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Underwater acoustics — Measurement of radiated underwater sound from percussive pile driving

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National foreword

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 3, *Underwater acoustics*.

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Introduction

This document was written to provide a standardized measurement method for the measurement of the radiated underwater sound during percussive pile driving.

Sound is often an unintended by-product of man-made activities, and the increasing number of sound-producing human activities in oceans, seas, lakes, rivers and harbours have led to concern over noise pollution from unwanted sound and its potential effect on aquatic life. In some countries, there is already incipient regulation with regard to the impact of the radiated underwater sound, requiring acoustic monitoring for environmental impact assessment during construction projects.

Percussive pile driving can be a significant source of low-frequency impulsive underwater sound. During the process, a pile is driven into the seabed (or river-bed, etc.) using a hammer, which is typically driven hydraulically. Such a technique is commonly used to position piles in shallow water construction applications. Examples of such applications include the following:

— construction of offshore wind farms;

— construction and mooring of platforms for the offshore oil and gas industry;

— construction of bridge supports and foundations in rivers, estuaries, harbours and quays (and close proximity to them);

— mooring and positioning of aquatic renewable energy devices.

In the scientific literature, a number of attempts to measure the water-borne noise levels have been reported[1]-[13]. Often, these are difficult to compare because different acoustic metrics are used, and this has led to guidance being provided to address the need within individual countries[14]-[16]. The measurement of piling noise is made difficult by a number of factors.

— The source extends from the water surface to the seabed (or river-bed, etc.), generating sound waves in water, air and seabed, and vibrating the seabed surface.

— The environment is often shallow water which gives rise to substantial reverberation, and bathymetric features and seabed (or river-bed, etc.) interaction can strongly influence the propagation of the sound.

Often, simple assumptions about equivalent point sources have been used in measurements and for propagation modelling without sufficient validation. Progress with modelling the source has been reported in the scientific literature, but a complete understanding has not yet been achieved[17]-[22].

The aim of this document is to provide procedures and methodologies for measurement of sound radiation into the water, and recommend acoustic metrics to describe the sound field. The assessment of impact of the radiated sound on marine life is not part of the scope of this document.

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Underwater acoustics — Measurement of radiated underwater sound from percussive pile driving

1 Scope

This document describes the methodologies, procedures, and measurement systems to be used for the measurement of the radiated underwater acoustic sound generated during pile driving using percussive blows with a hammer.

A major motivation for undertaking measurements of the sound radiated during percussive pile driving is as part of an assessment of impact on aquatic fauna required by regulatory frameworks. This document describes a generic approach to measurements that can be applied to different regulatory requirements.

This document is suitable for measurement of percussive pile driving undertaken for offshore installation of foundations (monopiles, jackets, tripods, etc.) used in construction of offshore wind farms, oil and gas platforms, and other inshore structures such as bridge foundations and aquatic renewable energy devices. This document does not cover measurement of the sound radiated by vibro-piling or sheet piling. This document does not cover piling in water of depth less than 4 m or greater than 100 m.

The procedures described herein provide guidance on making measurements to satisfy the following objectives:

— to monitor source output during piling, for example, for regulatory purposes;

— to provide consistency in comparison of piling noise from different construction projects;

— for validation of modelling or predictions.

This document covers only the measurement of the sound field radiated during percussive pile driving. The scope of this document does not include the assessment of exposure metrics, or the use of exposure criteria. No attempt is made to prescribe a methodology for generating maps of the acoustic field in the vicinity of the source.

In the normative part of this document, requirements and procedures are described for measurement of the sound field at specific ranges from the pile being driven. In this part of the document, no procedure is provided for determination of an acoustic output metric that is independent of the propagation path between source and receiver (such as a source level). Ideally, such a metric would have some predictive utility (for example, in calculating noise impact zones and noise maps). However, some information on the determination of a possible acoustic output metric is provided in Annex A.

This document covers only the measurement of *sound pressure* in the water column. The scope does not include measurement of sound particle velocity in the water column due to the propagating sound wave, or seabed vibration caused by waves propagating across the sea-floor. This exclusion does not imply that such measures are unimportant; indeed, their importance in assessing the impact on aquatic life is recognized. However, at the time of drafting, measurement of these quantities is not yet mature enough for standardization.

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*

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3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 18405 (especially: sound pressure, sound pressure level, mean-square sound pressure level, sound exposure, sound exposure level, peak sound pressure, peak sound pressure level) and the following apply.

NOTE Although the definitions of sound exposure and sound exposure level are taken from ISO 18405, specific nomenclature is used in this document for sound exposure level calculated over the duration of one acoustic pulse, and over the duration of multiple acoustic pulses; this nomenclature is described in 3.2.

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

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

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

3.1
pulse duration
percentage energy signal duration over the acoustic pulse

Note 1 to entry: The percentage energy signal duration is defined in ISO 18405.

Note 2 to entry: The energy percentage over which the pulse duration has been calculated should be stated with the result. For the purposes of this document, the energy percentage for the pulse duration is 90 %.

Note 3 to entry: In general, in shallow water, the acoustic pulse includes multiple arrivals of the outgoing acoustic waves, including multi-path signal arrivals from surface and seabed. In reverberant environments such as harbours, where sound waves may be reflected by boundaries such as harbour walls, it may be difficult to identify individual outgoing acoustic pulses.

3.2
sound exposure level
SEL
level of the sound exposure, for a specified reference value

Note 1 to entry: The sound exposure level is as defined in ISO 18405.

Note 2 to entry: The sound exposure level for an individual acoustic pulse (corresponding to a single hammer strike) is calculated over the pulse duration on the basis of 100 % of the pulse energy. For the purposes of this document, this is termed the *single strike sound exposure level* (abbreviated as SEL_{ss}). It is recognized that in the scientific literature, this parameter is sometimes called the single pulse sound exposure level.

Note 3 to entry: The sound exposure level over a defined period of time, which includes multiple acoustic pulses, is, for the purposes of this document, termed the *cumulative sound exposure level* (abbreviated as SEL_{cum}). When reporting the cumulative sound exposure level, the number of pulses and the time duration over which the cumulative sound exposure level has been calculated are stated.

Note 4 to entry: In the acoustic near field, sound exposure is not related to the sound intensity or energy in the straightforward manner that applies for the acoustic far field. Therefore, care should be taken when interpreting measurements of SEL made in the acoustic near field.

3.3
pulse repetition frequency
pulse repetition rate
number of hammer strikes per unit time

Note 1 to entry: Typically stated as the number of strikes (or acoustic pulses) per second.

Note 2 to entry: It is common for the pulse repetition frequency to be less than 1 per second.

3.4
background noise
all sound recorded by the hydrophone in the absence of the pile driving signal for a specified pile driving acoustic signal being measured

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3.5
measurement system
data acquisition system consisting of, but not limited to, one or more hydrophone(s), conditioning preamplifier(s), analogue-to-digital converter(s), computer and ancillary peripherals

3.6
frequency range
span from the lowest frequency to the highest frequency over which the measurement system is able to measure, for a given uncertainty

Note 1 to entry: The frequency range is expressed as the lowest frequency to the highest frequency.

3.7
dynamic range
amplitude range over which a measurement system is able to measure, for a given tolerance of distortion, expressed as a range from the lowest to the highest amplitude

Note 1 to entry: Dynamic range can also be expressed in decibels representing the difference between the level of the noise floor created by the system self-noise and the maximum level which can be measured with a specified maximum allowable distortion. It can be expressed for a single frequency or at a range of frequencies.

3.8
field calibration
method of using known inputs, possibly using physical stimuli (such as a known and calibrated/traceable acoustic or vibration source) or electrical input (charge or voltage signal injection) at the input (or other stage) of a measurement system in order to ascertain that the system is, in fact, responding properly (i.e. within the system's stated uncertainty) to the known stimulus [SOURCE: ISO 17208-1:2016, 3.9][23]

3.9
measurement uncertainty
estimate of the range (or dispersion) of values within which the true value is considered to lie to a specified degree of confidence (for example, for a confidence level of 95 %)

[SOURCE: ISO/IEC Guide 98-3:2008]

3.10
hydrophone
underwater sound transducer that provides an electrical signal in response to fluctuations in pressure, and is designed to respond to the pressure of a sound wave

Note 1 to entry: If the electrical signal is proportional to the incident sound pressure, the hydrophone is said to have a linear response.

3.11
hammer energy
kinetic energy of the hammer used for the pile driving for a specific blow

Note 1 to entry: This is equal to the kinetic energy with which the hammer mass strikes the pile.

Note 2 to entry: The hammer energy is expressed in kJ.

3.12
pile dimensions
dimensions of the pile in terms of the overall length, diameter and wall thickness (if hollow)

3.13
offshore
marine area, including coastal areas, regional seas and continental shelf, but excluding harbours, coastal inlets, inland waterways, river estuaries, and rivers

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3.14
inshore
marine or aquatic region, including harbours, coastal inlets, inland waterways, river estuaries, and rivers, but excluding regional seas, continental shelf and coastal areas

3.15
equivalent bandwidth noise pressure
p_W
ratio of the root-mean-square noise voltage at a specified central frequency in the relevant frequency band present at the electrical terminals of the hydrophone, in the absence of pressure fluctuations at the hydrophone input, to its free-field open-circuit hydrophone voltage sensitivity at a specified frequency

Note 1 to entry: Equivalent bandwidth noise pressure is expressed in pascals, Pa.

[SOURCE: IEC 60500:—][24]

3.16
equivalent bandwidth noise pressure level
ten times the logarithm to the base 10 of the ratio of the square of the value of equivalent bandwidth noise pressure, p_W, of a hydrophone to the square of a reference pressure, p_0, in decibels

Note 1 to entry: Equivalent bandwidth noise pressure level is expressed in decibels, dB.

Note 2 to entry: The value of the reference pressure, p_0, is 1 μPa.

[SOURCE: IEC 60500:—][24]

3.17
signal-to-noise ratio
ratio of the mean-square broadband signal voltage after all processing to the mean-square broadband noise voltage after all processing

Note 1 to entry: The noise voltage is the voltage caused by non-acoustic noise and background noise.

Note 2 to entry: The time duration for the mean-square operation on the signal voltage and the background noise voltage shall be the same. This averaging time is specified with the value of signal-to-noise ratio.

Note 3 to entry: As a broadband quantity, the signal-to-noise ratio is evaluated over a specified frequency band. This may be the entire range of interest, which for this document is a minimum of 20 Hz to 20 kHz, or a specific frequency band such as a third-octave band. The applicable frequency band is stated with the value of the signal-to-noise ratio.

Note 4 to entry: The signal-to-noise may be expressed as a level difference in decibels.

3.18
system sensitivity
quotient of the root-mean-square open-circuit voltage at a specified point in the measurement system (usually the electrical output terminals) to the incident root-mean-square sound pressure that would be present at the position of the reference centre of the hydrophone in the undisturbed free field if the hydrophone was removed for specified frequency and specified direction of plane wave sound

Note 1 to entry: The system sensitivity is defined here for an acoustic measurement system designed to measure sound pressure signals in water. The measurement system will typically consist of hydrophone(s) connected to amplifier(s) and filter(s), and will feed an output voltage into a digital acquisition and storage system. Note that the response of the hydrophone(s), amplifier(s) and filter(s) will in general vary with acoustic frequency.

Note 2 to entry: The system sensitivity is defined here as an acoustic free-field sensitivity using the free-field sensitivity of the hydrophone. If the hydrophone is physically attached to the body of an acoustic recorder (rather than deployed on an extension cable), diffraction and scattering of sound by the recorder body may affect the free-field sensitivity at kilohertz frequencies, causing enhanced directivity compared to the response of the free hydrophone.

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Note 3 to entry: The system sensitivity is described in terms of the electrical voltage developed per pascal of acoustic pressure, and is stated in units of V/Pa. The sensitivity *level* is sometimes expressed in decibels as dB re 1 V/µPa. The system sensitivity accounts for the response of the hydrophone(s), gain of amplifiers, and insertion loss of filters within the system.

Note 4 to entry: For *digital* systems, where the system records the sound as a digital waveform (rather than providing an analogue voltage output), the calibration of the digitiser (analogue to digital converter) may be incorporated into the overall sensitivity of the whole system including the digitizer. This may be termed the *digital system sensitivity*, which is the number of digital counts per unit change in sound pressure (unit Pa^{-1}).

Note 5 to entry: In general, the measuring system may introduce a phase delay into the measured signal. This may be accounted for by representing the system sensitivity as a complex valued quantity, the modulus of which represents the magnitude-only response (and is described by the definition above), and the phase of which describes the phase response of the system. Note that the complex-valued system sensitivity will in general vary with acoustic frequency.

[SOURCE: IEC 60500:—][24]

4 Instrumentation

4.1 General

This clause deals with the choice of measuring instrumentation and the key performance specifications, system calibration, and data quality assurance.

The measuring system generally consists of the following instruments:

— hydrophone(s);

— amplifier(s) and signal conditioning equipment;

— digitization and storage equipment.

The amplifier can be a separate element in the system with an adjustable gain, or may be an integral part of the hydrophone with no possibility for gain adjustment. Digitization is provided by an analogue to digital converter (ADC) and the electronic storage is typically provided by a computer hard drive or flash drive memory.

The measuring system may consist of individual components, as listed above, or an integrated system forming part of an autonomous recorder that provides a self-contained recording system.

4.2 Performance of the measuring system

4.2.1 Sensitivity

The sensitivity of the measuring system should be chosen to be an appropriate value for the amplitude of the sound being measured. The aim in the choice of the system sensitivity is to

— avoid poor signal-to-noise ratio for low amplitude signals, and

— avoid nonlinearity, clipping and system saturation for high amplitude signals.

NOTE 1 It is the latter of these two criteria that is most important for measurement of percussive pile driving because it is a high amplitude source, and distortion of the measured signal will render the results of no value. To build in some flexibility, it is preferable to have some selectable gain in the amplification stages, or in the settings of the ADC. These can then be set to appropriate values once the sound levels are known after some initial measurements. However, note that for autonomous recorders and hydrophones which have integral preamplifiers, the gain cannot usually be modified after deployment.

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