Foundation Design for the Beatrice Offshore Wind Farm

R. McLean – SUPERGEN Wind Hub General Assembly, 08th November 2018
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Introduction to Beatrice

Foundation Design Challenges

- Site characterisation
- Pile design
- Jacket design
- Fabrication approach
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- Other challenges

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Introduction
Overview

588MW offshore wind farm in the Moray Firth

Clean electricity for 450,000 homes

Overall project £2.6bn

Site:

Circa 13km offshore

132km²

Water depths 35-55m LAT

Scotland’s largest offshore wind farm!
Overview

Offshore structures
84no. 7MW wind turbine generators (WTGs)
2no. offshore transformer modules (OTMs)

Foundations = jackets on driven piles
86 jackets; 85,000 tonnes
344 piles; >14km total length; 44,000 tonnes

Deepest offshore wind fixed structures in the world
### SSE Offshore Wind Alliance
Framework of key suppliers designed to address the key challenges of Round 3 offshore wind and drive efficiencies in SSE's offshore wind programme.

Collaborative work through Concept and FEED between Developer, WTG and OSP Supplier, Installation contractor, Fabricator and Designer.

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
<th>Supplier/Contractor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>STW Grant</td>
<td></td>
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<tr>
<td>2011</td>
<td>Lease Agreement</td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>Concept Application</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>Quality CID</td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td>Consent</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>Piling Start</td>
<td>Atkins</td>
</tr>
<tr>
<td>2016</td>
<td>Jackets Start</td>
<td>Atkins</td>
</tr>
<tr>
<td>2017</td>
<td>Turbine Operation</td>
<td>Atkins</td>
</tr>
<tr>
<td>2018</td>
<td>First Generation</td>
<td>Atkins</td>
</tr>
<tr>
<td>2019</td>
<td>Full Generation</td>
<td>Atkins</td>
</tr>
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Foundation Design Challenges
Site Characterisation
Vast site
Available data - onshore
Available data - offshore
Phased investigation

- Geophys, 5 BH Prelim GM
- Desk study Review GM
- Interim GI
- Update GM
- Completion GI
- Final GM

2011 CONCEPT
2012 FEED
2013
2014
2015
2016 DETAILED DESIGN

Images: BOWL/ Fugro/ Atkins

NOTES:

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Pile Design Process
Loading

Relatively small vertical load
Large horizontal loads from wind, waves and currents
High overturning moment at mudline
Resisted by piles in ‘push / pull’
Piles work in compression & tension
Cyclic
Pile axial capacity

Need efficiency & reliability

- Efficient & reliable pile design
- Optimised pile length
- Reliable axial response
- Reliable level of safety
- Optimised safety
- Optimised CAPEX
- Reduced noise
- Reduced fatigue damage
- Reduced install. risk
- Reduced install. time

Which method?

![Graph showing pile penetration vs. pile tensile capacity with different standards and the 6m difference between ICP-05 and DNV / API highlighted.]

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Jacket Design Process

- Clustering approach
- Structural analyses
Pile stick-up height varies to provide an even bearing across cluster.

Ground conditions vary across cluster.
Design Process

- **Coupled Analysis**
  - Bookending Site

- **Uncoupled Analysis**
  - Variances in-Cluster

- **AFC Design**
  - Inclusive of all contributors
Design Process: Coupled Analysis

Pre-processing:
› ~1,000 wave loading simulations

SWP Analysis:
› Up to 20,000 combined wave + turbine simulations

Post-processing (Retrieval):
› ~300 critical ULS simulations
› 232 FLS simulations
› Code checking
Design Process: Uncoupled Analysis

**ULS:**
- **Baseline:** As per CA
- **Deep Water:** 5% WTG contingency, Water depth uncertainty
- **Shallow Water:** Short stickup, Stiff soil, 5% WTG contingency, Water depth uncertainty

**FLS:**
- **Baseline:** As per CA
- **Deep Water:** 5% WTG contingency, ± Water depth uncertainty
- **Shallow Water:** Short stickup, Stiff soil, 5% WTG contingency, ± Water depth uncertainty
Design Process: AFC Design

- Primary Steel AFC
- Weld Root Assessment
- Uncoupled Analysis Factors
- T&I & VIV Damage
- Joint Axial Stress
- TP & Joint FEM
- Attachments [sympathetic loading]

Factor for all FLS cases

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Fabrication
Beatrice Foundation Fabricators

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Design for Serial Fabrication

Common TP & Upper Jacket

Cluster Specific Lower Jacket
Installation
Pile Installation risks

Boulders

Bedrock horizons

Strong and laterally traceable seismic reflectors

Identified in intact Lower Cretaceous

Variable in lateral extent

Some have corresponding evidence in the borehole data

Some relate to sandstone beds
Mitigation

Remediation = drive-drill-drive

Derive method to assess

Reduction of capacity from drilling

Shaft friction increase from ageing that can be relied upon

Capacity gain from concrete plug

Analyse impact of drilling at varying depths with and without concrete plug

Installation contractor has clear pre-defined scenarios to know instantly whether:

Pile must be abandoned,

Pile can be saved with a concrete plug

Pile does not require a concrete plug
Jacket Installation

- Transportation fatigue
- Upending vs vertical towing
- Installation vessel limits
- Early age cycling
- Safe access
  - Walk to work systems
  - Evacuation procedures
Conclusions
Conclusions

› Multi-disciplinary approach required to manage risk and optimise standardisation

› Good design should consider:
  › Variable site conditions
  › Fabrication approach
  › Installation approach
  › Project programme
  › Through life user safety

› Innovation, collaboration and adaptability are key to future success of industry.
Successes to date

› Design AFC and certification to programme
› Pile installation completed December 2017
› Jacket installation completed July 2018
› First power generation July 2018
› Fully operational in 2019
Thank you