

INTERNATIONAL STANDARD



Environmental testing –
Part 3-3: Supporting documentation and guidance – Seismic test methods for
equipments



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IEC Central Office
3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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Environmental testing –
Part 3-3: Supporting documentation and guidance – Seismic test methods for
equipments

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ENVIRONMENTAL TESTING –

**Part 3-3: Supporting documentation and guidance –
Seismic test methods for equipments**

FOREWORD

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International Standard IEC 60068-3-3 has been prepared by IEC technical committee 104: Environmental conditions, classification and methods of test.

This second edition cancels and replaces the first edition published in 1991. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) the main aim of this revision is to connect the testing level to the seismic activity level of the zone where the equipment could be installed;
- b) a standard shape for the required response spectrum is also given for the general seismic class for which the seismic environment is either not known or is imprecisely known;
- c) Clauses 11 to 15 were renumbered and some adjustments were made as their content is very general and the requirements can be applied both to the general seismic class and to the specific seismic class;
- d) the word “envelope” is replaced with “dominance” and “to envelop” with “to dominate” in order to provide a more precise meaning from a mathematical point of view.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
104/835/FDIS	104/841/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

This International Standard is to be used in conjunction with IEC 60068-1.

A list of all parts in the IEC 60068 series, published under the general title *Environmental testing*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "<http://webstore.iec.ch>" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

Guidance is included in each of the ~~three~~ **two** test methods referred to in this document but it is specific to the test method. The guidance in this document is directed towards choosing the appropriate test method and applying it to seismic testing.

~~This standard is to be used in conjunction with IEC 60068-1.~~

ENVIRONMENTAL TESTING –

Part 3-3: Supporting documentation and guidance – Seismic test methods for equipments

1 Object Scope

This part of IEC 60068 applies primarily to electro-technical equipment but its application can be extended to other equipment and to components.

In addition, if some type of analysis is always performed when making a seismic qualification, for example for the choice of the representative sample to be tested or for the extension of the seismic qualification from the tested specimen to similar specimens, the verification of the performance of an equipment by analysis or by a combination of testing and analysis ~~may~~ can be acceptable but is outside the scope of this document, which is restricted to verification based entirely upon data from dynamic testing.

This document deals solely with the seismic testing of a full-size equipment which can be tested on a vibration table. The seismic testing of an equipment is intended to demonstrate its ability to perform its required function during and/or after the time it is subjected to the stresses and displacements resulting from an earthquake.

The object of this document is to present a range of methods of testing which, when ~~prescribed~~ specified by the relevant specification, can be applied to demonstrate the performance of equipment for which seismic testing is required with the main aim of achieving qualification.

NOTE Qualification by so-called “fragility-testing” is not considered to be within the scope of this document which has been prepared to give generally applicable guidance on seismic testing and specifically on the use of IEC 60068-2 test methods.

The choice of the method of testing can be made according to the criteria described in this document. The methods themselves are closely based on published IEC test methods.

This document is intended for use by manufacturers to substantiate, or by users to evaluate and verify, the performance of an equipment.

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.

IEC 60068-1, *Environmental testing – Part 1: General and guidance*

IEC 60068-2-6, *Environmental testing – Part 2-6: Tests – Test Fc: Vibration (sinusoidal)*

IEC 60068-2-47, *Environmental testing – Part 2-47: Test – Mounting of specimens for vibration, impact and similar dynamic tests*

IEC 60068-2-57, *Environmental testing – Part 2-57: Tests – Test Ff: Vibration – Time-history and sine-beat method*

IEC 60068-2-64, *Environmental testing – Part 2-64: Tests – Test Fh: Vibration, broadband random and guidance*

IEC 60068-2-81, *Environmental testing – Part 2-81: Tests – Test Ei: Shock – Shock response spectrum synthesis*

ISO 2041, *Mechanical vibration, shock and condition monitoring – Vocabulary*

3 Terms and definitions

~~The terms used in this standard are generally defined in ISO 2041 or in IEC 60068-1, IEC 60068-2-6, IEC 60068-2-57 and IEC 60068-2-59. Where, for the convenience of the reader, a definition from one of these sources is included here, the derivation is indicated and departures from the definitions in those sources are also indicated.~~

~~The additional terms and definitions that follow are also applicable for the purpose of this standard.~~

For the purposes of this document, the terms and definitions given in IEC 60068-1, IEC 60068-2-6, IEC 60068-2-57 and ISO 2041 and the following apply.

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

assembly

two or more devices sharing a common mounting or supporting structure

3.2

bandpass at –3 dB

frequency intervals defined by the points possessing an ordinate larger than or equal to $\sqrt{2}/2$ times the maximum value of the plot

SEE: Figure 2.

3.3

basic response spectrum

unmodified response spectrum defined by the characteristics of the building, its floor level, damping ratio, etc. and obtained from a specific ground motion

SEE: Figure 2.

Note 1 to entry: The basic response spectrum is generally of the narrow band type at floor level. The basic response spectrum is calculated by the architect engineer of the plant and it is generally not known by the equipment manufacturer and by the test engineer.

3.4

broadband response spectrum

response spectrum that describes the motion indicating that a number of interacting frequencies exist which ~~must~~ should be treated as a whole

SEE: Figure 3c).

Note 1 to entry: The bandwidth is normally greater than one octave.

3.5

critical frequency ~~(definition technically equivalent to that in 8.1 of IEC 60068-2-6):~~
frequency at which:

- malfunctioning and/or deterioration of performance of the specimen which are dependent on vibration are exhibited, and/or
- mechanical resonances and/or other response effects occur, for example chatter

[SOURCE: IEC 60068-2-6:2007, 3.9]

3.6

crossover frequency ~~(definition technically equivalent to that of ISO 2041)~~

frequency at which the characteristic of a vibration changes from one relationship to another

Note 1 to entry: For example, a crossover frequency may be that frequency at which the control of the test vibration amplitude changes from a constant displacement value versus frequency to a constant acceleration value versus frequency.

[SOURCE: ISO 2041:2009, 2.118, modified – Example omitted and note added.]

3.7

cut-off frequency

frequency in the response spectrum where the zero period acceleration (ZPA) asymptote begins

Note 1 to entry: The cut-off frequency is the frequency beyond which the single-degree-of-freedom (SDOF) oscillators exhibit no amplification of motion and indicate the upper limit of the frequency content of the waveform being analysed.

3.8

damping ~~(not identical with ISO 2041 definitions)~~

~~generic term ascribed to the numerous~~ energy dissipation mechanisms in a system.

Note 1 to entry: In practice, damping depends on many parameters, such as the structural system, mode of vibration, strain, applied forces, velocity, materials, joint slippage.

Note 2 to entry: This definition is not identical to that given in ISO 2041.

3.8.1

critical damping

minimum viscous damping that will allow a displaced system to return to its initial position without oscillation

3.8.2

damping ratio

ratio of actual damping to critical damping in a system with viscous damping

3.9

direction factor

factor taking account of the difference in magnitude at ground level that normally exists between the horizontal and vertical accelerations resulting from an earthquake

3.10

floor acceleration

acceleration of a particular building floor (or an equipment mounting) resulting from the ground motion of a given earthquake

Note 1 to entry: In practice the floor acceleration may be resolved into its horizontal and vertical components.

3.11**geometric factor**

factor required in single axis testing to take into account the interaction along the different axes of the equipment of simultaneous multi-directional input vibrations

3.12 **g_n**

standard acceleration due to the earth's gravity, which itself varies with altitude and geographical latitude

Note 1 to entry: For the purposes of this document, the value of g_n is rounded up to the nearest whole number, that is 10 m/s².

3.13**ground acceleration**

acceleration ~~of the ground~~ resulting from the motion of a given earthquake

Note 1 to entry: In practice the ground acceleration may be resolved into its horizontal and vertical components.

3.14**lateral frequencies**

two frequencies determined according to the –3 dB response around the overall resonance frequency

SEE: Figure 2.

3.15**malfunction**

loss of capability of the equipment to initiate or sustain a required function, or the initiation of undesired spurious action which may result in adverse consequences for safety

Note 1 to entry: Malfunction will be defined by the relevant specification.

3.16**narrowband response spectrum**

response spectrum in which single-frequency excitation predominates

SEE: Figure 3a).

Note 1 to entry: The bandwidth is normally 1/3 oct (one third octave) or less.

Note 2 to entry: When several widely spaced well-defined frequencies exist, if justified, each of their responses may be treated separately as a narrow-band response spectrum (see Figure 3b)).

3.17**damped natural frequency**

frequency of free vibration of a ~~structure~~ damped linear system depending only on its own physical characteristics (mass, stiffness, and damping)

3.18**overall resonance**

resonance frequency at which a complete structure amplifies the exciting motion

Note 1 to entry: Within the frequency range between 1 Hz and 35 Hz, overall resonance generally corresponds to the first mode of vibration. It is important to take into account the overall resonance frequencies when they are enclosed in the strong part of the required response spectrum (see 3.27).

3.19**pause**

interval between consecutive test waves (for example sine beats)

Note 1 to entry: A pause should be such that it results in no significant superposition of the response motions of an equipment.

3.20**preferred testing axes**

three orthogonal axes which correspond to the most vulnerable axes of the equipment

3.21**required response spectrum**

RRS

response spectrum specified by the user

SEE: Figures 1, 2 and 3.

3.22**resonance frequency**

frequency at which, in forced oscillation, a change in the frequency of excitation causes a decrease in the response of the system

Note 1 to entry: The value of resonance frequency depends upon the measured variable. For a ~~given mode~~ damped linear system, the values of resonance frequency for displacement, velocity and acceleration (respectively dynamic compliance, mobility and accelerance; see ISO 2041) are in increasing order of frequency. The differences between these resonance frequency values are small for the usual damping ratios.

Note 2 to entry: In seismic testing, it is often assumed that a resonance frequency is significant when the transmissibility of the response is greater than 2.

Note 3 to entry: For a damped linear system the resonance frequency is coincident with the damped natural frequency.

Note 4 to entry: This definition is not identical to that given in ISO 2041.

3.23**response spectrum** ~~(not identical with ISO 2041 definition)~~

plot of the maximum response to a defined input motion of a family of single-degree-of-freedom bodies at a specified damping ratio

SEE: Figures 1, 2 and 3.

Note 1 to entry: This definition is not identical to that given in ISO 2041.

3.24**S1-earthquake**

earthquake which would be expected to occur during the operating life of the equipment and for which safety related equipment is to be designed to continue to operate without malfunction

Note 1 to entry: An S1-earthquake corresponds in nuclear applications to the operating base earthquake (OBE).

3.25**S2-earthquake**

earthquake which produces the maximum vibratory ground motion for which certain structures, systems and components are designed to remain functional

Note 1 to entry: The structures, systems and components are those essential to ensure proper function, integrity and safety of the total system.

Note 2 to entry: An S2-earthquake corresponds in nuclear applications to the safe shutdown earthquake (SSE).

3.26**sine beat**

continuous sinusoidal wave of one frequency which is modulated by a sinusoidal wave of a lower frequency

SEE: Figure 5.

Note 1 to entry: The duration of one sine beat is half the period of the modulating frequency.

Note 2 to entry: In this document, the sine beat is considered as a single-frequency wave.

3.27

strong part of time history

part of time history from the time when the plot first reaches 25 % of the maximum value to the time when it falls for the last time to the 25 % level

SEE: Figure 6.

3.28

strong part of the response spectrum

part of the spectrum for which the response acceleration is higher than for the –3 dB bandpass of the required response spectrum

SEE: Figure 2.

Note 1 to entry: Generally, the strong part of the response spectrum is located in the first third of the frequency band.

3.29

superelevation factor

factor accounting for the change in the acceleration with respect to the earth due to the transmissibility of buildings and structures

3.30

synthesized time history

artificially generated time history such that its response spectrum ~~envelops~~ dominates the required response spectrum

3.31

test level

largest peak value within a test wave

Note 1 to entry: In seismic testing, acceleration is the parameter normally used.

3.32

test frequency

frequency at which the specimen is to be excited during a test

Note 1 to entry: A test frequency is one of two types as defined in 3.32.1 and 3.32.2.

3.32.1

predetermined test frequency

frequency ~~prescribed~~ specified by the relevant specification

3.32.2

investigated test frequency

frequency obtained by a vibration response investigation

3.33

test response spectrum

response spectrum derived from the real motion of the vibration table either analytically or by using spectrum analysis equipment

SEE: Figures 2, 3c) and 3d).

3.34

time history ~~(not identical with ISO 2041 definition)~~

recording, as a function of time, of acceleration or velocity or displacement

Note 1 to entry: This definition is not identical to that given in ISO 2041.

3.35

zero period acceleration

ZPA

high-frequency asymptotic value of acceleration of a response spectrum

Note 1 to entry: An example of ZPA is given in Figure 2.

Note 2 to entry: The zero period acceleration is of practical significance as it represents the largest peak value of acceleration, for example in a time history. This should not be confused with the peak value of acceleration in the response spectrum.

Note 3 to entry: This note applies to the French language only.

4 General and qualification considerations

4.1 General seismic class and specific seismic class

Two seismic classes have been established: a general seismic class and a specific seismic class. Neither of these classes can be considered to be more demanding than the other. The difference between the two classes lies in the availability of and/or the accuracy in defining the characteristics of the seismic environment. When high reliability safety equipment for a specified environment is required, such as safety related equipment in nuclear power plants, the use of precise data is necessary and, therefore, the specific seismic class is applicable and not the general seismic class. Annex A contains a flow chart for the selection of the test class (general seismic class or specific seismic class) and ~~four~~ **three** flow charts (Figures A.2 to A.4) covering the possibilities discussed in this document. To ~~obtain the maximum~~ **take full advantage** ~~from~~ of this document it is strongly recommended that the flow charts be studied very thoroughly.

Clauses 11 to 15 describe the recommended seismic testing methods for equipment covered by the general seismic class for which the seismic environment is either not known or is imprecisely known.

This class covers equipment for which the relevant seismic motion does not result from a specific study taking into account the characteristics of the geographic location and of the supporting structure or building.

~~In the case of equipments~~ In this class, the seismic motion is generally characterized by one datum which is a peak acceleration at the ground level. This acceleration is derived from the seismic data relative to the area of interest.

When an equipment is not mounted at ground level, the transmissibility of the building and/or the supporting structure should be taken into account.

Clauses 16 to 20 describe the recommended seismic testing methods for equipment covered by the specific seismic class for which the seismic environment is well known or the required response spectra and/or the time histories are specified in the relevant specification.

This class covers the equipment for which the relevant seismic motion results from a specific study taking into account the characteristics of the geographic location and of the supporting structure or building.

~~For equipment~~ In this class, the seismic motion is defined by response spectra (evaluated for different damping ratios) or by a time history.

The relevant specification should contain information relating to the subjects discussed in 4.2, 4.3 and 4.4.

4.2 Service conditions

Service conditions should be duplicated as closely as possible when an equipment is tested, particularly those conditions (electrical, mechanical, and thermal pressure, etc.) whose stresses combine with those of the seismic test to affect the operation or integrity of the equipment. When account is not taken of these service conditions in the test, the omission should be justified.

4.3 Malfunction criteria

When the service conditions and function are known or have been selected, the relevant specification will ~~prescribe~~ specify acceptance and/or malfunction criteria.

NOTE There are cases when the final service conditions or the conditions of use of the equipment which is to be tested are not known but have been selected. In these cases, malfunction criteria cannot be accurately established and are therefore assumed without formal justification; for example, in the absence of better information, the assumption is frequently made that the duration of a malfunction in electrical circuitry is 5 ms.

4.4 Qualification criteria

The following classification is introduced as it allows criteria to be assigned to equipment for a particular application.

Criterion 0: Equipment subjected to seismic testing which experienced no malfunction either during or after the test.

Criterion 1: Equipment subjected to seismic testing which suffered a malfunction during the test but reverted to its correct state after the test.

Criterion 2: Equipment subjected to seismic testing which experienced a malfunction during the test and required resetting or adjustment on completion of the test but required no replacement or repair.

5 Testing procedures

5.1 General

Testing should be in accordance with ~~Section Two (clauses 6 to 10)~~ Clauses 11 to 15 for the general seismic class or ~~Section Three (clauses 11 to 15)~~ Clauses 16 to 20 for the specific seismic class.

5.2 Mounting

The equipment ~~should~~ shall be mounted in accordance with IEC 60068-2-47.

NOTE For more detailed guidance in the case of equipment normally used with vibration isolators see IEC 60068-2-6:2007, Clause A.5.

The influence of connections, cables, piping, etc., should be taken into account when mounting the equipment. Also, unless justified, the normal “in service” mounting structure of the equipment should be included in the seismic test.

The orientation and mounting of the equipment during the test should be specified and is then the only condition for which the equipment is considered qualified, unless adequate justification can be made to extend the qualification to an untested condition (for instance, if it is proved that the effects of gravity do not influence the behaviour of the equipment).

5.3 Measurements

5.3.1 Vibration measurements at the vibration table

Measurements ~~should~~ shall be carried out in accordance with IEC 60068-2-6, IEC 60068-2-57 and ~~IEC 60068-2-59~~, IEC 60068-2-64 and IEC 60068-2-81 as relevant.

~~Vibration measurements at the vibration table~~

Vibration measurements at the vibration table are to be made to ensure that the correct levels of vibration are applied at the required measuring positions.

Parameters to be permanently recorded (displacement, velocity, acceleration), the equipment used, and the functions of each transducer (reference, measurement) should be specified.

5.3.2 Vibration measurements on the equipment

In addition to the measurements at the vibration table, measurements may be made on the equipment to provide further information about its performance during the test. These latter measurements are not a part of the vibration test requirements.

5.3.3 Functional monitoring of the equipment

Monitoring should be adequate to evaluate the performance of the equipment before, during and after the test.

The relevant specification for the equipment should ~~prescribe~~ specify any characteristics to be permanently recorded.

5.4 Frequency range

In earthquakes, the predominant frequencies are generally between 1 Hz and 35 Hz. This range is sufficient to determine the critical frequencies of the equipment and for its testing. In certain cases the test frequency range of 1 Hz to 35 Hz may be extended or reduced ~~dependent~~ depending on the effective value of the cut-off frequency of the ground response spectrum; moreover the test frequency range may be reduced depending on the critical frequencies ~~present~~ of the specimen, but this should be justified.

~~Section Two describes the recommended seismic testing methods for equipment covered by the general seismic class for which the seismic environment is either not known or is imprecisely known.~~

6 Conditioning

~~It is recommended that the equipment should be tested according to the procedure described in the specific seismic class when the following parameters are defined:~~

- ~~a) a required response spectrum and, if applicable, the duration of the earthquake, or~~
- ~~b) a required time history.~~

~~For this seismic class, it is normal to indicate the number of S1 and S2 earthquakes for which the effects are to be simulated, as well as the load conditions (other than seismic) to be taken into account.~~

For ~~specific~~ seismic ~~class~~ testing, the preferred test waves are in accordance with ~~the standards for~~ the following standards:

- sine sweep (primarily for the vibration response investigation) (IEC 60068-2-6)
- ~~— sine beat (IEC 60068-2-59)~~
- continuous sine (endurance at fixed frequencies) (IEC 60068-2-6);
- time history and sine beat (IEC 60068-2-57).

7 Standard amplitude conventional test method

7.1 Application

~~This conventional test has three performance levels, often referred to as qualification levels, (see table 2) and it is recommended when the conditions of use of the equipment are unknown. The user of the equipment should decide if the qualification level for which the equipment has been tested is suitable for the considered application. After achieving a specified qualification level, the equipment may then claim qualification up to and including that level, provided that all other requirements have been satisfied.~~

Table 2 – Performance level

Performance level*	Floor acceleration a_f	
	Horizontal	Vertical
	m/s ²	m/s ²
I	6	3
II	9	4,5
III	15	7,5
* These levels can be used above a crossover frequency of 1,6 Hz. Below this frequency, the amplitude of velocity is used down to 0,8 Hz. Below 0,8 Hz the amplitude of displacement is used (see figure 7a).		

7.2 Conditions of testing

~~The standard amplitude conventional test method is a single-axis test only. The different axes are excited one after another. The test acceleration is determined from the performance level (see 7.2.1), the wave factor (see 9.2.1) and the geometric factor (see 9.2.2).~~

7.3 Performance level (standard amplitude conventional test)

~~In the standard amplitude conventional test method the floor acceleration (a_f) is selected directly from the levels given in table 2.~~

7.3.1 Test wave

~~The recommended test wave is the five-cycle sine beat or the sine sweep. However, other waves, if justification is given, are permissible. The maximum value of acceleration of the excitation for the selected level should be corrected by the wave factor (see 9.2.1) and the geometric factor (see 9.2.2).~~

7 Test wave selection

7.1 General

Clause 7 should be read in conjunction with Clause 9. The test wave selection should take into account the anticipated characteristics of the equipment when it is in its installed position and under the influence of the specified earthquake. ~~Whichever is the adopted wave form, the test response spectrum measured envelops the required response spectrum and the total duration of the test should be at least equal to the strong part of the earthquake (see clause 11).~~

For the purposes of this document, the test waves are divided into two categories.

- a) Multifrequency waves:

- 1) time history (natural, synthesized or random motion sample);
- 2) other waves (requiring justification);
- b) single-frequency waves:
 - 3) sine sweep;
 - 4) sine beat;
 - 5) continuous sine (Figure 7);
 - 6) other waves (requiring justification).

7.2 Multifrequency waves

In general, when the vibration spectrum is broadband, the test wave should be of the multifrequency type. However, certain exceptions are allowed after justification (see 7.3).

7.3 Single-frequency waves

~~Sine sweep tests are not generally used for specific seismic class testing.~~

If the ground seismic motion is filtered by one of the structural modes, the resulting floor level motion may show a predominant frequency. This corresponds to a narrowband required response spectrum and in this situation a single-frequency vibration may be a satisfactory excitation.

The single-frequency test response spectrum should not be mistaken for ~~the envelope of the~~ overall test response spectrum obtained for each test frequency. The ~~single-frequency test response spectrum corresponding to each test frequency~~ should be larger than or equal to the ~~strong part (3 dB bandpass) of the basic response spectrum (see figure 1)~~ required response spectrum (RRS) (see Figures 3b) and 3d)).

~~The envelope of the~~ overall single-frequency test response spectrum ~~associated with each test frequency~~ should be larger than or equal to the required response spectrum ~~(see 13.2)~~.

Frequently only an artificially broadened response spectrum is available to take account of uncertainties such as site variations, axes of the structure or design uncertainties. In this situation and in the absence of additional evidence to demonstrate floor seismic motions to be narrowband, it should be assumed on the basis of this broadened response spectrum that the excitation is multifrequency.

Single-frequency tests can be used to qualify the equipment in the following cases:

- a) no interacting resonance frequencies (this is considered to be the case when they are more than 1/4 oct apart, ~~see Figure 3b~~);
- b) resonance frequencies of the equipment are located outside the strong part of the required response spectrum;
- c) special cases, if justified.

8 Test waves

8.1 General

8.1.1 Specification of test waves

The test wave used should:

- a) produce a test response spectrum larger than or equal to the required response spectrum;
- b) possess a maximum peak acceleration value at least equal to that of the zero period acceleration;

- c) reproduce with a safety margin the effects of the required earthquake (see 8.1.2);
- d) ideally not include any frequency greater than 35 Hz or the cut-off frequency if this is higher, but if such frequencies exist in the testing wave they should not be taken into account in evaluating the test response spectrum, especially when obtaining the ZPA-value.

8.1.2 Simulation with a safety margin of the effects of an earthquake

In evaluating the seismic risk of a particular site, it is necessary to make an allowance for the estimated number of S1- and S2-earthquakes to which the equipment might be subjected during the lifetime of the installation. Five S1-earthquakes and one S2-earthquake are generally assumed unless a different number can be justified. However, to achieve a greater safety margin, the equipment may be subjected to two tests corresponding to the level of the S2-earthquake.

The S1 tests should be followed by at least one S2 test. The duration of each test should be at least equal to the strong part of the time history used to define the required response spectrum (see 9.5). ~~Alternatively~~ The tests should simulate at least the same level of fatigue as that to which the equipment is liable to be subjected during both the S1- and S2-earthquakes.

Thus, each test should simulate with the same safety margin the effects of an earthquake. Resistance to fatigue decreases as the stress level increases and, therefore, the S1 test may be replaced by a number of S2 tests producing the same total ageing, providing the number chosen is justified.

The duration and number of S1 and S2 tests applied to the equipment may exceed the required values in order to provide for the functional checks ~~prescribed~~ specified by the relevant specification. In this case, as many test waves as necessary are applied but the probability of fatigue failure is increased.

The test waves simulating S1- or S2-earthquakes may be applied as “wave sequences” (see Figure 5). In this case, the waves ~~must~~ shall be sufficiently spaced (by at least 2 s) to avoid their effects being superimposed on the equipment.

8.2 Multifrequency wave testing

8.2.1 General requirements

Multifrequency wave testing should be carried out in accordance with the recommendations indicated in 8.1. In particular, a check should be made using an appropriate analysis to demonstrate that the test response spectrum ~~envelops~~ dominates the required response spectrum. The recommended values for the appropriate analysis are at least 1/6 oct for damping between 2 % and 10 % and 1/12 oct for 2 % or less. If the damping is greater than or equal to 10 %, an appropriate analysis in 1/3 oct is sufficient.

8.2.2 Time-history test

The test is performed by applying to the equipment a time history (see 3.34) to simulate the probable excitation of the equipment. ~~It should be demonstrated that the test response spectrum is equal to or greater than the required response spectrum (see figure 2c).~~ If not directly supplied by the relevant specification, the test time history shall be generated starting from the required response spectrum as described in IEC 60068-2-81.

The duration of the test wave should be at least equal to the duration of the strong part of an earthquake. This is generally taken to be between 5 s and 10 s.

~~13.2.2 Time history, with superimposed sine beat, test~~

~~To develop a suitable test response spectrum without using an unreasonably high peak value of the input, other waves, such as sine beats, may be added to the time history. It is acceptable, therefore, to adjust the input to meet the required response spectrum without using an input level substantially greater than the zero period acceleration of the required response spectrum.~~

~~One or more sine beats should be superimposed on the input to provide a test response spectrum larger than or equal to the entire required response spectrum over a frequency range which includes the resonance frequencies of the equipment up to 35 Hz (see figures 2a, 2b, 2c, 2d and 3).~~

~~If the bandwidth of the spectrum requires sine beats of more than one frequency, they are initiated simultaneously. However, if the bandwidth of the required response spectrum has been artificially broadened to account for building response uncertainty, or for the direction of the equipment, etc., the sine beats may be applied in sequence or the techniques of 13.3.2 applied. These variations in testing techniques should be justified.~~

8.2.3 Other multifrequency tests

In many cases the required motion may represent significant filtering of ground motion by one or more sharp building or soil resonances, or both. The corresponding RRS may include medium-to-low level amplification over a broad frequency range, with highly amplified narrow bands associated with each building resonance. For these cases a test may be performed by applying to the equipment a multifrequency excitation, the amplitude of which is adjusted either manually or automatically in multiple-frequency bands. However the use of a multifrequency motion test may require an unreasonably high maximum peak value of the input so as to meet the higher amplification associated with the building resonances. It is permissible to synthesize a complex signal that comprises the summation of several different types of individual narrowband components superimposed on lower level broadband random motion. This approach affords a better chance of producing a table motion whose TRS will envelop the RRS, without introducing excessive ZPA levels. Typical methods of synthesizing complex signals are (see Figures 3 and 4):

- a) random motion with sine dwells;
- b) random motion with sine beats;
- c) combination of multiple sinusoids;
- d) combination of decaying sinusoids.

8.3 Single-frequency testing

8.3.1 General requirements

The single-frequency wave is applied at a frequency and with an amplitude such that the test response spectrum is larger than or equal to the ~~maximum part~~ value of the ~~basic~~ required response spectrum at that frequency ~~(see figure 1)~~ (see Figures 3b) and 3d)). If the overall test response spectrum does not cover the ~~3 dB bandpass~~ RRS, justification is required.

In general, basic response spectra which may have similar amplitudes will show different frequencies depending upon the differences in soil modules, building height, or position of the equipment. In this case, single-frequency waves are applied at the critical frequencies of the equipment which occur in the strong part of the spectrum and at any specified predetermined frequencies unless justified (see 7.3). The test frequencies are applied over the specified frequency range as stated in 5.4, in steps not greater than 1/2 oct (see Figure 3d)). This guards against the possibility that some critical frequencies ~~are~~ will not be excited, which were undetected during the vibration response investigation generally made by a sine-sweep test. If applicable, tests should be carried out at the ~~lateral~~ critical frequencies (see 3.5) as well as at the overall resonance frequency of the equipment.

The input level to be applied to the vibration table is calculated taking into account the amplification of the test wave and ~~the plot of the basic response spectrum at a damping ratio of 5 %.~~ The maximum level of this wave should be at least equal to the zero period acceleration the ZPA of the required response spectrum at a damping ratio of 5 %. When the equipment possesses critical frequencies in the strong part of the spectrum with a damping ratio lower than 2 % or higher than 10 %, then the input level is determined by reference to the ~~plot of the basic~~ required response spectrum at a damping ratio corresponding to that of the equipment. After carrying out all the tests along each axis of the equipment, a modification of its mechanical characteristics may be noticed. In this case, ~~it should be demonstrated that the new critical frequencies, recorded by means of a repeated vibration response investigation test, remain within the frequency interval defined by the initial lateral frequencies~~ the relevant specification shall state what action is to be taken if any change of frequency occurs.

8.3.2 Sine-sweep test

The sine-sweep test is performed by means of a continuous, low-level logarithmic frequency sweep cycle at a rate not exceeding 1 oct/min over a frequency range equal to or larger than that for which the equipment is to be qualified.

8.3.3 Sine-beat test

~~The number of cycles per beat is adjusted so that the test response spectrum envelops the –3 dB bandpass of the basic response spectrum (see Figure 1). The peak value of acceleration of the beat should be at least equal to that of the zero period acceleration of the required response spectrum (except at low frequencies when the required response spectrum becomes lower than the zero period acceleration) (see figure 2a).~~

The number of cycles per beat is adjusted so that the test response spectrum dominates the required response spectrum (see Figure 3d)). The peak value of acceleration of the beat is calculated taking into account the amplification of the test wave and the ZPA of the required response spectrum at a damping ratio of 5 %.

For a given peak value of sine-beat acceleration, the safety margin of the test increases with the number of cycles. For the test response spectrum to be larger than or equal to the ~~–3 dB bandpass of the basic~~ required response spectrum, it is usual to use between 5 and 10 cycles per sine beat. The envelope of the test response spectra of these sine beats should ~~include~~ dominate the required response spectrum.

A sequence of five sine beats (or continuous sine) should be applied at test frequencies over the specified frequency range as stated in 5.4 and in steps not greater than 1/2 oct. The test amplitude should correspond to the zero period acceleration level corresponding to the S1-earthquake followed by one sine beat defined as above with the zero period acceleration level corresponding to the S2-earthquake. The envelope of the test response spectra of these sine beats should ~~include~~ dominate the required response spectrum.

8.3.4 Continuous sine test

~~For each test frequency a continuous sine motion is applied to the equipment so that the test response spectrum envelops the required response spectrum at least in a range around the considered frequency (–3 dB bandpass of basic response spectrum) (see Figure 1) and with a level at least equal to the zero period acceleration of the required response spectrum. The input signal should be of sufficient duration for at least five cycles to be at the maximum amplitude corresponding to the zero period acceleration (see Figure 9).~~

For each test frequency a continuous sine motion is applied to the equipment so that the test response spectrum dominates the required response spectrum at least in a range around the considered frequency (see Figure 3d)) and the input level to be applied to the vibration table is calculated taking into account the amplification of the test wave and the ZPA of the required

response spectrum at a damping ratio of 5 %. The input signal should be of sufficient duration for at least five cycles to be at the maximum calculated amplitude (see Figure 7).

8.4 Other test wave forms

Other wave forms can be used if justified in accordance with the recommendations of 8.1.

9 Testing conditions

9.1 ~~Introduction~~ General

The procedures indicated in Clause 9 are recommended for use in the testing of equipment designed to withstand earthquakes. The seismic tests are performed by subjecting the equipment to a vibratory motion simulating the seismic motion with a safety margin defined ~~either by a required response spectrum or by a time history~~ by a peak acceleration, a frequency distribution of the acceleration and a duration of the applied acceleration. The theoretical basis for this test procedure is considered to be outside the scope of this document but can be readily obtained from relevant technical literature.

A difficult problem in attempting to define tests for qualifying equipment is in the selection of suitable test waves, as described in Clause 7. Numerous factors should be taken into account, for example the type of equipment, its position and the nature of the earthquake expected. A further point is the need to determine whether the equipment is to be used for a specific application or for a more general purpose. In the first case, the seismic motion will probably be closely specified and the testing is then selected so as to comply with this condition, whereas in the latter case the test should be designed to qualify the equipment for a future application for which a more general required response spectrum is to be specified.

In writing the relevant specification a required response spectrum is normally generated and it is usually broadened in the maximum amplification area to cover the effects of unknown or variable factors such as the natural frequencies of the building structure which are not known with accuracy and the position of the equipment inside the building. This is called a broadband required response spectrum (see Figure 2). The extent to which the spectrum used can be broadened is to be ~~prescribed~~ specified by the relevant specification.

Another factor to be taken into account is the multi-directional nature of the earthquake. The equipment is tested so as to take these effects into account. This is described in Clause 10.

Difficulty arises when attempting to define the testing of individual components (relays, motors, sensors, etc.) or complex assemblies such as control cabinets. In the first case, it is reasonable to ensure that the component is subjected to the actual seismic tests whilst its operating conditions are applied or simulated and has its performance checked during the testing. This might, however, prove to be impractical in the second case, that ~~of~~ is for complex equipment, which may include many components forming parts of several systems and being connected to other equipment located at numerous positions within the structure.

The following alternatives are acceptable if it proves impossible to test such equipment in operation. In the first method each component is tested separately, simulating its service conditions so as to establish the maximum level of acceleration for which the equipment shows an acceptable performance. Then the equipment, with its components installed but out of service, or without its components and with devices simulating their dynamic properties, is subjected to a vibration test to demonstrate that the acceleration spectrum at the location of each component is equal to or less than the level for which that individual component has been qualified.

A second method consists in applying the input vibration appropriate to the ~~required response spectrum to~~ in-service mounting conditions of the equipment of which the components are inoperative or have their dynamic properties simulated. The acceleration levels at the

component locations are then measured and used as the input acceleration to qualify separately the components in service.

The purpose of installing inoperative components is to ensure that the equipment possesses the same dynamic characteristics as in normal operation. For instance, whenever possible, control cabinets should be dealt with as complete units and their components tested individually.

9.2 Vibration response investigation

The vibration response investigation supplies data on critical test frequencies. It can also be used to supply data both on the damping ratio of the equipment and to enable a choice of single or multi-axis testing to be made.

It is usually carried out using single-axis sinusoidal excitation and is run with a single logarithmic sweep cycle over a frequency range between 1 Hz and 35 Hz up and down at a sweep rate sufficiently low to determine the critical frequencies but not exceeding 1 oct/min.

Random vibration testing may also be used as an alternative method for the vibration response investigation (see IEC 60068-2-64:2008, 8.2).

The amplitude of vibration applied in the course of the vibration response investigation should not be so large as to produce an effect comparable to the effect of the test itself. However, the level should be sufficiently high to take into account the non-linearity effects which cause the critical frequencies and the damping to be dependent upon the amplitude of vibration.

NOTE An amplitude of vibration of 2 m/s² is often used. This value ~~may~~ can be reduced to 1 m/s² or less in the case of sharp resonances.

It should be noted that due to physical complexity or restricted access to critical parts (for example sealed relays), these vibration response investigation tests may not detect all the critical frequencies. Also, because of non-linearities, resonance responses at high levels may differ in frequency and damping from those recorded at lower levels and some resonances may not be visible at low excitation. The result of a low-level exploratory test may, therefore, not always provide complete information regarding the dynamic behaviour of an equipment. For these reasons, if no critical frequency has been noted, the test is performed according to the recommendations of 9.3.1.

9.3 Test methods

9.3.1 Test method for equipment without critical frequencies

As outlined in 9.2, even if the vibration response investigation test detects no critical frequencies, this does not guarantee that they will not occur at higher excitation levels. This may result from the following:

- a) Non-linearity of the structures (especially the generation of shocks when certain levels are exceeded).
- b) The absence of measurements in a critical position during the test. For instance, it is not possible to measure in a simple manner the vibrations of electrical contacts in unexcited relays. However, these contacts may be subjected to ~~micro~~-closings or ~~micro~~-openings of very short time duration with detrimental ~~to~~ impact on good operation of the equipment when the vibratory levels reach a certain threshold.
- c) The excitation level may be too weak to allow certain critical frequencies to be detectable.

After carrying out the vibration response investigation as indicated in 9.2 and showing that there is no detectable critical frequency lower than 35 Hz, the equipment is tested in accordance with Clause 10 and one of the following options chosen:

- 1) A logarithmic sweep cycle at between 1 oct/min and 2 oct/min (one cycle of 1 Hz to 35 Hz to 1 Hz) with the required ~~zero-period~~ acceleration levels corresponding respectively to S1- and S2-earthquakes.
- 2) A sequence of five sine beats (or continuous sine) should be applied at test frequencies over the specified frequency range as stated in Clause 5 and in steps not greater than 1/2 oct. The test amplitude should correspond to the ~~zero-period~~ acceleration level of the S1-earthquake followed by one sine beat defined as above with the ~~zero-period~~ acceleration level corresponding to the S2-earthquake.
- 3) Other waveforms (as, for example, time-histories) producing a test response spectrum at least equal to the required response spectrum corresponding either to S1- or S2-earthquakes.

9.3.2 Test method for equipment with critical frequencies

Equipment that have been found to have critical frequencies are tested in accordance with Clauses 7 and 10.

9.4 Selection of damping

Required response spectra are usually specified for various damping ratios. It is normal to select a single curve with a damping value representative of one of the main items of equipment being investigated, although most equipment possess several vibration modes, each with a different damping ratio. As a general rule a required response spectrum with a damping of 5% is considered to be appropriate for stresses near to the yield point of most materials.

A check should be made that the corresponding test response spectrum ~~exceeds~~ dominates the required response spectrum. If necessary, reference can be made to either a required response spectrum possessing a damping level corresponding to that measured on the equipment or to a value selected from Table 1.

Table 1 – Typical damping ratios (per cent of critical)

Item	Stresses corresponding to		
	1/4 yield stress	1/2 yield stress ^a	At yield stress ^b
Welded steel structures	0,5 to 1	2	4
Bolted steel structures	0,5 to 1	4	7
Reinforced concrete structures	0,5 to 1	4	7
Cabinets and panels	0,5 to 1	2	5
Assemblies	0,5 to 1	2	7
Large equipment, steel pipes > 300 mm diameter	0,5 to 1	2	3
Small pipes ≤ 300 mm diameter	0,5 to 1	1	2
^a Often used for S1-earthquakes.			
^b Often used for S2-earthquakes.			

The required response spectrum reference damping curve is:

- 2 %, if the equipment damping is equal to or less than 2 %;
- 5 %, if the equipment damping is between 2 % and 10 %;
- 10 %, if the equipment damping is equal to or greater than 10 %.

9.5 S1-earthquake and S2-earthquake testing

The definitions of S1 and S2 levels are currently used only in relation to nuclear power plants, but equivalent levels may be used for other types of application.

When seismic testing specifications include the effect of one (or more) S1- and S2-earthquakes, the number of tests corresponding to the S1 should be justified for each site. Five S1 tests and one S2 test are usually considered to be sufficient in the absence of more accurate information.

The purpose of multiple S1 testing is to demonstrate that low intensity earthquakes, which have the highest probability of occurring, are not detrimental to functional safety of the performance of the equipment, and that fatigue or ageing condition ~~is not generated~~, the undetected presence of which could lead to defective performance during a subsequent S2-earthquake ~~are not generated~~.

All tests indicated in ~~the following~~ Clauses 11 to 20 may be used for the determination of the performance of an equipment for an S1-earthquake. When the required number of equipment operational checks is high, it may be necessary to carry out more S2 tests than specified to allow checking of the equipment part by part.

Both the shape and magnitude of the spectrum may differ for the two seismic levels of S1 and S2. It is therefore necessary to know the spectra corresponding to each of these seismic levels. It is commonly assumed that the S2 spectrum has the same shape as that of S1, but twice the level.

9.6 Specific application testing

The purpose of this type of testing is to demonstrate that a particular equipment in a defined location for a specific application can withstand a specified earthquake. In the testing of safety related equipment in nuclear power plants this type of testing is referred to as “seismic qualification”.

9.7 Assembly testing

It is normal to test large complex assemblies by simulating the most critical in-service conditions. It is not, however, always possible to simulate all these in-service conditions at the same time, for example in the case of control panels containing items belonging to different circuits. In this situation, it is acceptable to perform “out of service” testing of the equipment with real or dummy components installed during testing of the assembly.

The test should enable the vibratory response at the point of installation of each component to be determined either by direct measurement or by transfer functions. For each simulated component, this response should be lower than that for which the individual components have been qualified.

In testing assemblies, the test waves referred to in Clauses 7 and 8 or any other justifiable wave, may be used. After testing, the assembly is inspected and the integrity of all the unmonitored components, such as cabling, ~~etc.~~, checked.

9.8 Component testing

Each component is subjected to testing by simulating its in-service condition. It is also installed on the vibration table under conditions which ensure dynamic simulation of the required installation, unless the response at the installation point of the component is reproduced in the assembly testing as described in 9.7. The component may be tested by the test waves referred to in Clauses 7 and 8 or any other wave.

10 Single and multi-axis testing

10.1 General

Seismic ground motion may occur simultaneously in all directions and in a random fashion, but this does not exclude single-axis or biaxial testing.

10.2 Single-axis testing

Single-axis testing applied successively in the three preferred testing axes of the equipment can be justified either:

- when the equipment is subjected only to single-axis excitation due to its installation conditions, or
- when there is little or no coupling between the three preferred testing axes of the equipment when taken in pairs.

For example, if a component is normally installed in an equipment which amplifies motion in a single direction, or if the construction and/or mounting of a component restricts its motion to one direction, a single-axis test may suffice. However, if testing in all three axes is not carried out, a justification should be given.

10.3 Biaxial testing

10.3.1 General requirements

Biaxial testing is necessary when significant coupling exists between two of the preferred testing axes of the equipment. The choice of the type of test depends upon the plane of the coupling.

10.3.2 Two horizontal axes

The two following cases may be encountered, according to the type of testing installation available.

a) Biaxial installation

In the case of an installation capable of simultaneous excitation by independent waves, the vibration is applied along two of the preferred testing axes of the equipment, the test response spectrum along each axis being at least equal to the corresponding required response spectrum. If the waves are not independent, the test may impose a penalty since the excitation peaks are occurring simultaneously along both axes.

The equipment is then rotated through 90° around the vertical axis and the above test repeated.

b) Single-axis installation

In the case when only a single-axis installation is available, the equipment may still be excited simultaneously along the two preferred testing axes in the horizontal plane using a single wave as follows.

The equipment is mounted so that the excitation axis is at a 45° angle with respect to both these testing axes. The vibration along the excitation axis is then increased to $\sqrt{2}$ times that used in biaxial testing. This imposes a penalty because the vibration peaks along the preferred testing axes occur simultaneously.

The equipment is then rotated through 90° around the vertical axis and the above test repeated.

10.3.3 One horizontal axis and one vertical axis

As in 10.3.2, two cases may be encountered according to the type of testing installation available:

a) Biaxial installation

The test is carried out by applying separate and independent simultaneous excitation waves along two of the preferred testing axes of the equipment, checking that the required response spectrum along each axis is achieved. If the waves are not independent, the test may be very conservative since the excitation peaks are occurring simultaneously along both axes.

The equipment is then rotated through 90° around the vertical axis and the above test repeated.

b) Single-axis installation

If a biaxial installation is not available, a table moving along an inclined plane is acceptable, the installation plane remaining horizontal. The equipment is mounted on the vibration table so that one of the two preferred testing axes in the horizontal plane is at a specified angle to the direction of excitation (see Figure 8).

Since in this case the motions along the two directions are not independent, four tests are then carried out in order to test both in and out-of-phase effects. The equipment is installed on the vibration table as indicated below:

position 1: in the position as described;

position 2: rotated through 180° around the vertical axis;

position 3: rotated through 90° around the vertical axis with respect to position 1;

position 4: rotated through 180° around the vertical axis with respect to position 3.

With this type of test, the spectra obtained have the same shape for all three preferred testing axes of the equipment but with horizontal relative to vertical levels determined by the slope of the excitation direction with respect to the horizontal surface of the table. If the table slope can be adjusted, it can be set to obtain the required ratio between the horizontal and vertical zero period acceleration (ZPA) levels. The excitation is defined as a zero period acceleration level by

$$a_e = (a_h^2 + a_v^2)^{1/2}$$

where

a_e is the zero period acceleration of the excitation;

a_h is the zero period acceleration in horizontal direction;

a_v is the zero period acceleration in vertical direction;

such that the zero period acceleration projected along each of the two axes of the equipment is at least equal to the ZPA of the required response spectrum for the corresponding axis. This test may impose a penalty since the excitation peaks are occurring simultaneously along both axes.

When the required slope of the vibration table cannot be obtained, the input level is increased to the highest zero period acceleration level of the required response ~~spectrum~~ spectra.

10.4 Triaxial testing

10.4.1 General

Triaxial testing is desirable when significant couplings exist simultaneously between all three preferred testing axes of the equipment.

10.4.2 Triaxial installation

The test is performed with simultaneous but independent inputs into the three preferred testing axes of the equipment, each producing the required response spectrum along that axis.

10.4.3 Biaxial installation (one horizontal axis, one vertical axis)

The vertical and horizontal waves are independent. Use can be made of a biaxial table by exciting the equipment horizontally at 45° with respect to its preferred testing axes. The procedure is similar to that indicated in 10.3.2a), namely to define the horizontal excitation level with the test response spectrum along each of the preferred testing axes of the equipment adjusted to be at least equal to the corresponding required response spectrum.

11 Conditioning for the general seismic class

11.1 Selection of test type

In order to prove the ability of equipment to withstand seismic forces, several types of test may be considered. These are listed in Table 2.

In the general seismic class, single axis testing with sine beat or sine sweep is preferred for the following reasons:

- a) sine beat, as its form is similar to that of the horizontal earthquake wave at floor levels in simple structures presenting one mode of resonance;
- b) sine sweep, as it is simple to achieve but may be less realistic than the actual earthquake waves appearing at the floor levels.

When there is significant coupling between the three preferred test axes of the equipment or if the use of geometric correction factors is not desirable, multi-axis testing (biaxial or triaxial) can be used, although not normally recommended. If multi-axis testing is used, caution should be taken with the use of single-frequency waves – sine beat, sine sweep or continuous sine – as the peak seismic accelerations for the various axes are not usually in phase. A multifrequency wave such as time history should therefore then be used.

Table 2 – Selection of test type

Test wave	Test type	
	Single-axis test	Multi-axis test
Sine sweep	a	c
Sine beat	a	c
Time history	b	a
Continuous sine	b	c
Key a = recommended b = suitable c = not normally recommended		

11.2 ~~Selection of the~~ Test method

~~Two methods exist:~~

- ~~a) standard amplitude conventional test: this is applied where the conditions of use of the equipment are unknown (see clause 7);~~
- ~~b) calculated amplitude test: this is applied where the conditions of use of the equipment are sufficiently known to allow the different parameters of the test to be specified (see clause 8).~~

The test method is a calculated amplitude test: this is applied where the conditions of use of the equipment are either totally unknown or insufficiently known to allow the different parameters of the test to be specified (see Clause 12).

12 Calculated amplitude test method for the general seismic class

12.1 Application

~~The calculated amplitude test method is recommended when sufficient information is available on the characteristics and on the location of the equipment to allow a more accurate estimation of test level than is possible with the standard amplitude conventional test method (see clause 7).~~

The calculated amplitude test method is recommended when sufficient information is available on the characteristics and on the location of the equipment to allow a sufficiently accurate estimation of test level; this would not be possible when the conditions of use of the equipment are unknown, nevertheless a conservative choice of the parameters is possible to calculate the test amplitude.

12.2 Testing conditions

12.2.1 General

In principle this is a single-axis test, where the different axes are excited one after the other. This is appropriate where, for example, there is little interaction between the different axes or the interaction can be accounted for by applying a geometric factor.

12.2.2 Performance level

The severity of the test is determined by the values ascribed to the following parameters, which the relevant specification for the equipment should ~~prescribe~~ specify:

- a) test wave (see 12.2.3),
- b) damping of the equipment (see 12.2.4),
- c) superelevation factor (see 12.2.6),
- d) direction factor (see 12.2.7),
- e) required response spectrum (see Clause 14),
- f) duration of the test (see 13.1),
- g) amplitude of the test wave (see 13.2).

12.2.3 Test wave selection

The test wave selected will have a noticeable influence on the response of the equipment when its damping value is significantly different from 5 % (see Figure 9) even with the use of a wave factor.

12.2.4 Damping ratio

A damping ratio of 5 % is recommended when the critical damping of the equipment lies between 2 % and 10 %. If the damping ratio is outside this range, it is recommended that a value representative of the actual vibrational behaviour of the equipment is used to determine the applicable wave factor. For further details, see 13.2.2 and Figure 9.

12.2.5 Ground acceleration (a_g)

The ground acceleration (a_g) depends upon the seismic conditions of the site where the equipment is to be located. When it is known, it should be ~~prescribed~~ specified by the relevant specification. Otherwise, the recommended values should be selected from those given in Table 3.

Table 3 – Ground acceleration levels

Ground acceleration reference	Description of earthquake				
	General	a_g m/s ²	For information only		
			Richter scale magnitude	UBC zone ¹⁾	Intensity MSK ²⁾
AG ¹⁾	Light to medium earthquakes	2	< 5,5	1-2	< VIII
AG3	Medium to strong earthquakes	3	5,5 to 7,0	3	VIII to IX
AG5	Strong to very strong earthquakes	5	> 7,0	4	> IX
¹⁾ —Approximate Uniform Building Code Zone (International Conference of Building Officials). ²⁾ —MSK (Medvedev-Sponheuer-Karnik corresponds to modified Mercalli intensity scale). NOTE —From Figure 7b it can be seen that there are crossover frequencies at 1,6 Hz to constant amplitude of velocity and at 0,8 Hz to constant amplitude of displacement.					

Seismic activity zone	Zone 0	Zone 1	Zone 2	Zone 3	Zone 4
Ground acceleration, a_g (m/s ²)	0	1	2	3	5

The ground acceleration values can be used above a crossover frequency of 1,6 Hz. Below this frequency, the amplitude of velocity is used down to 0,8 Hz. Below 0,8 Hz the amplitude of displacement is used (see Figure 10). The corresponding motion amplitude values are as follows:

- zone 1
 - peak displacement = 0,02 m for $f < 0,8$ Hz;
 - peak velocity = 0,01 m/s for $0,8 \leq f \leq 1,6$ Hz;
 - peak acceleration = 1 m/s² for $f \geq 1,6$ Hz;
- zone 2
 - peak displacement = 0,04 m for $f < 0,8$ Hz;
 - peak velocity = 0,02 m/s for $0,8 \leq f \leq 1,6$ Hz;
 - peak acceleration = 2 m/s² for $f \geq 1,6$ Hz;
- zone 3
 - peak displacement = 0,06 m for $f < 0,8$ Hz;
 - peak velocity = 0,03 m/s for $0,8 \leq f \leq 1,6$ Hz;
 - peak acceleration = 3 m/s² for $f \geq 1,6$ Hz;
- zone 4
 - peak displacement = 0,1 m for $f < 0,8$ Hz;
 - peak velocity = 0,05 m/s for $0,8 \leq f \leq 1,6$ Hz;
 - peak acceleration = 5 m/s² for $f \geq 1,6$ Hz.

For sake of knowledge of the specification writer, the correspondence among the peak ground acceleration, the seismic activity zone and the modified Mercalli index, taken from IEC TS 62271-210:2013, Table D.1, is shown in Table 4.

Table 4 – Correspondence between peak ground acceleration and some seismic scales

Seismic activity zone	Peak ground acceleration (PGA) (m/s ²)	Modified Mercalli index (MMI)	Richter scale
0	0,01	I	0 to 2
	0,01 to 0,02	II	1 to 2
	0,02 to 0,05	III	2 to 3
	0,05 to 0,1	IV	3 to 4
1	0,1 to 0,2	V	4 to 5
	0,2 to 0,5	VI	5 to 6
2	0,5 to 1	VII	5 to 7
3	1 to 2	VIII	6 to 8
4	2 to 5	IX	7 to 9
	5 to 10	X	8 or higher
	10 to 20	XI	
	more than 20	XII	
NOTE The grade of the seismic activity zones corresponds to a probable maximum intensity with a probability to be exceeded by 10 % in 50 years for medium subsoil conditions (see IEC 60721-2-6).			

The acceleration time history of the seismic excitation is extended in the frequency domain from 1 Hz up to 35 Hz and the duration, in the time domain, ranges from 15 s to 120 s.

A limited number of classes of environmental conditions is given, covering a broad field of applications. The user of this document should select the lowest classification necessary for covering the conditions of seismicity of the intended zone of installation.

Equipment to be used in seismic zones 1 through 4 shall be tested to determine the equipment's ability to withstand earthquakes. No earthquake requirements are provided for zone 0.

12.2.6 Superelevation factor (*K*)

The amplification of the ground acceleration resulting from the vibrational behaviour of buildings and structures is accounted for by means of the superelevation factor, *K*.

The recommended values are given in Table 5 but a relevant specification may ~~prescribe~~ specify other values for given site conditions, if known.

Table 5 – Recommended superelevation factors (*K*)

<i>K</i> factor	Application
1,0	Mounting of equipment on rigid foundations or on structures of high rigidity
1,5	Installations rigidly connected to buildings
2,0	Installations on stiff structures connected rigidly to buildings
3,0	Installations on low rigidity structures connected to buildings



12.2.7 Direction factor (D)

The seismic movement along either horizontal axis is normally greater than along the vertical axis. If the equipment mounting conditions are specified, the test should be carried out according to the preferred horizontal testing axes, x and y , with 100 % of the test level, but with only 50 % along the vertical axis, z .

In the case of specimens with unspecified mounting conditions, the full test should be carried out in all three preferred testing axes, unless otherwise ~~prescribed~~ specified by the relevant specification.

Direction factors are listed in Table 6.

Table 6 – Direction factors (D)

Axis of vibration	D factor	Limitations
Horizontal, D_x	$D_x = 1$	–
Horizontal, D_y	$D_y = 1$	–
Vertical, D_z	$D_z = 0,5$	Only with a specified vertical attitude
Vertical, D_z	$D_z = 1$	When the mounting attitude is not specified ^a
^a If the effect of gravity does not influence the behaviour of the equipment, these tests are carried out with each of the three main axes of the equipment in turn in the vertical plane. The direction factors for each case are $D_x = 1$, $D_y = 1$, $D_z = 0,5$.		

12.2.8 Floor acceleration (a_f)

In the calculated amplitude method of testing, advantage is taken of the greater knowledge of data. The ground acceleration (a_g) is known or has been ~~prescribed~~ specified by the relevant specification. Therefore the floor acceleration (a_f) can be determined from the formula:

$$a_f = a_g \times K \times D \quad (1)$$

where

a_g is the ground acceleration (see 12.2.5);

K is the superelevation factor (see 12.2.6);

D is the direction factor (see 12.2.7).

13 Testing parameters for the general seismic class

13.1 Duration of test

The duration of a seismic test should be appropriate for that of the strong part of the time history of the earthquake (see Figure 6).

For tests using sine-beat waves in accordance with 15.2.1, the duration of the test depends upon the test frequency, number of beats specified, and pauses. In the case of tests using vibration sweeping techniques in accordance with 15.2.2, the duration of the test depends upon the required frequency range, the sweep rate, the number of sweep cycles and the number of test directions involved.

For tests using a time history, the acceleration-time history waveform will be synthesized by following the procedure illustrated in IEC 60068-2-81. The test procedure forces the

equipment to follow the specified motion of the synthesized waveform by means of a vibration table.

The total duration of the time history shall be about 30 s, of which the strong part shall not be less than 20 s.

For a continuous sine test, the duration should be sufficient to reach at least five cycles at maximum acceleration amplitude (see Figure 7).

13.2 Test acceleration (a_t)

13.2.1 General

The amplitude of a test wave can be defined as the maximum value of an acceleration, velocity or displacement wave but only acceleration is referred to for earthquake behaviour.

The test acceleration (a_t) is established by taking the floor acceleration (a_f) as ~~found in the standard amplitude conventional test method (see 7.2.1) or the calculated amplitude test method (see 8.2.7)~~ calculated (see 12.2.8). The acceleration (a_f) is then adjusted for the test wave being utilized and any interaction between axes due to the installation location. This adjustment is accomplished by the application of a wave factor (α) and a geometric factor (G) to the floor acceleration. Thus, the value a_t represents the acceleration level to be applied to the equipment (**ZPA of the test**) and is calculated from the formula:

$$a_t = a_f \times \alpha \times G \quad (2)$$

where

a_f is the floor acceleration (see 12.2.8);

α is the wave factor (see 13.2.2);

G is the geometric factor (see 13.2.3).

13.2.2 Wave factor (α)

Different types of test waves produce different levels of severity depending upon the equipment damping. The effects are taken into account by the use of a wave amplification factor which is equal to 1 for ~~the 5 cycle sine beat. The 5 cycle sine beat~~ the test wave which is similar to the ~~floor~~ ground wave of an actual earthquake ~~after filtering through the intervening structure.~~

The values of the wave factor α for the other test waves are normally determined with a damping ratio of 5 %. Table 7 gives the value of α for a 5 cycle sine beat, for a continuous sine wave or a sine sweep with various damping ratios. These values are calculated from Figure 9 which can also be used to obtain wave factors for various numbers of cycles per sine beat and damping ratios. Examples of equipment damping values are given in Table 1.

Table 7 – Wave factor

Damping of equipment (% of critical damping)	Damping of the RRS (% of critical damping)	Wave factor		
		5 cycle sine beat	Time history	Continuous sine and sine sweep (1 oct/min)
$\xi \leq 2 \%$	$\xi = 2 \%$	0,66	1	~~0,3~~ 0,2
$2 \% < \xi \leq 10 \%$	$\xi = 5 \%$	0,59	1	~~0,55~~ 0,32
$\xi > 10 \%$	$\xi = 10 \%$	0,58	1	~~0,8~~ 0,44

13.2.3 Geometric factor (G)

If there is insufficient information about the excitation at the installation site of the equipment, the geometric factor, G , is taken:

- 1 for single-axis excitation with no interaction with the other axis,
- 1,5 for single-axis excitation with interaction with the other axis.

14 Required response spectrum for the general seismic class

Guidance for the development of a required response spectrum in the situation where environmental conditions are not well known is provided here below.

When the application or the environment is not well known, the following recommendations are given for defining a required response spectrum according to Figure 1 in log-log scale:

- a) the test frequency range is defined from $f_1 = 1$ Hz up to $f_2 = 35$ Hz;
- b) the zero period acceleration value, in m/s^2 , is calculated as indicated in 13.2 starting from the peak ground acceleration corresponding to the seismic zone where the equipment should be installed;
- c) between $f_1 = 1$ Hz and $2f_1$, the acceleration is specified by the slope of 12 dB/oct;
- d) the maximum value of the acceleration between $2f_1$ and $1/3 f_2$ is equal to
 - 2,24 times that of zero period acceleration for a 10 % damping ratio,
 - 3 times that of zero period acceleration for a 5 % damping ratio,
 - 5 times that of zero period acceleration for a 2 % damping ratio.

NOTE When the frequency f_1 is lower than 0,8 Hz, the acceleration below 1,6 Hz will be specified by the slope of 12 dB/oct.

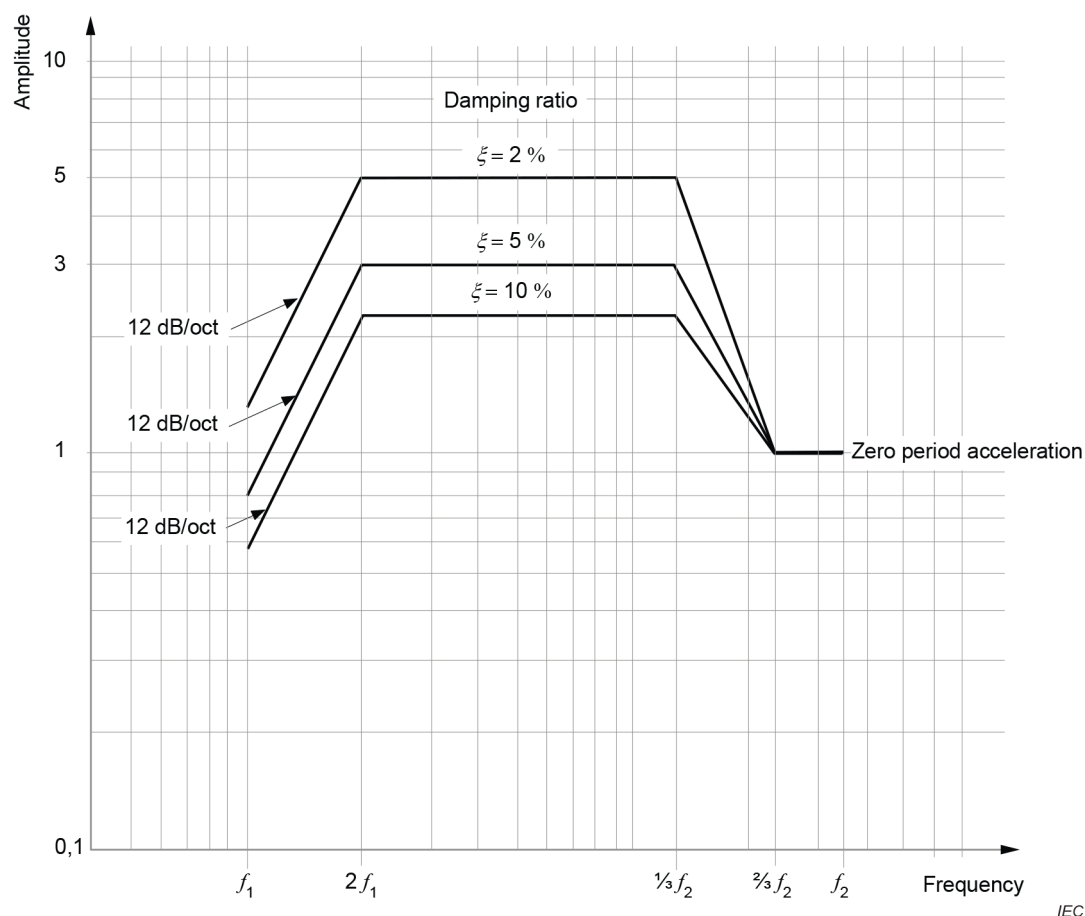


Figure 1 – Shape of a required response spectrum in generalized form (log-log scale) (as recommended by IEC 60068-2-57)

The RRS should be defined for each of the three translational degrees of freedom separately, or at least one spectrum should be given for the horizontal and one spectrum for the vertical direction of excitation.

The seismic movement along either horizontal axis is normally greater than along the vertical axis: see 12.2.7 for the correct choice of the direction factor.

It is commonly assumed that the S2 spectrum has the same shape as that of S1, but twice the level (see 9.5).

When the typical damping ratio of the specimen lies between 2 % and 10 %, the required response spectrum at 5 % is recommended. If the typical damping ratio of the specimen is lower than or equal to 2 %, only the required response spectrum at 2 % is recommended, and if the damping ratio is higher than or equal to 10 %, the required response spectrum at 10 % is recommended.

15 Testing procedures for the general seismic class

15.1 Vibration response investigation (VRI)

~~The vibration response investigation supplies data on critical frequencies. It can also be used to supply data on damping ratios and to enable a choice of single or multi-axis testing to be made.~~

~~It is usually carried out using single-axis sinusoidal excitation. The vibration response investigation and is run with a single logarithmic sweep cycle over a frequency range between 1 Hz and 35 Hz at a sweep rate sufficiently low to reveal the critical frequencies, but not exceeding one octave/min.~~

~~The amplitude of vibration applied in the course of the vibration response investigation should not be so large as to produce an effect comparable to the effect of the test itself. However, the level should be sufficiently high to take into account non-linearities which may cause the critical frequencies and the damping to be dependent upon the amplitude of vibration.~~

~~NOTE—An amplitude of vibration of 2 m/s² is often used. This value may be reduced to 1 m/s² or less in the case of sharp resonances.~~

~~It should be noted that due to physical complexity or restricted access to critical parts (sealed relays, etc.) these vibration response investigations may not detect all the critical frequencies. Also, because of non-linearities, resonance responses at high levels may differ in frequency and damping from those recorded at lower levels and some resonances may not be visible at low excitation. The result of a low-level exploratory test may, therefore, not always provide complete information regarding the dynamic of an equipment.~~

The vibration response investigation shall be carried out as described in 9.2.

The amplitude of vibration of 2 m/s² is often used. This value may be reduced to 1 m/s² or less in the case of sharp resonances. In any case the profile of the vibration amplitude can be accommodated in the frequency range below 1,6 Hz in a similar way as it is described in 12.2.5.

15.2 Types of test

15.2.1 Sine-beat test

~~The test is of a single-axis type and consists of a sequence of 5 sine beats according to IEC 60068-2-59 (see figure 4 and annex A) if not otherwise prescribed by the relevant specification.~~

~~The acceleration to be applied to the vibration table is that determined by the performance level in 7.2.1 or 8.2.1.~~

The test is of a single-axis type and consists of a sequence of sine beats according to 8.3.2 and to IEC 60068-2-57, if not otherwise specified by the relevant specification (see Figure 5 and Annex A).

The acceleration to be applied to the vibration table is that determined in 13.2. The profile of the vibration amplitude can be accommodated in the frequency range below 1,6 Hz in a similar way as it is described in 12.2.5.

The test is carried out within the specified frequency range as stated in 5.4:

a) Equipment without critical frequencies

The test frequencies need to be applied over the specified frequency range as stated in 5.4 and in steps not greater than 1/2 oct; any predetermined test frequencies not covered also need to be applied. Tests using less than these frequencies should be justified.

b) Equipment with critical frequencies

The test frequencies are the critical frequencies and the predetermined test frequencies as ~~prescribed~~ specified by the relevant specification. Tests using less than these frequencies should be justified.

15.2.2 Sine-sweep test

~~The test is of a single-axis type. The acceleration to be applied to the vibration table is that determined by the performance level in 7.2.1 or 8.2.1. A logarithmic sweep rate of 1 octave/min and with the frequency range as stated in 5.3.~~

The test is of a single-axis type. The acceleration to be applied to the vibration table is that determined in 13.2. The profile of the vibration amplitude can be accommodated in the frequency range below 1,6 Hz in a similar way as it is described in 12.2.5.

One sweep cycle shall be applied, as defined in IEC 60068-2-6, with a logarithmic sweep rate of 1 oct/min and with the frequency range as stated in 5.4.

15.2.3 Time-history test

The test is of a single-axis type if not otherwise specified in the relevant specification. The test is performed by applying to the equipment a time history (see 3.34) to simulate the probable excitation of the equipment according to IEC 60068-2-57. It should be demonstrated that the test response spectrum is equal to or greater than the required response spectrum specified in Clause 14.

The duration of the test wave should be at least equal to the duration of the strong part of an earthquake. This is generally taken to be between 5 s and 10 s.

15.2.4 Other test wave forms

~~If other wave forms, such as time history, are used, the relevant testing procedure should be justified.~~

Other wave forms can be used if justified in accordance with the recommendations of 8.1.

16 Conditioning for the specific seismic class

It is recommended that the equipment should be tested according to the procedure described in the specific seismic class when the following parameters are defined by the relevant specification:

- a) a required response spectrum and, if applicable, the duration of the earthquake, or
- b) a required time history.

For this seismic class, it is normal to indicate the number of S1- and S2-earthquakes for which the effects are to be simulated, as well as the load conditions (other than seismic) to be taken into account.

17 Test wave selection for the specific seismic class

17.1 General

Whichever is the adopted wave form, the test response spectrum measured should dominate the required response spectrum and the total duration of the test should be at least equal to the strong part of the earthquake (see 8.2.1).

17.2 Multifrequency waves

In general, when the vibration spectrum is broadband, the test wave should be of the multifrequency type. However, certain exceptions are allowed after justification (see 7.3).

17.3 Single-frequency waves

Sine-sweep tests are not generally used for specific seismic class testing. Other single-frequency waves are allowed on specific cases (see 7.3).

18 Test waves for the specific seismic class

18.1 General

As far as test waves are concerned, Clause 8 applies with the additional requirements indicated in 18.2 and 18.3.

18.2 Single-frequency testing

18.2.1 General

The maximum level of this wave should be calculated by applying the wave factor as stated in 13.2.2 to the zero period acceleration of the required response spectrum. Moreover the profile of the vibration amplitude can be accommodated in the frequency range below 1,6 Hz in a similar way as it is described in 12.2.5.

18.2.2 Sine-sweep test

The sine-sweep test is performed by means of a continuous, low-level logarithmic frequency sweep cycle at a rate not exceeding 1 oct/min over a frequency range equal to or larger than that for which the equipment is to be qualified.

The maximum level of the test should be calculated by applying the wave factor as stated in 13.2.2 to the zero period acceleration of the required response spectrum. Moreover the profile of the vibration amplitude can be accommodated in the frequency range below 1,6 Hz in a similar way as it is described in 12.2.5.

18.2.3 Sine-beat test

The peak value of acceleration of the beat should be calculated by applying the wave factor as stated in 13.2.2 to the zero period acceleration of the required response spectrum. Moreover the profile of the vibration amplitude can be accommodated in the frequency range below 1,6 Hz in a similar way as it is described in 12.2.5.

18.2.4 Continuous sine test

The input signal should be of sufficient duration for at least five cycles to be at the maximum amplitude calculated by applying the wave factor as stated in 13.2.2 to the zero period acceleration of the required response spectrum (see Figure 7). Moreover the profile of the vibration amplitude can be accommodated in the frequency range below 1,6 Hz in a similar way as it is described in 12.2.5.

18.3 Other test wave forms

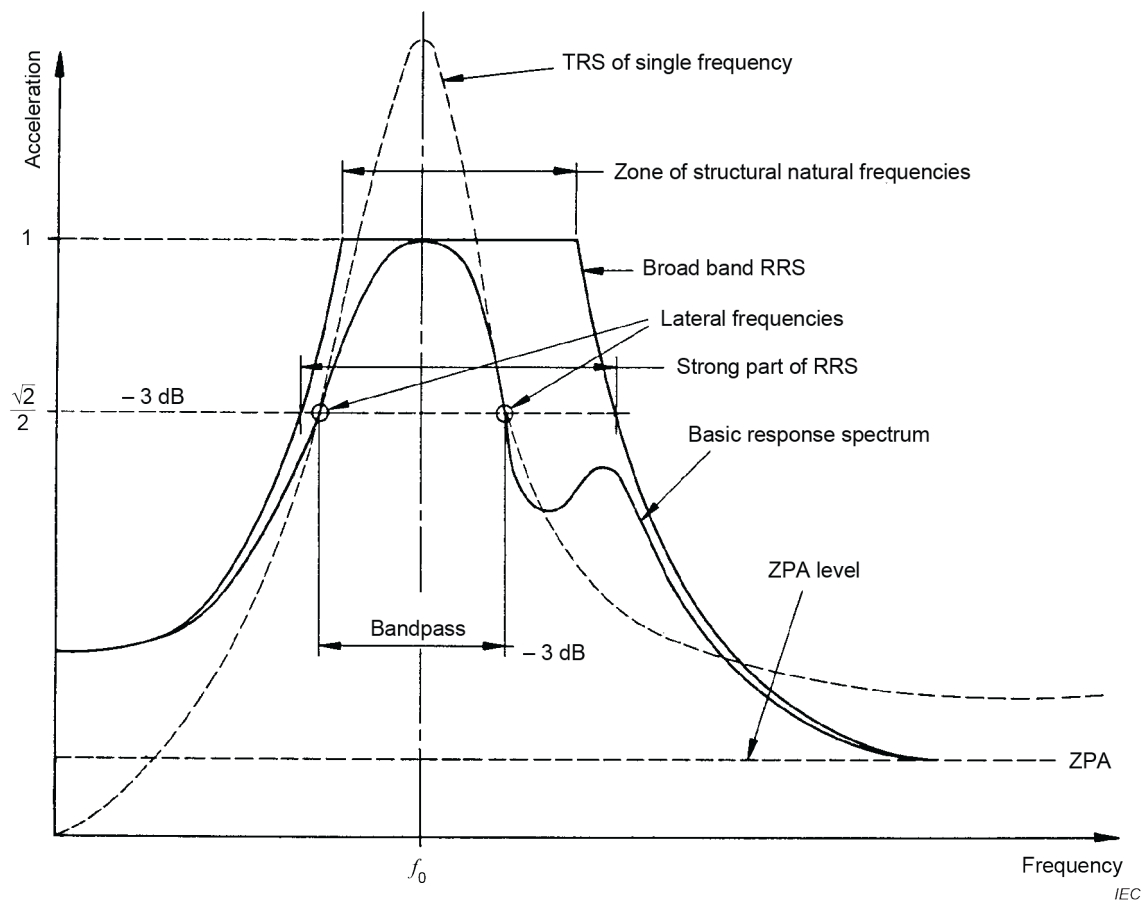
Other wave forms can be used if justified in accordance with the recommendations of 8.1.

19 Testing conditions for the specific seismic class

As far as test conditions are concerned, Clause 9 fully applies.

20 Single and multi-axis testing for the specific seismic class

As far as single and multi-axis testing is concerned, Clause 10 fully applies.



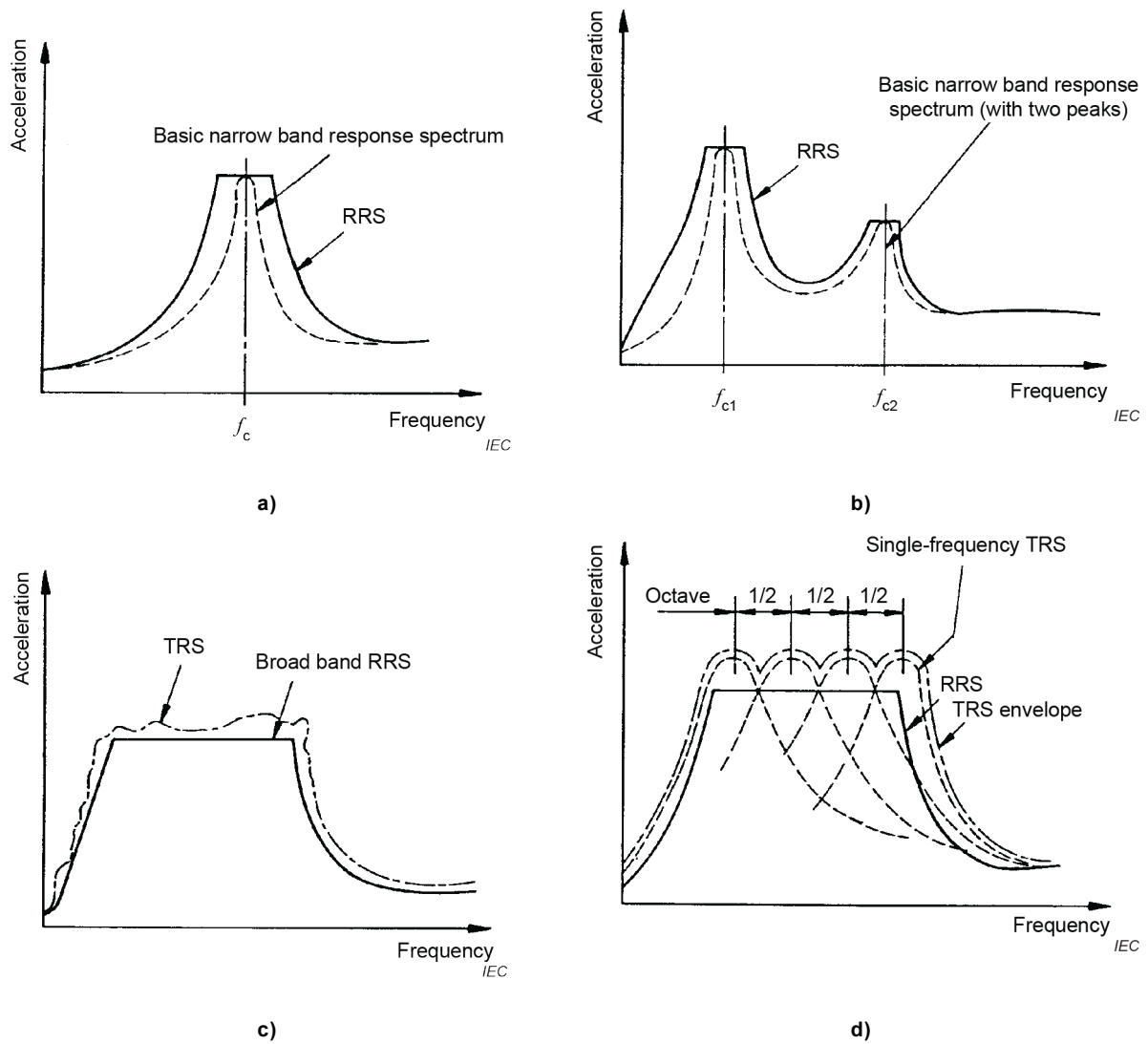
Key

TRS = test response spectrum

RRS = required response spectrum

ZPA = zero period acceleration

Figure 2 – Typical envelope response spectrum



Key

TRS = test response spectrum

RRS = required response spectrum

Figure 3 – Types of response spectrum envelopes

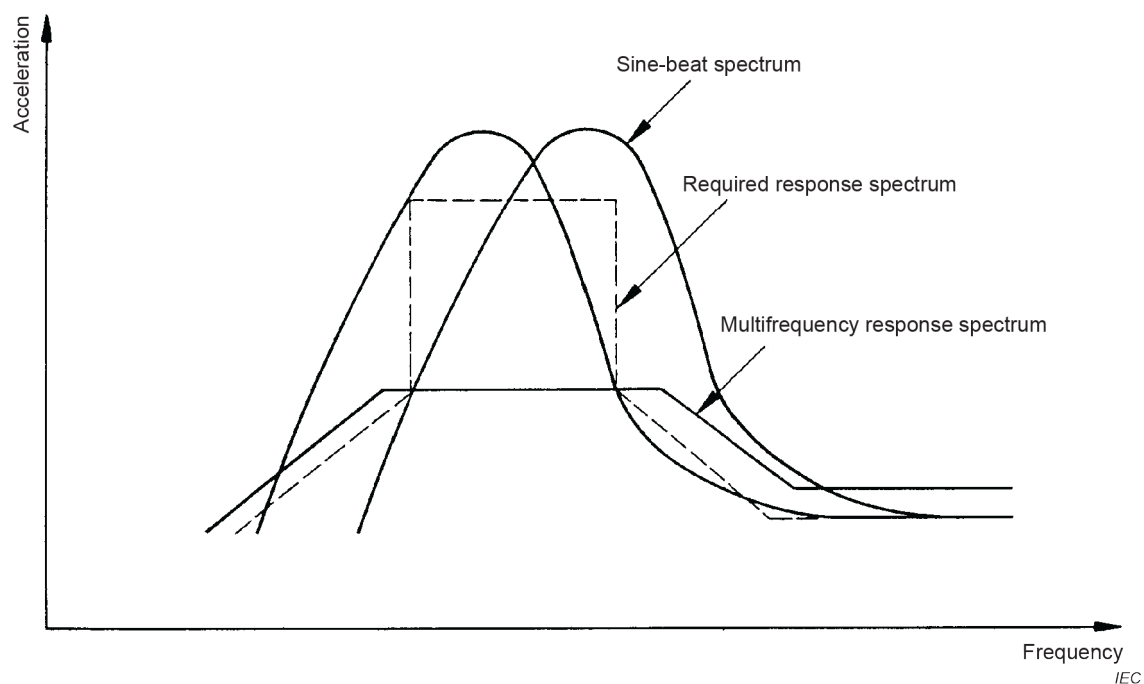


Figure 4 – Multifrequency response spectrum with superimposed sine beats

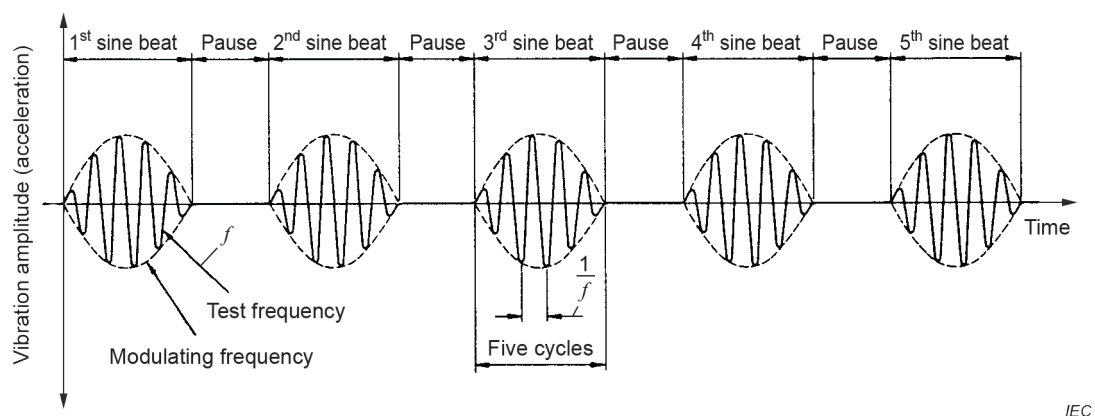


Figure 5 – Sequence of five sine beats with five cycles

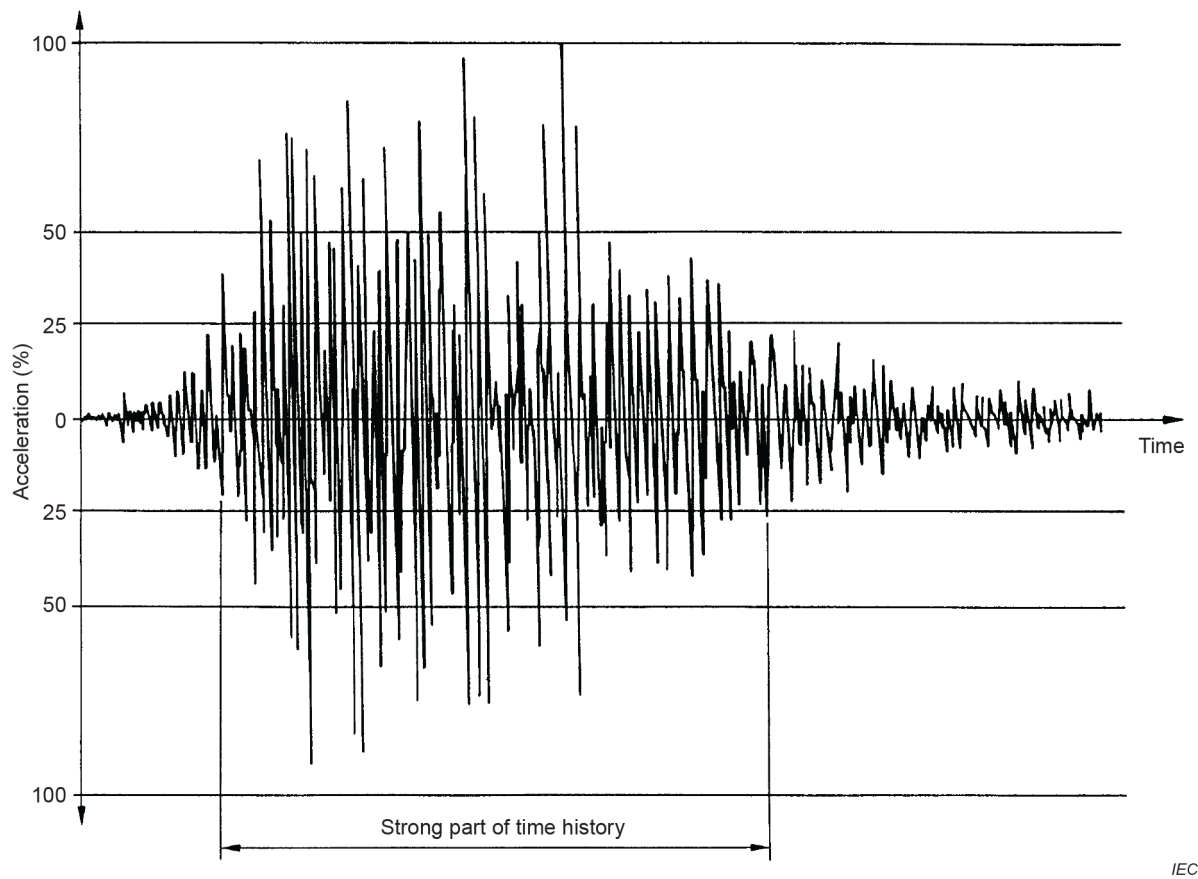
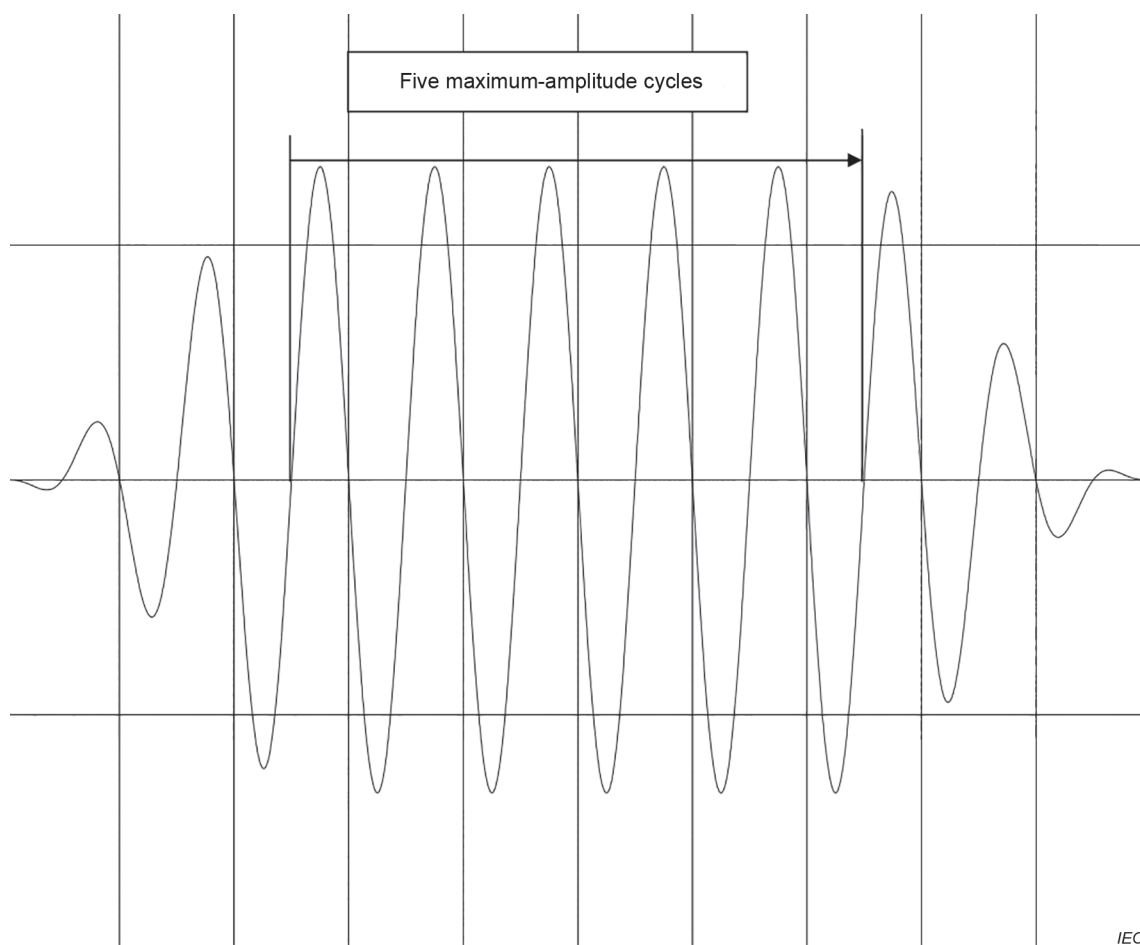
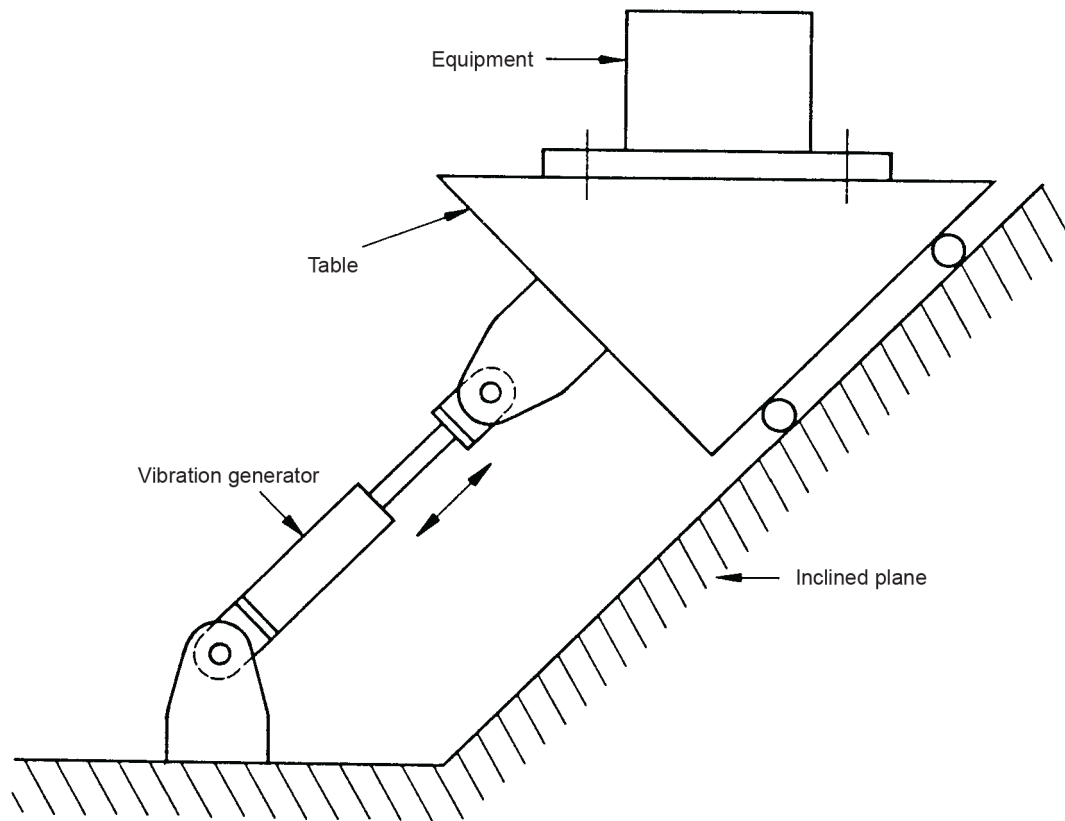


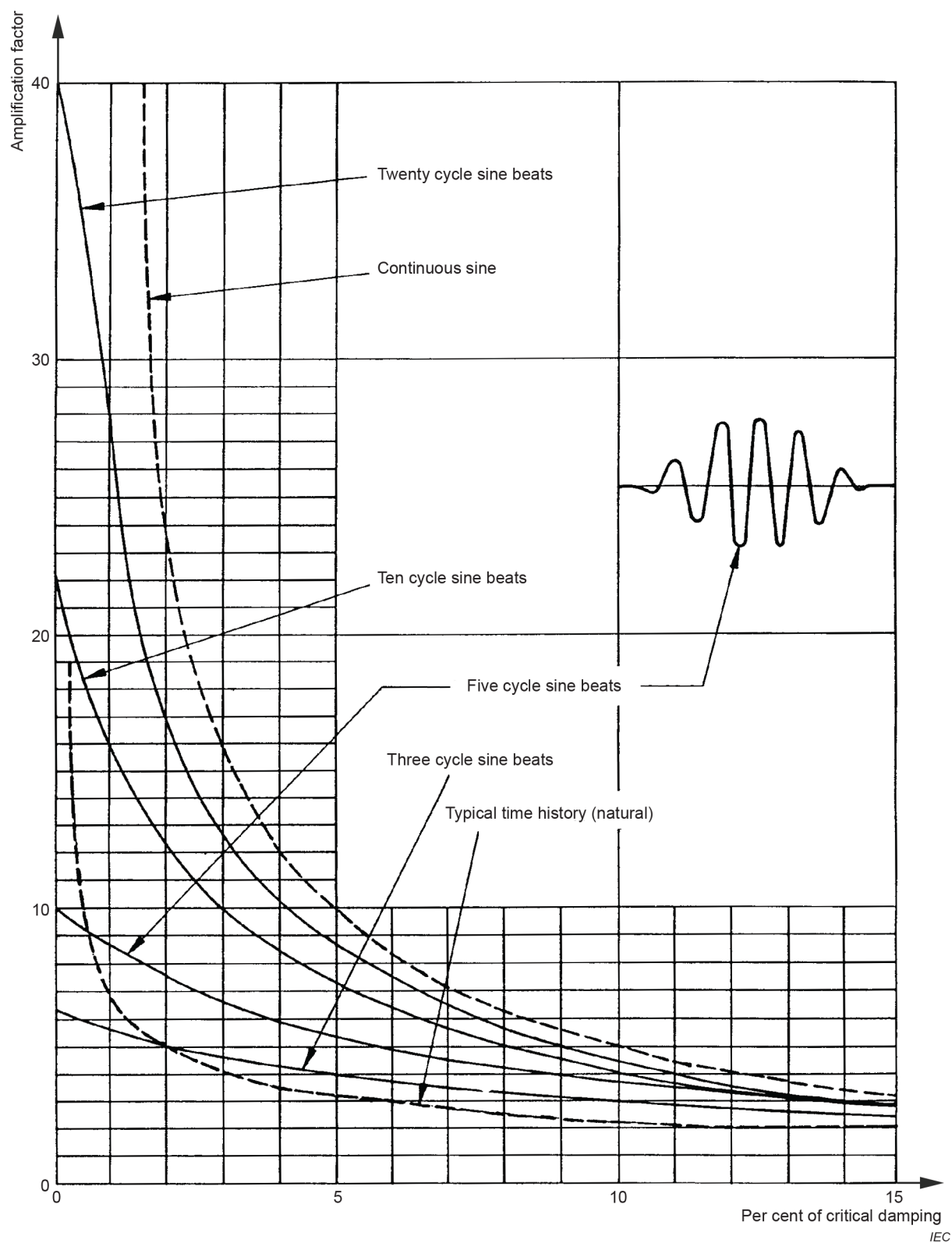
Figure 6 – Typical time history

**Figure 7 – Continuous sine**



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Figure 8 – Biaxial table along an inclined plane

**Figure 9 – Wave amplification factors**