The Bucket Foundation and its Competitiveness Versus Monopiles and Jacket Structures

- Carbon Trust Foundation Competition.
- Foundation concepts.
- Cost comparison.
- Conclusion.

Professor Lars Bo Ibsen, Aalborg University.
Structural and foundation for Wind Turbines but also applicable to other offshore renewable

Cost of energy
OWA focuses on strengthening economics of offshore wind
Stage I (Oct ‘08 to Apr ‘10) examined four technical areas

- Offshore wind returns
  - CAPEX
    - Foundations
  - OPEX
    - Access
  - Yield
    - Electrical systems
    - Wake effects
  - Financing costs

Four technology areas, selected on basis of detailed analysis of over 70 technical barriers

Source: Carbon Trust
Foundations vision: Reduce cost of deeper water foundations

- To demonstrate new, lower-cost foundation designs
  - For 30-60m depths expected in late Round 2 & Round 3

- To reduce lifecycle cost of foundations by 30%
  - TDC target £0.4-0.6m/MW

- To stimulate the supply chain
  - Particularly in volume manufacturing and installation
  - To provide more competition and flexibility in the market

Offshore wind CAPEX breakdown

<table>
<thead>
<tr>
<th>Category</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development &amp; consent</td>
<td>100</td>
</tr>
<tr>
<td>Electrical</td>
<td>15</td>
</tr>
<tr>
<td>Integrated support structure</td>
<td>22</td>
</tr>
<tr>
<td>Production, installation &amp; commissioning</td>
<td>26</td>
</tr>
<tr>
<td>Turbine</td>
<td>33</td>
</tr>
</tbody>
</table>

Source: Carbon Trust
The Challenges

Average distance to shore (km)

- Round 1: 8 km
- Round 2: 25 km
- Round 3: 65 km

Dogger Bank stretches 285km offshore

Source: Carbon Trust
Competition attracted 104 entries from around the World
Seven concepts were selected as finalists

- Total entries: 104
- Rejected in first round: 88
- Rejected in second round: 9
- Finalists: 7

Source: Carbon Trust
Stage I: Foundation Designs total 72

- Fixed prices
- Two turbine: 3.6 and 5 MW
- Water depts: 35m, 45m and 55m
- Two see condition Aver. and Exp.
- 6 seabed profiles
Estimated installed costs show promise
5MW turbine, normal climate

Estimated installed cost per MW (£m)

Leading designs at 35m & 45m depths

Equivalent to 15-30% cost reduction
Foundation concepts for offshore Wind Turbines
Shallow depth 10-30m

• Mono piles
  – 75% of all wind parks today
  – Simple fabrication with welded steel pile
  – No preparations of the seabed are necessary.
  – Requires heavy duty piling/drilling equipment
  – Not suitable for locations with many large boulders in the seabed.
Noise

• The recommended requirements of maximum: 160 dB SEL and 190 dB Peak for underwater pile driving noise levels.

• So far, Germany is the only country having ratified the legislation, but the remaining EU countries are expected to follow Germany’s example.
Foundation concepts for offshore Wind Turbines
Depth 30-60m

- Jackets and Tripod
  - Suitable for larger water depths.
  - Minimum of preparations are required at the site before installation
  - Complex welded main structure
  - Known technology from oil & gas industry
Foundation concepts for offshore Wind Turbines
Depth 30-60m

Tripod
Offshore wind turbine foundations

The flexibility of the bucket foundation gives wider range of application.

Sites with complex geotechnical properties can be covered by a single foundation concept.
The Bucket foundation
Universal foundation solutions

Variation in water depth
0 - 60 m

Variation in seabed properties
Hard clay, soft clay, sand, silt
Vision for Installation in 2001
Reference 1: Pos. 1-Frederikshavn in operation 9 years

The Ø12x6 m prototype bucket foundation was designed for a Vestas V90 3MW turbine placed on 4 m of water. The design is certified by DNV. The bucket was installed in late 2002 and is in normal operation. The structure/soil interaction has been investigated with sophisticated modal analyse equipment.
The bucket foundation technology

Installation advantages:

• **Minimum noise impact.** No pile driving hammers or drill drives are used.
• **No grouted** connections.
• **Minimum disturbance** to the existing seabed.
• The use of excess material for **scour protection is reduced** or not necessary.
• All steel materials can be recovered from the seabed and **reused / recycled** when the foundation is decommissioned.
"The Mobile Met Mast" is a prototype of a bucket foundation designed as support structure for a met-mast.

**Purpose:**
- To gain confidence that a monopod bucket foundation can be successfully installed offshore.
- To obtain a movable met-mast, which can be used in several offshore wind farms.

**Specification**
- Total height: 34 m
- Weight: 165 tones
- Skirt length: 6 m
- Skirt diameter: 12 m

Launching
Float out to site

- Floated to site using 2 tug boats
- 40 m³ water was pumped into the head of the Mobile Met Mast to ensure a horizontal orientation when floating.
Site for installation

Horns Rev 2

Wind turbines:
- 91 Siemens 2.3MW
- 200 MW

Scheduled installation:
- 2008: Foundations
- 2009: Turbines

The Mobile Met Mast

- 3 installation tests were planned at different locations. (depending on weather)
  - Was only installed on the final location.
  - No data from CPT or borings are available (yet)
The Mobile Met Mast
Offshore installation Horns Rev II 2009
Cases: Carbon Trust Wind Accelerator Project

<table>
<thead>
<tr>
<th>Water depth</th>
<th>5 m</th>
<th>15 m</th>
<th>25 m</th>
<th>35 m</th>
<th>45 m</th>
<th>55 m</th>
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</thead>
<tbody>
<tr>
<td>Moment kNm</td>
<td>127.000</td>
<td>156.000</td>
<td>196.700</td>
<td>255.000</td>
<td>300.000</td>
<td>350.000</td>
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<tr>
<td>Bucket size m</td>
<td>Ø14x11</td>
<td>Ø15x12</td>
<td>Ø16x13</td>
<td>Ø17x14</td>
<td>Ø17x15</td>
<td>Ø17x16</td>
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<tr>
<td>Weight tons</td>
<td>295</td>
<td>392</td>
<td>503</td>
<td>640</td>
<td>780</td>
<td>952</td>
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<tr>
<td>Moment kNm</td>
<td>355.000</td>
<td>405.000</td>
<td>480.000</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Bucket size m</td>
<td>Ø18x15</td>
<td>Ø18x16</td>
<td>Ø18x17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight tons</td>
<td>760</td>
<td>920</td>
<td>1080</td>
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</table>
Dogger Bank, 
Foundation loads at seabed

<table>
<thead>
<tr>
<th>Water Depths</th>
<th>25</th>
<th>35</th>
<th>45</th>
<th>55</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loads Bucket foundation [MNm]</td>
<td>*)</td>
<td>338</td>
<td>292</td>
<td>356</td>
</tr>
<tr>
<td>Loads 3,6 MW turbine</td>
<td>461</td>
<td>413</td>
<td>489</td>
<td>538</td>
</tr>
</tbody>
</table>

| Reference jacket 3,6 MW | 380 | 478 | 516 |
| Reference jacket 5 MW | 443 | 542 | 584 |

*) breaking waves
Comparison of Foundation Types

<table>
<thead>
<tr>
<th>Foundation Type</th>
<th>Steel Weight (Gross) each</th>
<th>Cost % comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tripod</td>
<td>1453</td>
<td>1.00</td>
</tr>
<tr>
<td>3-Leg Jacket</td>
<td>1394</td>
<td>0.96</td>
</tr>
<tr>
<td>4-Leg Lightweight Jacket</td>
<td>1170</td>
<td>0.84</td>
</tr>
<tr>
<td>Universal Foundation</td>
<td>992</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Comments

Note to balance the cost, Insurance, Bonds and Guarantees have been removed, where appropriate, as these were not applied equally to all tenders.

Where service cranes were required to certain types, these have been removed

Load out and transportation has been removed, where appropriate
Installation cost of 100 foundations incl. of turbine installation

Carbon Trust Installation derlok study

<table>
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<tr>
<th></th>
<th>A2SEA</th>
<th>DEME</th>
<th>Technip</th>
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</thead>
<tbody>
<tr>
<td>Buckets</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Ref jacket</td>
<td>128</td>
<td>162</td>
<td>149</td>
</tr>
</tbody>
</table>
Universal Foundation A/S

2011 - MBD Offshore Power A/S -> Universal Foundation A/S

Universal Foundations - Concept IP Holder
Universal Foundations – Solution Provider

Fred.Olsen
Dong Energi
Novasion
Aalborg University
The Supply Chain

Universal Foundation Solution Supplier

Concept IP's / Configuration / Contract Management / R&D

Client

Fred. Olsen United AS

Support by way of
- Legal
- Accounting
- HR
- Finance

Fred. Olsen & Co /

Buckets – a wide-ranging foundation solution
We are now launching Offshore Wind Accelerator Stage II
Objective: Reduce cost of energy by 10% through RD&D

Original partnership

- 4-year commitment
- Two new developers
  - Statkraft
  - Mainstream Renewable Power
- 56% of licensed capacity in UK waters (~27GW)
- Total budget of £10m for collaborative R&D
- Up to £30m of demonstration projects

Source: Carbon Trust
**Dogger Bank:** Two Metmast installations - August 2012. 24m of water.

**Firth of Forth:** Metmast installation – August 2012. 38m of water.
Conclusions
Mono Buckets - Versus Monopiles

- **Minimum noise impact.** No pile driving hammers or drill drives are used.
- **Few offshore operations,** with utilizing smaller equipment/vessels during installation.
- **No seabed preparation** and **no** or reduced need for **scour protection.**
- **No transition peace** - Adjusting the upper part of the shaft to fit the **standard wind turbine tower.**
- **Simple** decommissioning.
- **Cost reduction with 20%.**
Mono Buckets - Versus Jackets

- **Reduced steel** consumption compared to the Jacket.

- Use of **simple geometric** welded steel structures *suitable for mass production.*

- Bucket **20% expensive 80% cheap** welded steel. Jacket **80% expensive 20% cheap.**

- Few offshore operations, with utilizing smaller equipment/vessels during installation.

- **No seabed preparation** and no or reduced need for **scour protection.**

- **No transition peace** - Adjusting the upper part of the shaft to fit the standard wind turbine tower.

- **Simple** decommissioning.

- **Cost reduction 30-50%.**
Thank you for listening

Questions?

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