Assessment of Effects of Offshore Wind Energy Facilities on the Marine Environment

„ Underwater noise during impact pile-driving: Influencing factors on impulsiveness noise and technical options for complying with thresholds at activity level”

“Erfahrungsbericht Rammschall– ERa“

Non-technical summary

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The main objective of the R&D „ Underwater noise during impact pile-driving: Influencing factors on impulsiveness noise and technical options for complying with thresholds at activity level“ is to give insights in issues of technical mitigation applied to reduce impact from percussive pile driving on the marine environment. Information on the license procedures for offshore wind farms and data from the monitoring at offshore construction sites considered in the R&D Project and in the technical report has been available by BSH.

Authors are responsible for the contributions in the technical report.

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Underwater noise during impact pile-driving: Influencing factors on impulse noise and technical options for complying with thresholds at activity level

Lessons learned report on the application of noise abatement systems

Non-technical summary

1. Main objectives

The installation of renewable energy sources offshore is growing fast in Europe, also in Germany, forced by the energy turnaround after 2011. Currently, 18 Offshore Wind Farms (OWF) in Germany are in operation, 5 have already installed the turbines still being under construction and some OWFs are in the pre-construction phase. However, the demand for renewable energies has to go hand in hand with the awareness of sustainability issues, especially the conservation of nature and marine ecosystems. Besides other ecological topics, the underwater noise emissions have moved into focus due to the fact that most foundations are installed by using the impact pile-driving method. This noisy installation method leads to enormous acoustic emissions (pile-driving noise), which are potentially harmful to marine life. For nature conservation purposes, it is therefore necessary to reduce noise levels in the water, when harm to marine life is anticipated.

Beginning with 2008, German authorities following the precautionary principle include threshold values at activity level for pile-driving noise emissions in German waters in incidental clauses of approvals:

- unweighted broadband Sound Exposure Level (SEL or L_E) ≤ 160 dB (re 1 µ $Pa^2 s$) and
- Peak Level ($L_{p,pk}$ or zero-to-peak) ≤ 190 dB (re 1 µ Pa),

which must be complied with in a distance of 750 m to the piling site. Since 2011, all pile-driving activities in German waters deploy technical noise abatement systems to meet the thresholds. During the three first years (2011 – 2013) of experience with technical noise mitigation, the thresholds could not be reliably met. This was mostly due to the lack of state-of-the-art noise abatement systems (noise mitigation systems). In 2013, a concept for the protection of harbour porpoises was elaborated by the German Federal Ministry for the Environment with the main objective to prevent cumulative impacts and protect habitats of harbour porpoises from pile-diving noise.

Since 2014 and due to the enormous research and development effort of the industry, several technical noise abatement systems could evolve as state-of-the-art systems, leading to reliable compliance with the above mentioned German underwater noise thresholds.

The Federal Maritime and Hydrographic Agency of Germany (BSH) is responsible for the approval procedures in the German EEZ and for the monitoring of the compliance with these thresholds. The monitoring of pile-driving noise has been standardized according to the underwater noise measurement guideline in 2011 (BSH, 2011). In 2013, a measurement concept was developed to evaluate technical noise abatement systems (BSH, 2013). The guideline was converted into a German pre-standard DIN SPEC 45653 (2017). The ISO 18406 was established in 2017 and the German guideline (BSH, 2011) fulfills the requirement of this standard.

The BSH developed a specialist technical information system for underwater noise (marinEARS – Marine Explorer and Registry of Sound), which is now operational since 2017.

By now, detailed information and data from more than 1,200 pile-driving events including data on noise abatement systems have been stored in marinEARS, the data have been checked for quality assurance and have been evaluated.

To inform and enforce further development of noise abatement systems in a manner that they are applicable and affordable in offshore construction projects, the knowledge gathered from all projects from 2011 to 2018 in the German EEZ has been evaluated in a comprehensive report. The aim of the report is to give some insight in environmental variables and technical issues, that should be considered for achieving a reliable reduction of pile-driving noise in the marine environment.

2. Site characteristics and environmental variables

A good knowledge of the site characteristics and the environmental variables at the site is one of the main prerequisites for selecting and adjusting adequate technical noise abatement. Water depth, topography, soil profile and surface sediment structure are primary factors affecting application and performance of noise abatement systems.

Beyond environmental variables determining sound velocity, also currents may affect the performance of noise abatement systems like bubble curtains.

3. Project characteristics and source-related variables

The design of the foundation of wind energy turbines or substations as a whole and in particular, the pile design may affect the choice and performance of noise abatement systems as well. While monopile foundations are the most often used foundation type at the moment, all technical noise abatement systems are designed for monopiles; nevertheless, there are only a few systems also applicable for jacket foundations. But the dimension of jacket foundations is another limiting factor, when selecting suitable noise abatement systems.

The main factor affecting the performance of any noise abatement system seems to be the source, the impact hammer itself and the driving procedure applied. The properties of the hammer capacity/generation, type, RAM-weight, anvil configuration, acceleration and frequency spectrum seem to affect the radiated underwater noise. At the same time, the driving procedure (limitation of maximum energy used and control of energy/frequency ratio) applicable can affect the overall sound emission and thus the performance of noise abatement systems, too.

4. Technical issues of noise abatement systems

In the last eight years, three basic noise abatement systems have been applied successfully in German waters under real offshore conditions:

a) Big Bubble Curtain systems (BBC) at a distance => 60 m around the piling location,

b) isolating casing systems from IHC noise mitigation screen (NMS) also holding and positioning the pile and

c) Hydro Sound Damper (HSD) around the pile.

Several other noise abatement systems were partly tested or are under development, but these systems are currently not ready for a serial application under real offshore conditions.

Big Bubble Curtain systems and IHC-NMS systems could be applied successfully as single noise abatement system in water depths =< 25 m, sandy soil and pile diameters up to 6 m. HSD systems have always been applied in combination with Big Bubble Curtains. Projects at sites, where the water depth is > 25 m and thus the pile diameter is > 6 m have applied a combination of two systems. The combined systems applied so far include a Big Bubble Curtain system in the far field and an IHC-NMS or HSD system around the pile.

The practical experience with Big Bubble Curtains (BBC) shows, that the technical design and the components of the Big Bubble Curtain system directly affect the functionality of the system and thus the performance and effectiveness for noise reduction. The nozzle- and rise hoses as well as the compressed air amount incl. compressors type belong to the major components. The deployment design and the distance to the piling site are also essential for the performance. The constructive design and functionalities of each Bubble Curtain system seem to play the main role for achieving good reduction potential.

The frequency analysis of data with and without deployment of Big Bubble Curtain reveals higher reduction potential at frequencies of 2 to 4 kHz. At low frequencies of up to 250 Hz, the noise reduction potential is low. Since the hammer energy is introduced in low frequencies mostly up to 250 Hz for pile diameters > 6 m, a complementary noise abatement system is required to meet the threshold value. The most efficient double Big Bubble Curtain systems applied in projects in the German EEZ of the Baltic Sea achieved a reduction of up to 18 dB SEL_{05} re 1µPa^2 s and nearly no current. The same double Big Bubble Curtain achieved up to 16 dB in the North Sea by currents of up to 1 knot due to drifting effects. The differences between a single and a double Big Bubble Curtain with similar system configurations ranged almost between 3 and 4 dB. This indicates, that the effectiveness of two instead of one Bubble Curtain is on non-linear scale, since the output spectrum of the 1st Bubble Curtain acts as the input spectrum for the 2nd Bubble Curtain. Big Bubble Curtain systems are the most efficient systems due to their reduction potential at high frequencies with regard to the protection of the key species harbour porpoise. However, depending on the site and project characteristics, they should be applied in combination with an IHC-NMS system or a HSD system to comply with the thresholds.

The practical experience with IHC-NMS reveals a good reduction potential at low and higher frequencies at the same time. For pile diameters up to 6 m in sandy soils and water depths < 25 m, the IHC-NMS could comply with the threshold as single abatement system. For pile diameters > 6 m, the IHC-NMS has been applied in combination with Big Bubble Curtain systems. In 2018, a further developed IHC-NMS system was applied in 40 m water depth with a reduction potential of 17 dB SEL_{05} re 1µPa^2 s as single noise abatement system.

The practical experience with HSD systems in various constructive designs reveals a reduction potential of up to 10 dB SEL_{05} re 1µPa^2 s. The constructive design of the HSD system seems to be essential for the overall reduction potential. The HSD systems have the maximum of their reduction potential at low frequencies (< 200 Hz) and should be applied complementary to Bubble Curtains to comply with the threshold.

5. State-of-the-art

The question, if after years of development and application in offshore construction of wind farms noise abatement systems have reached a state-of-the-art, has a clearly positive respond. However, the state-of-the-art of each of the three mentioned noise abatement systems in single application or in combination aims at technical design, functionalities and applicability at offshore construction sites. The effectiveness of each noise abatement concept depends significantly on a series of site and project characteristics and system-related optimizations, which should be analyzed prior to construction. The results of geo-technical investigations, pile design, pile-driving analysis and forecasting of the unmitigated noise emissions should be used to choose and then adjust the system or systems chosen to the site- and project characteristics.

6. Final results

The main results of the study can be shortly summarized as follows:

- Big Bubble Curtain systems (single or double), IHC-NMS and HSD systems are currently the only noise abatement systems ready for offshore application,
- large variations regarding the overall broadband as well as frequency-depending insertion loss of different noise abatements were measured,
- the major part of the variation in the overall noise reduction can be explained by not optimized system configurations of the applied noise abatement systems,
- broadband noise reduction (SEL05 re 1µPa2 s):
    - ≤ 25 m water depth, sandy soils, mostly homogenous profile, pile diameter ≤ 6 m:
        - - single Big Bubble Curtain optimized up to 14 dB
        - - IHC-NMS system up to 14 dB
        - - HSD system up to 10 dB
    - 25 – 43 m water depth, sandy soils, heterogenous profiles, pile diameter 6 – 8 m:
        - double Big Bubble Curtain optimized up to 16 dB
        - IHC-NMS system up to 17 dB
        - HSD system up to 10 dB
        - combination Big Bubble Curtain/IHC-NMS up to 22 dB
        - combination Big Bubble Curtain & HSD up to 20 dB
    - > 43 m water depth no experiences!
- Each noise abatement system is a unique system, which will be used in a unique environment for a unique project. Therefore, each noise abatement system must be site- and project-specifically adapted and optimized to ensure a good performance and compliance with thresholds.