Danish Energy Agency

A Reader's guide to the Danish Energy Agency's "Guidelines for underwater noise from pile driving"

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Introduction

This reader's guide presents an overview of the Danish guidelines for underwater noise from impact or vibratory driven pile installations from 2023 guidelines to pile driving (Energistyrelsen, 2023). The reader's guide does not replace or supplement the official guidelines but gives a non-technical summary of key methodologies, requirements, and criteria.

The Danish guidelines for underwater noise from pile installations have evolved due to growing concern about the impact of underwater noise on marine mammals during pile installation. The guidelines were initially developed in 2016 based on recommendations given by an expert group, which had the task of investigating how underwater noise from the installation of impact driven foundations at the planned offshore wind farms could be regulated in order to take due consideration of protected

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marine species. These guidelines were subsequently successfully used during the installation of several offshore wind farms. The original 2016 guidelines focused on permanent hearing impact. Recent scientific advancements led to an update of the guidelines in 2023, incorporating behavioural disturbance of marine mammals and frequency weighting principles. The guidelines are linked to standard conditions to be included in construction permits for offshore windfarms. Guidelines[1] and standard conditions[2] for construction permits are available on the Danish Energy Agency's website[3]. Also available here is a number of background reports on which the updated guidelines were based as well a document containing guidelines for underwater noise prognosis for EIA and SEA assessments.

Guideline structure

When granted a construction permit, and prior to installation of the offshore wind turbine foundations, the Concession Holder must, as specified in construction permit conditions, demonstrate compliance with the Danish Energy Agency's requirements on limiting environmental impact from underwater noise. The prognosis must be based on project-specific environmental and sound source (impact or vibratory pile driving) parameters. For simplicity, and because impact pile driving is the prevalent method for installation of piles for offshore windfarms in Denmark, vibratory pile driving is not reflected in this reader's guide, and the reader is referred to the technical guideline document for details. Impact is measured through species-specific acoustic criteria, including Permanent Threshold Shift (PTS) and Temporary Threshold Shift (TTS), and a behavioural reaction criterion for harbour porpoises. On-site measurements of underwater sound are required for demonstration of compliance with acoustic criteria. In most cases, noise mitigation measures are needed to demonstrate compliance. In certain cases, Acoustic Deterrent Device (ADD) can also be necessary. If the Concession Holder can demonstrate compliance with acoustic criteria, the piling activity can start. The piling program is accompanied with an on-site measurements program. The measurements program serves to verify the propagation model used in the Prognosis and once again to demonstrate compliance with acoustic criteria.

[1] Guideline for underwater noise Installation of impact or vibratory driven piles, March 2023, ens.dk/media/2508/download
[2] Standardvilkår til havvindmølleprojekter om undervandsstøj fra installation af monopæle, Energistyrelsen, 2023. (Standard conditions for construction permits), ens.dk/media/2510/download
[3] https://ens.dk/energikilder/vindmoellers-miljoepaavirkning

The following sound prognoses and measurements need to be reported before, during and after the construction process, respectively:

Timing	Activity/product	Comments
Application for construction permit	EIA noise prognosis	Not covered by this reader's guide
Before construction begins	Noise prognosis - Reference case - Planned construction case - (ADD case)	According to standard conditions: Noise prognosis for 4 (+3) piles, to be sent to DEA two months prior construction starts, accept needed before construction.
During initial construction (first 4 – 8 foundations)	Verification measurements - Sound propagation measurement - Foundation specific impact range measurement Reports - Foundation specific measurement reports (1 per foundation)	Noise measurements must be carried out for first 4-8 piles, including a measurement of the sound propagation. Results and calculation of SEL_{cum} to be reported to, and approved by DEA before proceeding with installation of remaining foundations. One short report must be prepared per foundation, documenting calculated SEL_{cum}, based on measured sound propagation.
After construction	Final report	Demonstrating compliance with guidelines for the entire construction period, based on sound propagation and foundation specific measurements.

Acoustic criteria for compliance

Acoustic criteria for compliance include Permanent Threshold Shift (PTS) for all relevant marine mammal species, with the responsibility of identification resting on the concession holder. PTS criteria are species-specific frequency-weighted Cumulative Sound Exposure Levels ($L_{E,cum,24h,w}$). PTS impact ranges must not exceed a specified safe distance (r_{safe}), which is the minimum expected distance of marine mammals to the pile installation at onset of piling. A standard value of $r_{safe} = 200\ m$ shall be used, unless a larger distance can be justified for the specific project.

The concession holder must furthermore document Temporary Threshold Shift (TTS) for all relevant marine mammals, ($L_{E,cum,24h,w}$ as for PTS), and if relevant, harbour porpoise behavioural reaction criterion, which is the frequency weighted root-mean-square Sound Pressure Level over 125 ms ($L_{p,rms,125ms,VHF}$). For the calculation of PTS and TTS impact ranges, marine mammal fleeing behaviour must be included, assuming a constant 1,5 m/s swim speed away from the source position. Other species-specific swim speeds can be used if justified.

For impact pile driving, the species-specific threshold criteria are provided in Table 1.

I-type sounds				
Species (Danish)	**Weighting (*w*)**	**Threshold type**		
		PTS	**TTS**	**Behavioural Disturbance**
		$L_{E,cum,24h,w}$	**$L_{E,cum,24h,w}$**	**$L_{p,rms,125ms,w}$**
Harbour porpoise (Marsvin)	VHF	155	140	103
White-beaked dolphin (Hvidnæse)	HF	185	170	-
Pilot whale (Grindehval)	HF	185	170	-
Minke whale (Vågehval)	LF	183	168	-
Harbour seal (Spættet sæl)	PCW	185	170	-
Grey seal (Gråsæl)	PCW	185	170	-

Table 1: Species of marine mammals commonly occurring in Danish waters with corresponding auditory groups (w) and respective acoustic thresholds stated as $L_{E,cum,24h,w}$ in dB re 1 µPa²s and $L_{p,rms,125ms,w}$ in dB re 1 µPa. Only thresholds for impact pile driving are shown.

Acoustic definitions

Acoustic criteria for compliance are based on the calculation of cumulative sound exposure ($L_{E,cum,24h,w}$), to reflect PTS impact range. $L_{E,cum,24h,w}$ is defined as the 24-hour duration, species specific frequency weighted version of the basic expression:

Equation 1

$$L_{E,cum,t} = 10 \cdot \log_{10} \sum_{i=1}^{N} \frac{S_i}{100\%} \cdot 10^{\frac{L_{S,E} - X \cdot \log_{10}(r_0 + v_f \cdot t_i) - A \cdot (r_0 + v_f \cdot t_i)}{10}} \, dB \; re \; 1\mu Pa^2$$

Where the received SEL "$L_{E,p}$" of each pile strike "i" with hammer energy "S_i" applied, is summarized for all hammer blows "N", to provide the cumulative SEL "$L_{E,cum,t}$" over the time "t". For the Danish guidelines, the duration (t) is always set to 24 hours, and must include the underwater noise from all foundations installed within a 24-hour timeframe. The "$L_{E,p}$" is calculated from the maximum hammer energy source level "$L_{S,E}$", subtracted the sound energy loss over distance for a fleeing marine mammal, assuming 1,5 m/s swim speed "v_f". In this regard, "X" and "A" are the sound propagation coefficients, "r_0" is the initial distance of the marine mammal to the pile installation, "$v_f \cdot t_i$" is the distance (in meters) travelled by the marine mammal since onset of pile driving.

For part of the prognosis, Equation 1 is evaluated through an iterative process for "r_0", until the value of $L_{E,cum,24h,w}$ is equal to the acoustic PTS/TTS criteria. The resulting "r_0", is referred to as the PTS impact

range "r_{PTS}", or TTS impact range "r_{TTS}" respectively. For this calculation, all relevant marine mammal species are evaluated individually, using species-specific weighted $L_{E,cum,24h,w}$, and species-specific acoustic criteria (Table 1).

In addition to the sound exposure level, an important metric is the "rms" sound pressure level (SPL), for evaluating the harbor porpoise behavioural disturbance distance "r_{behav}". Evaluated for $L_{p,rms,125ms} = 103\ dB\ re\ 1\mu Pa$, as given by the expression:

Equation 2

$$r_{behav} = L_{S,E} - L_{p,rms,125ms} - 9 - X \cdot log_{10}(r) - A \cdot r$$

Where the source level $L_{S,E}$ represents the maximum hammer energy.

Prognosis

The Prognosis involves estimating the environmental impact of noise from offshore piling activities. It requires detailed descriptions of the noise source, sound propagation, pile driving duration, and hammer action. The Prognosis can utilize numerical modelling or semi-empirical estimations and must account for multiple piles and must predict the underwater noise emission in multiple directions from the source. The objective is to calculate the cumulative SEL experienced by relevant marine mammal species fleeing the noise. The Prognosis consists of two to three parts:

- Reference Case: Worst-case, without noise reduction techniques
- Planned Construction Case: As planned, possibly with noise reduction
- Acoustic Deterrent Device (ADD)[4] Case: If relevant, with the ADD as the only active noise source

Reference case

The reference case represents the installation scenario without any active noise mitigation measures. This is used for determining the mitigation needs for compliance with the acoustic criteria, and also for documenting potential worst-case sound emission in case of a mitigation system failure during installation.
The Reference case procedure requires the concession holder to:

1) Calculate the cumulative sound exposure level through Equation 1 for each relevant marine mammal species, using a safe starting distance of $200\ m$.
2) Calculate the minimum mitigation requirement as the difference between the species-specific cumulative sound exposure level for an animal starting at 200 m distance from the installation, and the corresponding acoustic PTS criteria (Table 1) for each relevant species.

[4] Use of ADD requires specific permission and is generally prohibited.

Note: One frequency weighted minimum mitigation requirement is calculated per relevant species. For the construction, all minimum mitigation requirements must be achieved.

Planned construction case

The planned construction case represents the installation as planned, with active mitigation measures ensuring compliance with the acoustic criteria for impact on relevant marine mammal species. Mitigation measures included must satisfy the minimum mitigation requirements of all relevant species, as calculated during the “Reference case”. Mitigation measures in this regard can be both installation-specific changes from the reference case, as well as added mitigation systems such as bubble curtains.

The Planned construction case procedure requires the concession holder to:

1) Calculate impact ranges for PTS and TTS impact through Equation 1 for each relevant marine mammal species, by inserting the species-specific threshold criteria for PTS and TTS (Table 1).
2) Calculate the behavioural impact range for harbour porpoise through Equation 2, if the species is relevant for the project.

Acoustic Deterrent Device (ADD) case

The ADD case represents the underwater noise impact resulting from the use of a specific ADD as a pre-piling deterrent for marine mammals. The use of an ADD is generally prohibited during the construction sequence of any single foundation. In special cases where it is not possible to comply with the acoustic criteria for PTS at a distance of 200 m, use of an ADD may be permitted. Any use of an ADD shall be approved by the Danish Energy Agency, who reserves the right to reject the specific ADD device of the application.

Prognosis requirements

Regardless of case, a common set of requirements for the prognosis applies, in addition to the case-specific methodologies presented in the previous section of this readers guide. The common set of requirements include source and sound propagation model specific requirements. Briefly, the prognosis inputs shall consist of 1) a source model, representing the pile driving activity (see bullets below), and 2) a sound propagation model representing the reduction in sound level as it travels through the water column.

Source model specific requirements include:

- A minimum number and length of transects (directions in which to model the sound emission)
- A minimum frequency range, depending on which marine mammal species are relevant to the project area
- The source level and spectrum of the source

- The pile driving procedure, including the hammer energy and time interval between consecutive pile blows throughout the pile installation. Conservative grouping of pile blows into soft-start, ramp-up and full power phases can be used.

The sound propagation model can be either semi-empirical or numerical. Both approaches are valid, but come with different requirements for inputs, methodology and outputs, as briefly described below.

A **semi-empirical approach** uses site-specific measurements at different ranges from an artificial underwater sound source to determine the sound propagation in the project area. Requirements for the measurements to be considered valid include, but are not limited to:

- The sound source must produce sufficient acoustic energy for all relevant frequencies.
- The sound level must be measured at distances of 750 m, 1000 m, 1500 m, 2000 m and 3000 m, at 50% and 75% of water depth, in a straight line from the sound source in at least four worst-case directions.
- The measurements must take place during environmental conditions representative for the installation time frame.
- Hydrographic conditions must be measured at least every 4 hours of acoustic measurements.

A **numerical approach** uses available environmental parameters to build a digital model of the project area, and uses appropriate numerical models (algorithms) to calculate the sound propagation for the area. Requirements for the numerical approach include, but are not limited to:

- Specification and justification of sound propagation algorithms used
- Sound propagation is modelled in at least 18 directions, with a calculation grid of maximum 20 m (horizontally) x 1 m (vertically).
- Water column conditions, including temperature, salinity and sound speed within the water column.
- Seabed sediment layer types and acoustic parameters
- Bathymetry

According to standard conditions[5] for construction permits, the noise prognosis must be presented to DEA two months prior construction begins, and must be accepted prior to initiation of installation.

Verification measurements

On-site measurements of underwater sound shall be taken with two purposes:

- Verification of propagation model used in the Prognosis

[5] Standardvilkår til havvindmølleprojekter om undervandsstøj fra installation af monopæle, Energistyrelsen, 2023. (Standard conditions for construction permits), ens.dk/media/2510/download

- Demonstration of compliance with acoustic criteria

The required number of measurements is outlined in the project-specific conditions, typically necessitating measurements during the first four (4) foundation installations for demonstration of compliance. However, additional measurements may be required if there is non-compliance with threshold criteria or the prognosis.

Verification of propagation model

Verification measurements are necessary to confirm the accuracy of the sound propagation model. This process includes conducting transect measurements using either 1) an artificial underwater sound source that represents the installation noise or 2) actual pile driving noise during the construction of the first foundations. The results of these transect measurements should be based on measurements at two depths (50% and 75% water depth) and at five to six specific distances between 750 meters and 10 kilometers. This procedure aims to verify that the Prognosis model accurately reflects the actual acoustic environment, thereby reducing the risk of inaccurate compliance assessments. The Concession Holder must report this to the Danish Energy Agency for approval before proceeding.

Demonstration of compliance

Sound exposure level measurements must be taken at 750 m, 1,5 km, and 3 km (it is recommended to also measure an additional distance further from the pile) during pile installation in the direction with the highest expected sound levels. Compliance with prognosis results, and thereby with thresholds, for species-specific PTS impact ranges can be determined using Equation 1 and the actual hammer energy applied at each blow. The distance measurements can also be used to interpolate/extrapolate the impact range for the harbour porpoise behaviour criterion.

The measured cumulative sound exposure levels should be compared against the predicted values. If the actual noise levels do not exceed the predicted values by more than 3 dB, the prognosis model can be deemed accurate. However, if the measured noise levels are in excess of 3 dB higher than the model, it will be necessary to update the prognosis accordingly.

Background noise measurements should be conducted in the absence of pile driving noise, preferably at the same location where pile driving noise is measured. These measurements are essential for correcting installation measurements and should also account for noise from support vessels.