Assessment of noise mitigation measures during pile driving of larger offshore wind foundations

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Abstract

Wind energy is an important source of electricity generation, but the construction of offshore wind foundations causes high underwater sound pressure, harming marine life. In this context limiting values for underwater noise emissions were set to protect the marine flora and fauna. Therefore, noise mitigation measures during pile driving are mandatory to comply with these limits. Current development in the wind industry lead to increasing wind turbine sizes, requiring a larger pile diameter, which leads to higher underwater noise emissions. As a result, the state of the art noise mitigation systems might not be sufficient and a combination of different technologies is necessary. This article focuses on the issue of noise mitigation during pile driving with respect to large pile sizes. First, the most tested and proven noise mitigation techniques (big bubble curtain, hydro sound damper, and IHC-noise mitigation system) are described, following an analysis of noise reduction measurements in applications at different offshore wind farm projects. In the end the suitability of current noise mitigation systems for large monopiles is evaluated, regarding their effectiveness and practicability.

Keywords: Noise mitigation measures, Offshore wind foundations, Big bubble curtain, Hydro sound damper, IHC-noise mitigation system

1 Introduction

Renewable energies are developing rapidly and become more important as a source of energy generation and therefore, in reducing the use of fossil energy sources. One of these fast growing renewable energy technologies is wind power. New offshore wind parks are under construction around the world. The foundation of offshore wind turbines often consists of a steel monopile which is driven into the seabed by impact pile driving. This technique causes high underwater sound pressure harmful to the marine environment and threatening marine life. To protect the marine flora and fauna several governments set limiting values for underwater noise emissions. To comply with these values noise mitigation measures must be applied [1]. Due to larger wind turbines, pile sizes increase and a higher blow energy is needed, generating higher underwater sound levels. Therefore, an ongoing development of effective noise mitigation measures in regard to larger monopiles is necessary [2].

This article discusses the issue of noise mitigation concerning larger pile sizes due to larger turbines, while describing the effectiveness of existing noise mitigation measures, especially for larger monopiles. Parameters that influence the noise level are the pile diameter, water depth, soil structure and blow energy. The larger the pile diameter and the higher the blow energy, the less likely it is that existing noise mitigation measures are effective to meet noise standards [3].

2 Theoretical Background

In 2011 the German regulatory Federal Maritime and Hydrographic Agency of Germany (BSH), as first country worldwide, set limiting values for underwater noise,

- sound Exposure Level (SEL) = 160 dB (re 1 μPa^{2}s)
- Peak Level(LPeak) = 190 dB (re 1 μPa^2)

which must be complied within a distance of 750 m to the construction site [4]. The sound pressure level (SPL), measured in (dB) uses the logarithmic scale to represent the sound pressure of a sound relative to a reference pressure. The sound exposure level (SEL) characterises the underwater noise for pile driving, measured in decibels (dB). It is defined as the level of a continuous sound with 1 s duration and the same sound energy as the pile driving impulse. The peak level (LPeak) is the peak level of the sound pressure wave with no time constant applied. Measurements over the last years show that sound emission levels during pile driving, which are depending on many parameters (mostly blow energy and pile size), show values of

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- up to 180 dB (SEL)
- up to 205 dB (LPeak)
- up to 210 dB (SPL)

in a distance of 750 m. [4] Therefore, noise mitigation measures must be applied during offshore construction to lower underwater noise. When the limiting values were established in 2011 noise mitigation technologies were a relatively new research area. Even though many solutions and prototypes existed, only a few were already tested offshore and near-shore studies did not correspond with offshore results [4]. In comparison to other types of offshore wind foundations, the most experience exists with monopiles when constructing offshore wind farms. Thus, monopiles are used for comparisons of different noise mitigation measurements. The most common installation method for monopiles is impact piling. This installation method comes with high impulse noise emissions as shown in figure 1, which can be harmful for the aquatic environment [5]. During pile driving sound levels mainly

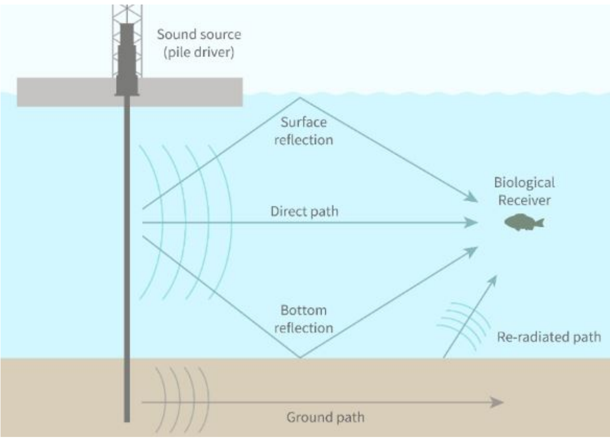

Fig. 1: Underwater sound emission paths associated with pile driving [6].

depend on the pile diameter and blow energy used. Moreover, the pile diameter can be used as key indicator of the expected noise emissions. Therefore, the required noise reduction mainly depends on the pile diameter. Measurements show, that a monopile with a diameter of 6 m can reach underwater noise levels of about 178 dB (SEL). To comply with the limits of the BSH a noise reduction of 18 dB (SEL) is necessary [4]. Currently, monopiles have a diameter of 7 to 8 m. For the next generation of wind turbines with 12 to 14 MW, the steel industry is ready to provides monopiles with a diameter of 10 to 12 m and a length of 100 m for greater water depth. Noise mitigation can be achieved by using two different principles:

1. by attenuating the generation of noise directly at the source (primary noise reduction)
2. by placing noise barriers (secondary noise reduction) [5].

3 State of the art noise mitigation systems

Several noise mitigation systems are available on the market. The following chapters summarize the noise mitigation measures, that are already proven systems under offshore conditions and considered as state of the art. These technologies use the principle of the secondary noise reduction, by placing a noise barrier.

3.1 Big Bubble Curtain (BBC)

A big bubble curtain (BBC) is a perforated hose lying on the seabed, positioned in a ring around the construction site, where the pile driving takes place. Air is pumped into the perforated hose and a bubble curtain is generated as shown in figure 2. Air bubbles change the water density, attenuating sound emissions due to pile driving [5]. The sound attenuating effect is caused by sound scattering and absorption on the air bubbles as well as the reflection at the transition from water to air. If a higher noise reduction is required, e. g. for large monopiles, a double bubble curtain (DBBC) can be deployed, where two perforated hoses are placed on the seabed in a specific distance to each other [7].

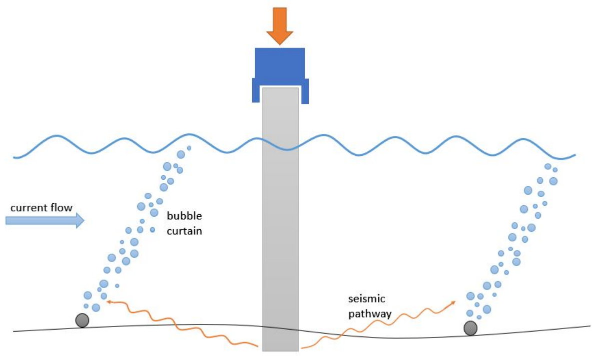

Fig. 2: Principle of the big bubble curtain

3.2 Hydro Sound Damper (HSD)

Hydro sound damper (HSD) are encapsulated resonator systems, which are gas filled elastic balloons or robust PE-foam elements. These are fixed to a net surrounding the pile in a short distance of around 5-6 m [8] as it is displayed in figure 3. The principle of noise attenuation of HSD elements is similar to that of a bubble curtain: Reflection of the sound waves as well as scattering, reflection and absorption due to resonance effects. In contrast to a conventional air bubble curtain the frequencies at which HSD provide a maximum noise reduction are adjustable by variations in balloon size and dissipation effects due to damping properties of the material [3]. A major

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advantage is the high control over different characteristics such as size of the bodies, effective frequency range, selected material, damping rate, number and distribution. Moreover, the HSD is not influenced by any current and unlimited by deep waters due to its static structure [2].

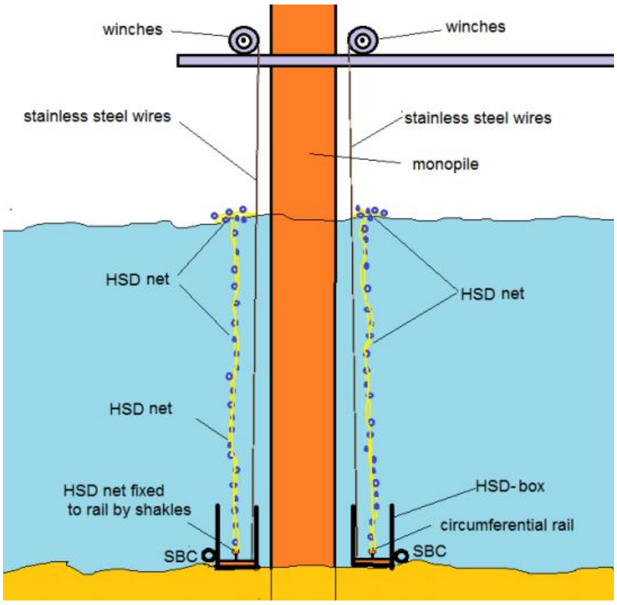

Fig. 3: Principle of the hydro sound damper [2].

3.3 IHC noise mitigation system (IHC-NMS)

The IHC noise mitigation system (IHC-NMS) is a shell-in-shell system, consisting of a double walled steel screen surrounding the pile as a tube, which is shown in figure 4. The space between the two walls is filled with air. In addition, the water column between pile an NMS can be supplied with air bubbles. Therefore, sound waves pass through two barriers, the bubble curtain as well as the air filled double wall screen, where the principle of noise attenuation is the reflection at phase transitions (air-steel-water) [7]

Fig. 4: IHC noise mitigation system, © Ørsted.

4 Results

The best studied and most regularly applied mitigation measure is the big bubble curtain in its various applications. Depending on the conditions at the construction site, noise reduction measurements can vary. Moreover, during pile installation some thousand blows per pile are necessary, also resulting in varying noise reduction results. Therefore a minimum and a maximum value of the noise reduction for each noise mitigation system were determined based on several projects [4]. Following, figure 5 and the two tables 1 and 2 show the measured reduction of sound exposure levels during pile driving at different water depths.

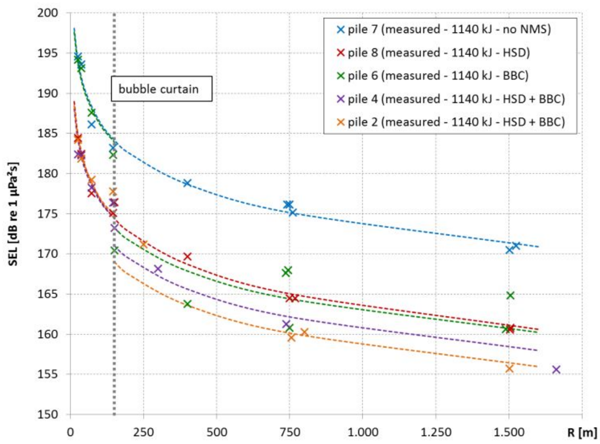

Fig. 5: Sound exposure levels measured in water depths around 20 m at different distances for piles with varying noise mitigation measures at 1140 kJ pile driving energy [9].

Tab. 1: Noise reduction measurements of varying noise mitigation systems in water depths of 30 m in a distance of 750 m [7].

noise mitigation system	ΔSEL (dB)	piles
BBC	10 - 15	≥ 300
DBBC	14 - 18	≥ 300
HSD	8 - 13	≥ 10
IHC-NMS	10 - 14	≥ 140
IHC-NMS +BBC	17 - 23	≥ 90
HSD+BBC	15 - 20	≥ 30
HSD+DBBC	14 - 22	≥ 20

Altogether the measurements show that noise mitigation measures reduce noise emissions significantly and the combination of tho different systems increases the effectiveness. A single noise mitigation system at 20 m water depth reduces sound levels by at least 9 dB at 750 m distance and the combination of two systems reduces noise emissions by at least 13 dB at 750 m. At water depth up to 30 m a single optimized

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Tab. 2: Noise reduction measurements of varying noise mitigation systems in water depths of 40 m in a distance of 750 m [5].

noise mitigation system	ΔSEL (dB)	piles
BBC	7 - 11	≥ 700
DBBC	15 - 16	
HSD	10 - 13	≥ 340
HSD+DBBC	18 - 24	

noise mitigation system can reduce noise levels by a minimum of 10 dB (SEL) and a maximum of 18 dB (SEL). For higher water depths up to 40 m the minimum is 7 dB (SEL) and the maximum 16 dB (SEL). Whereas a combination of two systems results in a minimum noise reduction of 14 dB (SEL) and maximum of 23 dB (SEL) in water depth of up to 30 m and for a water depth of 40 m the minimum is 18 dB (SEL) and the maximum 24 dB (SEL).

5 Conclusion

To protect the environment, reducing sound emissions during pile driving is of great interest. To date, several noise mitigation systems are available on the market, but only a few systems are commonly used and tested under offshore conditions. These systems are the BBC, HSD and IHC-NMS, which can be considered state of the art for water depths of up to 40 m and pile diameters of up to 8 m [4].

- The BBC is a proven technology with an independent installation process and the best tested noise mitigation system with potential for optimization with respect to effectiveness and handling. It was successfully applied in several projects where under certain environmental conditions the SEL of 160 dB can be met. With a DBBC or triple BBC, noise reduction increases and the system can be further combined with other noise mitigation measures such as HSD, IHC-NMS or reduced blow energy. However, the systems efficiency is impacted by the air volume stream pumped into the hose, strong currents, a sub-optimal configuration and it is highly dependent on water depth, making a project specific configuration necessary for a successful application. With regard to larger monopiles the greater water depth will make the combination with other noise mitigation systems necessary to achieve desired noise reduction.

- The IHC-NMS as well is a proven system, that is robust and reliable with no impact in installation time. At small and intermediate piles with shallow depth the SEL of 160 dB can be met. Moreover, the system is largely independent of water depth, but regarding lager monopiles more research is needed [5].

- HSD are an often used and tested noise mitigation technique. The system is lightweight and cost-efficient, with an easy handling causing no larger delays of the piling process and needs to be customized for each project. Even though the efficiency is independent of the water depth and currents, practicability and efficiency still need to be proven for larger water depths, but there are already concepts for large monopiles [2].

6 Outlook

The literature research revealed that noise mitigation systems are sufficient for water depth of up to 40 m and and pile diameters of up to 8 m. Large monopiles with diameters up to 12 m will cause higher noise emissions and greater water depth of over 40 m with higher hydro static pressure will cause further challenges in reducing underwater noise levels. Thus, more research concerning the successful application and noise reduction of noise mitigation systems to larger pile diameters at greater water depths is needed. Based on current project measurements, for large diameter monopiles the use of a single noise mitigation system will not be sufficient. To keep the limiting values for under water noise emissions, the combination of different noise systems will be mandatory. Alternative pile driving methods such as modification of the piling hammer and reducing the maximum blow energy are in the experimental stage of their development status, but are promising to reduce noise emission by an additional 1-4 dB [4]. Furthermore, noise mitigation concepts always need to be customized for each project. Factors such as local environmental conditions and the required degree of noise reduction need to be considered in the project specific evaluation. [9].

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