

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

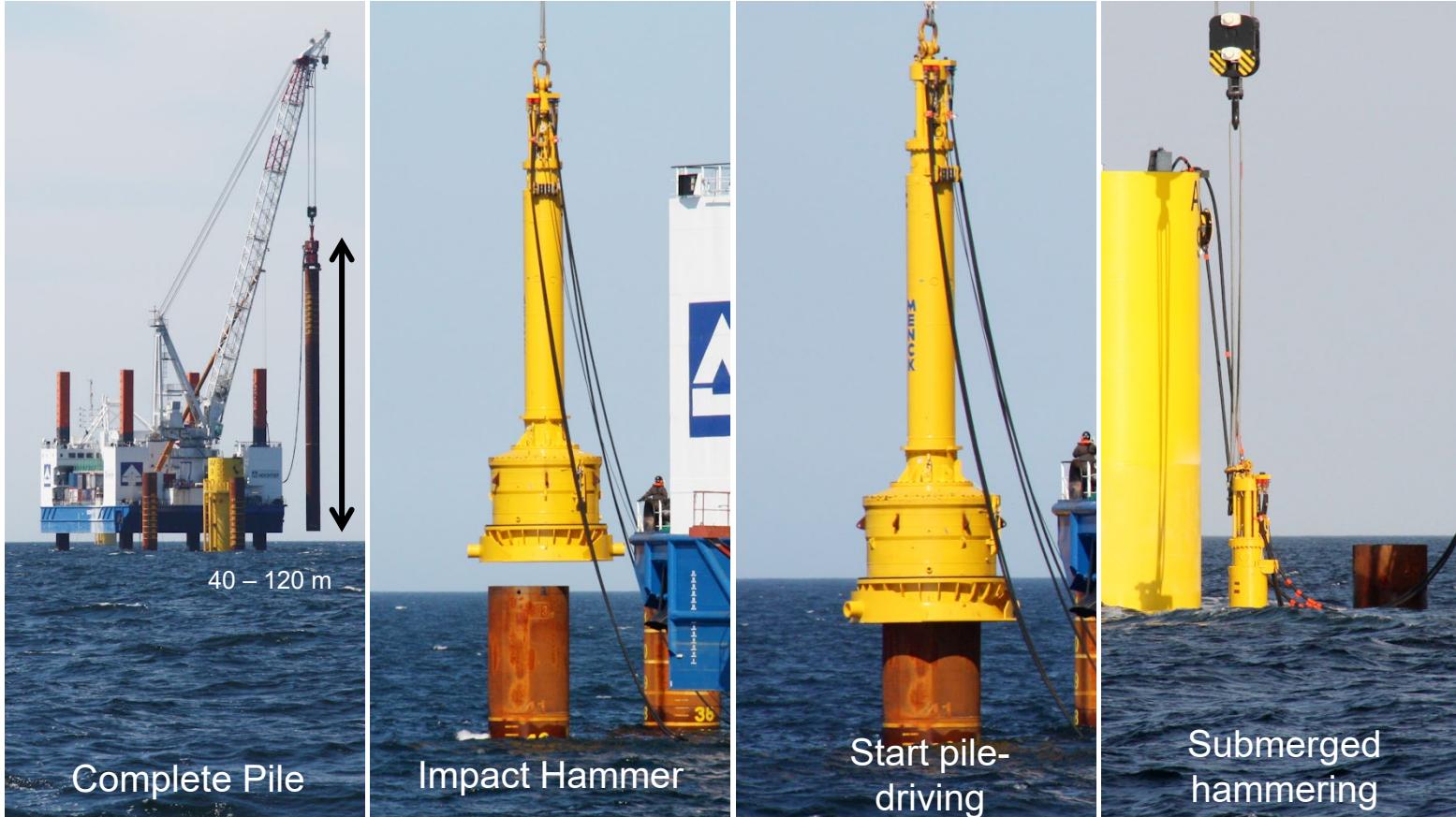


**Anthropogenic
Noise**

**Natural or Abiotic
Background Noise**

**Natural Biological
Noise**

Impact Pile-Driving



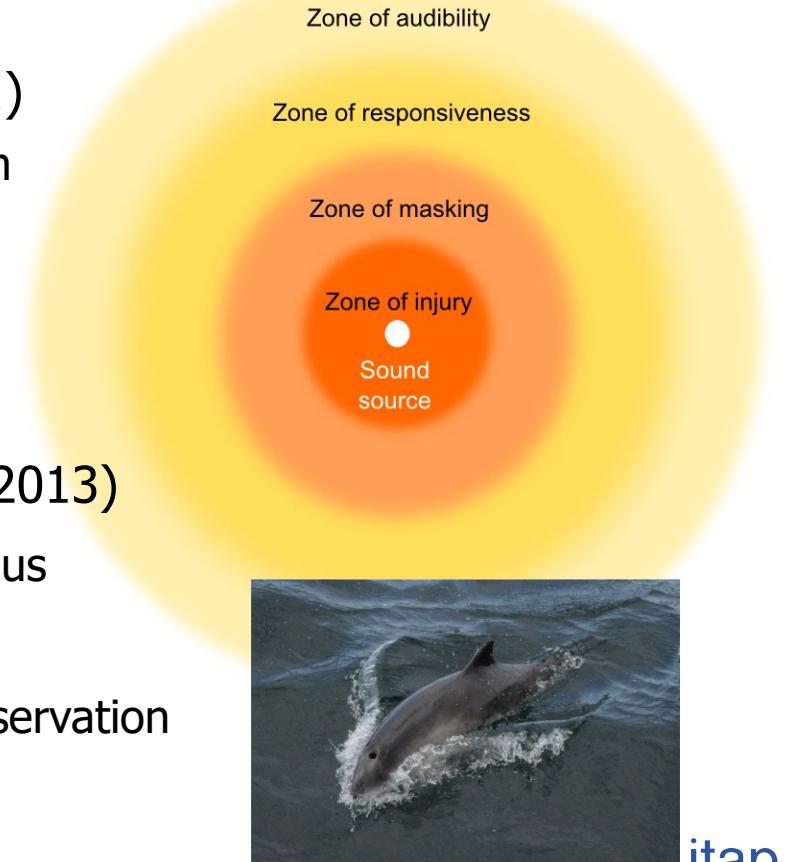
Underwater noise regulation in Germany



BNatSchG: Not allowed to harm any protected species

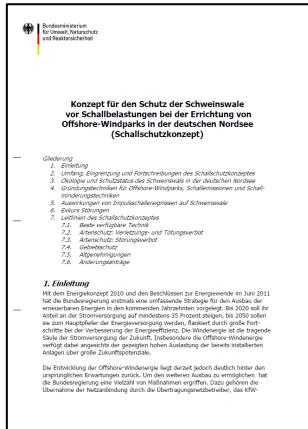
Impulsiveness noise (since 2011)

- Noise Mitigation Values @ 750 m
($160 \text{ dB}_{\text{SEL}05}$, $190 \text{ dB}_{\text{Lp,pk}}$)
- Piling duration: 180 minutes

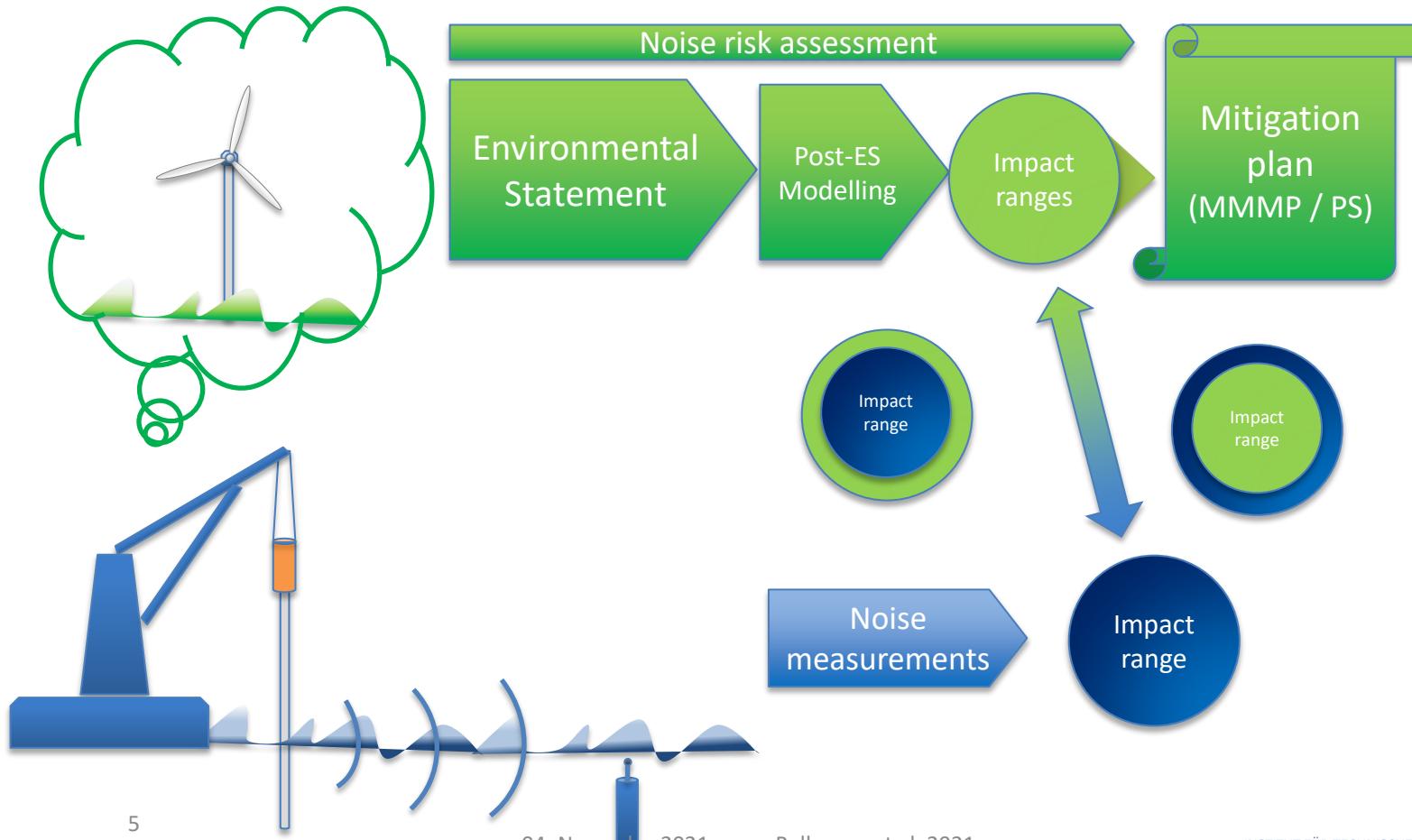


BMU Noise Mitigation Concept (2013)

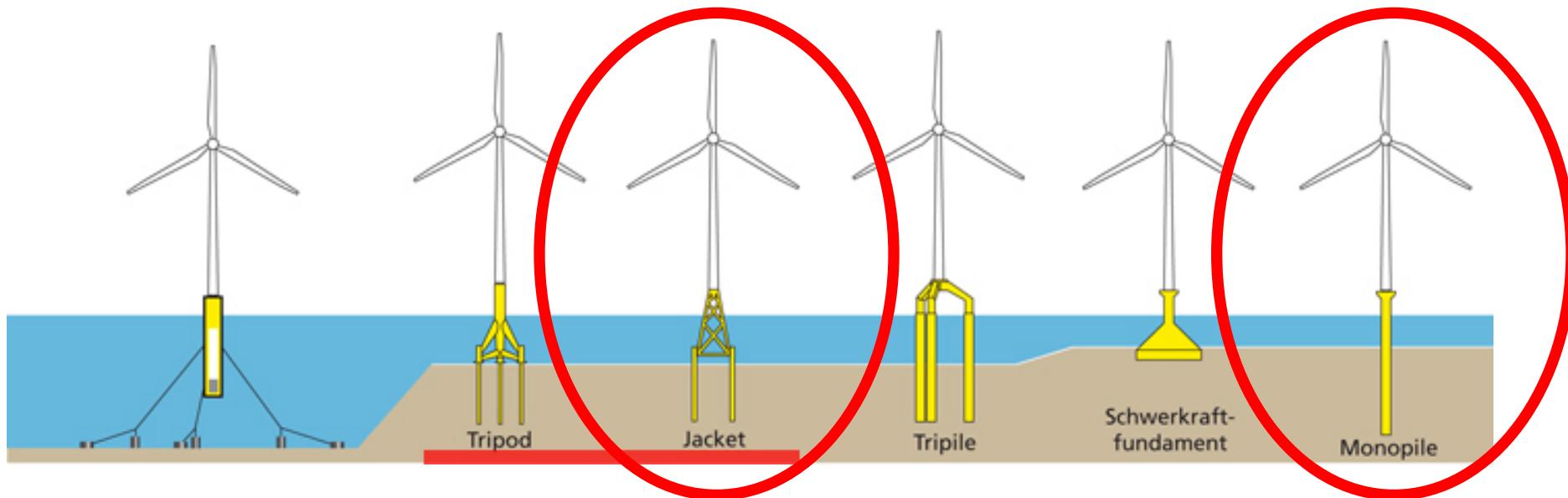
- North Sea 8 km disturbance radius
- Max. 10% of German Sea
- Max. 1% of Special Area of Conservation



Underwater noise regulation in UK/USA

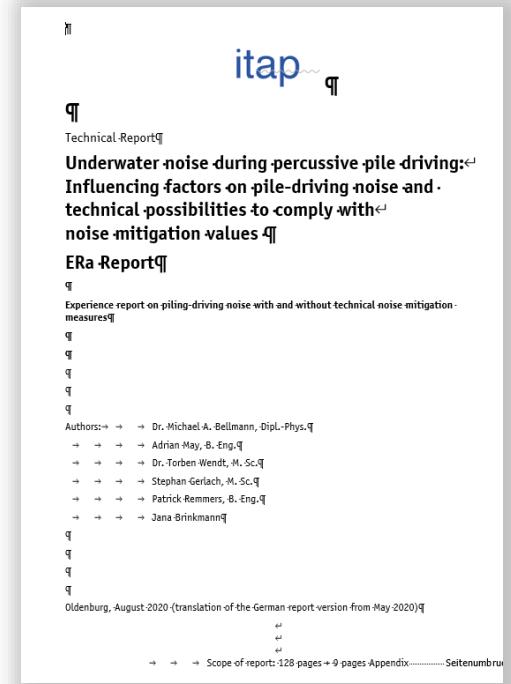


Foundation Types



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: $1,829 \text{ mm} \leq \emptyset \leq 8,100 \text{ mm}$
 - All available **noise mitigation systems** as well as **noise abatement systems** tested in German waters



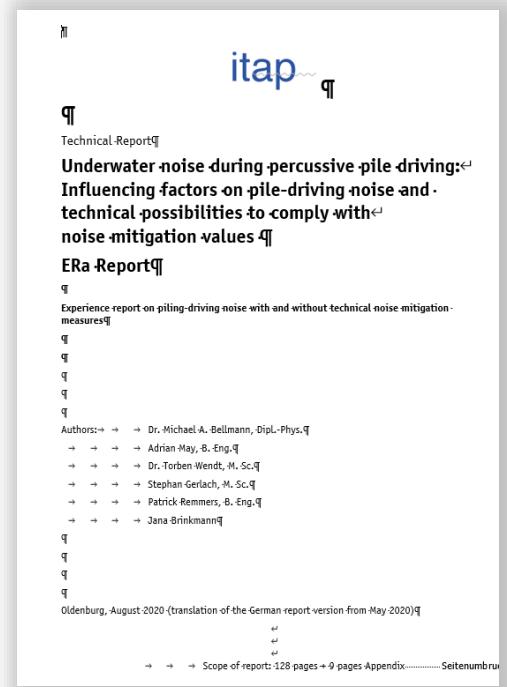
Lessons learnt report (2/2)

Aims:

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

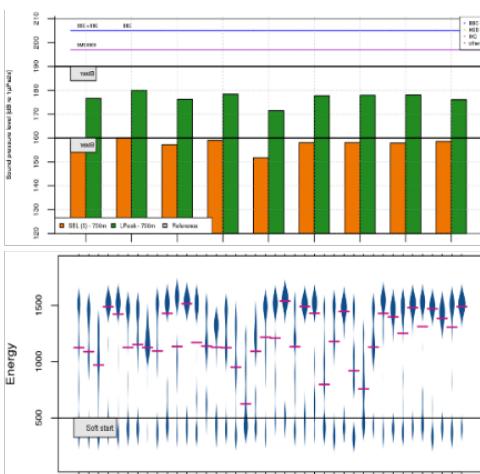
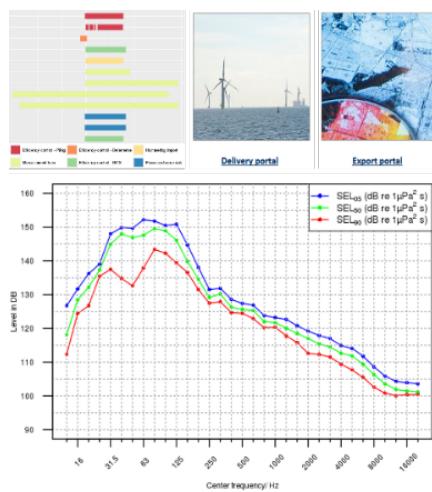
Output:

- ✓ 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



Bigest underwater noise data base for impact pile-driving.

- ✓ 1500 Offshore Foundations
- ✓ 2500 Piles

Continous noise data base is in progress

➤ Information Tool

Produkt 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

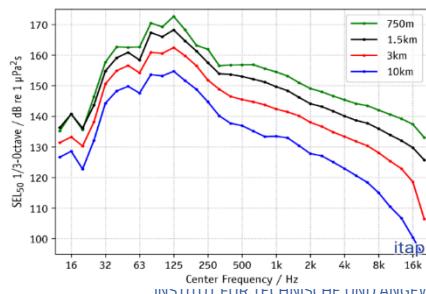
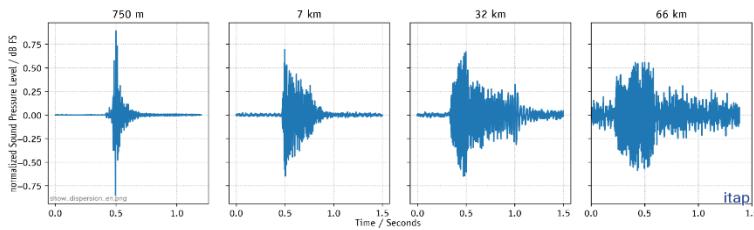
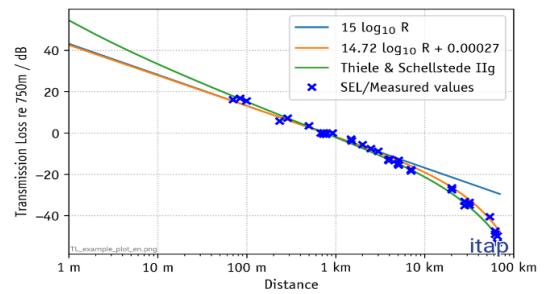
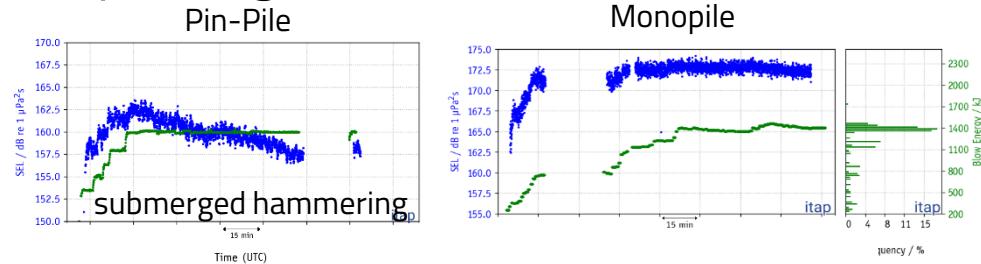
Unmitigated pile-driving noise depending on:

- ✓ 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

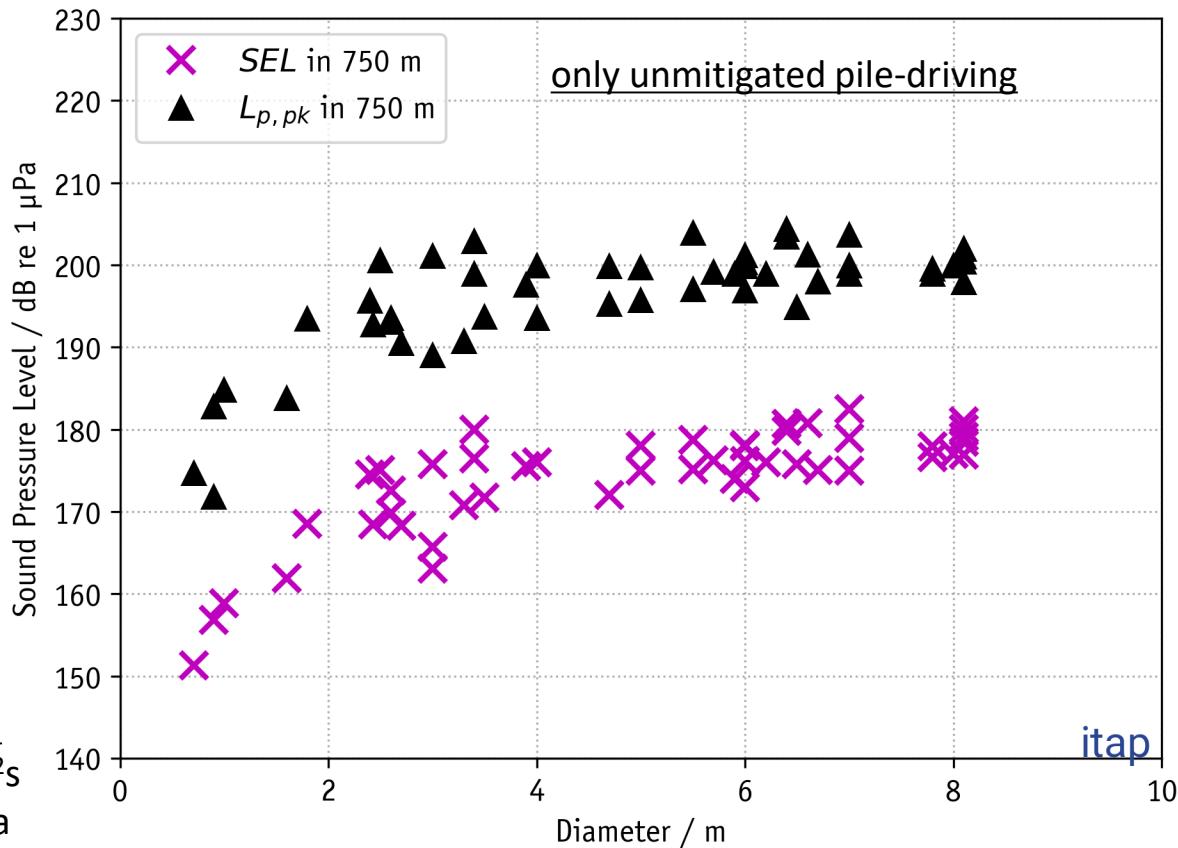
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Influencing factor on pile-driving noise

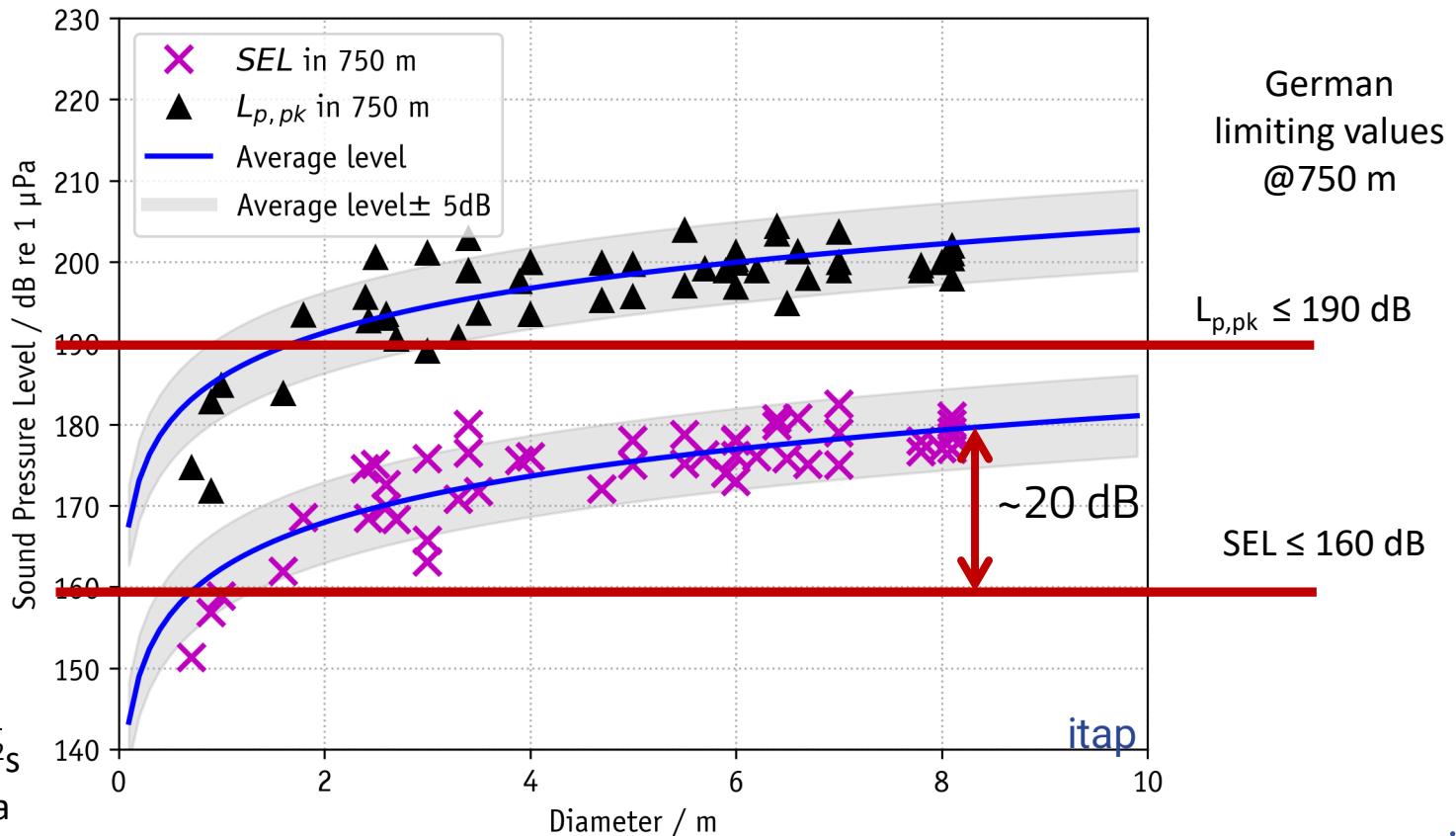
Pile Diameter



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

Pile-Driving Results @ 750 m

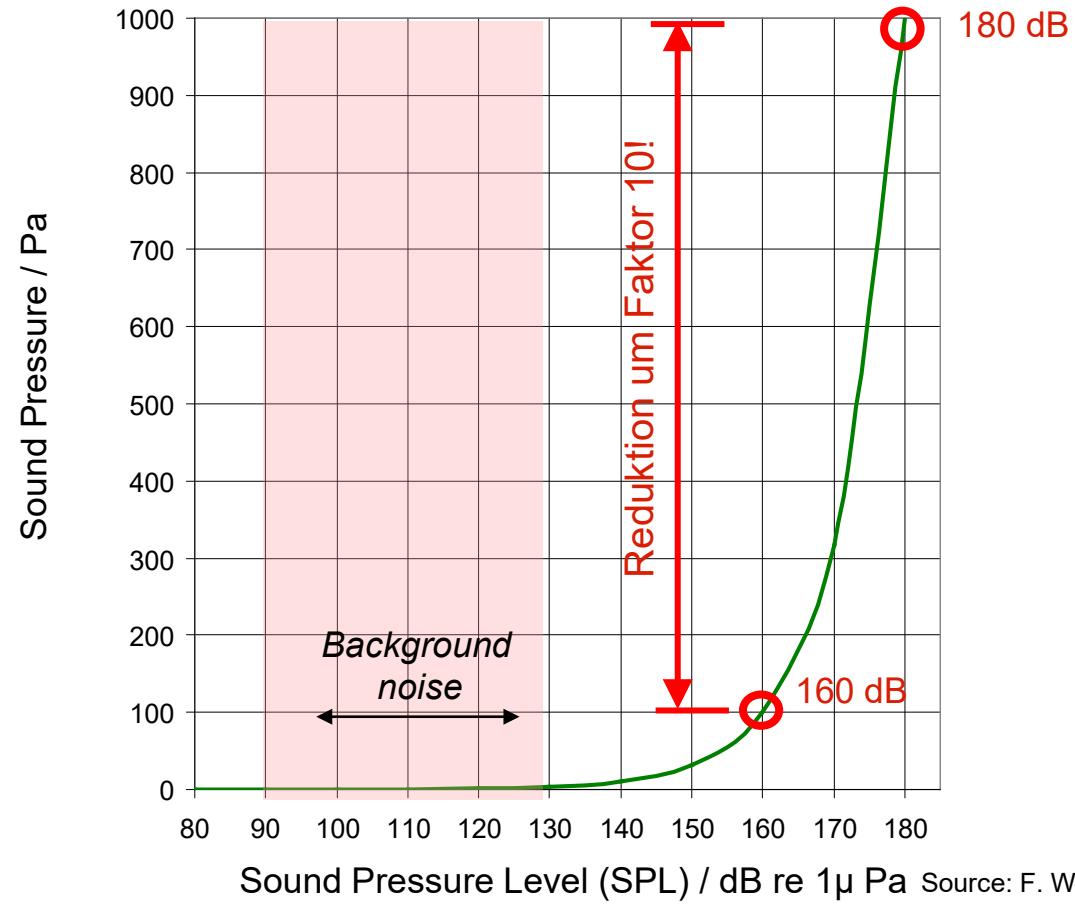
Requirements on Noise Mitigation Systems





Impact Pile-Driving

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 (continuous 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

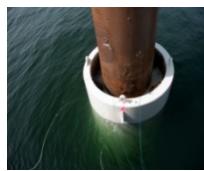
Bubble Curtain system



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

BBC

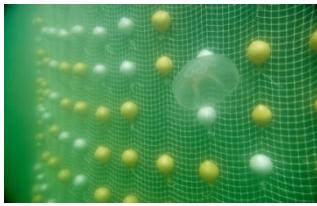
„Shell-in-shell“ system



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

IHC-NMS

other systems



- Pile wrapped with foam
- Hydro-Sound Damper
- Resonator system
- HydroNas (W³GM)

HSD

Noise Abatement Systems

Bubble Curtain system



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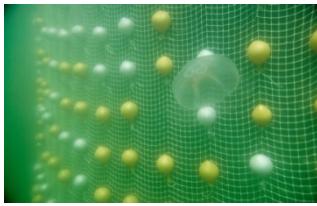
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other systems



- Pile wrapped with foam
- Hydro-Sound Damper HSD
- 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

malfuction: < ~1%

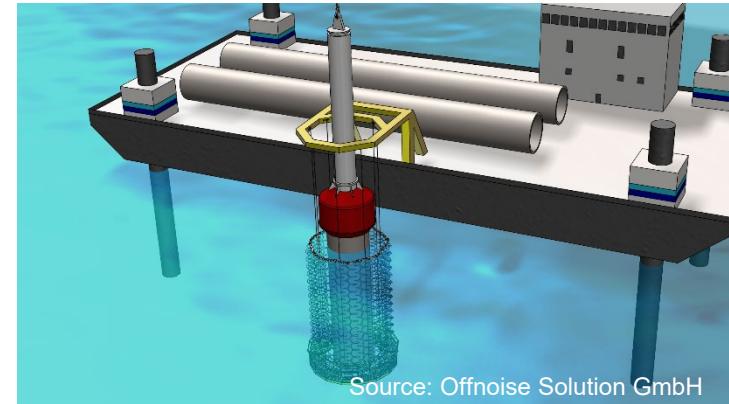
➤ measured noise reduction: $\Delta \text{SEL} = 13 \leq 15 \leq 16 \text{ dB}$
even @ 40 m water depth

➤ robust and ready for offshore Noise Mitigation System



Hydro Sound Damper (HSD)

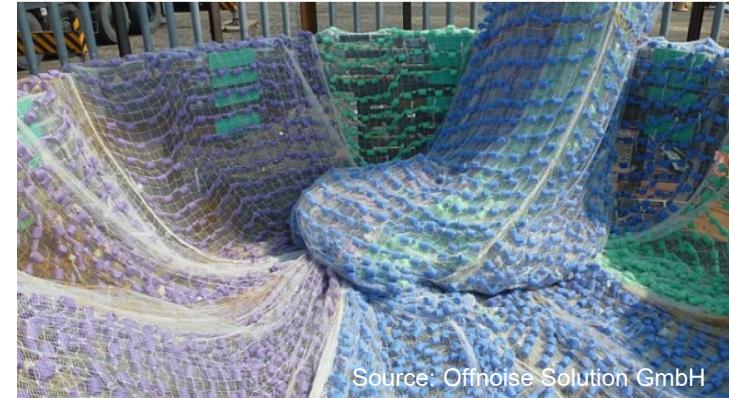
- Helmholtz Resonator system
- close-to-pile NMS
- consist of: Net + HSD Elements + ballast box
- used in water depth ≤ 45 m
- Used for pile diameter ≤ 8 m



Source: Offnoise Solution GmbH

Advantage

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



Source: Offnoise Solution GmbH

Disadvantage

- ground coupling effects
- ballast box incl. lifting tool
- „life time of HSD – Elements“

Hydro Sound Damper (HSD)

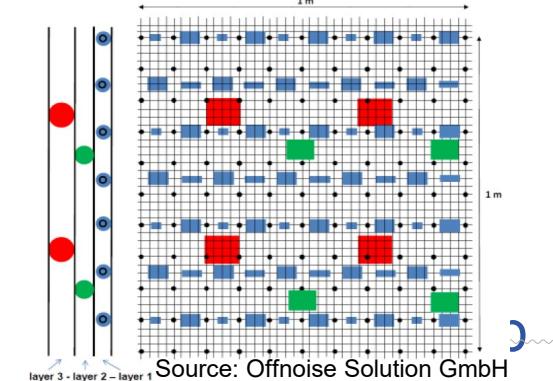
Noise reduction is independent from

- 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

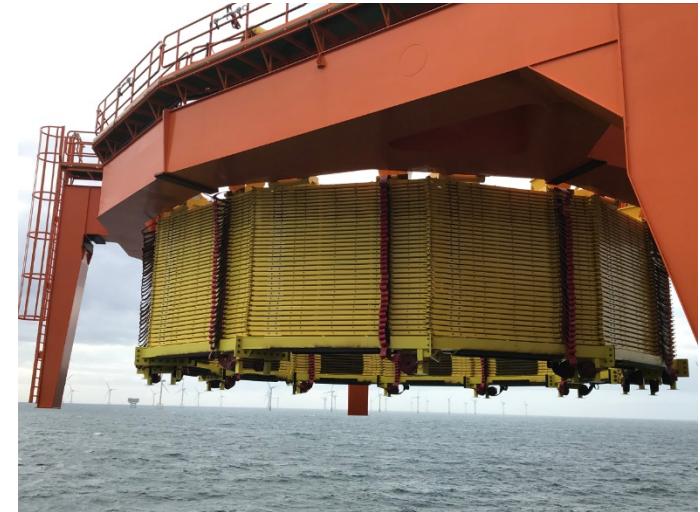


AdBm System by AdBm Technologies

- resonator system
- close-to-pile NMS
- consist of: vertical shape blocks + lifting tool
- used in water depth ≤ 30 m
- used for pile diameter ≤ 8 m

Advantage

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



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: $\Delta \text{SEL} = 5 \text{ to } 8 \text{ dB}$ (1st application)
- require project specific design
- prototype (next applications planned in October 2022?)



(double) Big Bubble Curtain

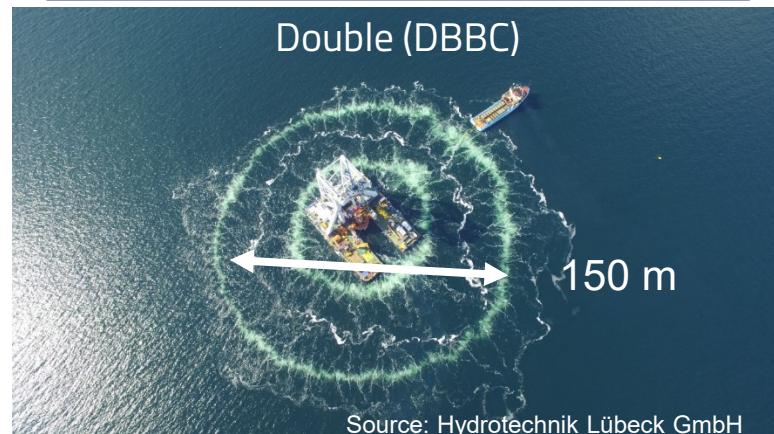
- impedance shifts (water vs water-air mixture)
- far-from-pile NMS (the only one)
- consists of: compressed air + nozzle hose on sea bed
- used in water depth ≤ 45 m (UXO clearance ≤ 70 m)
- used for pile diameter ≤ 8 m

Advantage

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

Disadvantage

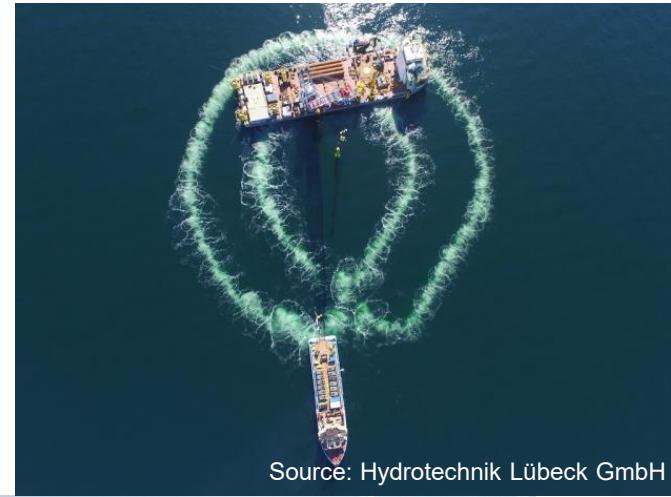
- separate vessel + compressors required
- coordination installation vessel vs nozzle hoses



(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



Source: Hydrotechnik Lübeck GmbH



Source: Hydrotechnik Lübeck GmbH

(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

No.	Noise Mitigation System	ΔSEL [dB]	# of tests (piles)
1	Combination of IHC-NMS + optimised BBC ($> 0,3 \text{ m}^3/(\text{min} * \text{m})$, water depth < 25 m)	$17 \leq 19 \leq 23$	> 100
2	Combination of IHC-NMS + optimised BBC ($> 0,4 \text{ m}^3/(\text{min} * \text{m})$, water depth ~40 m)	17 - 18	> 10
3	Combination of IHC-NMS + optimised DBBC ($> 0,5 \text{ m}^3/(\text{min} * \text{m})$, water depth ~40 m)	$18 \leq 19 \leq 20$	> 65
4	Optimised BBC+ HSD ($> 0,4 \text{ m}^3/(\text{min} * \text{m})$, water depth ~30 m)	$19 \leq 21 \leq 22$	> 30
5	optimised DBBC + HSD ($0,4 \text{ m}^3/(\text{min} * \text{m})$, water depth 30 m)	$15 \leq 16 \leq 20$	> 50
6	optimised DBBC + HSD ($> 0,5 \text{ m}^3/(\text{min} * \text{m})$, water depth < 40 m, North Sea)	18 - 19	> 30
XXX	Reducing used blow energy	additional 2,5 dB by halving	

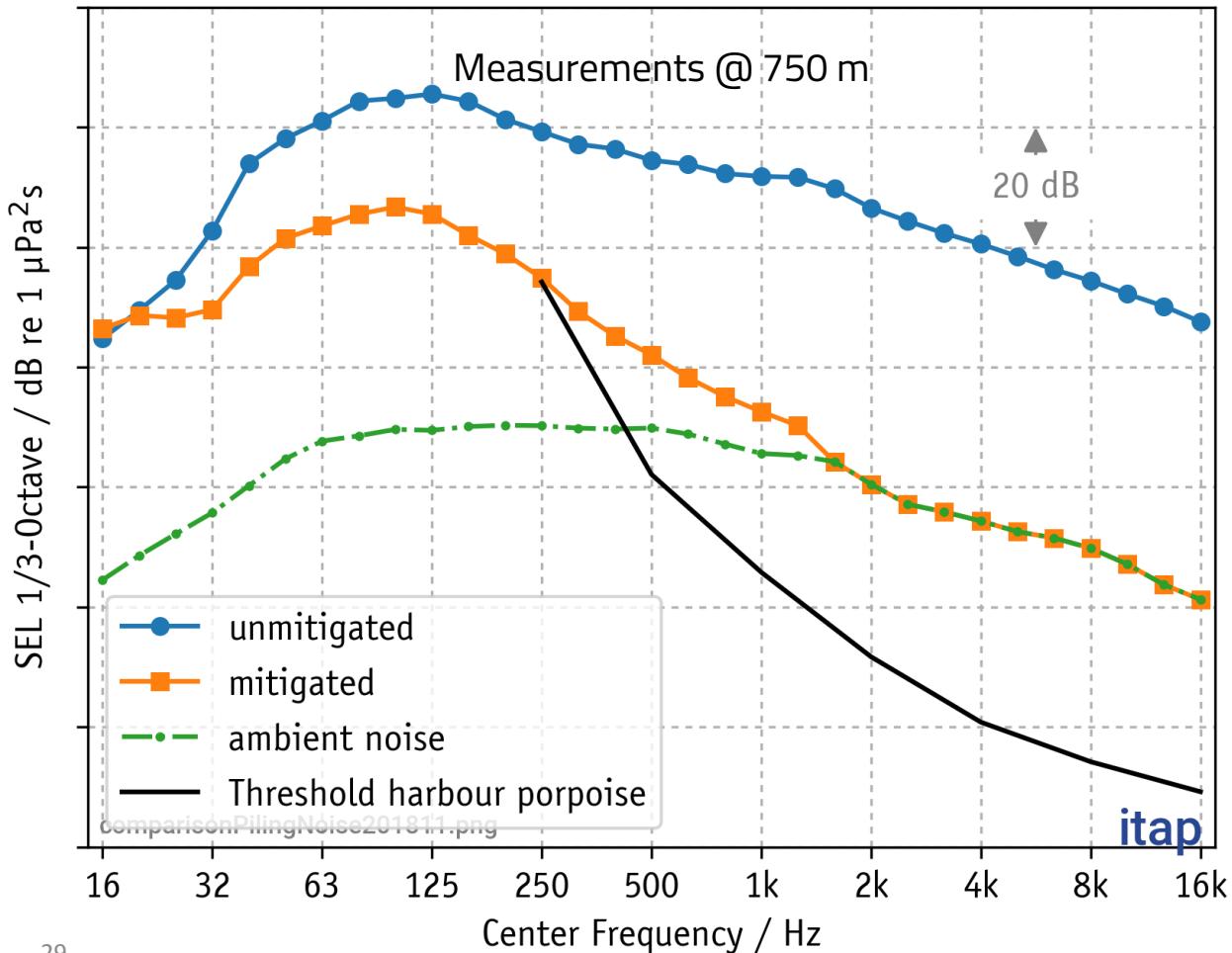
All NMS in optimized system configuration, no malfunction or disturbing influences like strong current

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3	Cor ($> 0,5 \text{ m}^3/(\text{min} * \text{m})$)	But: $\Delta SEL_{\text{System 1}} + \Delta SEL_{\text{System 2}} \geq \Delta SEL_{\text{Combination}}$	65
4	Optimised BBC+ HSD ($> 0,4 \text{ m}^3/(\text{min} * \text{m})$)	$19 \leq 21 \leq 22$	> 30
5	optimised DBI ($0,4 \text{ m}^3/(\text{min} * \text{m})$)	Noise Reduction: $\Delta L_{p,pk} \geq \Delta SEL$ but $L_{p,pk}$ very sensitive metric (large uncertainty)	> 50
6	optimised DBI + HSD ($> 0,5 \text{ m}^3/(\text{min} * \text{m})$, water depth < 40 m, North Sea)	18 - 19	> 30
XXX	Reducing used blow energy	additional 2,5 dB by halving	

All NMS in optimized system configuration, no malfunction or disturbing influences like strong current

Effectivness 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 ?

Take Home Message

- 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 ?

