Noise Abatement Systems for impact pile-driving
Technical options for complying with noise limits

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Competent under the terms of ISO/IEC 17025 to carry out test in:
Determination of emissions and immissions of vibrations; underwater noise.
Motivation

Anthropogenic Noise

Natural or Abiotic Background Noise

Natural Biological Noise

04. November 2021
Bellmann et al, 2021
Impact Pile-Driving

Complete Pile

Impact Hammer

Start pile-driving

Submerged hammering

40 – 120 m
Underwater noise regulation in Germany

BNatSchG: Not allowed to harm any protected species

Impulsiveness noise (since 2011)
- Noise Mitigation Values @ 750 m
  (160 dB_{SEL05}, 190 dB_{Lp, pk})
- Piling duration: 180 minutes

BMU Noise Mitigation Concept (2013)
- North Sea 8 km disturbance radius
- Max. 10% of German Sea
- Max. 1% of Special Area of Conservation
Underwater noise regulation in UK/USA

Environmental Statement → Post-ES Modelling → Impact ranges → Mitigation plan (MMMP / PS)

Noise risk assessment

Impact ranges

Noise measurements

Impact range

Impact range

Impact range

04. November 2021
Bellmann et al, 2021
Foundation Types
Lessons learnt report (1/2)

• Funded R&D-project on behalf of BSH (2016 – 2019) based on German regulator (BSH) uW data base MarinEARS

• 21 German OWF and 28 single installation projects
  • 1,458 foundation installations
  • 2,464 pile installations
  • diameter: 1,829 mm ≤ Ø ≤ 8,100 mm
  • All available noise mitigation systems as well as noise abatement systems tested in German waters

https://www.itap.de/media/experience_report_underwater_era-report.pdf
Lessons learnt report (2/2)

Aims:

- Investigation of site-specific and project-specific influencing factors on unmitigated pile-driving noise
- Lessons learnt regarding noise mitigation concepts

Output:

- Summary of legal requirements (author BSH)
- Identified site-specific and project-specific factors
- Definition of state-of-the-art noise mitigation concepts

https://www.itap.de/media/experience_report_underwater_era-report.pdf
MarinEARS – Underwater noise knowledge data base

Biggest underwater noise data base for impact pile-driving.

- 1500 Offshore Foundations
- 2500 Piles

Continous noise data base is in progress

Information Tool

Product der am BSH geführten Forschungsvorhaben NaVES (Implementierung) und Sound Mapping (Weiterentwicklung)

Gefördert durch

Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit

marinears@bsh.de
Influencing factor on pile-driving noise

Unmitigated pile-driving noise depending on:

✓ pile diameter
✓ pile design and blow energy used
✓ water depth / bathymetry
✓ distance / transmission loss
✓ soil conditions
✓ inclination of pile
✓ hammer – pile interaction
✓ etc.
Influencing factor on pile-driving noise

Unmitigated pile-driving noise depending on:
- pile design & pile diameter
- blow energy used
- water depth / bathymetry
- distance / transmission loss
- soil conditions
- hammer – pile interaction
Influencing factor on pile-driving noise

Pile Diameter

In ISO 18406 (2017):
- SEL in dB re 1µPa²s
- $L_{p, pk}$ in dB re 1µPa

In Itap data base (IONIS):
- 30 OWF projects
- > 35 OSS and converter platforms

Only unmitigated pile-driving
Pile-Driving Results @ 750 m
Requirements on Noise Mitigation Systems

ISO 18406 (2017):
SEL in dB re 1μPa²s
$L_{p, pk}$ in dB re 1μPa

German limiting values @750 m

- $L_{p, pk} \leq 190$ dB
- SEL $\leq 160$ dB

~20 dB
20 dB noise mitigation correlates to a reduction of the physical metric:
• 90% sound pressure
• 99% sound intensity

Source: F. Wilke, RWE
Noise Mitigation

Noise reduction by

• avoiding underwater noise = Noise Mitigation System (NMS)
• reducing existing underwater noise = Noise Abatement Systems (NAS)

Primary NMS

• reduced impact Pile-Driving Energy (eg. HiLo- procedure)
• Vibro-Piling (continous noise)
• Suction Buckets (not viable for all projects)
• Gravity foundations (not viable for all projects)
• Blue Piling hammer (prototype, currently not available)
• .......
Noise Abatement Systems

Bubble Curtain system
- Guided & unguided „Little Bubble Curtain“
- Small Bubble Curtain (Menck)
- Big Bubble Curtain (BBC)

„Shell-in-shell“ system
- Noise Mitigation Screen (IHC) (IHC-NMS)
- Cofferdam & shell-in-shell constructions
- BeKa shell (Weyres Offshore)
- Fire Hose Methode (Menck)

Other systems
- Pile wrapped with foam
- Hydro-Sound Damper (HSD)
- Resonator system
- HydroNas (W³GM)
- .....

Bellmann et al., 2021
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other systems
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- Resonator system (AdBm)
- HydroNas (W³GM)
- .....
Noise Mitigation Screen (IHC)

- shell-in-shell system
- close-to-pile NMS
- used in water depth ≤ 40 m
- used for pile diameter ≤ 8 m (sizeable shells)

**Advantage**
- pile guiding system integrated
- inclination measurement tool integrated

**Disadvantage**
- weight / dimension
- ground coupling effects
- application @ varied water depth?
- increased safety risks during deployment
Noise Mitigation Screen (IHC)

Noise reduction is independent from
• water depth (more or less)
• current / direction

successfully applied: > 450
malfunction: < ~1%

➤ measured noise reduction: \( \Delta \text{SEL} = 13 \leq 15 \leq 16 \text{ dB} \)
even @ 40 m water depth

➤ robust and ready for offshore Noise Mitigation System
Hydro Sound Damper (HSD)

- Helmholtz Resonator system
- close-to-pile NMS
- consist of: Net + HSD Elements + ballast box
- used in water depth ≤ 45 m
- Used for pile diameter ≤ 8 m

Advantage
- „light-weighted“
- HSD-elements tunable (frequency < 500 Hz)

Disadvantage
- ground coupling effects
- ballast box incl. lifting tool
- „life time of HSD – Elements“
Hydro Sound Damper (HSD)

Noise reduction is independent from
• water depth (more or less)
• current / direction

successfully applied: > 340
malfunction: < ~1%

➤ reduce noise < 100 Hz with different HSD elements

➤ measured noise reduction: $\Delta \text{SEL} = 10 \leq 11 \leq 12 \text{ dB}$
  even @ 40 m water depth

➤ require project specific design

➤ ready for offshore Noise Mitigation System
AdBm System by AdBm Technologies

- resonator system
- close-to-pile NMS
- consist of: vertical shape blocks + lifting tool
- used in water depth \( \leq 30 \text{ m} \)
- used for pile diameter \( \leq 8 \text{ m} \)

**Advantage**
- „light-weighted“
- Block shapes partly tunable (frequency < 500Hz)

**Disadvantage**
- ground coupling effects
- only prototype available (not a lot experiences)
- lifting tool
AdBm System by AdBm Technologies

Noise reduction seems to be independent from

• water depth (more or less)
• current / direction

successfully applied: > 6
malfunction: /

➢ reduce noise ~ 100 Hz with only one block shape

➢ measured noise reduction: $\Delta$ SEL = 5 to 8 dB (1\textsuperscript{st} application)

➢ require project specific design

➢ prototype (next applications planned in October 2022?)
(double) Big Bubble Curtain

- impedance shifts (water vs water-air mixture)
- far-from-pile NMS (the only one)
- consists of: compressed air + nozzle hose on sea bed
- used in water depth \( \leq 45 \) m (UXO clearance \( \leq 70 \) m)
- used for pile diameter \( \leq 8 \) m

**Advantage**
- independent from foundation design
- „independent“ from installation vessel (pre-laying)

**Disadvantage**
- separate vessel + compressors required
- coordination installation vessel vs nozzle hoses
(double) Big Bubble Curtain

Noise reduction depends on

- water depth
- current / direction / shape (max 0.75 m/s current)
- distance between foundation and nozzle hose
- number of nozzle hoses (1, 2, 3 or 4)
- distance between nozzle hoses
- used air flow / pressure distribution
- length of nozzle hose (> 1.000 m)
- used hole configuration
- maintenance of used nozzle hoses
(double) Big Bubble Curtain

- > 1,000 piles in North & Baltic Sea
- 2 R&D projects (OFF BW II; enhancing BBC @ OWF GT I)
- different supplier on the market
- > 2,000 measured data sets in distances between 80 m and 5,000 m to pile available
- measurements: inside & outside the BBC nozzle hose
- pressure & air flow measurements inside the BBC nozzle hose

- life time of nozzle hoses
- less noise reduction due to material fatigue, current, not optimzied config.
- needs partly „enhancements“ during first application
- ready for offshore Noise Mitigation System
## Combinations of NMS

<table>
<thead>
<tr>
<th>No.</th>
<th>Noise Mitigation System</th>
<th>$\Delta SEL$ [dB]</th>
<th># of tests (piles)</th>
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<tbody>
<tr>
<td>1</td>
<td>Combination of IHC-NMS + optimised BBC ($&gt;0.3$ m$^3$/min*m, water depth $&lt;25$ m)</td>
<td>$17 \leq 19 \leq 23$</td>
<td>$&gt;100$</td>
</tr>
<tr>
<td>2</td>
<td>Combination of IHC-NMS + optimised BBC ($&gt;0.4$ m$^3$/min*m, water depth $\sim40$ m)</td>
<td>$17 - 18$</td>
<td>$&gt;10$</td>
</tr>
<tr>
<td>3</td>
<td>Combination of IHC-NMS + optimised DBBC ($&gt;0.5$ m$^3$/min*m, water depth $\sim40$ m)</td>
<td>$18 \leq 19 \leq 20$</td>
<td>$&gt;65$</td>
</tr>
<tr>
<td>4</td>
<td>Optimised BBC + HSD ($&gt;0.4$ m$^3$/min*m, water depth $\sim30$ m)</td>
<td>$19 \leq 21 \leq 22$</td>
<td>$&gt;30$</td>
</tr>
<tr>
<td>5</td>
<td>Optimised DBBC + HSD ($0.4$ m$^3$/min*m, water depth $30$ m)</td>
<td>$15 \leq 16 \leq 20$</td>
<td>$&gt;50$</td>
</tr>
<tr>
<td>6</td>
<td>Optimised DBBC + HSD ($&gt;0.5$ m$^3$/min*m, water depth $&lt;40$ m, North Sea)</td>
<td>$18 - 19$</td>
<td>$&gt;30$</td>
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<td>Reducing used blow energy</td>
<td>additional 2.5 dB by halving</td>
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All NMS in optimized system configuration, no malfunction or disturbing influences like strong current.
# Combinations of NMS

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<td>Combination of IHC-NMS + optimised BBC (&gt; 0.4 m³/(min*m), water depth ~40 m)</td>
<td>17 - 18</td>
<td>&gt; 10</td>
</tr>
<tr>
<td>3</td>
<td>Corr (&gt; 0.5 m³/(min*m), water depth ~40 m)</td>
<td>But: ΔSEL _System 1 + ΔSEL _System 2 ≥ ΔSEL _Combination</td>
<td>65</td>
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<td>&gt; 30</td>
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<td>5</td>
<td>Optimised DBl (0.4 m³/(min*m), water depth ~40 m)</td>
<td>Noise Reduction: ΔL_p,_pk ≥ ΔSEL but L_p,_pk very sensitive metric (large uncertainty)</td>
<td>&gt; 50</td>
</tr>
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<td>Optimised DBBC + HSD (&gt; 0.5 m³/(min*m), water depth &lt; 40 m, North Sea)</td>
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All NMS in optimized system configuration, no malfunction or disturbing influences like strong current.
Effectiveness of Noise Mitigation Systems

Mitigated pile-driving: no pile-driving noise in water @ high frequencies

Do we underestimate the efficiency of NMS regarding Sensation Level?
Anthropogenic noise is capable to harm and to disturb marine life
Therefore, noise mitigation values are defined to comply with

- NMS are limited available: reduced blow energy, new hammer techniques, alternative foundation designs
- NAS ready for offshore: HSD, IHC-NMS and (D)BBC (AdBm will come)
- Project specific adaptation/optimization of each NMS required!

Do we underestimate the efficiency of NAS and NMS for some marine species regarding disturbance?