Technical Noise Mitigation during Offshore-Windfarm Foundation Installation

Examples from Offshore Windfarms:
Meerwind Süd Ost, Global Tech I, Nordsee Ost, DanTysk, EnBW Baltic 2, Borkum Riffgrund 1, Amrumbank West und Butendiek

as part of
Offshore Wind R&D Conference 2015
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Bremerhaven
Phases of Noise Mitigation

Duration from preparation to practical implementation of Noise Mitigation System (NMS) can be up to 3 years

**Phase 1**

**Analysis and preparation (up to 1 year)**

- Noise emission prognosis and background noise measurement
- Technical analysis of available Noise Mitigation System(s) and decision making with installation companies
- Preparation of Noise Mitigation Concept and approval by BSH (important for finalisation of contracts)

**Phase 2**

**Detailed design, planning, engineering and production (up to 2 years)**

- Project-specific engineering, production and preparation of Noise Mitigation System(s)
- Establishing procedures, method-statements and vessel and installation equipment modification if necessary
- Creating noise mitigation implementation plan

**Phase 3**

**Implementation during construction phase**

- Marine mammal deterrence procedures
- Use of Noise Mitigation System(s) and if necessary applying maximum hammer energy settings
- Efficiency control of noise reduction and acoustic deterrence success
- Documentation
### Noise Mitigation Systems Used (2012 – 2014)

Up to now, there is no state of the art NMS none tested at all water depths, types of soil conditions and foundations!

<table>
<thead>
<tr>
<th>Project</th>
<th>No. of Foundation and Ø</th>
<th>NMS: Bubble Curtain</th>
<th>NMS: Others</th>
<th>water depth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>BBC (HTL)</td>
<td>BBC (Wey)</td>
<td>DBBC (HTL)</td>
</tr>
<tr>
<td>Meerwind</td>
<td>80 MPs, Ø 5,5m</td>
<td>X</td>
<td></td>
<td></td>
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<tr>
<td>GT 1</td>
<td>80 Tripods, each 3 piles, Ø=2,48 m per pile</td>
<td>X</td>
<td></td>
<td></td>
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<tr>
<td>NSO</td>
<td>49 Jackets, each 4 Piles, Ø=2,4 m per pile</td>
<td>X X</td>
<td></td>
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<tr>
<td>DanTysk</td>
<td>80 MPs, Ø = 6 m</td>
<td>X X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baltic 2</td>
<td>80 WTG, 89 MP: Ø = 5,2-6,5 m, 41 JKTs: Ø = 3 m per pile</td>
<td>X</td>
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<td></td>
</tr>
<tr>
<td>Borkum Riffgrund 1</td>
<td>77 MP, Ø=5.9 m</td>
<td>from 21. MP</td>
<td></td>
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<tr>
<td>Amrumbank West</td>
<td>30 MP, Ø = 6 m</td>
<td></td>
<td>X</td>
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<tr>
<td>Butendiek</td>
<td>80 MP, Ø = 6-6,5m</td>
<td>X</td>
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</tbody>
</table>

Additionally e.g. Small Bubble Curtain (SBC) at Alpha Ventus (2009) and Bard Offshore 1 (3 locations 2010/2011)
Offshore Logistics

**Need for several additional vessels:** e.g. for efficiency monitoring, for deployment of bubble curtain systems or even a separate vessel for operation of compressors.

**Need of additional personnel for the efficiency monitoring:** e.g. for online monitoring additional 3 persons.

**Modification of the installation vessels:** deck layout, capacity of cranes (weight and height), piling frame.

**Additional installation vessel:** if construction concept needs to be changed into two separate construction steps (e.g. foundation and transition piece).

**Increased risks:** through additional (offshore) activities and more vessel operation.

Higher effort in work, time and costs e.g. through modified/additional engineering, complex workflow procedures (method statements), requirements of intensive risk assessment and increased marine coordination needs.
Cost Distribution for Implementation of Noise Mitigation Systems

Total costs for noise mitigation systems per project: between 15 and 36 million Euros

Costs for noise protection are around 15% of foundation construction costs

Offshore Windfarm Cost Distribution Implementation NMS

- Noise Mitigation System (NMS): 45%
- Measurement and Results: 6%
- Vessels: 45%
- Additional Costs for Process Changes/Delays: 4%

Vessel costs are higher with BBC implementation.
Costs for NMS and additional costs are higher with other alternative NMS.
Deterrence and Efficiency Monitoring

BSH requirement for acoustic deterrence, hydro-sound measurement and harbour porpoise detection (C-PODs) at all locations

**Acoustic Deterrence:** mostly from the installation vessel or from „Bubble Curtain Vessel“
- 2-3 pingers 40-50 min. before start of piling or operation of NMS
- 1-2 Seal Scarer 30-40 min. before start of piling or operation of NMS (parallel to pinger)

**Hydro-sound measurement:**
- 1-2 hydrophones at 750m, 1-2 hydrophones at 1500m and increased effort at reference locations (4-6 positions)
- 1-2 hydrophones further field (e.g. at POD station and/or nature conservation areas nearby)
- Furthermore more frequently **online** hydro-sound monitoring

**Harbour porpoise (CPOD) measurement:**
- 1-2 mobile PODs at 750m, 1-2 mobile PODs at 1500m,
- 4-5 single POD stations,
- 1-2 PODs further field (e.g. at POD station and/or nature conservation areas nearby)
- Furthermore **online** POD monitoring conducted
Meerwind Süd Ost

1. **Implementation**
   Installation 80 Monopiles September 2012 to April 2013 using Double Big Bubble Curtain (DBBC)

2. **Offshore Logistics**
   Coordination between installation vessel "Zaratan", bubble curtain vessel "Noortruck" and "Arne Tiselius"

3. **Construction Time Impact**
   Delays of 19.2 days due to DBBC vessel conversion, DBBC breakdowns and from increase in hammering time

4. **Costs**
   Noise mitigation system and vessels: additional costs due to conversions and efficiency monitoring: **15 Mio. EUR**

5. **Achievements - Challenges**
   **Achievements:**
   - Noise reduction of approx. 15 dB
   - Hammer energy reduction from 2000kJ to 1000kJ

   **Challenges:**
   - Implementation of DBBC deployment into the construction process without large time delays
   - Ground-coupling
   - Weather
   - Vessel failure
   - Leaks of bubble curtain
1. **Implementation**
Installation 80 Tripods October 2012 to July 2014 (break between Feb-June 2014) using BBC, SLBC, DLBC and TLBC

2. **Offshore Logistics**
Coordination between installation vessel and bubble curtain vessel

3. **Construction Time Impact**
Construction times at some locations prolonged due to BBC operations and reduction of hammer energy

4. **Costs**
Noise mitigation system and efficiency monitoring: **Total costs approx. 17 Mio. €**

5. **Achievements - Challenges**

   **Achievements:**
   - Significant improvements of the BBC through use of swivel joints and BBC deployment „under pressure“
   - Noise reduction up to approx. 13 dB
   - Maximum Hammer energy: 900 - 1200 kJ

   **Challenges:**
   - Twisting and wear of hose-system
   - Deployment accuracy at each location at 40 m water depth and in offshore sea-conditions
   - Compliance of safety distance between BBC- and Jack-up-Installation- vessel
   - Differences in weather restrictions between Installation- and BBC- vessel
1. Implementation
Installation 48 jackets foundations from October 2012 - March 2014. Two different BBC-systems + SLBC or DBLC

2. Offshore Logistics
Numerous BBC configurations -> Multiple changes during installation and at times simultaneous use of two BBC vessels

3. Construction Time Impact
Construction times prolonged by 1-2 hours at some locations due to BBC operations and reduction of hammer energy

4. Costs
Noise Mitigation System, Increased Offshore Logistics and Efficiency Monitoring: Total costs approx. 18 Mio. €

5. Achievements - Challenges
Achievements:
• Improvement of NMS: From 22nd installation 2nd BBC System or combination of systems as well as reduction of hammer energy meant noise limits were complied with at 91% of pile driving events
• Additionally harbour porpoises presence monitored using real-time online monitoring (WDS)
• Hammer energy: 80% of installations under 1000 KJ and 60% under 900 KJ

Challenges:
• Strong currents at some locations resulted in drifting of bubble curtain
• Compliance with safety distance between BBC and installation vessel
1. **Implementation**

Installation 80 Monopiles 28.02.13-11.12.13, two different D/BBC-systems, TBBC and SLBC

2. **Offshore Logistics**

14 different BBC configurations -> vessel change and parallel use of 2 BBC vessels for 60 MPs

3. **Construction Time Impact**

Through use of NMS construction time prolonged by 1-2 hours at some locations

4. **Costs**

Noise Mitigation System, Increased Offshore Logistics and Efficiency Monitoring:
Total costs approx. 20 Mio. €

5. **Achievements - Challenges**

**Achievements:**
- Improvement of noise mitigation systems: Configuration BBC-HTL plus DBBC-Weyres lead to a maximum noise reduction and compliance of noise limits
- Hammer-energy from 15th Monopile max. 1000 kJ

**Challenges:**
- HSE Requirements limited possibilities for BBC configurations and an increased process effort and costs.
- Limitation of BBC providers and materials (hose) → Bottlenecks and delays by implementation of BBC configurations.
EnBW Baltic 2

1. Implementation


MP (6 variants): DBBC with 810m-1010m length and spiral-, pretzel-, circular deployment layout, 7-9 compressors

JKT (5 variants): DBBC 1150 m length, 9-12 compressors

2. Offshore Logistics

Different water depths(23-44m) – two foundation types MP and JKT - two parallel offshore installation sites. Rapid installation progress - two vessels for noise mitigation per installation site respectively (1. deploying hoses, 2. operating compressors and further efficiency monitoring.

3. Construction Time Impact

Due to difficult soil conditions no clear conclusion possible

4. Costs

Noise Mitigation System and Efficiency Monitoring: Total costs not communicated

5. Achievements - Challenges

Achievements:
- Continuous increase of noise reduction through optimisation (5-20 dB);
- No technical failure of noise mitigation systems;
- Coordinated weather limits between the involved installation vessel and NMS vessels;

Challenges:
- Timely implementation of optimisation measures due to speed of installation;
- Timely delivery of measurement results and reports;
- Coordination between the two installation sites regarding acoustic deterrence
Borkum Riffgrund 1

1. **Implementation**
   Installation 77 Monopiles 21.01.2014 – 29.07.2014 with IHC NMS tube

2. **Offshore Logistics**
   Further development of IHC NMS tube for integration into installation procedure and extend functionality

3. **Construction Time Impact**
   Construction times through NMS use, extended hammering time and repair of IHC NMS tube (approx. 10-14 days)

4. **Costs**
   Noise mitigation system and efficiency monitoring: **Total costs approx. 20 Mio. €**

5. **Achievements - Challenges**
   **Achievements:**
   - Good and constant noise mitigation
   - Combination IHC NMS tube and reduced hammer energy <1000kJ (from Pile 15): 97% of noise levels below noise limits
   - Noise reduction especially good in the high-frequency range (>20 dB up to 30 dB)
   - Reduction of temporal influence through optimised functionality and handling of the NMS as well as good cooperation with installation company.

   **Challenges during Implementation:**
   - Technical- / handling- problems of IHC-NMS tube at three locations lead to increased noise emission values
   - Compliance of noise limits through IHC-NMS tube only not possible, reduction of hammer energy necessary
   - Repeated lost of measurement devise through weather conditions and other vessels
   - Operating limits for deployment of measurement devices / Installation vessel, measurement device deployment/retrieval not possible in rough weather
Amrumbank West

1. Implementation
Installation 80 monopiles 14.01.2014 – 18.03.2015, different BBC or DBBC combinations and HSD or IHC NMS tube

2. Offshore Logistics
Split of MP-installation in three phases with different NMS and different installation vessels and NMS vessels

3. Construction Time Impact
The prototype nature of HSD lead to additional handling times of 3-4 h per pile
Restriction of hammer energy → additional 0.5-1 h per pile

4. Costs
Total costs 36 Mio. €; of which 21 Mio. € direct costs (contracts) and approx. 15 Mio. € additional costs through the extension of installation time

5. Achievements - Challenges

Achievements:
- Improvement of noise mitigation through successive modifications of hose-length
- Deployment radius, maintenance intervals (hole reboring), hose-ballasting
- Improvement of noise mitigation through change/exchange of HSD-net and noise optimised hammer energy control
- Reduction of handling time of HSD through successive improvements

Challenges:
- Breakdown of DBBC vessel and HSD breakdown lead to one week stop in construction
- Weather limits HSD < Weather limits of monopile installation
1. **Implementation**


2. **Offshore Logistics**

Further development of the IHC NMS 6500 during preparatory phase -> necessary modification of installation process → Separation of MP and TP installation (2 installation units.)

In addition modification of the installation vessel (piling template and crane).

Use of BBC-vessel and further vessel for efficiency monitoring.

3. **Construction Time Impact**

Through use of NMS construction time prolonged by 1-2 hours at each location plus approx. 14 days due to IHC repair.

4. **Costs**


5. **Achievements - Challenges**

**Achievements:**
- 69/80 locations below noise limits, overall between 150-167 dB SEL₀⁵, noise reduction up to 18 dB
- Hammer energy ≤ 750 kJ
- Good logistics concept of installation company and positive cooperation → temporal impact could be minimised

**Challenges:**
- Part failure of IHC NMS tube at first location
- Anchor logistics were hampered due to BBC → increased logistic effort and costs of BBC deployment modification
- Speed of MP installation
NMS Development of the eight German projects from 2011-2014

<table>
<thead>
<tr>
<th>Big Bubble Curtain (BBC)</th>
<th>Combinations of BBC</th>
<th>Other NMS</th>
<th>Combination of other NMS + BBC</th>
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<tbody>
<tr>
<td><strong>Noise Mitigation System (NMS)</strong></td>
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<tr>
<td>basis measurement (bm)</td>
<td>bm + additional measurement (am)</td>
<td>bm + am and /or online measurement (om) harbour porpoise (hp)</td>
<td>bm + am and /or om hp and om hydro sound (hs)</td>
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<td></td>
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<tr>
<td><strong>scope of efficiency monitoring</strong></td>
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<tr>
<td>2000 kJ</td>
<td>Ø 750 kJ</td>
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<td><strong>pile driving hammer energy used</strong></td>
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<td>0%</td>
<td>86.25%</td>
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<td><strong>compliance with noise emission value</strong></td>
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<tr>
<td>15 million</td>
<td>36 million</td>
<td></td>
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<tr>
<td><strong>costs</strong></td>
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Summary

The results and developments described show the strong commitment of the industry. Noise emission limits were often achieved following adjustments to the noise mitigation systems and were sometimes even well below.

The different projects are however still limited in comparability due to:

• Different water depths
• Different soil conditions
• Different current and weather conditions
• Different foundations
• Different pile-diameter and length
• Different hammer
• Different vessels
• Different installation tools (e.g. piling-templates, gripper)

There is therefore no general state of the art noise mitigation system standard available yet, with a NMS needing to be developed, tested and adjusted specifically for each project.
Thank you for your attention!

On behalf of the OFW working group noise mitigation
(AK Schallschutz)

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Appendix: List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>BBC</td>
<td>Big Bubble Curtain</td>
</tr>
<tr>
<td>CTD-Sonde</td>
<td>Conductivity, Temperature and Depth</td>
</tr>
<tr>
<td>DBBC</td>
<td>Double Big Bubble Curtain</td>
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<tr>
<td>DLBC</td>
<td>Double Length Bubble Curtain</td>
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<tr>
<td>HSD</td>
<td>Hydrosound Damper</td>
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<tr>
<td>HTL</td>
<td>Hydrotechnik Lübeck (BBC system supplier)</td>
</tr>
<tr>
<td>IHC</td>
<td>IHC Merwede B.V. (producer of IHC tube)</td>
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<tr>
<td>JKT</td>
<td>Jacket</td>
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<tr>
<td>MP</td>
<td>Monopile</td>
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<tr>
<td>NMS</td>
<td>Noise Mitigation System</td>
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<tr>
<td>TBBC</td>
<td>Triple Big Bubble Curtain</td>
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<tr>
<td>OSS</td>
<td>Offshore Substructure (platform)</td>
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<tr>
<td>C-POD</td>
<td>Continuous Porpoise Detector</td>
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<tr>
<td>Ref.</td>
<td>Reference</td>
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<tr>
<td>SLBC</td>
<td>Single Length Bubble Curtain</td>
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<tr>
<td>TLBC</td>
<td>Triple Length Bubble Curtain</td>
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<tr>
<td>WTG</td>
<td>Wind turbine generator</td>
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<tr>
<td>Wey</td>
<td>Weyres-Offshore (BBC system supplier)</td>
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<tr>
<td>WDS</td>
<td>Wireless Detection System</td>
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