INTERNATIONAL STANDARD

ISO 13474

First edition
2009-06-15

Acoustics — Framework for calculating a distribution of sound exposure levels for impulsive sound events for the purposes of environmental noise assessment

Acoustique — Cadre pour le calcul d'une distribution des niveaux d'exposition sonore pour les sons impulsionnels pour les besoins de l'évaluation du bruit environnemental

Reference number
ISO 13474:2009(E)

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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.

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 13474 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

It cancels and replaces ISO/TS 13474:2003, which has been technically revised.

Introduction

The aim of this International Standard is to provide a framework for the evaluation of descriptor quantities for use in environmental noise assessment. Part of this framework includes an engineering method for calculating a statistical distribution of event sound exposure levels at locations which are some distance from high-energy impulsive sound sources. It is specifically intended for environmental noise assessment and not for the assessment of the risk of damage to buildings or the risk of injury to animals or people.

In ISO 9613-2, the immission level from sources such as traffic and industry is calculated for a so-called “downwind” condition. The long-term average level is estimated using a correction factor, C_{met}. This concept holds for distances where sound from such sources is assessed as environmental noise. ISO 9613-2 excludes impulses in its scope and holds only for A-weighting, for near-ground sources and receivers and for distances up to about 1 000 m. For high-energy impulsive sound sources, the impulsive sound event duration is short, and low frequencies are more prominent than for traffic and industrial sound sources. Lower-frequency sounds are generally less attenuated over a given distance in the atmosphere than higher frequencies and, as a consequence, the level-influencing effects of propagation over much larger distances need to be taken into account.

A general outline is given of a method that takes into account ground reflection, shielding by topography and the meteorological effects of refraction and turbulence. Starting from the source strength, this method calculates a distribution of immission levels for a set of replica atmospheres, each replica being a specific combination of atmospheric-absorption class and excess-attenuation class. To carry out practical calculations using the procedure, it is useful to exploit the statistical contribution of the meteorological and ground surface conditions. In particular, histograms of the frequencies of occurrence of the wind velocity, wind direction, temperature, humidity and atmospheric stability can be used to describe the classes. From the distribution of the immission levels, a number of assessment metrics can be obtained. For instance, the long-term averaged immission level can be calculated as a weighted average. The weighting factors are determined by the probability of occurrence of each replica atmosphere during the relevant time period for the location of interest.

Acoustics — Framework for calculating a distribution of sound exposure levels for impulsive sound events for the purposes of environmental noise assessment

1 Scope

This International Standard specifies the framework of an engineering method for calculating a statistical distribution of sound exposure levels for impulsive sound events for the purposes of environmental noise assessment. This International Standard is applicable to impulse sounds propagating over large distances (e.g. 0,5 km to 30 km) from sources such as mine blasting, artillery fire and bomb explosions, using conventional explosives of moderate charge mass (e.g. 0,05 kg to 1 000 kg of TNT equivalent). The effects of meteorological conditions and terrain upon sound propagation are considered.

2 Normative references

The following referenced documents are indispensable for the application 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 1996-1, *Acoustics — Description, measurement and assessment of environmental noise — Part 1: Basic quantities and assessment procedures*

ISO 3534-1, *Statistics — Vocabulary and symbols — Part 1: General statistical terms and terms used in probability*

ISO 9613-1, *Acoustics — Attenuation of sound during propagation outdoors — Part 1: Calculation of the absorption of sound by the atmosphere*

ISO 9613-2, *Acoustics — Attenuation of sound during propagation outdoors — Part 2: General method of calculation*

ISO 17201-1, *Acoustics — Noise from shooting ranges — Part 1: Determination of muzzle blast by measurement*

ISO 17201-2, *Acoustics — Noise from shooting ranges — Part 2: Estimation of muzzle blast and projectile sound by calculation*

ISO 17201-4, *Acoustics — Noise from shooting ranges — Part 4: Prediction of projectile sound*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

VDI MSR 8/559, *Standard Method to Measure the Sound Exposure Emissions and Immissions from Large Weapons (Standardmethode zur Messung der Geräuschemissionen und -immissionen von schweren Waffen)*, Edmund Buchta (ed.), in *Meß-, Steuerungs- und Regelungstechnik*, No. 8/559, Fortschritt-Berichte, VDI Verlag, Düsseldorf, 1996 (in English and German)

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
atmospheric absorption
attenuation of sound by air, resulting from viscous molecular processes, molecular rotation and molecular vibration

3.2
atmospheric-absorption class
range of meteorological parameters yielding approximately the same attenuation of sound by air, all within a specified uncertainty

NOTE See also atmospheric absorption.

3.3
atmospheric stability
tendency of the atmosphere to reduce or enhance vertical motion of the air

NOTE Enhanced (or reduced) vertical motion of the air usually implies enhanced (or reduced) atmospheric turbulence.

3.4
atmospheric-stability class
subset formed from partitioning the set of atmospheres according to stability

NOTE See also atmospheric stability.

3.5
direct path
position displacement vector, in metres, originating at the source and describing a straight trajectory terminating at the receiver

NOTE The direct path may intercept objects such as buildings or terrain.

3.6
directed sound speed
algebraic sum of the adiabatic sound speed and the horizontal component of the wind velocity along the direct path

NOTE Directed sound speed is expressed in metres per second.

3.7
directed sound speed profile
sound speed along the direct path, expressed as a function of height

NOTE See directed sound speed.

3.8
event
single short burst, or rapid sequence of bursts, associated with a sound source

NOTE A single activity, such as firing a gun, could produce multiple sound events. In the case of firing an explosive projectile from a high-velocity gun, sound events are associated with each of the following sound sources: the muzzle blast, the ballistic shock and the projectile impact.

3.9
event duration
T
time interval starting just before immission, at time t_1, and ending just after immission, at time t_2, to encompass all significant sound of a single short blast or rapid sequence of blasts

NOTE The time interval $t_2 - t_1$ is expressed in seconds.

3.10
exceedance level
sound level of a stated type, in decibels, exceeded by no more and no less than a stated percentage of samples

NOTE The sampling set shall be identified, e.g. percentage of times during a stated time interval or percentage of firing events from an exercise.

3.11
excess attenuation
that part of sound attenuation not included when accounting for geometric divergence (from a small sound source in non-refracting and non-moving air), atmospheric absorption of sound waves along the direct path from source to receiver and attenuation of screens and/or barriers

NOTE Excess attenuation is expressed in decibels.

3.12
excess-attenuation class
range of combined directed sound speed profiles and ground types yielding approximately the same attenuations, all within a specified uncertainty

3.13
ground condition
sound reflection and absorption properties of outdoor surface(s) along the sound path(s) between source and receiver

3.14
impulsive sound event
occurrence of a single short blast or series of blasts of sound in which the pressure-time history, close to the source, includes a rapid rise to the peak sound pressure followed by decay of the pressure

3.15
sound pressure
p
difference between instantaneous total pressure and static pressure

[ISO 80000-8:2007, 8-9.2]

NOTE 1 Sound pressure is expressed in pascals.

NOTE 2 The symbol *p* is often used without modification to represent a root-mean-square sound pressure. However, root-mean-square values should preferably be indicated by the subscript “eff”.

[ISO/TR 25417:2007, 2.1]

3.16
open-air explosion
blast, taking place out-of-doors, in which no part of the exploding material or gaseous products is limited by a container or any other obstructing surface

3.17
peak sound pressure
p_{peak}
greatest absolute sound pressure during a certain time interval

NOTE 1 Peak sound pressure is expressed in pascals.

NOTE 2 A peak sound pressure may arise from a positive or negative sound pressure.

[ISO/TR 25417:2007, 2.4]

NOTE 3 This definition is technically in accordance with ISO 10843.

3.18
peak sound pressure level
$L_{p,\,\text{peak}}$
ten times the logarithm to the base 10 of the ratio of the square of the peak sound pressure, p_{peak}, to the square of a reference value, p_0, expressed in decibels

$$L_{p,\text{peak}} = 10\,\lg \frac{p_{\text{peak}}^2}{p_0^2}\ \text{dB}$$

where the reference value, p_0, is 20 µPa

NOTE Because of practical limitations of the measuring instruments, p_{peak}^2 is always understood to denote the square of a frequency-weighted or frequency-band-limited peak sound pressure. If a specific frequency weighting as specified in IEC 61672-1 is applied, this should be indicated by appropriate subscripts; e.g. $L_{p,\,\text{C peak}}$ denotes the C-weighted peak sound pressure level.

[ISO/TR 25417:2007, 2.5]

3.19
receiver height
h_{r}
distance, in metres, of the sound receiver above the local ground surface

NOTE This definition is technically in accordance with ISO 9613-2.

3.20
replica atmosphere
conditions representing the atmosphere corresponding to a stated excess-attenuation class and a stated atmospheric-absorption class

3.21
roughness height
distance above local ground level to the elevation where the time-average horizontal wind velocity becomes non-zero

NOTE 1 The roughness height is expressed in metres.

NOTE 2 The time interval over which the wind velocity is averaged is 300 s.

3.22
sound exposure
E_T
integral of the square of the sound pressure, p, over a stated time interval or event duration T (starting at t_1 and ending at t_2) (see 3.9)

$$E_T = \int_{t_1}^{t_2} p^2(t)\,\mathrm{d}t$$

NOTE 1 Sound exposure is expressed in pascals squared seconds, $\mathrm{Pa}^2{\cdot}\mathrm{s}$.

NOTE 2 Because of practical limitations of the measuring instruments, p^2 is always understood to denote the square of a frequency-weighted and frequency-band-limited sound pressure. If a specific frequency weighting as specified in IEC 61672-1 is applied, this should be indicated by appropriate subscripts; e.g. $E_{\mathrm{A},1\,\mathrm{h}}$ denotes the A-weighted sound exposure over 1 h.

NOTE 3 When applied to a single event of impulsive or intermittent sound, the quantity is called “single-event sound exposure” and the symbol E is used without a subscript.

NOTE 4 This definition is technically in accordance with ISO 80000-8:2007, 8-18.

[ISO/TR 25417:2007, 2.6]

3.23
sound exposure level
$L_{E,T}$
ten times the logarithm to the base 10 of the ratio of the sound exposure, E_T, to a reference value, E_0, expressed in decibels

$$L_{E,T} = 10\,\lg \frac{E_T}{E_0}\,\mathrm{dB}$$

where the reference value, E_0, is $4 \times 10^{-10}\ \mathrm{Pa}^2{\cdot}\mathrm{s}$

NOTE 1 If a specific frequency weighting as specified in IEC 61672-1 is applied, this should be indicated by appropriate subscripts; e.g. $L_{E,\mathrm{A},1\,\mathrm{h}}$ denotes the A-weighted sound exposure level over 1 h.

NOTE 2 When applied to a single event, the quantity is called “single-event sound exposure level” and the symbol L_E is used without further subscript.

NOTE 3 This definition is technically in accordance with ISO 80000-8:2007, 8-24.

[ISO/TR 25417:2007, 2.7]

3.24
source height
h_s
distance of the sound source above the local ground surface

NOTE 1 The source height is expressed in metres.

NOTE 2 This definition is technically in accordance with ISO 9613-2.

3.25
source forward direction
horizontal and vertical rotation angles assigned as references in the source-directivity coordinate system

3.26
adiabatic sound speed
c
speed of sound in the absence of ambient flow

NOTE The speed is expressed in metres per second.

4 Basic equations

4.1 General

ISO 1996-1 suggests a number of descriptors for environmental noise, some of which can be calculated from a statistically weighted summation of single-event sound exposures. Other descriptors can be evaluated by using order statistics derived from the distribution.

The single-event sound exposure level is subject to variation, in large part due to the effects of weather on the propagation to the receiver. In sound propagation measurements, it has been observed, for example, that the received sound level of a steady source can vary by several decibels from moment to moment, as well as from day to day or from season to season. Because the atmospheric temperature and wind can vary from point to point and from time to time, it is impractical to measure these values at all points during each event. It would also be equally impractical to employ so many measurements within a detailed calculation for making a routine noise assessment.

As a practical approach, the detailed atmosphere is described by several replica atmospheres, each being the (short term) average state of the atmosphere for various atmospheric conditions and ground conditions. Computations can be performed to estimate the single-event sound exposure level for the prevailing conditions for each replica atmosphere. For practical computations, only a limited number of representative situations can be managed. Therefore, the atmosphere is subject to classification in which each replica atmosphere is representative of its class. Histograms of the frequencies of occurrence of the wind velocity, wind direction, temperature, humidity and atmospheric stability are used to describe the different classes.

In this International Standard, two different classifications are used: atmospheric-absorption classes and excess-attenuation classes. Each replica atmosphere represents a combination of an atmospheric-absorption class with an excess-attenuation class. Using the calculated values of the short-term single-event sound exposure level, combined with the frequencies of occurrence of the various classes, as shown in this International Standard, it is feasible to calculate the sound exposure level as well as the exceedance level for a long-term interval.

4.2 Probability of occurrence

Consider a continuous random variable X. For any particular x, one can consider the likelihood that $X \leqslant x$. Accordingly, the cumulative distribution function is defined as:

$$F(x) = \mathrm{P_r}\left(X \leqslant x\right) \tag{1}$$

where

X is a random variable (possibly with dimensional units);

x is any value (with the dimensional units of X).

The cumulative distribution function is a monotonically increasing one and ranges in value from 0 to 1, as x ranges from $-\infty$ to $+\infty$.

Here and below, the role of the random variable can be taken by any of several types of quantity. The role includes, for example, such things as atmospheric parameters, sound exposure levels or sound attenuations. Two examples follow.

EXAMPLE 1 A measurement is performed to evaluate the probability distribution of the weather by atmospheric stability (see 8.4). In this case, the Monin-Obukhov length (see 8.3) is the random variable. The sample space is the list of all possible values of the Monin-Obukhov length.

EXAMPLE 2 The experiment is conducted to measure the probability distribution of the Z-weighted (unweighted) event sound exposure level of cannon fire measured at the receiver, for a specified type of cannon, ammunition, direction and elevation of fire, firing position and receiver position. In this case, the random variable is L_E. The sample space is the set of all values of the event sound exposure level.

For practical use, it is convenient to segment the range of a continuous distribution into several intervals. To this end, the following bin is defined:

$$\{x : x_i - \delta_i < x \leqslant x_i + \delta_i\} \tag{2}$$

and the discrete probability:

$$\wp_i(x) = \mathrm{P_r}\left(x_i - \delta_i < x \leqslant x_i + \delta_i\right) = F(x_i + \delta_i) - F(x_i - \delta_i) \tag{3}$$

where

$\wp_i$ is the probability (dimensionless) of obtaining an outcome in the ith bin;

x_i is the central value of the ith bin (possibly with dimensional units);

δ_i is the bin half-width (with the dimensional units of x_i);

i is the index of the bin.

NOTE For simplicity, the probability bins are chosen to be equally spaced and contiguous, so that the sum of the probability of occurrence over the discrete domain is equal to one.

4.3 Band sound exposure level

The band sound exposure level, in decibels, from an impulse sound source shall be calculated by:

$$L_{E,k,l}(j) = S_{\phi,\theta}(j) - \left[A_{\mathrm{div}} + A_{\mathrm{atm},k}(j) + A_{\mathrm{rec}}(j) + A_{\mathrm{diff}}(j) + A_{\mathrm{exc},l}(j)\right] \tag{4}$$

where

$L_{E,k,l}(j)$ is the band sound exposure level, in decibels, under the conditions described by the kth atmospheric-absorption class and the lth excess-attenuation class;

j is the frequency band index;

$S_{\phi,\theta}(j)$ is the direction-dependent source band sound exposure level, in decibels, using a reference distance of one metre (see Clause 9);

ϕ is the (azimuth, yaw) angle, in degrees, between the source forward direction and the direct-path direction when all angles are projected onto the horizontal plane;

θ is the (elevation, pitch) angle, in degrees, between the source forward direction and the horizontal plane;

A_{div} is the attenuation, in decibels, due to geometric divergence (see 6.2);

$A_{\mathrm{atm},k}(j)$ is the band attenuation, in decibels, due to atmospheric absorption under conditions described by the kth atmospheric-absorption class (see 6.3);

