installation methods

Refine the models for cyclic loading
(e.g. NGI cyclic diagrams, HARM, MIDAS, PICASO, Hysand...)

Research to support offshore wind

Improving monopile design

Establish Monopile Design Method

≈ early 2000s - 2017
Enable commercial viability of offshore wind in Northern Europe waters

Monopile Design Optimisation

≈ 2010s – Today
Improve design robustness and installation methods

- Refine the models for cyclic loading (e.g., NGI cyclic diagrams, HARM, MIDAS, PICASO, ...)
- Improve installation methods to reduce risks associated with installation and the environmental impact of pile driving (e.g., Blue Piling, Gentle Pile Driving, Development of pile hammers and vibro hammers for centrifuge modelling)

Dr Christelle Abadie – Research Fellow
christelle.abadie@univ-eiffel.fr

Maatouk, S., Blanc, M., Thorel, L. (2022)
Impact driving of monopiles in centrifuge: effect on the lateral response in sand
International Journal of Physical Modelling in Geotechnics
Research to support offshore wind

Improving monopile design

- Refine the models for cyclic loading (e.g. NGI cyclic diagrams, HARM, MIDAS, PICASO, ...)
- Improve installation methods to reduce risks associated with installation and the environmental impact of pile driving (e.g. Blue Piling, Gentle Pile Driving, Development of pile hammers and vibro hammers for centrifuge modelling)
- Tackle installation and design in weak rocks, chalk (e.g. ALPACA, EDF onshore field testing)

Establish Monopile Design Method

Monopile Design Optimisation

≈ early 2000s - 2017
Enable commercial viability of offshore wind in Northern Europe waters

≈ 2010s – Today
Improve design robustness and installation methods

Elisabeth Palix – Offshore technical lead – APAC
First part of this TC209 talk: A developer’s perspective of geotechnics for offshore wind
Research to support offshore wind
Gravity Base Foundations

➢ Subsidy-free offshore wind (bottom-fixed)

Establish Monopile Design Method ≈ early 2000s - 2017
Enable commercial viability of offshore wind in Northern Europe waters

Monopile Design Optimisation ≈ 2010s – Today
Improve design robustness and installation methods

Gravity, Jacket Piles & Caissons ≈ 2010s - Today
Provide a wider foundation mix to adapt to large range of offshore environnements

Dr Christelle Abadie – Research Fellow
christelle.abadie@univ-eiffel.fr

Univ. Gustave Eiffel
Université
CG LABORATORY
GEOTECHNICAL CENTRIFUGE

Design of gravity base foundations

Photo of 31 m diameter gravity-base foundations for the support of 71 turbines in Fécamp, France
(©Parc éolien en mer de Fécamp - Laurent Critot)
Research to support offshore wind
Gravity Base Foundations

Dr Christelle Abadie – Research Fellow
christelle.abadie@univ-eiffel.fr

Ifeobu, C.U., Abadie, C.N. and Haigh, S.K. (2023)
Young Scientist Award - Cyclic response of shallow onshore wind turbine foundations resting on dense sand
Geotechnics for Sustainable Infrastructure Development - Geotec Hanoi 2023
Research to support offshore wind
Suction Bucket Jackets (SBJ)

Subsidy-free offshore wind (bottom-fixed)

Establish Monopile Design Method

≈ early 2000s - 2017
Enable commercial viability of offshore wind in Northern Europe waters

Monopile Design Optimisation

≈ 2010s – Today
Improve design robustness and installation methods

Gravity, Jacket Piles & Caissons

≈ 2010s - Today
Provide a wider foundation mix to adapt to large range of offshore environments

Design of gravity base foundations

Design of Suction Bucket Jackets (SBJ)
Suction Installed Caisson Foundations for Offshore Wind: Design Guidelines

February 2019
Research to support offshore wind
Improving support structure design

Subsidy-free offshore wind (bottom-fixed)

Establish Monopile Design Method
≈ early 2000s - 2017
Enable commercial viability of offshore wind in Northern Europe waters

Monopile Design Optimisation
≈ 2010s – Today
Improve design robustness and installation methods

Gravity, Jacket Piles & Caissons
≈ 2010s - Today
Provide a wider foundation mix to adapt to large range of offshore environments

Design of gravity base foundations
Design of Suction Bucket Jackets (SBJ)
Design of jacket piles
Introduce monitoring and AI techniques to permit more efficient and safer maintenance of wind farms
Research to support offshore wind

Progress to date

Subsidy-free offshore wind (bottom-fixed)

Establish Monopile Design Method

≈ early 2000s - 2017
Enable commercial viability of offshore wind in Northern Europe waters

Monopile Design Optimisation

≈ 2010s – Today
Improve design robustness and installation methods

Gravity, Jacket Piles & Caissons

≈ 2010s - Today
Provide a wider foundation mix to adapt to large range of offshore environments

Credit: Global Wind Atlas
## Research to support offshore wind
### Progress to date

<table>
<thead>
<tr>
<th>Establish Monopile Design Method</th>
<th>Monopile Design Optimisation</th>
<th>Gravity, Jacket Piles &amp; Caissons</th>
<th>New Site Locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enable commercial viability of offshore wind in Northern Europe waters</td>
<td>Improve design robustness and installation methods</td>
<td>Provide a wider foundation mix to adapt to large range of offshore environments</td>
<td>Extend design methods to rest of the world, with different soil conditions and geological hazards</td>
</tr>
</tbody>
</table>

**Subsidy-free offshore wind (bottom-fixed)**

**Expansion to East Asia and America**
Research to support offshore wind

Offshore wind world expansion

Investigate new and challenging soil conditions: carbonate soils, boulders, glauconite (PIGS project)

Improved site investigation and integrated design approaches to reduce geotechnical risks (e.g. pile run)

Understand the behaviour of the foundation and scour protection to Earthquake loads (centrifuge modelling, numerical modelling)

➢ Expansion to East Asia and America

New Site Locations

- Improved site investigation and integrated design approaches to reduce geotechnical risks (e.g. pile run)
- Understand the behaviour of the foundation and scour protection to Earthquake loads (centrifuge modelling, numerical modelling)

- 2023 Cooling Prize - Diarmid Xu
  Rock-scour protection of offshore foundations subjected to earthquake-induced liquefaction
Research to support offshore wind

Progress to date

- **Establish Monopile Design Method**
  
  - ≈ early 2000s - 2017
  - Enable commercial viability of offshore wind in Northern Europe waters

- **Subsidy-free offshore wind (bottom-fixed)**
  
  - ≈ 2010s – Today
  - Improve design robustness and installation methods

- **Gravity, Jacket Piles & Caissons**
  
  - ≈ 2010s - Today
  - Provide a wider foundation mix to adapt to large range of offshore environments

- **Expansion to East Asia and America**
  
  - ≈ 2018 – 2030?
  - Extend design methods to rest of the world, with different soil conditions and geological hazards

- **Floating Offshore Wind Anchors**
  
  - Today Onwards
  - Expand to deeper water depths
Next Steps in the Research: Anchors for Floating Offshore Wind

Credit: Global Wind Atlas
Next Steps in the Research: Anchors for Floating Offshore Wind

Credit: Global Wind Atlas
Research to support offshore wind

Anchors for Floating Offshore Wind

Dr Christelle Abadie – Research Fellow
cristelle.abadie@univ-eiffel.fr

ISSMGE Interactive Technical Talk:
TC209 – Geotechnics for Offshore Wind

28 February 2024
Research to support offshore wind

Anchors for Floating Offshore Wind

Top view

Shared Anchor

FOWT

Mooring line

Vertically tethered

Taut

Semi-taut

Catenary

Anchor chain horizontal and resting on soil surface

Anchor chain perpendicular to soil surface

©Christelle Abadie

T_cyclic,1

T_cyclic,2

T_cyclic,3

©Christelle Abadie

CG LABORATORY
GEOTECHNICAL
CENTRIFUGE

Université Gustave Eiffel

Dr Christelle Abadie – Research Fellow
christelle.abadie@univ-eiffel.fr

ISSMGE Interactive Technical Talk:
TC209 – Geotechnics for Offshore Wind

28 February 2024
Research to support offshore wind
Anchors for Floating Offshore Wind

Traditional Anchor Designs

Gravity Anchor
Suction Anchor
Anchor Pile

Developmental Anchors

Helical Pile
Dynamically Embedded Anchor
Dynamically Embedded Plate Anchor (DEPLA)
Suction Embedded Plate Anchor (SEPLA)

Dr Christelle Abadie – Research Fellow
christelle.abadie@univ-eiffel.fr

ISSMGE Interactive Technical Talk:
TC209 – Geotechnics for Offshore Wind
28 February 2024
Research to support offshore wind
Anchors for Floating Offshore Wind

Ancres mutualisées pour les éoliennes offshores flottantes
Research to support offshore wind

The MUTANC Project

Objective: Explore the viability of shared anchors as a means to lower the levelized cost of energy for floating offshore wind farms

Scientific and technical content

WP1 - Mooring system design and shared anchor load analysis
WP2 - Geotechnical modelling with 3D finite element numerical method
WP3 - Centrifuge tests on small-scale models to study multidirectional loadings and cyclic loadings
WP4 - Cost estimation of mooring systems through experts consultation and existing cost models
Research to support offshore wind

Anchors for Floating Offshore Wind

- Testing of small-scale physical models in the enhanced gravity field of a geotechnical centrifuge
- Prototype stresses and strains are recreated in the models
- Representative multi-directional cyclic loading can be applied via a set of actuators

Dr Christelle Abadie – Research Fellow
christelle.abadie@univ-eiffel.fr

Centrifuge modelling of anchor piles under multi-directional loading for floating wind turbines
5th European Conference on Physical Modelling in Geotechnics (ECPMG 2024)
Research to support offshore wind

Thank you for listening

- **Subsidy-free offshore wind (bottom-fixed)**
  - Establish Monopile Design Method
    - ≈ early 2000s - 2017
    - Enable commercial viability of offshore wind in Northern Europe waters
  - Monopile Design Optimisation
    - ≈ 2010s – Today
    - Improve design robustness and installation methods
  - Gravity, Jacket Piles & Caissons
    - ≈ 2010s - Today
    - Provide a wider foundation mix to adapt to large range of offshore environnements

- **Expansion to East Asia and America**
  - New Site Locations
    - ≈ 2018 – 2030?
    - Extend design methods to rest of the world, with different soil conditions and geological hazards

- **Floating Offshore Wind Anchors**
  - Floating Wind Anchors
    - Today Onwards
    - Expand to deeper water depths