International Standard

ISO 7447

Underwater acoustics — Measurement of radiated underwater sound from percussive pile driving — In situ determination of the insertion loss of barrier control measures underwater

Acoustique sous-marine — Mesurage de l'émission sonore sous-marine lors de l'enfoncement de pieux marins par percussion — Détermination in situ de la perte par insertion de barrières sous-marines

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Foreword

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Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Within the scope of approval and licensing procedures for offshore wind energy farms worldwide an assessment is required of whether sound caused by the construction, operation and demolition of wind energy farms represents a possible hazard for the marine environment. To reduce the noise output effective noise abatement systems (noise control measures underwater) can be used to protect the marine environment, see References [12] to [25].

Examples of noise-generating activities are pile driving (e.g. by impact hammer) or pile extraction. Examples for noise abatement systems are bubble curtains and cofferdams whose acoustic efficiency can be demonstrated by applying the methodology described in this document.

This document describes measuring methods for the in situ characterization of the effectiveness of noise abatement systems underwater. The acoustic effectiveness of a system can be derived from measurements carried out with and without the considered noise abatement system, e.g. References [10] and [11]. This acoustic effectiveness of the system is given as insertion loss.

The principles of the method can also be applied in other cases such as construction of docks, piers, wharfs, bridge supports, etc., a procedure is described in Annex A. Sound particle motion and seabed vibration are of increasing interest in ocean acoustics and are dealt with in Annex B.

In general, in acoustic underwater measurements, the influences of the noise source and the noise propagation cannot be completely separated. For example, the soil properties have a direct influence on the noise source. Another influence is the sound propagation and sound radiation via the sea bottom.

Results acquired in accordance with this specification are necessary and useful for

— comparison with acoustical specifications, e.g. within the scope of approval procedures,

— comparison with different noise abatement systems, and

— further development and improvement of noise abatement systems.

Underwater acoustics — Measurement of radiated underwater sound from percussive pile driving — In situ determination of the insertion loss of barrier control measures underwater

1 Scope

This document specifies two procedures for the in situ determination of the insertion loss of underwater noise abatement measures (noise abatement systems). The impulsive sound of pile driving is used as the sound source for the investigation of noise abatement systems. This document does not apply to artificial sound sources and investigations under laboratory conditions.

Apart from the correct application of the respective noise abatement system, the achieved sound attenuation also depends on the installation conditions (e.g. type of hammer, driving energy, pile dimensioning) as well as on the environmental conditions (e.g. water depth, seafloor classification and bathymetry, current and wind conditions) and the flanking transmission via the seafloor.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 18405, *Underwater acoustics — Terminology*

ISO 18406:2017, *Underwater acoustics — Measurement of radiated underwater sound from percussive pile driving*

3 Terms and definitions

For the purpose of this document, the terms and definitions given in ISO 18405, ISO 18406 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
insertion loss of barriers
$D_p(f)$
difference, in sound pressure levels at a specified receiver position before and after the installation of a barrier

Note 1 to entry: $D_p(f)$ is the sound pressure level without barrier minus the sound pressure level with barrier, in one-third octave (base 10) bands. According to ISO 18405, an alternative name for one-third octave (base 10) is decidecade.

Note 2 to entry: The sound pressure level is determined over multiple pulses.

Note 3 to entry: The insertion loss can also be calculated with sound exposure level. The results are identical to the calculations with sound pressure level using the same integration time *T*.

Note 4 to entry: For calculation of insertion loss, see 7.3.

Note 5 to entry: Insertion loss is expressed in decibels.

[SOURCE: ISO 10847:1997, 3.5, modified — Abbreviation modified and Notes 1 to 4 to entry added.]

3.2
noise abatement system
mitigation measure that attenuates the sound output from the sound source

Note 1 to entry: There are near-pile noise abatement systems, such as cofferdams, where a pipe is built into the water enclosing the pile and the water is pumped out between the pile and the pipe. Applications away from the pile are mostly bubble curtains, see References [12] to [25].

3.3
flanking transmission
transmission of sound from a source (pile) to receiver point but not via the *noise abatement system* (3.2)

[SOURCE: IEC 60050-801-31-40:1994, modified — Term from building acoustics, changed for underwater applications.]

4 Instrumentation

4.1 General information

Clause 4 describes relevant information on instrumentation for underwater measurements. ISO 18406 provides further considerable details on the type of measurements and instrumentation.

4.2 Hydrophones and analysers

The measurement chain for hydroacoustic measurements consists of the following components:

— omnidirectional hydrophone (with preamplifier) with a constant sensitivity that deviates by less than 2 dB over the analysed frequency range;

— analogue high-pass filter (which may be integrated in the measuring amplifier) to limit the low-frequency dynamics of the measuring data;

— measuring device, including the possibility to record time raw data, consisting of low-pass filters (anti-aliasing filters), amplifiers, and A/D converters;

— cables, connecting components, etc.

Furthermore, the following test equipment, devices and recording equipment are required:

— pistonphone for checking the calibration of the hydrophone measuring chain before and after each measurement;

— distance meter (e.g. laser, GPS based);

— equipment to record the data required to determine the sound speed profile (sound speed as a function of depth). For example, CTD sensors are used to determine the temperature, conductivity and the depth below the water surface at the CTD probe. With the measured quantities the sound speed profile can be determined.

4.3 Analysis software

For data post-processing and evaluation, an analysis software is required which comprises the following methods:

— one-third octave (base 10) bands analysis, with the filters corresponding to the requirements in IEC 61260-1;

— narrow-band analysis;

— time averaging.

Filtering may be accomplished using analogue electronic filters, but is more commonly undertaken using digital processing. The digital methods can either utilise implementations of digital filters, or may be achieved by aggregating levels in the frequency domain over the requisite bands (subsequent to a Fourier transform of the time-domain waveform).

Data processing can also be carried out within the measuring device.

4.4 Calibration

The organization performing the measurements shall make sure that the devices of the acoustic measuring chain (including hydrophones) are calibrated traceable to appropriate standards using a suitable method (IEC 60565-1 and IEC 60565-2).

The calibration interval shall be 24 months at maximum. The required calibration certificates shall be kept available for at least 10 years.

5 Methods

5.1 General remarks

Two methods are common for the in situ characterization of noise abatement systems underwater: the direct method (see 5.4) and the indirect method (see 5.5).

5.2 Comparability of measurements

Two methods are described in this document. Both have the objective to determine the in situ insertion loss of an underwater noise abatement system. The descriptions for both approaches are to ensure that excitation and conditions of the sound source as well as transmission properties to the hydrophone positions are comparable for the situation with and without noise mitigation system.

In the following, parameters are listed that could have an influence on the direct and indirect measurements:

a) configuration and pile characteristics relating to

  — pile geometry (e.g. diameter, length, wall thickness distribution),

  — material,

  — pile head design (e.g. flange), and

  — slant angle to the seabed;

b) environmental conditions:

  — water depth at pile and hydrophone location and in between pile and hydrophone (bathymetry);

  — distance between pile and noise mitigation system;

  — distance between hydrophone and noise mitigation system;

  — hydrophone depth;

  — properties and layering of the seabed, cpt (cone penetration test) values at site;

  — ocean current[27];

  — wind conditions[27];

- significant wave height[27] and direction;
- swell height[27] and direction;

c) operating conditions:

- type of pile driver (e.g. manufacturer, driving/rotational mass, maximum blow energy/operating frequency);
- type of force-conducting connecting elements between pile driver and pile (e.g. anvil);
- hammer energy;
- pulse repetition rate;
- penetration depth;
- number of blows in the noise measurement period.

Any changes in the above conditions that occur between measurements with and without the noise attenuation in place shall be determined and documented.

To ensure comparability of measurements between the unmitigated and mitigated situation, these parameters should all be sufficiently equal.

Ideal equal conditions cannot always be achieved, so quantitative minimum requirements are listed below:

- pile material should be equal, and pile and pile head geometry should not differ more than 10 %;
- flat bathymetry is required: the variation in water depth should not exceed 10 % between source and measurement site;
- measurement geometry (distance between noise mitigation measure and hydrophones to pile and hydrophone depths should not differ more than 10 %);
- hammer energy and pulse repetition rate should not differ more than 10 %.

The combined standard uncertainty should remain <20 %, so that the error in the determination of the insertion loss is <1 dB, see also 7.4 on the uncertainty of measurement according to ISO/IEC Guide 98-3.

NOTE 1 Experience shows that the background noise which includes self-noise of the hydrophone measurement device including mooring concept and measurement device can limit the validity of the determination of the in situ insertion loss. In concrete terms, this means that the noise abatement system used can have a higher insertion loss than can be verified by measurement. However, this case would be excluded if requirement 5.3. is considered.

NOTE 2 The measurements describe an in situ "insertion loss". The in situ determined insertion loss is therefore dependent on the environmental parameters and the selected measurement configuration. Thus, for each measurement report, the validity range is documented by representations of the above-mentioned parameters, see also Clause 8.

NOTE 3 The parameters water depth, wind, significant wave height and current are important for the documentation of acoustic measures such as the bubble curtain, as the properties can be/are influenced by these parameters. Up to a significant wave height (Hs) of 2 m, no relevant effects on the performance of the noise abatement systems are known from experience. For currents above ~0,75 m/s (and water depths up to ~40 m), experience has shown that the noise reduction in the direction of flow decreases significantly due to drift effects, see Reference [24].

NOTE 4 The parameter soil or soil layering is fundamentally important to document for all noise abatement systems, as this parameter can influence the properties of the insertion loss determined in situ.

5.3 Background noise

According to ISO 18406, the background noise is all sound recorded by the hydrophone in the absence of the pile driving signal for a specified pile driving signal being measured. The sound pressure level of the sound source shall be high enough to create a sound pressure level at the measuring location which exceeds – with and without the respective noise abatement system – the background noise level in the frequency bands of interest by at least 6 dB, or 10 dB ideally, (see 7.2). Background noise such as chain rattling (anchor chains), pitching noise caused by sea state, ship aggregates, or movement of crew, sea markers, buoys, etc., in the immediate vicinity of the measurement device shall be avoided. Background noise shall be recorded and documented. If additional noise is caused by the operation of the respective measure, it shall also be recorded and documented.

Background noise measurements shall be performed before and after each single measurement with and without sound mitigation measure to record the time-dependent change of the noise at least for 10 minutes.

5.4 Measurements on one single pile (direct method)

The measurement is performed on one pile and consists of two parts which are carried out in quick succession to reduce the influence of the pile penetration depth on the sound radiation. One of the measurement setups described in 6.4 is used for this kind of measurement. Firstly, the measurement is preferably performed without the noise mitigation measure while the pile driver is running (see 6.2). After these measurements, the noise mitigation measure is put into operation, and the measurement is repeated with active noise abatement system. Comparability of the conditions without and with noise control measure shall be ensured (see 5.2).

Advantage of this measuring method: For both parts of the measurement the comparability of the conditions can easily be ensured if both the penetration depth of the pile and the coupled seabed layers are comparable during both measurements.

Disadvantage of this measuring method: Only a short period can be evaluated for each of the two measurements to be compared to fulfil the requirement of comparable penetration depth. The propagation conditions underwater before, on and after activation of the noise abatement system vary. Statements on changed flanking transmission, depending on penetration depth, soil layer, etc., can only be made if comparing measurements are carried out for different penetration depths.

5.5 Measurements on two different piles (indirect method)

This type of measurement is based on carrying out two measurements at two different piles, where both measuring positions shall have the same distance to the respective pile (6.3.3). One measurement shall be carried out at the pile without the noise abatement system (measure not applied), and another measurement is carried out at the pile with the noise abatement system (measure applied) according to one of the measurement setups described in 6.4. For this method, it is necessary that the environmental conditions and the measurement setup for both separate measurements are comparable (see 5.2).

Advantage of this measuring method: Taking into account the environmental and acoustical conditions, this method can be used to evaluate the insertion loss for the whole pile-driving process (with and without measure applied) and not only for a short period as described in 5.4.

Disadvantage of this measuring method: It is unlikely that completely identical conditions exist at the two different measuring locations. Especially the flanking transmission of sound via the seafloor can have an influence on the results and increase the uncertainty of the judgement concerning the effectiveness of the noise abatement system. Additionally, different soil conditions can lead to changed radiation characteristics of the source.

6 Measurement procedure

6.1 General remarks

The measuring positions are linked to the installation process and to the basic conditions dictated by the acoustical environment. For security reasons and to avoid a measurement in the acoustic near field, a minimum distance of the acoustic measuring system to the pile-driving location (safety zone) shall be observed. According to ISO 18406 a preferable distance to the pile is 750 m. See Annex A for minimum monitoring distance requirements for near shore applications.