Hydro sound emissions during impact driving of monopiles using Hydro Sound Dampers and Big Bubble Curtain

Philipp Stein¹, Hauke Sychla¹, Jörg Gattermann¹, Jan Degenhardt²

¹Institute for Soil Mechanics and Foundation Engineering
Technische Universität Braunschweig

²E.ON Climate & Renewables GmbH
Hamburg
motivation

• energy input
  – into the pile
  – into the seawater
  – into the subsoil

• wave propagation
  – in the pile
  – in the seawater
  – in the subsoil

• soil water pile interactions

• damping effects of noise mitigation systems (NMS)
  – Hydro Sound Dampers (HSD)
  – big bubble curtain (BBC)
OWF Amrumbank West

80 turbines (3.6 MW) → 288 MW
German Bight, water depth approx. 20 m
monopile foundations (D = 6 m, L ≈ 55 m)
impact driven (Menck MHU 1900S)
noise mitigation at OWF Amrumbank West

hydro sound dampers (HSD) OffNoise-Solutions GmbH
- at the pile
- 2nd phase of installation

big bubble curtain (BBC) HydroTechnik Lübeck GmbH (HTL)
- approximately 70 m from pile
- whole installation process
measuring concept research project triad – pile, soil, water

monopile

HSD

ML25 ML37 ML72 ML97 ML145 ML150

hydrophone

geophone

and DAQ

ML400 ML750

homogenous soil:
sand, medium dense to dense

strain gauges, accelerometers

ML25: Measuring Location
25 m from pile

homogenous soil:

sand, medium dense to dense

homogenous soil:

sand, medium dense to dense

homogenous soil:

sand, medium dense to dense
SEL over piling – combined use of HSD and BBC

SEL over piling - pile 3 (HSD + DBBC)

HSD + DBBC
156 dB SEL @ 750 m

DBBC only

HSD + DBBC
SEL over piling – reference (no noise mitigation system)

176 dB SEL @ 750 m
reference measurement
w/o NMS!!!
approved by BSH
SEL over piling – reference (no noise mitigation system)

SEL over piling - pile 7 (no noise mitigation)

SEL = f (distance) ?
geometrical damping

logarithmic decrease

\[ \Delta \text{SEL} = k \log (R) \]

- spherical wave:
  \( k = 20 \)
- plane wave:
  \( k = 10 \)
- fit:
  \( k \approx 12..13 \)
geometrical damping

1/3 octave spectra - pile 7 (no noise mitigation)

logarithmic decrease

\[ \Delta SEL = k \log (R) \]

- spherical wave: 
  \[ k = 20 \]
- plane wave: 
  \[ k = 10 \]
- fit: 
  \[ k \approx 12..13 \]

lower cut-off frequency

depending on water depth and soil conditions
geometrical damping

logarithmic decrease

\[ \Delta \text{SEL} = k \log (R) \]

- spherical wave: 
  \[ k = 20 \]
- plane wave: 
  \[ k = 10 \]
- fit: 
  \[ k \approx 12..13 \]
geometrical damping

noise mitigation
- HSD: - 10..12 dB
- ½ piling energy: - 1..4 dB
influence of noise mitigation systems

different piles with different noise mitigation systems

- Hydro Sound Dampers (HSD)
  - phase 1 without HSD
  - phase 2 with HSD
    → hammer strokes with comparable driving energy
- big bubble curtain (BBC)
  - ML25 .. ML145 inside BBC
  - ML150 .. ML1500 outside BBC
    → geometrical extrapolation
- combined use of HSD + BBC
- reference measurements without noise mitigation

measurements and noise mitigation configurations within research project triad approved by Federal Maritime and Hydrographic Agency (BSH)
influence of noise mitigation systems

investigated NMS configurations:
- no NMS
- HSD only
- BBC (HTL) only
- HSD + BBC (HTL)
influence of noise mitigation systems

investigated NMS configurations:
- no NMS
- HSD only
- BBC (HTL) only
- HSD + BBC (HTL)

extrapolation of measured sound levels
\[ \Delta \text{SEL} = k \log (R) \]
\[ k \approx 12..13 \]
Influence of noise mitigation systems

- **HSD:**
  \[ \Delta SEL = -10 \text{ dB} \]

- **BBC (HTL):**
  \[ \Delta SEL = -10 \text{ dB} \]

- **HSD + BBC (HTL):**
  \[ \Delta SEL = -13..15 \text{ dB} \]
influence of noise mitigation systems

1/3 octave spectra @750m

noise mitigation (@ 1140 kJ)
- HSD: \( \Delta \text{SEL} = -10 \text{ dB} \)
- BBC (HTL): \( \Delta \text{SEL} = -10 \text{ dB} \)
- HSD + BBC (HTL): \( \Delta \text{SEL} = -13...15 \text{ dB} \)
Summary

• high density of sensors inside BBC
  → good description of wave propagation around pile driving
• measurements of pile deflections (and soil vibrations)
  → investigation of phenomena in offshore pile driving noise emissions

❖ noise mitigation concept (HSD + BBC) suitable to keep limiting values ($\Delta SEL$ up to 19 dB) at monopile foundations ($\varnothing$ 6m) under given conditions at Amrumbank West OWF
  - HSD  $\rightarrow$ $\Delta SEL \approx 10$ dB
  - BBC (HTL)  $\rightarrow$ $\Delta SEL \approx 10$ dB
  - HSD + BBC (HTL)  $\rightarrow$ $\Delta SEL \approx 15$ dB
  - HSD + DBBC (HTL + Weyres)  $\rightarrow$ $\Delta SEL \approx 19$ dB

• keeping of limiting values of hydrosound pressures remains a challenge
  - greater diameter piles
  - realisation of noise mitigation under offshore conditions
  - combined noise mitigation systems $\rightarrow$ complex logistics, high costs
Something else about acoustics:

\[ \text{triad} \]

1/3 octave