Acoustic emissions from offshore monopile installation using jetting technology

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Abstract: *This study presents comprehensive underwater noise recordings collected from first offshore installation of large monopile foundations using a novel low-noise jetting technology in Ørsted's German project Gode Wind 3. Variability of the measured sound levels is assessed across different installation locations, distances from the foundation and phases of the installation. Measurements are analysed against standard acoustic metrics such as peak pressure level, sound pressure level and cumulative sound exposure level. Additionally, the measurements are compared against typical previously measured acoustic emissions from impact piling. Both sets of data are integrated with a sound propagation model to derive corresponding sound source levels and simulate propagation to extended distances. The results are subsequently discussed in the context of various underwater noise regulations from different markets. It is demonstrated how the low-noise jetting technology produces significantly lower sound levels by more than 30 dB. Consequently, this also yields lower distances to environmental thresholds.*

Keywords: *Pile Driving, Underwater Noise, Noise mitigation, Acoustic measurements.*

1. INTRODUCTION

The rapid expansion of offshore wind energy projects has brought significant attention to the environmental impacts associated with the installation of wind turbine foundations. One of the primary concerns is the underwater noise generated during the installation process, particularly from traditional methods such as impact piling. These high noise levels can have detrimental effects on marine life, including behavioural disturbances and physical harm to marine mammals and fish [1, 2].

In response to these environmental challenges, there is a growing need for innovative installation techniques that minimize underwater noise emissions. The industry has initially focused on reduction of acoustic emissions from impact piling at the source. These solutions are typically referred to as noise abatement systems (NAS). Examples of NAS are big bubble curtains, Hydro-sound damper or AdBm [3]. These systems are considered mature and capable of removing majority of acoustic emissions in the water column. However, NAS alone are often these days not sufficient to comply with regulatory requirements due to the growing size of foundations and increasingly more stringent underwater acoustic regulations. Primary focus over the past years has therefore been on reduction of sound emissions of the source itself. This either means modifying the traditional impact piling method or replacing it with another technology. Recent examples of such incentives are announcements of intended GBM trials [4], deployment of CAPE Holland Vibro Lifting technology [5] or further development of the IQIP's EQ-Piling method [6].

Ørsted has pioneered the use of a novel low-noise jetting technology in its German offshore wind project, Gode Wind 3 demonstrating a significant advancement in reducing the acoustic footprint of offshore installations.

This study presents a comprehensive analysis of underwater noise recordings collected during the first offshore installation of large monopile foundations using the jetting technology. Three monopiles of maximal outer diameter of 9 meters were installed to their final penetration depths. The recordings are evaluated using standard acoustic metrics including peak pressure level, sound pressure level, and cumulative sound exposure level [7]. Variability of sound levels is assessed across different installation locations, distances from the foundation, and phases of the installation process. The measurements are further compared against typical acoustic emissions from conventional impact piling methods [3] and discussed in the context of various underwater noise regulations from different markets. The findings demonstrate that the low-noise jetting technology produces significantly lower sound levels, achieving reductions of more than 30 dB compared to traditional methods. This substantial decrease highlights the potential for this technology to mitigate the environmental impact of offshore wind farm installations.

2. MEASUREMENT METHODOLOGY

All underwater noise measurements were conducted using Soundtrap ST600 [9] underwater noise measuring device with sampling rate and processing setup to capture frequency range from 10 Hz to 16 kHz. The hydrophones were calibrated using a pressure chamber method, ensuring compliance with the requirements of DIN 45653 [10] and ISO 18406 [11] standards.

The measurement layout consisted of fixed positions set at three distinct distances from the installation site: 500 meters, 750 meters, and 1500 meters. Two measurement positions were established at both 500 meters and 750 meters, while a single position was set at 1500 meters.

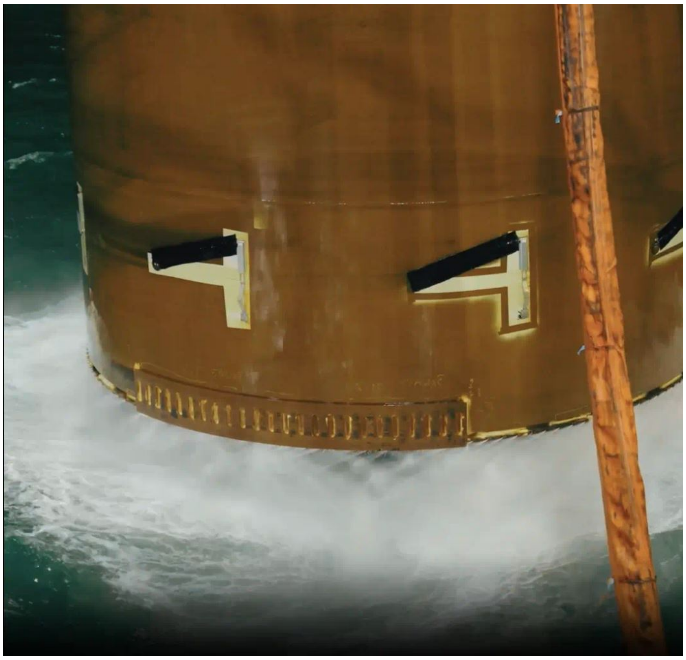

Figure 1: Lower-noise-technology used to install monopile foundations at Gode Wind 3 in Germany [8].

These positions were arranged along two transects oriented 180 degrees from each other: one in an east/north-east direction and the other in a west/south-west direction.

The acoustic emissions from the jetting process can be categorized as a continuous and non-impulsive sound source. The pressure time series measurements were, therefore, analyzed in terms of sound pressure level (SPL) with averaging period of 5 seconds and peak pressure level ($L_{p,pk}$), as defined by ISO 18405 ([7])

3. INSTALLATION METHOD

The tested low-noise installation method utilizes a jetting system mounted at the toe of the pile around its entire annulus. The system injects high-pressure water into the surrounding soil breaking structure-soil interaction and allowing the monopile to descend toward its final penetration depth. Specific phases of the installation procedure could in most cases be identified in the recordings with their acoustic signatures as discussed in the next section.

4. UNDERWATER NOISE MEASUREMENT RESULTS

Example of measured SPL over the duration of the jetting installation is presented in Figure 2. The example shows recordings sound levels at a distance of 750 m from the installation location. Chronologically stepping through the different phases of the installation, a pressure test was observed first with sound levels clearly elevated above ambient noise. The pressure test involves flushing of jetting nozzles. The toe of the pile is in approximately middle of the water column and pumps are operating at the medium pressure. This was followed by a long interval corresponding to the positioning of the installation vessel, deployment of the

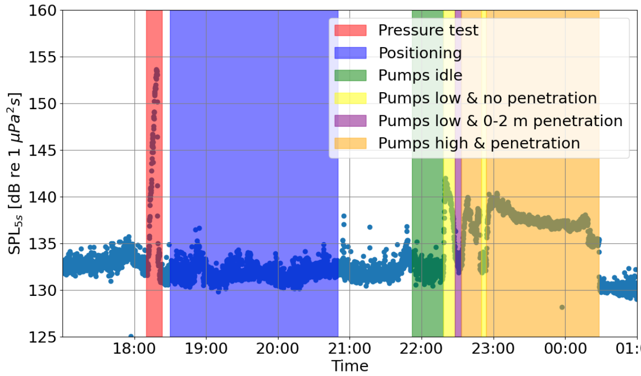

Figure 2: Example of SPL *time series at distance of 750 m from foundation with different installation phases highlighted.*

reference frame and setting the monopile into a pile gripper. No significant increase of sound levels is observed during this interval. The same can be said about the subsequent phase where pumps are turned on but operating on idle pressure. The sound levels start increasing once the operating pressure increases and the toe of the pile is still within the water column. The same pressure on pumps is maintained as the pile is lowered towards the seabed and the pile starts penetrating the first meters of the sediment which results in a decrease in the measured sound levels back to the ambient values. The pumps' operating pressure afterwards increases again resulting in elevation of sound levels close to the values observed during the first meters of penetration. A temporal decrease in sound levels is also observed during this time interval which corresponds to a temporal decrease of the pumps' operating pressure. The pressure is then lowered down for a few minutes and sound levels drop down to ambient values. Finally, the installation using the high pressure is resumed and continues until final penetration depth is reached. The sound levels initially slowly decrease by approximately 3 dB over the duration of 1 hour and 20 minutes. They then suddenly drop by another 2 dB which is most likely caused by lowering the operating pressure slightly.

Equivalent features can be observed for $L_{p,pk}$ time series . There is however, greater variability in the measured $L_{p,pk}$ values and lower signal-to-noise ratio which is a common observation since the peak pressure level quantifies instantaneous maximal amplitude in pressure measurements. Given the values tend to be very low (typically well below 160 dB of $L_{p,pk}$) this acoustic metric is not discussed in greater detail in the rest of this work as it is highly unlikely it will cause any significant environmental impacts/produce large distances to environmental thresholds currently applicable in underwater noise regulations across markets.

Similarly, the pressure test is not a requirement for future deployments and pressure testing can be done onshore / on board the vessel. The rest of this work, therefore focuses on discussing acoustic measurements and the corresponding implications to environmental impacts from the jetting phases only.

The following key findings applicable to all installed foundations can be derived from the measurements: 1) Positioning cannot be reliably detected from the recordings and does not significantly contribute to the ambient sound levels. 2) Pumps operating at idle pressure do not results in elevation of measured sound levels. 3) Pumps operating at low pressure result in elevated sound levels only if the toe of the pile is not embedded into the sediment. 4) Sound levels during the first meters of penetration drop toward ambient sound levels when the pumps operate at low pressure. 5) Jetting with high pressure raises sound levels above ambient values

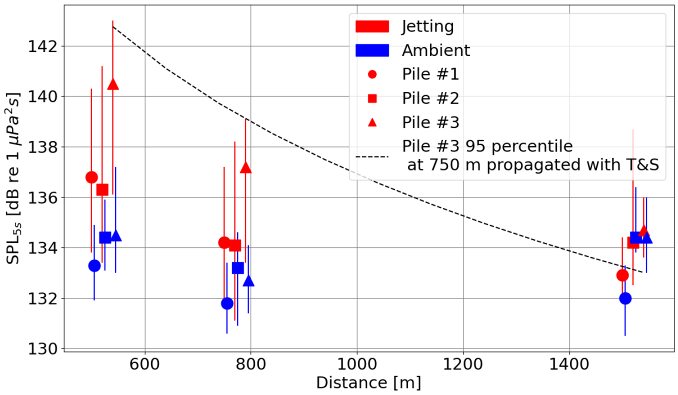

Figure 3: SPL *sound levels vs. distance from the installation location. Dots denote median (50 percentile) values, vertical lines denote spread between 95 and 5 percentile exceedance values. The dashed line depicts 95 percentile value from 750 m propagated with Thiele and Schellstede [12] transmission loss used in the environmental impact assessment section. Measurement points are artificially shifted from the actual measurement positions for better readability.*

regardless of the penetration depth. 6) Elevation of sound levels is likely primarily caused by jetting nozzles if the toe of the pile is in the water column. 7) Elevation of sound levels is likely primarily caused by pumps if the operating pressure is high, and toe of the pile is sufficiently embedded into sediment.

Aggregated overview of measured SPL across different distances from the foundation is presented in Figure 3. The plot depicts basic statistical metrics of SPL, namely 50 (median), 95 and 05 percentile exceedances for intervals when pumps were operating at low/high pressure (jetting) and for the time interval right before penetration when pumps were idle (ambient).

The following key findings applicable to all installed foundations can be derived from the measurements: 1) Sound levels from jetting are significantly elevated above ambient level at the distances of 500 m and 750 m for two (piles # 1 and # 3) out of three foundations. 2) Sound levels from jetting cannot be reliably distinguished from ambient levels at the distance of 1500 m for all 3 foundations. 3) Ambient sound levels from jetting trials are considered high (median values of 132-135 dB SPL) compared to other regions.

An example of measured 1/3 octave SPL spectra at distance of 750 m from the foundation # 3 for jetting and ambient periods is presented in Figure 4. This example depicts the case where signals from jetting could be separated from ambient levels across largest frequency range, namely from 200 Hz onwards. The threshold frequency for # 1 was 400 Hz and 630 for #2. Overall, the jetting emissions appear to be of a more broadband nature without any distinct harmonics compared to a typical impact piling spectrum which is also depicted in the figure. The piling spectrum was adopted from ITAP empirical measurements ([3], Figure 14 right plot). The spectrum was scaled to correspond to a broadband sound level for an equally sized foundation (9 meter diameter monopile) and hammer energy of 4000 kJ. The value was obtained by considering logarithmic trend of sound levels scaling with diameter as depicted in Figure 12 in [3]. Additionally, ITAP's prognosis submitted as part of the Revolution Wind Underwater Acoustic Analysis [15] estimates sound levels of 184 dB and 185 dB for 12 meter and 15 meter diameter monopile respectively for hammer energy of 4000 kJ. This translates to a broadband sound level of 182.7 dB for the 9 m monopile.

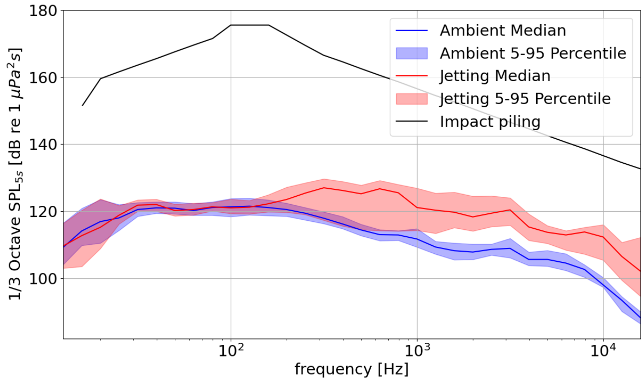

Figure 4: 1/3 Octave SPL *sound levels at distance of 750 m from foundation for ambient and jetting periods compared to a typical impact piling spectrum [3].*

5. ENVIRONMENTAL IMPACT ASSESSMENT

The above presented measurements were used to calculated distances to various environmental thresholds typically used for assessing impact of installation activities on marine fauna. The measurements from pile # 3 were used as a reference as these exhibited highest sound levels and cleanest separation from background noise at the distance of 500 and 750 m. The limited number of distances and their close proximity, however, still prohibits to calculate any reliable transmission loss. An alternative approach was, therefore, taken where measured 750 m sound levels were propagated using Thiele and Schellstede (T&S) [12] frequency dependent transmission loss model. This gives a theoretical estimate of what the true acoustic contribution from jetting is at further distances (e.g. beyond 1500 m where installation measurements were already masked by the background noise) and still agrees well with the near-source measurements as depicted in Figure 3. Same exercise was conducted for traditional impact piling using the previously discussed spectrum. A set of permanent threshold shift (PTS) criteria commonly used in the U.S. [13] was selected for this study. These criteria or its subset are often also adapted in other regulatory markets such as the United Kingdom, Denmark or Poland. All the criteria utilize cumulative sound exposure level (SEL_{cum}) as the acoustic metric. This often corresponds to total acoustic exposure produced from an installation of a single foundation (monopile) and the 750 m sound levels have to be adjusted accordingly. A correction factor of 38.6 dB which corresponds to 2 hours of continuous installation was added to 95 percentile of measured jetting sound levels (139.1 + 38.6 = 177.7 dB SEL_{cum}). Similarly, a correction factor of 37 dB was added to the impact piling sound level (182.7 + 37 = 219.7 dB SEL_{cum}). This correction was derived from publicly available underwater noise assessments and corresponds to 5000 hammer blows at 4000 kJ which is a representative level of total driving energy assumed in such modelling exercises [14, 15]. Results of calculated distances to threshold are presented in Table 1 for both low noise installation method and the impact piling with various levels of broadband attenuation. The PTS criteria distinguish between impulsive and non-impulsive sounds with different threshold values for both types. While the low-noise method produces non-impulsive noise, distances to both sets of thresholds are presented for this method to offer more direct comparison against the piling ranges. The low-noise consistently yields lower distances to thresholds, often one or two orders of magnitude lower than the traditional impact piling. The differences become smaller when a broadband reduction of 20 dB is considered for

Hearing group	Threshold impulsive (non-impulsive) [dB SELcum]	LN impulsive [m]	LN non-impulsive [m]	IP unabated [m]	IP 10 dB reduction [m]	IP 20 dB reduction [m]
LF	183 (197)	366	91	23972	9958	3279
HF	193 (201)	50	27	286	129	58
VHF	159 (181)	523	100	2664	1299	615
PW	183 (195)	233	81	5374	1771	578
OW	185 (199)	203	59	2769	1028	382

Table 1: Distances to various PTS acoustic threshold calculated for low-noise (LN) installation method and impact piling (IP)

impact piling. One exception is the range to the low-frequency (LF) hearing group that remains an order of magnitude higher even for the maximal considered sound reduction.

6. DISCUSSION

The low-noise jetting method offers an alternative to traditional pile driving, substantially reducing acoustic impacts in marine environments both in terms of absolute sound level values as well as producing less intrusive different type of noise, namely continuous and non-impulsive. The presented study discusses aggregated findings from the first set of real offshore application measurements. Additional measurements collected in quieter environments would provide further insights into true acoustic emissions at broader frequency range and at further distances.

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