Wave Forces on Offshore Windturbine Foundations on Borkum Riff

Part C: Summary
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**Introduction**

The present report is a summary of the reports by Juul Larsen and Frigaard (2004) and Lykke Andersen and Frigaard (November 2004). It also contains some additional force measurements on a cone shaped structure and some new force measurements on the concrete tripod.

For further information on the conducted test programme contact Brian Juul Larsen (phone: +45 96 35 72 31, email: i5bjl@civil.aau.dk), Thomas Lykke Andesen (phone: +45 96 35 84 86, email: i5tla@civil.aau.dk) or Peter Frigaard (phone: 96 35 84 79, email: peter.frigaard@civil.aau.dk).

All measures given in this report is in prototype values unless otherwise is stated.
Tests
The overall test setup in the new tests are similar to the setup used in Juul Larsen and Frigaard (2004) and Lykke Andersen and Frigaard (November 2004). The water depth is 25 meters in all tests. At a water depth of 25 meters the models have the following eigenfrequencies:

<table>
<thead>
<tr>
<th>Model</th>
<th>Frequency</th>
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<tbody>
<tr>
<td>Cone</td>
<td>0.53 Hz</td>
</tr>
<tr>
<td>Concrete tripod</td>
<td>0.39 Hz</td>
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Table 1. Eigenfrequencies with a water depth of 25 m.

The JONSWAP wave spectrum has been used with a peak enhancement factor of 3.3. The concrete tripod is placed with two legs in the direction facing the waves and one directly backward. A description of the models can be found on page 47 and 48 in the report by Juul Larsen, De Vos and Frigaard (November 2004). As in Lykke Andersen and Frigaard (November 2004) the data analysis has been performed by use of Wavelab using the same methods and techniques.
Results

The largest positive and negative forces and moments measured during the tests are listed in table 2.

<table>
<thead>
<tr>
<th>Test</th>
<th>Structure</th>
<th>$H_{1/3}$ [m]</th>
<th>$T_p$ [s]</th>
<th>$F_{\text{max}}$ [kN]</th>
<th>$F_{\text{min}}$ [kN]</th>
<th>$M_{\text{max}}$ [kNm]</th>
<th>$M_{\text{min}}$ [kNm]</th>
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</table>

Table 2. Largest positive and negative forces and moments measured during the tests.
As a reasonable representative for the maximum and minimum forces of the tests the 1/250 values are compared in figure 1.

Figure 1. Comparison of measured 1/250 forces and moments.
A summary of the works by Aalborg University on the Borkum Riffgrund project gives the following result plots:

Figure 2. Comparison of largest measured forces and moments.
Figure 3. Comparison of measured attack point of largest forces with some Boussinesq calculations.

References
Wave Forces on Offshore Windturbine Foundations on Borkum Riff. Department of Civil Engineering, Aalborg University, Hydraulic and Coastal Engineering No. 5, ISSN 1603-9874

Lykke Andersen, T. and Frigaard, P. (November 2004):
Wave Forces on Offshore Windturbine Foundations on Borkum Riff – Part B: Verification Tests. Department of Civil Engineering, Aalborg University, Hydraulic and Coastal Engineering No. 5, ISSN 1603-9874

Scour around Offshore Windturbine Foundations on Borkum Riffgrund. Department of Civil Engineering, Aalborg University, Hydraulic and Coastal Engineering No. 9, ISSN 1603-9874
Appendix 1 – Result Plots

Test TB01

- With a cone structure
- $H_{1/3} = 3.56$ m, $T_p = 9.5$ s
- Maximum force: 4345 kN
- Minimum force: -4415 kN
- Maximum moment: 56810 kNm
- Minimum moment: -47610 kNm
Test TB02

- With a cone structure
- $H_{1/3} = 4.23$ m, $T_p = 9.5$ s
- Maximum force: 5328 kN
- Minimum force: -4506 kN
- Maximum moment: 73090 kNm
- Minimum moment: -50610 kNm
Test TB03

- With a cone structure
- $H_{1/3} = 6.86$ m, $T_p = 12.1$ s
- Maximum force: 8436 kN
- Minimum force: -6616 kN
- Maximum moment: 117000 kNm
- Minimum moment: -68820 kNm
Test TB04

- With a cone structure
- $H_{1/3} = 7.51$ m, $T_p = 13.9$ s
- Maximum force: 8665 kN
- Minimum force: -6653 kN
- Maximum moment: 113100 kNm
- Minimum moment: -68280 kNm

![Graphs showing wave forces and spectra](image-url)
Test TB05

- With a cone structure
- $H_{1/3} = 8.71\,\text{m}$, $T_p = 13.9\,\text{s}$
- Maximum force: $8745\,\text{kN}$
- Minimum force: $-6808\,\text{kN}$
- Maximum moment: $123400\,\text{kNm}$
- Minimum moment: $-76210\,\text{kNm}$
Test TB06

- With a concrete tripod structure
- $H_{1/3} = 3.67 \text{ m}$, $T_p = 9.5 \text{ s}$
- Maximum force: $3413 \text{ kN}$
- Minimum force: $-3241 \text{ kN}$
- Maximum moment: $47880 \text{ kNm}$
- Minimum moment: $-37590 \text{ kNm}$

![Graphs showing wave forces on offshore wind turbine foundations](image_url)
Test TB07

- With a concrete tripod structure
- $H_{1/3} = 4.06$ m, $T_p = 9.3$ s
- Maximum force: 3511 kN
- Minimum force: -3322 kN
- Maximum moment: 51090 kNm
- Minimum moment: -37050 kNm
Test TB08

- With a concrete tripod structure
- $H_{1/3} = 6.50$ m, $T_p = 12.5$ s
- Maximum force: 5044 kN
- Minimum force: -4901 kN
- Maximum moment: 67870 kNm
- Minimum moment: -48720 kNm
Test TB09

- With a concrete tripod structure
- $H_{1/3} = 7.27 \text{ m}, T_p = 12.9 \text{ s}$
- Maximum force: $6416 \text{ kN}$
- Minimum force: $-4920 \text{ kN}$
- Maximum moment: $90370 \text{ kNm}$
- Minimum moment: $-50120 \text{ kNm}$

Incident wave spectrum at structure

Incident wave height distribution at structure
Wave Forces on Offshore Windturbine Foundations – Part C

Test TB10

- With a concrete tripod structure
- $H_{1/3} = 8.53$ m, $T_p = 14.5$ s
- Maximum force: 7196 kN
- Minimum force: -5084 kN
- Maximum moment: 90560 kNm
- Minimum moment: -52720 kNm