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Mechanical vibration and shock — Vibration of fixed structures — Guidelines for the measurement of vibrations and evaluation of their effects on structures

Vibrations et chocs mécaniques — Vibrations des structures fixes — Lignes directrices pour le mesurage des vibrations et l'évaluation de leurs effets sur les structures

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 4866 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 2, *Measurement and evaluation of mechanical vibration and shock as applied to machines, vehicles and structures*.

This second edition cancels and replaces the first edition (ISO 4866:1990), of which it constitutes a technical revision. It also incorporates the Amendments ISO 4866:1990/Amd.1:1994 and ISO 4866:1990/Amd.2:1996.

Introduction

The necessity for structures to sustain vibration is increasingly recognized, and requires consideration both in the design for structural integrity, serviceability and environmental acceptability, and in the preservation of historic structures.

Measurement of vibration in a structure is carried out for a variety of purposes:

a) *problem recognition*, where it is reported that a structure is vibrating at such a level as to cause concern to occupants and equipment, possibly making it necessary to establish whether the levels warrant concern for structural integrity;

b) *control monitoring*, where maximum permitted vibration levels have been established by an agency and those vibrations have to be measured and reported;

c) *documentation*, where dynamic loading has been recognized in design, and measurements are made to verify the predictions of response and provide new design parameters (These may use ambient or imposed loading. Strong motion seismographs, for example, may be installed to indicate whether the responses to earthquake warrant changes on operating procedure in a structure.);

d) *diagnosis*, where it has been established that vibration levels require further investigation, measurements are made in order to provide information for mitigation procedures (another diagnostic procedure is to use structural response to ambient or imposed loading to establish structural condition, e.g. after a severe loading, such as an earthquake).

Such diverse purposes call for a variety of measuring systems, ranging from simple to sophisticated, deployed in different types of investigations.

Technical guidance is needed by many interested parties on the most appropriate ways of measuring, characterizing and evaluating those vibrations that affect structures. This applies to both existing structures, which may be subjected to different types of excitation, and new structures erected in an environment where sources of excitation may be significant.

The effects of vibration may also be determined analytically.

Although the material in this International Standard may be used to evaluate the relative severity of structural vibration, it is not to be regarded as suggesting acceptable or non-acceptable levels. Nor does it consider economic and social aspects, which are dealt with as appropriate by national regulatory bodies.

Mechanical vibration and shock — Vibration of fixed structures — Guidelines for the measurement of vibrations and evaluation of their effects on structures

1 Scope

This International Standard establishes principles for carrying out vibration measurement and processing data with regard to evaluating vibration effects on structures. It does not cover the source of excitation except when the source dictates dynamic range, frequency or other relevant parameters. The evaluation of the effects of structural vibration is primarily obtained from the response of the structure, using appropriate analytical methods by which the frequency, duration and amplitude can be defined. This International Standard only deals with the measurement of structural vibration and excludes the measurement of airborne sound pressure and other pressure fluctuations, although response to such excitations is taken into consideration.

This International Standard applies to all structures built above or below ground. Such structures are used or maintained and include buildings, structures of archaeological and historical value (cultural heritage), bridges and tunnels, gas and liquid installations including pipelines, earth structures (e.g. dykes and embankments), and fixed marine installations (e.g. quays and wharfs).

This International Standard does not apply to some special structures, including nuclear plants and dams.

The response of structures depends upon the excitation. This International Standard examines the methods of measurement as affected by the source of excitation, i.e. frequency, duration, and amplitude as induced by any source (e.g. earthquake, hurricane, explosion, wind loading, airborne noise, sonic boom, internal machinery, traffic, and construction activities).

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 2041, *Mechanical vibration, shock and condition monitoring — Vocabulary*

3 Terms and definitions

For the purpose of this document, the terms and definitions given in ISO 2041 and the following apply.

3.1
vibration source
simple or multiple solid, liquid or gaseous body causing vibration in its environment

[ISO 14964:2000[8], 3.10]

3.2
vibration event
modification of existing ambient vibrations due to single or multiple sources

3.3
vibration receiver
all structures or elements of structures responding to vibration energy emitted by an internal or external source

[ISO 14964:2000[8], 3.11]

3.4
work cycle
description and duration of a production operation used to manufacture a product or to fulfil an operation

NOTE Adapted from ISO 14964:2000 [8], 3.2.

3.5
measuring interval
⟨mechanical vibration and shock⟩ minimum measurement duration that accurately represents the response of a structure excited by a known vibration

3.6
observation interval
time during which continuous or non-continuous measurements to characterize the vibration activities take place

3.7
reference interval
⟨mechanical vibration and shock⟩ time period considered to include the vibration emission of interest as defined by regulation and contract

3.8
transducer sensitivity
ratio of transducer output to transducer input

3.9
measuring dynamic range
ratio, expressed in decibels, of the maximum measured amplitude to the minimum measurable amplitude of the instrument while measuring

3.10
operational dynamic range of measurement
ratio, expressed in decibels, of the contractual, regulatory or estimated maximum amplitude to the minimum measurable amplitude of the instrumentation system

3.11
dynamic range of measuring system
ratio, expressed in decibels, of the maximum amplitude to the minimum amplitude measured by a measuring instrument

4 Source-related factors to be considered

4.1 General

The source, which is the origin of the vibration event, shall be identified and described accurately to consider its characteristics when a measurement programme has to be established or when the results have to be compared to regulatory or contractual limits.

For this description, three classifications are necessary: one related to the duration of exposure; another related to the variation of amplitude with time; and a third comprising the category of the vibration signals.

4.2 Classification of events according to their duration

4.2.1 Permanent

The source emission is permanent or quasi-permanent during the selected reference interval.

4.2.2 Intermittent

A succession of events, each of relatively short duration, is separated by irregular intervals during which the vibration amplitude is equivalent to the background level.

4.2.3 Single occurrence

Sources generating vibration events, which are of short duration (a few seconds) and which can occur only once. Single occurrences do not exceed five per day.

4.3 Classification of events according to the variation of their amplitude with time

4.3.1 Stable

The variation of the amplitude with time does not exceed 10 %.

4.3.2 Cyclic

Repeated events with the same magnitude occur.

4.3.3 Other events

“Other” events cannot be classified as stable or cyclic.

4.4 Classification according to the category of signals emitted by the source

Source signal categories include:

a) stationary (e.g. generators);

b) non-stationary (e.g. trains);

c) transient or impulsive vibrations with separated (e.g. blasting) or repeated impulses (e.g. forging hammers).

5 Structure-related factors to be considered

5.1 General

The reaction of structures and structural components to dynamic excitation depends upon their response characteristics (e.g. natural frequencies, mode shapes, and modal damping) and the spectral content of the excitation. Cumulative effects, especially at high response levels, and the extent of exposure where fatigue damage is possible should be considered.

5.2 Type and condition of structures

In order to describe and categorize the visible effects of vibration, a classification of the structures dealt with in this International Standard is needed. For the purposes of this International Standard, a classification of buildings is set out in Annex B.

NOTE For a classification of tunnels, see ISO 10815[5].

5.3 Natural frequencies and damping

The fundamental natural frequency of a structure or of a part of the structure influences its response and shall be known to allow the several methods of analysis to be applied. This may be achieved by spectral analysis of low-level response to ambient excitation or by the use of artificial excitation, e.g. exciters.

Experimental studies have indicated the range of fundamental shear frequencies of low-rise structures, 3 m to 12 m high, to be from 15 Hz to 4 Hz (see Reference [26]). The damping content is generally amplitude dependent. The natural frequency and damping content of stationary structures is dealt with in Annex D.

5.4 Structure dimensions

Ground-borne vibration may have wavelengths of less than 1 m to several hundred metres. The response to excitations from shorter wavelengths is complex and the foundations may act as a filter. Smaller domestic structures generally have base dimensions that are smaller than the long wavelength which is typical for ground condition. Longer structures such as dams are more affected by larger wavelength excitations.

5.5 Influence of ground conditions

It is now common in engineering studies to take into account the influence of the soil.

An evaluation of soil-structure interaction is sometimes justified for man-made vibration; such an evaluation requires that the shear wave velocity or dynamic modulus of rigidity in an appropriate volume of ground material be determined (see Annex E). Empirical, numerical and analytical procedures may be obtained from the literature (e.g. Reference [28]).

Foundations on poor soils and fills may be subject to settlement or loss of bearing capacity due to ground vibration. The risk of such effects is a function of the particle size and shape of the soil, its uniformity of grading, compaction (which may be monitored by precise levelling), degree of saturation, internal stress state, as well as the peak multiaxial motion amplitude and duration of the ground vibration. Loose, cohesionless, saturated sands are especially vulnerable and, in extreme circumstances, may undergo liquefaction. This phenomenon shall be taken into consideration in evaluating vibrations and explaining their effects (see References [28], [29] and Annex B). For larger structures, fault line and associated differential ground conditions should be separately assessed.

The evaluation of vibration effects on a structure shall include:

a) direct effects which result from the real-time response of a structure to induced vibrations;

b) indirect effects which can be initiated by other factors and accelerated by vibration (construction activities, ground settlement, existing damage, water levels).

NOTE A construction activities example is an inadequately propped or braced basement excavation. This can lead to ground movement and thereby damage to the building, which is a mechanism that can be exacerbated by vibration.

6 Quantities to be measured

The characterization of both the nature of the vibration input and the response may be effected by a variety of displacement, velocity or acceleration transducers. Velocities and accelerations are kinematic quantities that are commonly measured. From knowledge of the appropriate transfer function of the sensing system, each quantity can be derived from another by integration or differentiation. It is recommended that the appropriate transducer be used to measure the required quantity directly, thus avoiding the processes of integration or differentiation. As long as the requirements on data collection, processing and presentation are met, any quantity may be measured. Experience suggests that there are preferred quantities for different situations.

CAUTION — Integration at lower frequencies calls for care and confidence in the amplitude-phase response of the transducer and measurement setup (see Clause 8) and care should be exercised when using the phase information from the velocity transducer at the lower frequencies.

Both the amplitude and phase responses of the system are critical when measuring peak quantities. In such cases, the linear performance of the entire measurement and analysis system should be validated. The signal of interest shall sufficiently exceed the electrical noise of the measuring system used, typically by a factor of 10. During measurement, the signal of interest should exceed the ambient vibration, but this is not always under the control of the investigator. If feasible, arrange for ambient vibration to be reduced where relevant (e.g. switch off mechanical plant unrelated to the source of interest).

7 Frequency range and vibration amplitude

The frequency range of interest depends upon the spectral content of the excitation and upon the mechanical response of the structure. For simplicity, this International Standard deals with frequencies ranging from 0,1 Hz to 500 Hz which cover a wide variety of structures subject to natural (winds and earthquakes) and man-made (construction, blasting, and traffic) sources of excitation. Internal machinery may require measurements over a wider frequency range.

Most structural damage from man-made sources occurs in the frequency range from 1 Hz to 150 Hz. Natural sources, such as earthquakes and wind excitation, usually contain damage-level energy at lower frequencies, in the range from 0,1 Hz to 30 Hz.

Vibration levels of interest, for analysis and characterization of structural responses, range from a few to several hundred millimetres per second depending on the frequency (Tables A.1 and A.2 show ranges of structural response for various sources and typical values and conditions of measurement).

8 Instrumentation

8.1 General requirements

Vibrations are measured for the purpose of evaluating, diagnosing or monitoring a structure. A single instrumentation system is not expected to meet all frequency and dynamic range requirements for the wide range of applications for which this International Standard can be used.

The measuring system includes:

a) transducers (see 8.2);

b) signal-conditioning equipment;

c) data recording system.

The frequency response characteristics, amplitude, and phase shall be specified for the complete measurement system once it is connected as intended for use.

The accuracy of the measured vibration depends partly upon the characteristics of the equipment which shall be established by regular calibration on dates specified by the manufacturer or by regulation. Each device shall be accompanied by its calibration certificate.

At minimum, the vibration shall be characterized by a continuous measurement of the vibration amplitude, recorded over a sufficiently long time, and taken with sufficient accuracy to extract its spectral content.

8.2 Choice of transducers

The choice of transducers is important for the correct evaluation of vibratory motion. In general, transducers are divided into two groups: a) the so-called velocity transducer (geophone), widely used in structural vibration measurement, is typically of electromagnetic nature operating at frequencies above its natural frequency; and b) the piezoelectric accelerometer usually operates below its natural frequency. Other electromagnetic transducers whose useful range is below their natural frequency, such as strong-motion seismographs, are also available.

When measuring signals of low frequencies and small amplitudes, the piezo-accelerometer output is so low that the integration result is affected by the integrator noise. In this case, use other (capacitative) types of accelerometers. It is better to use an appropriate transducer to measure the required quantity directly and avoid the process of integration or differentiation.

8.3 Signal-to-noise ratio

Generally, the signal-to-noise ratio should be not less than 5 dB. Background noise is defined as the sum of all the signals not due to the phenomenon under investigation.

8.4 Instrumentation classes

8.4.1 General

Data collection systems which are adequate for establishing even a single parameter index (e.g. peak particle velocity) may not be adequate for defining a more complex periodic motion over a specified frequency range.

For the applications dealt with in this International Standard, two main classes of measurement are considered:

a) class 1 for engineering analysis;

b) class 2 for field monitoring.

Instrumentation with particular parameters can be used for special applications and considered as subclasses of class 2.

8.4.2 Instrumentation class 1 for engineering analysis

The optimal parameters are:

a) the storage capability of the instrument shall be at least 30 s per channel, at a minimum rate of 1 000 digital time samples/s — in certain cases, when the frequency of interest approaches the upper end of 500 Hz, the minimum sampling rate shall be 2 500 samples/s;

b) the sampling shall carried out at a frequency of at least five times the highest frequency to be analysed;

c) for digital acquisition, the recording system shall comprise an analogue anti-aliasing filter having a minimum attenuation factor of 100 (40 dB) at half the sampling frequency;

d) the digital data collection system shall include an indication device for observing the sampled time data as well as the processed data to help verify proper system operation;

e) the frequency span of the entire digital data collection system shall extend from at least 1 Hz to 150 Hz (3 dB points) or wider as necessary to properly measure the frequency content of the vibration signal being encountered;

f) the dynamic range of the measuring equipment shall be at least 72 dB;

g) the minimum measurable amplitude of the recording system shall be at least 10 µm/s;

h) the amplification ranges shall be such that the dynamic range of measurement (higher/lower amplitude) is more than 40 dB;

i) the frequency response deviation of the measuring equipment in the range from 2 Hz to 80 Hz shall not exceed 8 % (0,7 dB) of the amplitude determined at the reference frequency.

8.4.3 Instrumentation class 2 for field monitoring

This category of instrumentation is used for vibration control after definition of major parameters by engineering analysis or to monitor known vibration phenomena. The frequency and amplitude characteristics are determined by the results obtained by the engineering analysis and, if necessary, by contractual or regulatory obligations. The optimal parameters are:

a) the dynamic range of the measuring equipment shall be at least 66 dB;

b) the operational dynamic range of the measurement shall be at least 20 dB;

c) the frequency response deviation of the measuring equipment in the range from 2 Hz to 80 Hz shall not exceed 8 % (0,7 dB) of the amplitude determined at the reference frequency;

d) the monitoring equipment shall record and report vibration events that exceed the designated threshold amplitude — the following recorded information shall be reported immediately after detection of an event:

   1) the maximum amplitude value,

   2) date and time of the starting event.

8.4.4 Instrumentation for special applications

For some special applications, alternative optimal required parameters can be used for class 2 only:

a) lowering the sampling rate when monitoring tall buildings and bridges;

b) reducing the length of each recording segment when monitoring brief events such as blasting;

c) increasing the sampling rate and amplitude range when monitoring vibration waves propagating in concrete structures and hard rock.

9 Position and mounting of transducers

9.1 Position, number and orientation of transducers

9.1.1 General

The choice of number and position of transducers shall consider:

a) any contractual or regulatory obligations;

b) the object of measurement;

c) the type of structure monitored, its state, its geometry, its dynamic response;

d) the foundation system and soil-foundation interaction;

e) the distance between the source and the measuring points;

f) the energy and vibratory mode generated by the source.

9.1.2 Position of transducers

Transducer placement in a structure depends on the vibration response of concern. Assessment of the vibrations being input to a structure from ground-borne sources is best undertaken using measurements on or

