IEC/IEEE 60980-344

Edition 1.0 2020-10

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Nuclear facilities – Equipment important to safety – Seismic qualification

Installations nucléaires – Équipements importants pour la sûreté – Qualification sismique

IEC/IEEE 60980-344:2020-10(en-fr)

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Nuclear facilities – Equipment important to safety – Seismic qualification

Installations nucléaires – Équipements importants pour la sûreté – Qualification sismique

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NUCLEAR FACILITIES – EQUIPMENT IMPORTANT TO SAFETY – SEISMIC QUALIFICATION

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It is published as an IEC/IEEE dual logo standard.

This new edition cancels and replaces the first edition of IEC 60980, published in 1989, and constitutes a technical revision. It also supersedes IEEE Std 344™-2013.

The text of this standard is based on the following IEC documents:

FDIS	Report on voting
45A/1323/FDIS	45A/1334/RVD

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

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- replaced by a revised edition, or
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INTRODUCTION

a) Technical background, main issues and organisation of the Standard

This standard is applicable to electrical equipment important to safety and its interfaces that are necessary to perform a safety function, or whose failure could adversely affect the safety functions of other equipment.

Electrical equipment in nuclear facilities shall meet its safety function requirements throughout its installed life. This is accomplished by a thorough programme of quality assurance, design control, quality control, qualification, production, transportation, storage, installation, maintenance, periodic testing, and surveillance. This IEC/IEEE standard specifically focuses on seismic qualification. This standard shall be used in conjunction with IEC/IEEE 60780-323.

Other aspects, relating to quality assurance, reliability, selection and use of electronic devices, design and modification of digital systems including Verification and Validation (V&V) activities are not part of this standard.

Industry research in the area of equipment qualification and decades of its application have greatly benefited this standard. Future activities of the working group to update this standard will consider the following:

- Experience and knowledge gained by using condition monitoring techniques,
- Knowledge gained on ageing mechanisms and kinetics,
- Improvement in the use of methods (test and analysis) described throughout the standard,
- Improvement of computation tools and modalities of use.

It is intended that the Standard be used by operators of NPPs (utilities), systems evaluators, equipment manufacturers, test facilities, qualification laboratories and by licensors.

b) Situation of the current standard in the structure of the IEC SC 45A standard series

IEC 61513 and IEC 63046 are first level IEC SC 45A documents that give guidance applicable to Instrumentation and Control (I&C) system and electrical power systems (at system level). They are completed by guidance relative to functional classification (IEC 61226).

These documents are supplemented by second level IEC SC 45A documents. Second level IEC SC 45A documents give guidance on hardware design (IEC 60987), software (IEC 60880 and IEC 62138), selection and use of HDL programmed integrated circuits (IEC 62566), requirements in order to reduce the possibility and limit the impact of common cause failure of category A functions (IEC 62340), qualification (IEC/IEEE 60780-323, IEC/IEEE 60980-344 and IEC 62003), control room design (IEC 62342) and cybersecurity (IEC 62645).

IEC/IEEE 60980-344 is a second level IEC SC 45A document which focuses on seismic qualification of electrical equipment important to safety.

For more details on the structure of the IEC SC 45A standard series, see item d) of this introduction.

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c) Recommendations and limitations regarding the application of this standard

This dual logo standard applies to all electrical equipment important to safety in accordance with IAEA terminology. If using IEEE standards, this standard applies to systems, structures, and components classified as safety or safety-related. If using the IEC 61226 and IEC 61513 classification guidance, this standard applies to all Class 1, 2 and 3 equipment. This document shall only be applied in accordance with the single selected classification scheme, either IEC or IEEE.

To ensure that the Standard will continue to be relevant in future years, the emphasis has been placed on issues of principle, rather than specific technologies.

d) Description of the structure of the IEC SC 45A standard series and relationships with other IEC documents and other bodies documents (IAEA, ISO)

The top-level documents of the IEC SC 45A standard series are IEC 61513 and IEC 63046. IEC 61513 provides general requirements for I&C systems and equipment that are used to perform functions important to safety in NPPs. IEC 63046 provides general requirements for electrical power systems of NPPs; it covers power supply systems including the supply systems of the I&C systems. IEC 61513 and IEC 63046 are to be considered in conjunction and at the same level. IEC 61513 and IEC 63046 structure the IEC SC 45A standard series and shape a complete framework establishing general requirements for instrumentation, control and electrical systems for nuclear power plants.

IEC 61513 and IEC 63046 refer directly to other IEC SC 45A standards for general topics related to categorization of functions and classification of systems, qualification, separation, defence against common cause failure, control room design, electromagnetic compatibility, cybersecurity, software and hardware aspects for programmable digital systems, coordination of safety and security requirements and management of ageing. The standards referenced directly at this second level should be considered together with IEC 61513 and IEC 63046 as a consistent document set.

At a third level, IEC SC 45A standards not directly referenced by IEC 61513 or by IEC 63046 are standards related to specific equipment, technical methods, or specific activities. Usually these documents, which make reference to second-level documents for general topics, can be used on their own.

A fourth level extending the IEC SC 45 standard series, corresponds to the Technical Reports which are not normative.

The IEC SC 45A standards series consistently implements and details the safety and security principles and basic aspects provided in the relevant IAEA safety standards and in the relevant documents of the IAEA nuclear security series (NSS). In particular this includes the IAEA requirements SSR-2/1, establishing safety requirements related to the design of nuclear power plants (NPPs), the IAEA safety guide SSG-30 dealing with the safety classification of structures, systems and components in NPPs, the IAEA safety guide SSG-39 dealing with the design of instrumentation and control systems for NPPs, the IAEA safety guide SSG-34 dealing with the design of electrical power systems for NPPs and the implementing guide NSS 17 for computer security at nuclear facilities. The safety and security terminology and definitions used by SC 45A standards are consistent with those used by the IAEA.

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IEC 61513 and IEC 63046 have adopted a presentation format similar to the basic safety publication IEC 61508 with an overall life-cycle framework and a system life-cycle framework. Regarding nuclear safety, IEC 61513 and IEC 63046 provide the interpretation of the general requirements of IEC 61508-1, IEC 61508-2 and IEC 61508-4, for the nuclear application sector. In this framework IEC 60880, IEC 62138 and IEC 62566 correspond to IEC 61508-3 for the nuclear application sector. IEC 61513 and IEC 63046 refer to ISO as well as to IAEA GS-R part 2 and IAEA GS-G-3.1 and IAEA GS-G-3.5 for topics related to quality assurance (QA). At level 2, regarding nuclear security, IEC 62645 is the entry document for the IEC/SC 45A security standards. It builds upon the valid high level principles and main concepts of the generic security standards, in particular ISO/IEC 27001 and ISO/IEC 27002; it adapts them and completes them to fit the nuclear context and coordinates with the IEC 62443 series. At level 2, IEC 60964 is the entry document for the IEC/SC 45A control rooms standards and IEC 62342 is the entry document for the ageing management standards.

NOTE 1 It is assumed that for the design of I&C systems in NPPs that implement conventional safety functions (e.g. to address worker safety, asset protection, chemical hazards, process energy hazards) international or national standards would be applied.

NOTE 2 IEC/SC 45A domain was extended in 2013 to cover electrical systems. In 2014 and 2015 discussions were held in IEC/SC 45A to decide how and where general requirements for the design of electrical systems were to be considered. IEC/SC 45A experts recommended that an independent standard be developed at the same level as IEC 61513 to establish general requirements for electrical systems. Project IEC 63046 is now launched to cover this objective. When IEC 63046 is published, this Note 2 of the introduction of IEC/SC 45A standards will be suppressed.

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NUCLEAR FACILITIES – EQUIPMENT IMPORTANT TO SAFETY – SEISMIC QUALIFICATION

1 Scope

This International Standard describes methods for establishing seismic qualification procedures that will yield quantitative data to demonstrate that the equipment can meet its performance requirements. This document is applicable to electrical, mechanical, instrumentation and control equipment/components that are used in nuclear facilities. This document provides methods and documentation requirements for seismic qualification of equipment to verify the equipment's ability to perform its specified performance requirements during and/or after specified seismic demands. This document does not specify seismic demand or performance requirements. Other aspects, relating to quality assurance, selection of equipment, and design and modification of systems, are not part of this document. As seismic qualification is only a part of equipment qualification, this document is used in conjunction with IEC/IEEE 60780-323.

The seismic qualification demonstrates equipment's ability to perform its safety function(s) during and/or after the time it is subjected to the forces resulting from at least one safe shutdown earthquake (SSE/S2). This ability is demonstrated by taking into account, prior to the SSE/S2, the ageing of equipment and the postulated occurrences of a given number of lower intensity operating basis earthquake (OBE/S1). Ageing phenomena to be considered, if specified in the design specification, are those which could increase the vulnerability of equipment to vibrations caused by an SSE/S2.

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

IEC/IEEE 60780-323, *Nuclear facilities – Electrical equipment important to safety – Qualification*[1,2]

IEEE Std 382™, *IEEE Standard for Qualification of Safety-Related Actuators for Nuclear Power Generating Stations*

3 Terms and definitions

The terminology and definitions used in this document are consistent with IAEA Safety Glossary[3].

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[3] IAEA safety glossary is available at https://www.iaea.org/publications/11098/iaea-safety-glossary-2018-edition

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

ISO, IEC, and IEEE 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
- IEEE Standards Dictionary Online: available at http://dictionary.ieee.org

The *IEEE Standards Dictionary Online* should be consulted for terms not defined in these databases.[4]

3.1
acceptance criteria
specified bounds on the value of a functional indicator or condition indicator used to assess the ability of a structure, system or component to perform its design function

Note 1 to entry: Value(s) of performance parameters and other criteria to demonstrate that equipment can perform the safety function(s) shall be identified.

[SOURCE: IAEA Safety Glossary, 2018]

3.2
assembly
comprising all electrical, mechanical, and structural components of the equipment including a common mounting and supporting structure

3.3
broadband response spectrum
response spectrum that describes motion in which amplified response occurs over a wide (broad) range of frequencies

3.4
Class 1E
safety classification of the electric equipment and systems that are essential to emergency reactor shutdown, containment isolation, reactor core cooling, and containment and reactor heat removal, or otherwise are essential in preventing significant release of radioactive material to the environment

Note 1 to entry: Users of this standard are advised that “Class 1E” is a functional term. Equipment and systems are to be classified Class 1E only if they fulfill the functions listed in the definition. Identification of systems or equipment as Class 1E based on anything other than their function is an improper use of the term and should be avoided.

[SOURCE: IEEE Standards Dictionary Online]

3.5
components
one of the parts that make up an equipment. A component may be a hardware component (e.g., wires, transistors, integrated circuits, motors, relays, solenoids, pipes, fittings, pumps, tanks and valve or a software component). A component may be made up of other components

Note 1 to entry: Components are items from which equipment is assembled.

Note 2 to entry: The terms component and device are interchangeable.

[SOURCE: IAEA Safety Glossary, 2018]

[4] *IEEE Standards Dictionary Online subscription* is available at: http://dictionary.ieee.org

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3.6
coherence function
comparative relationship between two time histories as a function of frequency

Note 1 to entry: It provides a statistical estimate of how much two motions are related, as a function of frequency.

Note 2 to entry: The numerical range is from zero for unrelated to +1,0 for related motions.

3.7
correlation coefficient function
comparative relationship between two time histories, as a function of time delay

Note 1 to entry: It provides a statistical estimate of how much two motions are related, as a function of time delay.

Note 2 to entry: The numerical range is from −1,0 for inversely related motions, zero for unrelated, to +1,0 for related motions.

3.8
critical damping
least amount of viscous damping that causes a single-degree-of-freedom (SDOF) system to return to its original position without oscillation after initial disturbance

[SOURCE: IEEE Standards Dictionary Online]

3.9
critical seismic characteristics
design, material, and performance characteristics of an equipment item that provide reasonable assurance that the item will perform its required function under seismic loads

3.10
cutoff frequency
frequency in the response spectrum where the zero period acceleration (ZPA) asymptote begins

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

3.11
damping
energy dissipation mechanism that reduces the amplification and broadens the vibratory response in the region of resonance

Note 1 to entry: It is usually expressed as a percentage of critical damping.

3.12
design basis events
postulated events used in the design to establish the acceptable performance requirements for the structures, systems, and components

Note 1 to entry: The postulated design basis event (DBE) conditions including specified high-energy line break, loss-of-coolant accident, main steam line break, and/or seismic events to be taken into account for plant design, during or after which the equipment is required to perform its safety function(s), shall be specified.

Note 2 to entry: Equipment shall be qualified for the duration of its operational performance requirement for each applicable DBE condition, including any required post-DBE operation period.

[SOURCE: IEEE Standards Dictionary Online]

3.13
earthquake experience spectrum
response spectrum that defines the seismic capacity of a reference equipment class based on earthquake experience data

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3.14
equipment important to safety
equipment that is part of a safety group and/or whose malfunction or failure could lead to undue radiation exposure of the site personnel or members of the public. Equipment including:

- Those structures, systems and components whose malfunction or failure could lead to undue radiation exposure of site personnel or members of the public;
- Those structures, systems and components that prevent anticipated operational occurrences from leading to accident conditions;
- Safety features for design extension conditions;
- Those features that are provided to mitigate the consequences of malfunction or failure of structures, systems and components.

Note 1 to entry: For usage consistent with IEC 61226, equipment important to safety are as follows:

- all I&C equipment performing Category A to Category C functions (in accordance with the IEC 61226 categorisation scheme),
- all electrical equipment needed to ensure emergency energy supply to this equipment in case of a loss of normal power supply,
- all electrical equipment needed to ensure ultimate energy supply in case of total loss of on-site power (if selected as design extension condition to be mitigated).

Note 2 to entry: For usage consistent with other IEEE documents and a Class 1E categorization; for equipment important to safety, qualification is essential for the following:

- equipment and systems that are essential to emergency reactor shutdown, containment isolation, reactor core cooling, and containment and reactor heat removal, or
- equipment that are otherwise essential in preventing significant release of radioactive material to the environment.

[SOURCE: IAEA Safety Glossary, 2018]

3.15
flexible equipment
equipment, structures, and components whose lowest resonant frequency is less than the cutoff frequency on the response spectrum

3.16
floor acceleration
acceleration of a particular building floor (or equipment mounting) resulting from the motion of a given earthquake

Note 1 to entry: The maximum floor acceleration is the zero period acceleration (ZPA) of the floor response spectrum.

3.17
fragility level
highest level of input excitation, expressed as a function of input frequency, acceleration and test duration, under which equipment remains able to fulfill its performance requirements

3.18
fragility response spectrum
response spectrum that defines the ultimate seismic capability of the equipment under test based upon fragility data

3.19
ground acceleration
acceleration of the ground resulting from the motion of a given earthquake

Note 1 to entry: The maximum ground acceleration is the zero period acceleration (ZPA) of the ground response spectrum.

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3.20
inclusion rules
rules that define the bounds of equipment included in a reference equipment class based on an acceptable range of equipment physical characteristics, dynamic characteristics, and functions for which seismic ruggedness has been demonstrated by experience data

Note 1 to entry: See A.2.4.2 and A.3.4.2.

3.21
independent items
components and equipment that:

a) have different physical characteristics, or

b) experience different seismic motion characteristics, e.g., different earthquakes, different sites, different buildings, or different orientations/locations in the same building

3.22
median-centered in-structure response spectrum
in-structure response spectrum developed using realistic damping and best estimate modeling parameters to obtain the most probable structural amplification that could realistically occur for the level of the specified earthquake ground motion

3.23
narrowband response spectrum
response spectrum that describes the motion in which amplified response occurs over a limited (narrow) range of frequencies

3.24
natural frequency
frequency(ies) at which a body vibrates due to its own physical characteristics (mass and stiffness) when the body is distorted in a specific direction and then released

3.25
operating basis earthquake
earthquake that could reasonably be expected to occur at the plant site during the operating life of the plant considering the regional and local geology and seismology and specific characteristics of local subsurface material

Note 1 to entry: It is that earthquake that produces the vibratory ground motion for which those features of the nuclear power plant, necessary for continued operation without undue risk to the health and safety of the public, are designed to remain functional.

3.26
performance requirement
requirement that imposes performance characteristics (conditions) on the functional and structural requirements of the equipment or system

3.27
power spectral density
mean squared amplitude per unit frequency of a waveform

Note 1 to entry: Expressed in acceleration spectral density versus frequency $[m/s^2]^2$ /Hz (g^2 /Hz) for acceleration waveforms.

Note 2 to entry: The characterization of random vibration typically results in a frequency spectrum of power spectral density (PSD), or Acceleration Spectral Density (ASD).

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3.28
prohibited features
design details, materials, construction features, or installation characteristics that have resulted in seismic induced failure or malfunction of the equipment to maintain its structural integrity and perform its specified function at earthquake or test excitations up to and including the defined seismic capacity level

3.29
proof testing
test used to qualify equipment for a particular application or to a particular requirement

[SOURCE: IEEE Standards Dictionary Online]

3.30
qualified condition
condition of equipment, prior to the start of a design basis event, for which the equipment was demonstrated to meet the design requirements for the specified service conditions

Note 1 to entry: This could include certain post-accident cooling and monitoring systems that are expected to remain operational.

3.31
qualified life
period for which a structure, system or component has been demonstrated, through testing, analysis or experience, to be capable of functioning within acceptance criteria during specific operating conditions while retaining the ability to perform its safety functions in accident conditions or earthquake

Note 1 to entry: At the end of the qualified life, the equipment shall be capable of performing the safety function(s) required for the postulated design basis and post design basis events.

[SOURCE: IAEA Safety Glossary, 2018]

3.32
reference equipment
equipment used to establish a reference equipment class

3.33
reference equipment class
group of equipment sharing common attributes as defined by a set of inclusion rules and prohibited features

3.34
reference site
site containing equipment or items used to establish a reference equipment class

3.35
required response spectrum
response spectrum issued by the user or the user's agent as part of the specifications for qualification or artificially created to cover future applications

Note 1 to entry: The required response spectrum (RRS) constitutes a requirement to be met and includes the test margin required by IEC/IEEE 60780-323.

3.36
resonant frequency
frequency at which a response peak occurs in a system subjected to forced vibration. This frequency is accompanied by a phase shift of response relative to the excitation

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3.37
response spectrum
plot of the maximum response, as a function of oscillator frequency, of an array of single-degree-of-freedom (SDOF) damped oscillators subjected to the same base excitation

3.38
rigid equipment
equipment, structures, and components whose lowest resonant frequency is greater than the cutoff frequency on the response spectrum

3.39
safe shutdown earthquake
earthquake that is based upon an evaluation of the maximum earthquake potential considering the regional and local geology and seismology and specific characteristics of local subsurface material. It is that earthquake that produces the maximum vibratory ground motion for which certain structures, systems, and components are designed to remain functional. These structures, systems, and components are those necessary to provide reasonable assurance of the following:

a) Integrity of the reactor coolant pressure boundary;

b) Capability to shut down the reactor and maintain it in a safe shutdown condition;

c) Capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposures comparable to applicable regulatory requirements.

3.40
safety function
a specific purpose that must be accomplished for safety of a facility to prevent or to mitigate radiological consequences in normal operation, anticipated operational occurrences and accident conditions

[SOURCE: IAEA Safety Glossary, 2018]

3.41
seismic capacity
highest seismic level for which required adequacy of performance has been verified

3.42
service conditions
actual physical states or influences during the service life of equipment, including normal operating conditions, abnormal operating conditions, design basis event conditions and design extension conditions

Note 1 to entry: In 2007 edition of IAEA safety glossary, accident conditions include both design basis accident and beyond design basis accident. This second notion has been replaced within IAEA by the notion of design extension conditions (DEC) [IAEA, SSR-2/1]. Equipment needed in case of DEC shall be qualified accordingly. It explains the need of changing the definition.

[SOURCE: IAEA Safety Glossary, 2007, modified: see Note 1 to entry.]

3.43
service life
period from initial operation to final withdrawal from service of a structure, system or component

[SOURCE: IAEA Safety Glossary, 2018]

3.44
Seismic Category I equipment
equipment designed to withstand the effects of the safe shutdown earthquake (SSE/S2) and perform its safety function during and/or after the SSE/S2 while maintaining structural integrity

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3.45
Seismic Category II equipment
equipment that is not required to function but whose failure could adversely affect the safety function of other equipment

Note 1 to entry: It should be designed to mitigate against failure that could adversely affect the performance of any Seismic Category I equipment or could result in incapacitating injury to occupants of the facility (e.g., control room) that could impact the safe operation of the plant.

3.46
seismic ruggedness
ability to resist the damaging effects of an earthquake imparted by robust design and manufacture

3.47
seismic vulnerability
physical and/or electrical characteristic that renders an equipment item susceptible to structural damage or malfunction from the effects of an earthquake

3.48
sine beats
continuous sinusoid of one frequency, amplitude modulated by a sinusoid of a lower frequency

3.49
sine dwell
continuous sinusoid at a single-frequency

3.50
stationarity
condition that exists when a waveform's amplitude distribution, frequency content, and other descriptive parameters are statistically constant with time

3.51
strong motion
time portions of the test acceleration time history where the first acceleration peak reaches and exceeds 25 % of the maximum peak value to the time when it falls for the last time below the 25 % of maximum peak value

3.52
structure diameter
diameter of a circle having the equivalent area of the facility's foundation

3.53
test experience spectra
test-based response spectra that define the seismic capacity of a reference equipment class

3.54
test frequency
frequency of the applied force by which equipment is excited during the test

3.55
test response spectrum
response spectrum that is developed from the actual time history of the motion of a seismic test table (commonly called a shake table)

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3.56
transfer function
complex frequency response function that defines the dynamic characteristics of a constant parameter linear system

Note 1 to entry: For an ideal system, the transfer function is the ratio of the Fourier transform of the output to that of a given input.

3.57
zero period acceleration
acceleration level of the high-frequency, nonamplified portion of the response spectrum

Note 1 to entry: This acceleration corresponds to the maximum peak acceleration of the time history used to derive the spectrum.

4 Abbreviated terms

ASCE	American Society of Civil Engineers
ASD	Acceleration Spectral Density
ASME	American Society of Mechanical Engineers
DBE	Design Basis Event
DEC	Design Extension Conditions
EES	Earthquake Experience Spectrum
FFT	Fast Fourier Transform
HELB	High Energy Line Break
HVAC	Heating, Ventilation, and Air Conditioning
IAEA	International Atomic Energy Agency
I&C	Instrumentation and Control
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
LOCA	Loss-of-Coolant Accident
OBE/S1	Operating Basis Earthquake
PSD	Power Spectral Density
QA	Quality Assurance
RMS	Root Mean Square
RRS	Required Response Spectrum
RSA	Response Spectrum Analysis
SC-I	Seismic Category I
SC-II	Seismic Category II
SC-II/I	Seismic Category II over I
SDOF	Single-degree-of-freedom
SRSS	Square Root of the Sum of the Squares
SRV	Safety Relief Valve
SSE/S2	Safe Shutdown Earthquake
TES	Test Experience Spectrum
TRS	Test Response Spectrum
U.S. NRC	United States Nuclear Regulatory Commission

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V&V Verification and Validation

ZPA Zero Period Acceleration

3D Three-dimensional

5 General discussion of earthquake environment and equipment response

5.1 General

This clause provides background information on earthquake behaviour and on the performance of equipment during simulated seismic events. Numerical values provided are typical and illustrative and should not be considered as standards. The flowchart provided in Figure G.1 illustrates the establishment of the seismic conditions from the earthquake to the equipment being qualified.

5.2 Earthquake environment

Earthquakes are initiated by rupture and slippage along geologic faults. Earthquakes produce three-dimensional (3D) random ground motions that are characterized by simultaneous but statistically independent horizontal and vertical components. The ground motion is typically broadband random and produces potentially damaging effects over a frequency range of 1 Hz to the cutoff frequency of the response spectra. The cutoff frequency is generally between 32 Hz and 50 Hz for a building structure subjected to an earthquake with the exception of hard rock regions of the Central and Eastern U.S. and other parts of the world which may experience energy content up to 100 Hz. The cutoff frequency may be greater if additional vibration induced loads are combined with seismic loads.

The strong motion portion of the earthquake may last from 10 s to 15 s, although the complete event may be considerably longer and produce a horizontal ground acceleration from 0,1 g to 0,6 g or higher. Duration of strong motion is dependent upon ground soil type, distance from the fault, energy released by the rupture, and slippage along a geological fault.

5.3 Equipment on foundations

The vibratory level of the ground motion (both horizontal and vertical) can be amplified or attenuated in foundation-mounted equipment. For any given ground motion, the alteration depends on the natural frequencies of vibration (soil, foundation, intermediate structure and equipment), the stiffness, the mass and the geometry of the building and intermediate structures and the damping mechanisms (damping coefficient may depend on frequencies considered). The broadband response spectra that typically describe the ground motion indicate that multiple-frequency excitation predominates.

5.4 Equipment on structures

The ground motion (horizontal and vertical) can be filtered by intervening building structures to produce amplified or attenuated narrowband motions within the structure. The dynamic response of equipment on structures can be further amplified or attenuated to an acceleration level many times more or less than that of the maximum ground acceleration, depending upon the equipment damping and natural frequencies. The narrowband response spectra that typically describe a building floor motion indicate that single-frequency excitation can be predominant. Filtering of in-structure motion can occur in flexible piping systems. For components mounted away from piping supports, the resultant motion can be predominantly single frequency in nature and centered near or at the resonant frequency of the piping system. This resonance condition can produce the most critical seismic load on components mounted on the pipe line.

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5.5 Interfaces and adverse interactions

Some equipment may have interfaces in an electrical or mechanical way or located in close proximity to each other. Seismic qualification of equipment shall consider installation features (e.g., support assembly and anchorage) and the potential for adverse seismic interactions (such as falling of overhead components, proximity impacts, differential displacements, spray, flood, or fire). If two pieces of equipment have mechanical or electrical interfaces, the effect of differential relative displacement of both equipment induced by earthquake shall be evaluated by considering resulting constraints at interface level and by proving (through analysis and/or test) there is no impact to performance function(s) required during and/or after seismic conditions. This demonstration may rely on specific test modalities (methods and procedures).

5.6 Simulating vibration induced by an earthquake

5.6.1 General

The main damaging potential of equipment caused by an earthquake is dependent on the ground motion excitation intensity (ZPA), the number of peak amplitude cycles, duration of excitation, and the excitation amplification caused by the structural response of the building and/or system upon which the equipment is installed. The goal of seismic simulation is to replicate the postulated earthquake environment in a realistic manner. The form of the simulated seismic motion used for the qualification of equipment by analysis or testing can be described by one of the following functions:

a) Response spectrum;

b) Time history;

c) Power spectral density (PSD).

The simulated seismic motion may be generated for the foundation, floor of the building, or substructure upon which the equipment is to be mounted. It is supplied by the user or the user's agent as a part of the specifications for that equipment (see Clause 6) or generated by others for generic applications.

Because of the directional nature of seismic motion and the filtered output motion of building and equipment structures, the directional components of the motion and their application to the equipment should be specified or accounted for in some other appropriate manner.

5.6.2 Response spectrum

The response spectrum provides information on the maximum response of single-degree-of-freedom (SDOF) oscillators as a function of oscillator frequency and damping when subjected to an input motion. The frequency content and the peak value of the input motion, that is, the ZPA, are indicated.

It is important to recognize that the response spectrum does not supply the following information:

a) The waveform or time history of the excitation that produced it;

b) The duration of motion (shall be defined in the qualification specification);

c) The dynamic response of any particular equipment.

The waveform of the excitation is generally determined by considering existing earthquake records and specificities of the site. The total duration of motion as well as the duration of strong motion shall be defined in the procurement or design specification. If strong motion duration is not specified, or no other site-specific information/requirement is specified, then the duration of strong motion for seismic testing should be a minimum of 15 s. Dynamic response of equipment is determined by considering its natural frequency and damping characteristics. If the equipment exhibits no amplification below the cutoff frequency, the equipment is considered to be rigid.

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5.6.3 Time history

A time history is a form of earthquake-induced motion defined in terms of acceleration as a function of time. The simulated motion is derived from existing or artificially generated earthquake records. For application at any floor, the time history record generated includes the dynamic filtering and amplification effects of the building and other intervening support structures. It is possible by knowing time history displays to determine, through discrete Fast Fourier Transform (FFT) analysis, acceleration as a function of frequency. There is no one-to-one relationship between a response spectrum and a time history, since a given response spectrum can be fulfilled by several different time histories.

5.6.4 PSD function

The Power Spectral Density (PSD) is the mean squared acceleration of the vibratory motion and is characterized in terms of the PSD as a function of frequency. PSD gives an indication of the frequency distribution of power in the acceleration signal (measure of signal power over the frequency range) and is typically used to characterize broadband stationary random vibration motion. For vibration data, PSD amplitude is in units of $[m/s^2]^2$ /Hz or g^2 /Hz. According to Parseval's theorem the square root of the total area under the PSD-curve is equal to the root mean square (RMS) acceleration calculated in the time domain. The PSD provides information regarding the excitation directly without including the effects on an array of SDOF oscillators as is done for the response spectrum. The PSD function does not define the exact waveform or duration of the excitation but enables significant frequency-dependent properties of the motion to be seen at a glance from one curve. The PSD allows application of relationships between excitation and response by way of the transfer functions for linear systems.

5.7 Damping

5.7.1 General

Damping is the generic name ascribed to the numerous energy dissipation mechanisms in a system. In practice, damping depends on many parameters, such as the structural system, mode of vibration, strain, normal force, velocity, materials, joint, and slippage. In linear vibration theory, the simplifying assumption is made that damping is purely viscous or proportional to the relative velocity of moving parts. Therefore, when a value of damping is associated with a practical system, it is usually assumed to be equivalent to viscous or linear. This is a convenient simplification relating real-world hardware behaviour, which may be nonlinear to some degree, with theoretical concepts that normally utilize linear methods of analysis.

It is reasonable to state that actual damping is nonlinear by nature. In most equipment, it is a function of response amplitude owing to such factors as internal friction within material, or at connections between components, or Coulomb-type sliding friction. For analytical purposes, these energy dissipation damping mechanisms may often be treated in terms of linear damping approximations if proper consideration is given to the fact that these approximations vary, sometimes significantly, with increasing response. As an example, the use of low-impedance testing to determine damping shall be exercised with caution since at strong motion shaking, indicative of significant earthquakes, the aforementioned factors may cause the real damping to be quite different and higher than that measured at low levels.

For equipment composed of an assembly of components, there is usually no single value of damping. Damping is associated with every part of the equipment, ranging from bolted or welded construction to uniform material. The value of damping may vary from place to place, depending on numerous factors. Therefore, when a value of damping is ascribed to equipment, it is common to give a range of typical values. Since each mode of vibration of a structure can, and most often does, have a different value of damping, a useful practice in analysis is to associate a value of damping to each mode of vibration of the equipment that is in the frequency range of interest.

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5.7.2 Measurement of damping

5.7.2.1 General

Linear vibration theory indicates that there are numerous methods for measuring damping. Considerable care shall be exercised in making the correlation between an idealized model and a practical system. For example, it is rarely possible to locate precise points in equipment that have exact correspondence with the lumped mass elements in a model. Some methods of calculating modal damping rely purely on modelling assumptions (e.g., modelling the structure through an assembly of single degree of freedom oscillators).

Damping calculated directly from the maximum response at the resonance peak measured at any point in the equipment and the magnitude of the sine-sweep input excitation is not acceptable since the response of points in equipment are usually determined by the mode shape vector and the participation factor for each vibration mode. The following methods for evaluating damping are commonly used but other justifiable methods may be used. They assume that a single mode of vibration can be excited in the equipment and that motion transducers are mounted at positions other than at a point of zero motion. In all cases, care should be exercised to determine whether damping nonlinearity with response amplitude is significant.

5.7.2.2 Damping by measuring the decay rate

The equivalent viscous damping can be calculated by recording the decay rate of the particular vibration mode. This procedure is often referred to as the logarithmic decrement method.

5.7.2.3 Damping by measuring the half-power bandwidth

The equipment should be excited with a slowly swept sinusoidal vibration. The response of any desired location in the equipment is measured and plotted as a function of frequency. From these response plots, the damping associated with each mode can be calculated by measurements of the width of the respective resonance peak at the half-power point. This procedure is often referred to as the half-power bandwidth method.

5.7.2.4 Damping by curve-fitting methods

The equipment is excited by swept sine, random, or transient excitation, and a response transfer function is developed. The modal damping is obtained by fitting a mathematical model to the actual frequency response data (transfer function). This curve fitting will smooth out any noise or small experimental errors.

5.8 Application of damping

5.8.1 General

Ranges of damping, measured as described in 5.7.2, are valuable data for the equipment designer. Damping is used differently in equipment qualification testing and analysis as described in 5.8.2 and 5.8.3.

5.8.2 Application of damping in testing

5.8.2.1 General

In testing, the equipment may be qualified by subjecting it to a simulated seismic motion as defined by the RRS. The response spectrum defines the seismic motion by way of the peak response of an array of SDOF damped oscillators.

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5.8.2.2 Broad band excitation

Since the oscillators are hypothetical, any practical value of critical damping, for example 5 %, may be employed in the RRS for testing, and it need not correspond to the actual equipment damping (note the distinction from the use of the RRS in analysis where the value of damping shall be related to the actual equipment). The application of the RRS and the test response spectrum (TRS) in selecting acceptable test motions is given in 8.6.1. The following relationships exist for the values of critical damping in the response spectra:

a) In comparing the RRS and the TRS, it is preferred that the damping in the two be the same.

b) In comparing the RRS and TRS when the damping is not the same, the following circumstances apply:

   1) When the damping for the TRS is greater than that for the RRS and the criteria in 8.6.1 are satisfied, then the qualification is acceptable, since under this circumstance it is conservative.

   2) When the damping in the TRS is less than that in the RRS, a conclusive statement is not possible without further evaluation. One possibility is to reanalyze the test motions to produce a TRS for an acceptable damping value and apply the criteria given in either item a) or item b1).

5.8.3 Application of damping in analysis

In analysis, a mathematical model is made of the equipment so as to predict the response to the seismic motion. The value of damping used in this model should correspond to the actual energy dissipation in the equipment to enable the response to be accurately predicted. An alternative approach is to use a conservative value of linear damping to obtain a conservative estimate of response. In any case, there is a need to know the ranges of damping for the specific equipment and the nature of nonlinearities and their effect on the response. Appropriate values of damping may be obtained from tests or other justifiable sources.

Generally, most treatment of structural systems assumes viscous damping; however, certain cabinets or housings may exhibit nonviscous damping. The treatment of such a problem is analytically complex and should be performed using appropriate techniques.

Nonlinearities may exist in addition to those associated with damping. See 11.3 for details.

6 Seismic qualification requirements

6.1 General

Qualification is a formal process by which the required demonstration is achieved in an unambiguous recorded and traceable manner so that its applicability and validity can readily be confirmed. The requirements for qualification are typically defined in a procurement or design specification. The specification identifies in detail the requirements for qualification along with the applicable codes and standards to be met. Throughout this document, it is assumed that the requirements are well-specified, understood and provided as part of the equipment qualification specification. The specification shall include special requirements for test, analyses, similarity, or experience-based methods. Specification for a seismic qualification programme shall include the following elements as a minimum:

– specification of equipment to be qualified;

– identification of ageing conditions that need to be taken into account in the qualification process;

– specification of the seismic requirements;

– specification of acceptance criteria.

Once these requirements have been defined, it can be determined whether qualification will be obtained by test, analysis, similarity, experience-based, or a combination thereof.

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Methods used to qualify equipment are further described in Clause 7.

6.2 Specification of equipment to be qualified

The equipment shall be clearly specified. The specification shall include:

– Physical description of equipment, its make/model/type number, drawing, issue number, physical/performance characteristics, etc.;
– Identification of important to safety devices and circuitry and their safety function(s), during and after ageing and SSE/S2;
– Boundaries of the equipment to be qualified (including spatial constraints or potential interaction constraints);
– Electrical and mechanical loads and interfaces;
– Installation and mounting details including orientation up to the first support;
– Environment in which the equipment is required to perform its safety function(s);
– Operating and performance conditions of equipment.

6.3 Specification of ageing condition

Ageing conditions due to plant environmental (normal, abnormal, accident) and operational conditions that need to be taken into account in the qualification process shall be identified with respect to component identification and condition of use of equipment. Condition monitoring (e.g., IEC/IEEE 60780-323) in conjunction with ageing conditions to evaluate degradation, if considered, should only be applied if there is a known relationship between the ageing degradation of the component monitored and the degradation of the equipment's safety function. Margins applied during ageing testing shall be specified (e.g., IEC/IEEE 60780-323). See Clause 8 for additional information.

6.4 Specification of seismic requirements

These requirements shall be clearly specified. They shall include at least:

– Time duration of strong motions for the earthquake (see 5.6.2);
– Horizontal and vertical seismic motions (e.g., RRS, PSD, time history) associated with the OBE/S1 and SSE/S2 levels for seismic testing;
– When an RRS is not provided, the maximum accelerations of either the floor or structural motion at all significant frequencies, needs to be specified, or a time history;
– Number of OBE/S1 to which equipment shall be qualified prior to SSE/S2 shall be justified for each site or five OBEs/S1s shall be used;
– Details of multiple SSE/S2 (if required);
– Relative constraints/displacement at mechanical/electrical interfaces of equipment (other than mounting interfaces) due to earthquake;
– Margin applied to OBE/S1 and SSE/S2 levels for seismic testing. See IEC/IEEE 60780-323 for additional details.

6.5 Specification of acceptance criteria

The evaluation of equipment operability should be based on a pre-specified set of acceptance criteria for qualification of equipment. The following minimum conditions shall not occur, as far as applicable:

a) Structural failure or deflection which would inhibit or prevent performance of any function that is important to safety;
b) Loss of output signal;
c) Spurious or unwanted output;
d) Significant drift of set point or trip setting by considering specified accuracy;

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e) Loss of required performance characteristics (functional and electrical);

f) Loss of pressure boundary integrity.

These acceptance criteria shall be defined before and after ageing tests as defined in Clause 8, and before, during, and after earthquake tests. Baseline functional and post-seismic functional tests shall be performed at the beginning and at the end of the programme, respectively, in order to obtain accurate benchmark data on the performance of the specimens being tested. The number and type of tests performed during baseline functional testing may be different than those tests performed during post-seismic functional testing.

7 Seismic qualification approach

7.1 Safety function

The seismic qualification of Seismic Category I (SC-I) equipment shall demonstrate an equipment's ability to:

- perform its required safety function(s) during and/or after the time it is subjected to the forces resulting from an SSE/S2.
- avoid spurious operation during the time it is subjected to the forces resulting from an SSE/S2, that could jeopardize the fulfilment of safety function(s).

Seismic Category I equipment being qualified shall demonstrate that it can perform its safety function during and/or after an earthquake. The required safety function(s) depends not only on the equipment itself but also on the system and plant in which it is to function. The safety function(s) during the earthquake may be the same but is often different from the safety function(s) required after the earthquake. For example, an electrical device may be required:

a) to have no spurious operations during the earthquake, or

b) to perform an active function(s) both during and/or after the earthquake, or

c) to survive during the earthquake and perform an active function after the earthquake, or any combination of these.

Another device may only be required to maintain structural integrity during the earthquake. Throughout this standard, it is assumed that the requirements given here are understood and that the definition of the safety function(s) is provided as part of the equipment qualification specification. It is the responsibility of the user to verify that the qualification approach selected complies with the requirements.

When the safety function(s) of equipment requires a demonstration of operability during the earthquake, it shall be demonstrated during the strong motion portion of the qualification simulation.

For equipment being qualified by test and having more than one safety function, multiple SSE/S2 may be required to demonstrate satisfactory performance of all the safety function(s). In addition, the equipment shall withstand the effects of a number of OBEs/S1s [see 9.1.7, 11.5, A.2.4.2 item b), and Clause A.3] prior to the application of an SSE/S2. Five OBE/S1 tests are usually considered to be sufficient in the absence of more accurate information.

7.2 Seismic qualification methods

The most commonly used methods for seismic qualification are contained in this document. The seismic qualification methods are grouped into the following five general categories:

a) Test (under simulated seismic conditions);

b) Similarity (considering seismic tests on similar equipment);

c) Analysis;

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d) Combination of test and analysis;

e) Experience-based data.

Illustrative flowcharts are given in Annex G.

The seismic testing, when part of an overall qualification programme, shall be performed in its proper sequence and with appropriate test margins applied as indicated in IEC/IEEE 60780-323, and care should be taken to identify and account for significant ageing mechanisms with test margins as discussed therein. Within these guidelines, it shall be demonstrated that the equipment is capable of performing its safety function throughout its qualified life, including its functional operability during and/or after an SSE/S2 at the end of its qualified life.

The similarity method of qualification relies on comparison to previous testing on similar equipment. Qualification test and analytical data is extrapolated from a reference equipment based on similarity to excitation (seismic environment), physical system, and functionality of the equipment. Similarity of equipment physical system and functionality are demonstrated based on a review of information related to design, operation, procurement, manufacturing and testing to verify the candidate equipment is operating within established specifications to the qualified reference equipment.

The analysis method is intended for equipment where structural integrity alone is sufficient to demonstrate its design-intended function considering seismic and other static and dynamic loads.

The qualification of equipment through experience-based data (see Annex A) is considered as a specific sub-case of similarity (method b).

Each of the preceding methods, or other justifiable methods, may be adequate to verify the ability of the equipment to meet the seismic qualification requirements including margin to account for uncertainties. The choice should be based on the practicality of the method for the type, size, shape, and complexity of the equipment configuration, whether the safety function can be assessed in terms of operability or structural integrity alone, and the reliability of the conclusions. Whatever the method chosen, care should be taken to identify and account for ageing mechanisms (Clause 8) that could have influence on equipment degradation states and behaviour during and after an earthquake.

Seismic Category II (SC-II) equipment whose continued function is not required during or after an earthquake but whose failure or interaction could reduce the functioning of SC-I equipment that is in close proximity to an unacceptable level shall be capable of maintaining structural integrity so that seismic events up to and including the SSE/S2 would not cause such a failure of the SC-I equipment. The seismic qualification methods in this standard can be used to evaluate SC-II equipment. SC-II equipment in proximity to SC-I equipment is typically referred to as Seismic Category II over I (SC-II/I) equipment.

8 Ageing

8.1 General

In compliance with IEC/IEEE 60780-323, an assessment of equipment ageing effects in connection with a test programme is required to determine if ageing has a significant effect on the ability of the equipment to perform its safety function(s). Equipment important to safety determined to have significant ageing mechanisms are required to be aged to the end of their service life prior to the Design Basis Events (DBE) testing. For equipment with significant ageing mechanisms a qualified life shall be established. The qualified life determination shall consider degradation of equipment capability prior to, during and in post-accident conditions as applicable. Inherent in establishing a qualified life is that a qualified condition is also established. This qualified condition is the state of degradation for which successful performance during a subsequent DBE was demonstrated.

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In compliance with IEC/IEEE 60780-323, for equipment without significant ageing mechanisms in a mild environment, age conditioning and establishing a qualified life is not required if an evaluation or ageing analysis is performed which determines that the service conditions within the service life of the equipment do not result in increased susceptibility to failure during a seismic event.

8.2 Thermal ageing

Thermal ageing shall be considered if it could change the mechanical property of constitutive materials of equipment (tightness, damping factor). Special attention shall be put on thermal ageing of polymers for insulation, joints and connectors. Thermo-oxidation can lead to embrittlement of material. Thermal ageing may be simulated through an accelerated thermal ageing test. Specific attention should be put on the choice of accelerating temperature and associated duration of such a test.

8.3 Radiation ageing

Radiation ageing shall be considered if it could change the mechanical property of constitutive materials of equipment. Special attention shall be put on ageing under irradiation of polymers that are located in containment and of metals that are submitted to high neutron fluence (e.g., vessel, instrumentation yoke nearby the core).

8.4 Material degradation and corrosion

Material degradation and corrosion of equipment shall be studied with due consideration. Temperature/humidity tests (for normal and abnormal environmental conditions) and chemical test(s) (as needed) shall be performed to take into account these phenomena.

8.5 Mechanical or electrical cycle ageing

Wear out under mechanical or electrical cycles shall be taken into account for any equipment whose mobile parts are frequently solicited during plant operation. Operation tests may be performed to take into account these phenomena. Modalities of those tests depends strongly on technology considered and are not described any further in this document.

8.6 Vibration ageing

8.6.1 General

Seismic qualification tests on equipment designed to show adequacy of performance during and/or following an SSE/S2 shall be preceded by tests that produce the equivalent fatigue effect of the number of OBEs/S1s specified for each site and the equivalent fatigue effects of specified in-plant vibration resulting from normal and transient plant operating conditions. It is suggested that the equivalent conditions consistent with the service life of the facility be simulated if possible; however, as a minimum, the equivalent fatigue effects consistent with the qualified/service life of the equipment shall be achieved.

The purpose of the vibrational ageing is to show that the levels of normal and transient vibration, associated with plant operation and the lower intensity earthquake (OBE/S1) that has a higher probability of occurrence, will neither adversely affect an equipment's performance of its safety function nor cause any condition to exist that, if undetected, would cause failure of such performance during a subsequent SSE/S2. These tests may also provide part of the ageing requirement of IEC/IEEE 60780-323.

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Vibrational ageing tests shall be performed preceding the OBE/S1 and SSE/S2 tests. Plant operation vibration test is generally performed in accordance with IEC 60068-2-6 (Test Fc) or IEEE Std 382™ unless otherwise justified. Vibrational ageing requirements such as sweep rate, range for sweep cycle, number of sweep cycles or time duration, and specified amplitude are defined in the test specification. Testing is normally performed on each axis separately by sweeping frequency from a lower bound frequency (e.g., 1 Hz) to an upper bound frequency "F Hz" that is at least twice greater than the cutoff frequency. Unless otherwise specified the sweep rate shall be 1 octave/min.

8.6.2 Ageing from non-seismic vibration conditions

Portions of the seismic tests may be used to provide part of the ageing requirement of IEC/IEEE 60780-323 for the specified non-seismic related vibration due to normal and transient plant operating conditions and in-plant vibration. It shall be demonstrated that the equivalent amplitude response cycles achieved in the seismic tests, excluding those required for the seismic low-cycle fatigue requirement, exceed the amplitude response cycles required for the non-seismic vibration loads (see 9.6.5 and Annex E for discussion on equivalent cycles). Credit may be taken for any test preceding the SSE/S2.

However, special care shall be taken in establishing equivalency when the non-seismic vibration loads, such as a safety relief valve (SRV) discharge load, contain significant frequency content greater than the cutoff frequency, or when the applied non-seismic forcing function is substantially different from that achieved during the base excited motions simulated in the tests discussed in 9.2 through 9.5. In the latter case, the non-seismic loading could result in excitation of equipment vibration modes not excited by base motions.

The amplitude response cycles may be determined by analysis as discussed in Clause 11 or by short tests conducted with the equipment in a simulated non-seismic vibration condition.

8.6.3 Hydrodynamic loads

Some of the equipment in nuclear power plants is subjected to vibratory loads that are categorized as hydrodynamic loads (including the loads associated with SRV discharge and the Loss-of-Coolant Accident (LOCA). Hydrodynamic loads affect the ageing requirement and thus the testing requirement.

Since the structural integrity and operability of the components shall be evaluated under the specifications for seismic and other vibratory loads, a combined spectrum may be required for the RRS, that is, OBE/S1 or SSE/S2 combined with vibratory loads. The RRS for testing may be obtained by an appropriate combination of the individual spectra, such as square root of the sum of the squares (SRSS) or absolute sum. This situation can result in changes to the RRS for test including increasing the cutoff frequency.

8.6.4 Seismic ageing (OBE/S1)

Seismic qualification tests on equipment shall include OBE/S1 tests, preceding the SSE/S2, that produce a number of equivalent maximum peak cycles (at least as given in 9.6.5) for each specified seismic event. See 9.1.7 for further discussion.

9 Testing

9.1 General

9.1.1 Test programme

Equipment shall be tested simulating operating conditions to either the levels dictated by expected service requirements or their ultimate capability. The devices shall be mounted on the shake table in a manner that dynamically simulates the recommended mounting. The test facility is responsible to judge if the shake table is suitable to perform the specified vibration test.

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Some types of equipment, such as cabinets with bolted doors or panels, produce conditions such as rattling, chatter, drumming, or banging. These conditions are transmitted throughout the equipment and may result in increased acceleration levels at frequencies higher than the original frequencies that were input to the shake table. A low-frequency input thereby may produce a high-frequency response that may adversely affect devices mounted in the equipment and shall be considered in their qualification. When this is the case, assembly testing is preferred. Alternatively, the device mounting location RRS shall be obtained from an assembly test that includes the effects of these conditions in the time history by analyzing the motion to sufficiently high frequencies. Devices may then be tested using the methods described in 9.4 or any other justifiable method. When such conditions are present, additional provisions should be included to demonstrate that the time history for device testing is conservative in terms of duration, amplitude, and frequency content. Methods of demonstrating adequate frequency content include plotting a TRS or a PSD to higher frequencies.

Methods are presented in this clause that can be used to seismically qualify equipment by test. The flowchart provided in Figure G.2 illustrates seismic qualification by testing. Seismic tests should be performed by subjecting equipment to vibratory motion that conservatively simulates that postulated at the equipment mounting during an earthquake. The details of the test procedures given herein constitute the more common methods currently in use but do not preclude other justifiable methods. It is outside the scope of this document to give the theoretical basis for the test procedures. These may be found in the literature on dynamics. One practical problem that arises when attempting to establish the tests to be used to qualify equipment is the choice of the earthquake environment. Many factors should be considered (see Clause 5). These involve the location of the equipment, the nature of the equipment, the nature of expected earthquakes, and others. An additional consideration is whether the equipment is to be used in one application or many. When the equipment is used in only one application, the seismic motion can be specified and the qualification test can be chosen to meet the specification (proof testing). When the equipment is used in many applications, the test should be designed to qualify the equipment for those applications through multiple individual proof tests or generic testing. Proof testing and generic testing are discussed further in 9.2. Fragility testing, conducted to determine the limit of the equipment's capabilities, is discussed in 9.3. Another factor to be considered is the multi-directional nature of earthquakes. Equipment should be tested to conservatively account for these multi-directional effects. These are discussed in greater detail in 9.6.6.

Another practical problem arises in attempting to describe tests for devices (relays, motors, sensors, etc.) and for complex assemblies such as control panels. In the first case, it is reasonable to assume that the device can be subjected to seismic tests while simulating the operating condition and monitoring its performance during the test; however, in the case of complex equipment such as control panels, this may not be true. Such panels usually contain many devices that are part of several systems extending over many other panels located in various parts of the facility. To test such panels while in an operating condition may be impractical, and in such cases, the following alternate approach is recommended. Apply the appropriate vibration input (RRS) to the panel with the actual devices installed but inoperative or with the device's dynamic properties simulated. The dynamic response at the devices' locations is measured and is used as input criteria to qualify the devices separately in an operating condition (see 9.4 and 9.5). The purpose of installing the nonoperating devices is to simulate the dynamic characteristics the panel will have when in use.

It is noted that equipment that has been shake table tested, in general, should not be installed in a plant, unless it can be demonstrated that the accumulated stress cycles already experienced by the equipment will not degrade its ability to perform its safety function(s) under all postulated conditions of use (including an earthquake).

Regardless of whether devices or assemblies are to be proof tested, generically tested, or fragility tested there are certain common considerations. These are listed in 9.1.2 through 9.1.6.

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Specified acceptance criteria shall be met before, during and/or after the SSE/S2 tests. Equipment functionality during and/or after the SSE/S2 is addressed in the following subclauses. It is important to note that equipment with more than one safety function or operating mode may require additional SSE/S2 testing to demonstrate satisfactory performance of all safety functions and operational modes.

9.1.2 Mounting

The equipment to be tested shall be mounted on the shake table in a manner that simulates the intended service mounting. The mounting method should be the same as that recommended for actual service and should use and document the recommended bolt size and type, torque, configuration, or the weld pattern, size and type, etc. The effect of electrical connections, conduit, sensing lines, and any other interfaces shall be considered and included in the setup up to the first interface support unless otherwise justified. The orientation of the equipment during the test shall be documented and shall be the only one for which the equipment is considered qualified unless adequate justification can be made to extend the qualification to an untested orientation. The method of mounting the equipment to the shake table shall be documented, and a description of any interposing fixtures and connections shall be provided. The equipment when installed to an interposing test fixture shall be mounted in a manner to replicate the intended mounting and orientation at the plant site. Interposing fixtures, when used, shall be such that their use will not filter out or change any frequencies from the input motion. The effect of such fixtures and connections (including gravitational acceleration effects) shall be evaluated and addressed in the report when they are only used during qualification and not for in-service mounting to ensure differences do not adversely affect the safety function(s) of the equipment.

9.1.3 Monitoring

Functional and vibrational response parameters shall be considered for monitoring equipment during vibration testing.

Sufficient monitoring instrumentation shall be used to evaluate the functionality of the equipment before, during, and following its vibration test exposure. Details of executing this requirement shall be obtained from documents that pertain to the specific equipment. It should be noted that compliance with this requirement often takes a significant effort in test planning and implementation.

Sufficient vibration monitoring instrumentation should be used to determine the applied vibration levels. If required, deflections and/or displacements at relevant locations and at the top of the assembly shall be determined. It is recommended that vibration response monitoring instrumentation also be used to determine the response of the equipment along all three orthogonal input axes simultaneously, at those points within the structure that reflect the equipment response associated with its structural integrity and its functionality. This data may be useful for structural design analysis, functionality failure analysis, future design changes or device change-out, determining in-structure response spectra, and other applications. The location of the vibration sensors and the functional monitoring system(s) shall be documented.

9.1.4 Loading

Seismic qualification tests on equipment shall be performed with the equipment subjected to normal operating conditions (electric loads, mechanical loads, thermal loads, pressure, etc.) and other plant design basis conditions that may adversely affect the safety function. Simulation of these loads is acceptable if it is justified. If not included as part of the test, the absence of the loading effect shall be justified.

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9.1.5 Refurbishment

9.1.5.1 General

Any refurbishment performed on equipment during a test programme may be classified into maintenance or repair according to its degree. Examples of maintenance activities include calibration of relays and retorquing of hardware. Examples of repairs include welding or rewelding of portions of an equipment, replacing damaged components, such as sheared bolts, and retightening loose electrical terminals.

Equipment devices which fail to give satisfactory test results shall be repaired, modified or replaced but in any case, the entire test of the equipment shall be repeated and satisfactory results obtained, unless justified otherwise. If devices are replaced during a test, they shall be replaced and aged if necessary, according to general criteria given by IEC/IEEE 60780-323.

9.1.5.2 Inspection

Inspections shall be performed at the beginning and throughout the test sequence to ensure that the test sample(s) are not damaged due to transportation, handling, or testing and to verify compliance with the specifications. Appropriate precautions should be taken if disassembly is required for proper inspection. Description of the physical condition of equipment shall be included in the qualification documentation. The condition of electrical insulation, mechanical parts, bearings, lubricants, electrical contacts, wiring, gear drive trains, linkages and other related constituents shall be recorded.

Upon completion of testing, the equipment shall be visually inspected, including disassembly when required, and a description of its physical condition and verification of performance condition shall be included in the qualification documentation.

9.1.5.3 Maintenance

When maintenance is required, the severity of the problem shall be determined and documented in detail in the test report. Maintenance may be performed and testing continued. When maintenance is performed during OBE/S1 testing, it becomes part of the post-earthquake field maintenance checks and procedures for the equipment.

9.1.5.4 Repairs

When repairs are necessary during the OBE/S1 test, retest is required unless justified otherwise. When repairs are necessary during or after the SSE/S2 test, the general requirement is to retest unless justified otherwise. When the condition requiring repair during the SSE/S2 tests does not interfere with the performance of the safety function, during or after the test, and the SSE/S2 can be shown not to be cumulative due to testing in other axes and does not unacceptably affect equipment performance in subsequent qualification tests, such as the Loss-of-Coolant Accident (LOCA), then continuation without retest may be justifiable. When repairs constitute a design change, the equipment shall be retested, unless justified otherwise. When repairs are made, the details shall be included in the test report.

9.1.6 Exploratory tests

9.1.6.1 General

Exploratory testing such as resonance search tests to determine natural frequency and damping of equipment can be performed before vibration ageing tests and after seismic testing to detect degradation of equipment. This data may be used to improve the design of equipment and to qualify it by performing a limited number of complementary tests.

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Exploratory vibration tests are generally not part of the seismic qualification requirements but may be run on equipment to aid in the determination of the best test method for qualification or to determine the dynamic characteristics of the equipment. These low input level vibration tests are normally described as resonance searches. They are generally performed at input levels well below the required seismic qualification vibration level. These tests can be performed in several ways. The most common method is the resonance search that is performed as a slowly swept sinusoidal vibration test with the input uniaxial. The equipment responses may be measured biaxially or triaxially to determine resonances and cross coupling. A second method involves impacting the equipment in a controlled manner at critical points on the structure, capturing the impact and response data, and computing the transfer function between impact and response locations. The output is the transfer function and associated phase information. A third method involves the use of a broadband random input signal and simultaneous measurement of response at locations of interest.

9.1.6.2 Resonance search by base excitation

This method offers the advantage that it can be performed on the same type of vibration equipment used for the qualification vibration test. The resonance search is generally performed just prior to the qualification seismic vibration test as the information gathered may be useful. Resonances are determined by instrumenting the structure with accelerometers at the input location and at those locations where the structural response is desired. Generally, a slowly swept low-level sinusoidal vibration should be employed. The sweep rate should be two octaves per minute, or less, to allow for resonance buildup. A 0,2 g peak input is the conventional input level, but it may be adjusted lower to avoid equipment damage or higher to take nonlinearities into consideration. It is recommended that the resonance search be carried out at least a factor of 1,5 beyond the RRS cutoff frequency to obtain data on equipment dynamic characteristics that may be valuable to justify qualification for other dynamic loads.

The user is cautioned that if the equipment is not mounted on its service foundation for the resonance search, the mass and stiffness of the mounting used may have a significant effect on the accuracy of the results.

When large equipment is tested on a table, coupled table/equipment modes may exist, which should not be interpreted as equipment modes. The vibrational coupling of these two vibrating systems occurs because they are connected and energy can transfer from one system to another. Separate exploratory vibration tests can be performed on the equipment and shake table independently to determine their dynamic characteristics.

Structural resonances are normally detected by observing amplifications of the input motion in the test item. Phase relationships between the sinusoidal input signal and the structural response at the point of measurement may also be helpful in defining resonances. A higher degree of confidence in establishing resonance is obtained by combining amplification and phase data. Similar results may be obtained by base excitation with low-level broadband random motion. In this case, transfer functions and phase data are obtained by fast Fourier transform (FFT) analysis of excitation and response time histories. Caution should be exercised to ensure that the number of data samples acquired and the resolution bandwidth correspond to the transfer function accuracy desired. An FFT analyzer is usually required for this technique.

9.1.6.3 Resonance search by impedance methods

Resonance search by impedance methods may be accomplished by exciting the structure with a small portable shaker or by impact testing. The induced vibration under such conditions is usually of small amplitude in nature. Caution should be exercised in applying the test results for large amplitude earthquake response conditions. See 12.2 for further discussion.

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9.1.6.4 Application of resonance search data

All resonances should be recorded for possible use as the following:

a) Design information;

b) Necessary data for certain test methods;

c) Data for use in potential qualification efforts.

When it can be shown that the equipment has no resonance below the cutoff frequency of the RRS, the equipment may be considered rigid and analyzed or tested accordingly. On the other hand, when resonances exist, or when the configuration of the equipment is such that critical resonant frequencies cannot be ascertained due to either the complexity of the equipment or the inaccessibility of critical parts, the equipment should be tested according to one of the various methods of 9.6 or another justifiable method.

It shall be noted that, because of nonlinearities, resonance responses at high levels may differ in frequency and damping from those at low levels; and further, that resonance response may not be excited at all at low levels. Therefore, a low-level exploratory test may not be conclusive as an indication of either equipment dynamic response or lack of resonances. When nonlinearities are suspected, it may be necessary to perform an exploratory test at more than one input acceleration level.

9.1.7 Seismic ageing (OBE/S1)

Seismic qualification tests on equipment designed to show adequacy of performance during and/or following an SSE/S2 shall be preceded by tests that produce the equivalent fatigue effect of the number of OBEs/S1s specified for each site and the equivalent fatigue effects of specified in-plant vibration resulting from normal and transient plant operating conditions. The OBE/S1 and SSE/S2 tests shall produce a number of equivalent maximum peak cycles (at least as given in 9.6.5) for each specified seismic event. For example, one SSE/S2 may be equivalent to multiple OBEs/S1s and may be used in place of multiple OBEs/S1s. The site condition is normally consistent with the service life of the facility; however, as a minimum, the equivalent fatigue effects consistent with the qualified life of the equipment shall be achieved. The number of OBEs/S1s shall be justified for each site or shall produce the equivalent effect of five OBEs/S1s.

9.2 Proof and generic testing

Proof testing is used to qualify equipment for a particular requirement. A proof test requires equipment to be subjected to one of the tests described in 9.6. The equipment shall be subjected to the particular response spectrum, time history, or other parameters defined for the mounting location of the equipment. No attempt need be made to explore the failure thresholds of the equipment. Therefore, the proof test requires the preparation of a detailed specification. The equipment is tested to the specified performance requirement and not to its ultimate capability. Generic testing may be considered a special case of proof testing. The specification is usually written to encompass most, or all, of the known requirements. The objective is to show qualification for a wide variety of applications during one test. The resultant generic RRS typically encompasses a wide frequency bandwidth with relatively high acceleration levels. The user is cautioned that the enveloping of a variety of requirements can produce a very severe test motion.

In general, the proof or generic test seismic simulation waveforms should:

a) Produce a TRS that closely envelops the RRS using single- or multiple-frequency input as required to provide a conservative (but not overly so) test-table motion;

b) Have a peak acceleration equal to or greater than the RRS ZPA;

c) Not include frequency content above the RRS ZPA asymptote;

d) Have a duration in accordance with the requirements of 9.6.5.

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Consideration shall also be given to the choice of single-axis or multiple-axis testing as described in 9.6.6 and margins as noted in Clause 7.2.

9.3 Fragility testing

Fragility testing is used to determine the ultimate capability of equipment. Such information may later be used to prove adequacy for a given requirement or application.

Fragility testing should be performed in a manner that yields equipment capability data that can be related to and compared with any of the various requirements from various installations and agencies.

For some requirements, an equipment's capability can be best defined by a demonstration of its response to sine-beat (or transient) type excitation. For other requirements, it may be defined by a demonstration of its response to continuous sine excitation. Still other equipment capability may be defined by a demonstration of its response to multi-frequency waveforms. A measurement of the equipment's fragility level for a particular motion excitation constitutes a demonstration of its ultimate capability to perform its required safety function(s) when subjected to that motion.

Variations in the seismic environment have been shown to influence the fragility level of an equipment or system. One such variation is the directional nature of the excitation. In addition, the environment may possess the characteristics of a shock, a transient, or a steady-state vibration. The tests outlined in 9.6 may be performed to establish fragility data using the guidelines of that subclause for proper application (see Annex D for additional guidance on fragility testing).

9.4 Component testing

Components shall be tested simulating operating conditions to either the levels dictated by expected service requirements or their ultimate capability. The components shall be mounted on the shake table in a manner that dynamically simulates the recommended mounting. When a component is intended to be mounted on a panel, the panel should be included in the test mounting or the response at the device mounting location should have been monitored during the assembly testing (see 9.5), in which case the device may then be mounted directly to the shake table for the simulation of in-service excitation.

9.5 Assembly testing

9.5.1 General

9.5.1.1 Overview

It is preferred that large complex assemblies (equipment) be tested as a complete and total assembly so that operating conditions can be simulated and monitored for proper functional performance. However, in cases such as control panels, switchgear, motor control centers, etc. containing numerous subcomponents, it is not always practical to simulate all conditions simultaneously. Seismic qualification of any important to safety subcomponents not tested during the assembly-level seismic test shall be verified in a separate programme. It is acceptable to conduct the testing in two phases:

- Phase 1 – Assembly-Level Seismic Test: The overall structure of the assembly, including as many subcomponents that can be installed and functionally monitored during this initial seismic test programme.
- Phase 2 – Subcomponent Seismic Test: The various subcomponents that were not included in the Phase 1 test programme are seismically tested to verify they will perform their safety function(s).

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9.5.1.2 Phase 1 – Assembly-Level Seismic Test

The overall (host) assembly is tested to verify its structural integrity and position retention are intact. If there are any other functional requirements for the overall structure, those should be tested/verified as well. Dummy weights should be used to simulate the local impact of missing subcomponents if their absence will significantly impact the overall equipment global and local dynamic response. Local accelerometers should be installed at the intended mounting locations of the missing subcomponents in order to produce in-structure OBE/S1 and SSE/S2 RRS for the Phase 2 test programme.

Either actual or simulated subcomponents (dummy weights, construction/configuration/ mounting employed shall not change the dynamic behaviour of the assembly (e.g., mass and stiffness) due to a too simplified approach), are installed on and/or in the assembly so that it undergoes maximum deflections/stress cycles during the seismic test. This also ensures the assembly's resonant natural frequencies recorded during the test are representative of the complete assembly once the missing subcomponents are installed. During OBE/S1 and SSE/S2 seismic tests, the in-structure response spectra at the component locations shall be obtained from the response time history data by direct measurement or to be determined utilizing the transfer function from the assembly control accelerometer location to the subcomponents' mounting locations. The in-structure response spectra at the subcomponent locations (i.e. the local TRS) are enveloped as needed to take into account the different possibilities of loading the equipment in each axis of excitation to define the subcomponent RRS in the next phase of the testing.

9.5.1.3 Phase 2 – Subcomponent Seismic Test

The various missing subcomponents from Phase 1 are mounted onto the shake table surface or onto a rigid test fixture so that they are properly oriented with respect to gravity. The resulting OBE/S1 and SSE/S2 TRS shall envelop the OBE/S1 and SSE/S2 subcomponent RRS as indicated in Phase 1 of the testing. The OBE/S1 and SSE/S2 RRS for these seismic tests are derived from the in-structure response spectrum calculated from local accelerometer(s) representative of the installed location of these subcomponents that were obtained from Phase 1 of the test programme. Intermediate structure on which equipment is fixed can induce higher equipment excitation. In such cases, those excitations shall be taken into account in defining the TRS.

In either case, the test methods described in 9.6 or other justifiable methods may be used. The assembly, and subcomponents, shall be examined during (if needed) and following the test programme to verify their structural and functional integrity were maintained.

NOTE It is recognized that when testing assemblies with actual and/or simulated devices installed, the TRS from the device location may be excessive due to over-test of the assembly since it is not practical to closely envelop all RRS with the table motion.

9.6 Test methods

9.6.1 General

9.6.1.1 Test categories

Present test methods generally fall into three major categories. They are proof testing (see 9.2), generic testing (see 9.2), and fragility testing (see 9.3). The types of motion available to best simulate the postulated seismic environment fall into two categories: single frequency and multiple-frequency. The method chosen will depend upon the nature of the expected vibration environment and also somewhat on the nature of the equipment. The various technical requirements appropriate to each test method may provide extra benefits for specific applications.

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9.6.1.2 Artificially broadened response spectra

For a floor-level motion, the RRS may be dominated by a single structural resonance. For this case, the RRS is usually broadened to cover the uncertainty in the building structural frequency. This has the effect of making the RRS artificially conservative since the response peak can occur only at a specific frequency and not throughout the entire broadened band. An acceptable testing procedure in this case is as follows:

When the center frequency in the broadened area is f_c, testing may be conducted at this frequency and in addition at the frequencies $f_c \pm \Delta f_c$, $f_c \pm 2\Delta f_c$, …, $f_c \pm n\Delta f_c$, where Δf_c corresponds to an acceptable interval (typically 1/6 to 1/3 octave) to envelop the entire broadened area. The TRS generated during each individual test shall have the same shape and width as the original narrowband response spectrum (similar to Figure 3). The specification should state clearly the existence of this case to avoid confusion with an RRS that results from genuine broader frequency motion requirements.

9.6.1.3 TRS analysis

TRS shall be computed using either justifiable analytical techniques or response spectrum analysis equipment and should be developed over the frequency range of interest. It is recommended that the TRS be computed with 1/6 octave or narrower bandwidth resolution to generate adequate data over the frequency range of interest. Any filtering of the acceleration signal performed within the frequency range of analysis shall be defined.

9.6.1.4 Damping selection

The RRS are usually specified at several levels of critical damping. When available, the RRS with a critical damping of 5 % is the recommended choice for use in testing. The application of damping for testing is described in 5.8.2.

9.6.2 Single-frequency test

9.6.2.1 General

When the seismic ground motion has been filtered due to one predominant structural mode, the resulting floor motion may consist of one predominant frequency. In this case, a short duration steady-state vibration can be a conservative input excitation to the equipment. Further, single-frequency testing may be used to determine (or verify) the resonant frequencies and damping of equipment. If it can be shown that the equipment has no resonances, only one resonance, widely spaced resonances that do not interact, or if otherwise justified, single-frequency testing may be used to fully test the equipment.

The TRS from single-frequency testing results from each individual frequency and may not be generated as the composite of several non-simultaneous single-frequency tests unless otherwise justified.

9.6.2.2 Derivation of test input motion

9.6.2.2.1 General

For any waveform employed, the shake table motion should produce a TRS acceleration at the test frequency at least equal to that given by the RRS. The peak input acceleration shall be at least equal to the ZPA of the RRS except at low frequencies where the RRS goes below and stays below the ZPA for which the value of the RRS shall be met. See 9.6.6 for guidance on the number of axes required for testing. For flexible equipment with more than one predominant frequency, and when the RRS has the characteristics of a multiple-frequency broadband response spectrum, the conditions in 9.6.2 may be difficult to fulfill. Specifically, it may not be practical to attempt a demonstration where modes do not interact to reduce the seismic fragility of equipment. When this is the case, single-frequency tests may be applied according to

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9.6.2.2.3 based on the expected behaviour or fragility of equipment under vibratory conditions used to determine its seismic qualification.

9.6.2.2.2 Equipment performance assessed by structural integrity alone

When the performance of equipment can be assessed by structural integrity alone, in terms of stress and strain such as in structures and static electrical or passive devices, then the maximum response in equipment governs without regard to the precise vibratory nature or frequency content of the excitation. The motion of the shake table should produce a TRS at the test frequency of 1,5 times that given by the specified RRS peak unless justified to be less. This conservatively allows for combined multi-mode response. The choice of the preceding factor depends on the shape of the RRS with the largest value (1,5) applicable to a broadband RRS. As a consequence, the TRS need not completely envelop the RRS. Alternatively, when all the resonances of the equipment can be definitely established by an actual test, it will be sufficient for the single-frequency TRS to envelop the RRS only at the equipment resonances with one single-frequency input.

9.6.2.2.3 Equipment performance assessed by structural integrity and operability

When the performance of equipment shall be assessed by the combination of structural integrity and operability, as for example in electromechanical devices such as relays or instruments, then the precise vibratory nature and frequency content of the excitation will produce equipment responses that determine its fragility. Justification shall be provided so that the 1,5 factor (see 9.6.2.2.2) is sufficient to allow for combined multi-modal response and to produce a vibratory motion to adequately simulate the effects that the intended multi-frequency motion would have on equipment performance. The choice of the factor depends on the nature of the equipment and the shape of the RRS with the largest value, which may require a factor greater than 1,5, applicable to broadband RRS. Consequently, the TRS need not completely envelop the RRS provided proper justification is given. In addition, testing shall be performed at all equipment resonances and at frequencies spaced no farther apart than 1/2 to 1/3 octave intervals up to a frequency of 33 Hz unless otherwise justified. When the equipment resonances exceed 33 Hz, the testing shall be narrowed to 1/6 octave or less at frequencies above 33 Hz. Alternatively, when all the resonances of the equipment can be definitely established by an actual test, it will be sufficient for the single-frequency TRS to envelop the RRS only at the equipment resonances with one single-frequency input.

9.6.2.3 Continuous-sine test

A test at any frequency should consist of the application of a continuous sinusoidal motion at the frequency and amplitude of interest and with a total duration and low-cycle fatigue potential at any frequency, at least as given in 9.6.5. The test frequencies of interest are those at the resonances of the equipment being tested and others as given in 9.6.2.2. The maximum acceleration corresponds to that for which the equipment is to be qualified and should at least produce the maximum response acceleration given in 9.6.2.2.

9.6.2.4 Sine-beat test

A test at any frequency should consist of the application of a series of at least five sine beats with a sufficient pause between each so that no significant superposition of equipment response motion results. The sine beats consist of sinusoids at the frequency and amplitude of interest, as shown in Figure 1. Each sine beat should consist of a number of cycles of motion (usually 5 or 10) to produce a TRS acceleration in accordance with the criteria given in 9.6.2.2. The test frequencies of interest are those at the resonances of the equipment being tested and others as given in 9.6.2.2. The total test duration and the low-cycle fatigue potential at any frequency should be at least as given in 9.6.5.

For a given beat-peak amplitude, the degree of test conservatism will increase as the number of cycles per beat increases until the conservatism approaches that of the sinusoidal waveform in 9.6.2.3.

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NOTE 1 As used in this document, the amplitudes of the sinusoids represent acceleration, and the modulated frequency represents the frequency of the applied seismic stimulus.

NOTE 2 Beats are usually considered to be the result of the summation of two sinusoids of slightly different frequencies, with the frequencies within the beats as the average of the two, and the beat frequency as half the difference between the two. However, as used herein, the sine beats may be amplitude-modulated sinusoids with pauses between the beats.

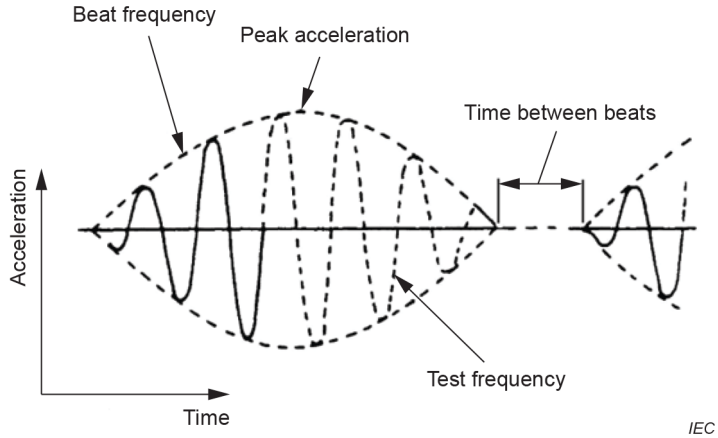

Figure 1 – Sine beat

9.6.2.5 Decaying-sine test

A test at any frequency should consist of the application of at least five decaying sinusoids at the frequency and amplitude of interest with a sufficient pause between the sinusoids so that no significant superposition of equipment response motion results. The total test duration and low-cycle fatigue potential at any frequency should be at least as given in 9.6.5. The decaying sinusoids consist of a single frequency of exponentially decaying amplitude, as shown in Figure 2. The test frequencies of interest are those at the resonances of the equipment being tested and others, as given in 9.6.2.2. The peak acceleration of the sinusoid corresponds to that for which the equipment is to be qualified and should at least produce the maximum response acceleration given in 9.6.2.2. For a given peak amplitude, the degree of conservatism will increase as the decay rate decreases until the conservatism approaches that of the sinusoidal waveform in 9.6.2.3.

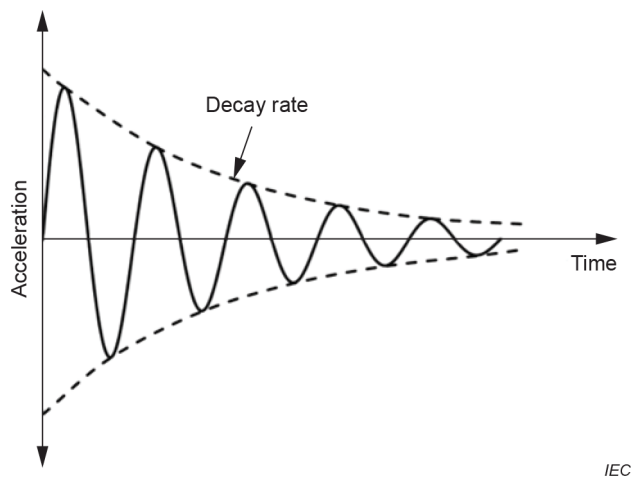

Figure 2 – Decaying sine

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9.6.2.6 Sine-sweep test

In this test, a sinusoidal input with continuously varying frequency is applied to the equipment. The frequency band should cover the range for which the equipment is to be qualified, including the equipment resonances and other frequencies, as given in 9.6.2.2. This closely approaches the conservatism of the continuous-sine test in terms of producing maximum response. The percentage of steady-state resonance response obtained depends on the sweep rate and the equipment damping. For sweep rates of two octaves per minute or less, and for typical equipment damping, this percentage exceeds 90. Maximum response is obtained separately at every frequency in the test range. Consequently, this test produces the most thorough search for all resonant frequencies, and it is customarily used for this purpose as an exploratory test, with a low input level such as 0,2 g.

To qualify the equipment, the total sine-sweep test duration and equivalent maximum peak cycles at any frequency should be at least as given in 9.6.5. The maximum acceleration corresponds to that for which the equipment is to be qualified and should at least produce the maximum response acceleration given in 9.6.2.2. The TRS may not be a composite of the entire frequency sweep. It shall be the response spectrum centered around any single frequency.

9.6.3 Multiple-frequency tests

9.6.3.1 General

Seismic ground motion is recognized to contain multiple-frequency energy content normally up to approximately 33 Hz with the exception of hard rock regions of the Central and Eastern U.S. and other parts of the world which may experience energy content up to 100 Hz. When this relatively broadband ground motion has not been strongly filtered by the building or the soil or both, the resulting floor motion that affects the equipment tends to retain the original broadband characteristics. Furthermore, even if strong filtering is present but is caused by two or more distinct building modes, the floor motion will still comprise a complex wave with dominant frequencies at each of the building or soil natural frequencies, or both. In these cases, multiple-frequency testing is applicable for qualification. Specific shake table excitation includes random or complex time histories, depending on the frequency distribution necessary to simulate the required floor motion. The intent is to produce a table motion that reasonably approximates that which is postulated to occur at the mounting of the equipment for the particular earthquake.

Multiple-frequency testing is intended to provide a broadband test motion that is particularly appropriate for producing a simultaneous response from all modes of a multi-degree-of-freedom system whose malfunction may be caused by modal interaction. Multiple-frequency testing provides a closer simulation of a typical seismic motion without introducing a higher degree of conservatism.

There are a number of available waveforms that may be used as test motions to simulate the particular seismic excitation at the mounting of the equipment. Several types of multiple-frequency tests employing these different waveforms are given in 9.6.3.3 through 9.6.3.5. Some test types will be better than others for simulating a specific type of equipment excitation condition, and the degree of conservatism will vary from one type of test to another. The choice of test type will depend on the extent to which the ground motion is filtered by the dynamic characteristics of the building, or soil, or both, to produce the excitation to the equipment at the particular floor level of the building. Other waveforms, or types of multiple-frequency tests, not specifically discussed herein may also be employed provided they can be shown to possess similar characteristics for exciting the equipment being tested. Generally, the criteria described in 9.6.3.2 for the derivation of the test input motion are used to justify the adequacy of the test.

9.6.3.2 Derivation of test input motion

The strong motion portion of the test waveform shall be demonstrated to meet the requirements as specified in 5.6.2. For any waveform employed, the motion of the shake table shall be adjusted so that:

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a) The TRS envelops the RRS over the frequency range for which the particular test is designed. The RRS shall include test margin as specified in IEC/IEEE 60780-323.

b) For comparison of the TRS and the RRS, the TRS is computed with a critical damping value equal to or greater than that of the RRS, using the appropriate damping values in 5.8.2, 5.8.2.2 and 9.6.1.4.

c) The shake table maximum peak acceleration is at least equal to the ZPA of the RRS (see Annex B for suggestions on the measurement of ZPA).

d) The total test duration and low-cycle fatigue potential are as those in 9.6.5.

e) Analysis of the time history indicates frequency content at least as broad as that defined by the amplified region of the RRS.

f) The time history indicates waveform stationarity, that is, the statistical parameters (e.g., frequency content and amplitude probability distribution) do not vary significantly throughout the test.

To account for the factors in items a) through f), it is necessary to show that the frequency content of the test waveform is at least as broad as the frequency content of the amplified region of the RRS (except perhaps at the low-frequency end due to limitations of vibration test equipment, see the following items j) and m)). There are several techniques for showing this; for example, show that:

g) The enveloping of the RRS by the TRS is obtained with similar spectrum shapes so that similar amplifications at significant spectrum peaks in the amplified regions of the spectra result.

h) The frequency content of the Fourier transform of the test waveform is compatible with the amplified portion of the RRS.

i) The frequency content of the test waveform PSD is compatible with the amplified portion of the RRS.

It is also intended that stationarity exists over the strong motion portion of the test waveform. This can be demonstrated by showing that the frequency/amplitude content of the waveform is statistically constant with time (see Annex C for further explanation of frequency content and stationarity). The RRS occasionally requires high acceleration levels at the lowest frequencies that require very high test-table displacement capability. The general requirement for enveloping the RRS by the TRS can be modified under the following criteria except at the principal natural frequencies of the equipment:

j) In those cases where it can be shown by a resonance search that no resonance response phenomena exist below 5 Hz, it is required to envelop the RRS only down to 3,5 Hz. Excitation shall continue to be maintained in the 1 Hz to 3,5 Hz range to the full capability of the test facility.

k) When resonance phenomena exist below 5 Hz, it is required to envelop the RRS only down to 70 % of the lowest frequency of resonance.

l) When the absence of resonance response phenomena or malfunction below 5 Hz cannot be justified, the general requirement applies and the low-frequency enveloping should be satisfied down to 1 Hz.

m) Under any circumstances, failure to envelop the RRS at, or above, 3,5 Hz shall be justified.

In the performance of a test programme, the TRS may, on occasion, not fully envelop the RRS. The general requirement for a retest may be exempted if the following criteria are met:

n) A point of the TRS may fall below the RRS by 10 %, or less, provided the adjacent 1/6 octave points are at least equal to the RRS and the adjacent 1/3 octave points are at least 10 % above.

o) A maximum of five of the 1/6 octave analysis points may be below the RRS, as in item n), provided they are at least one octave apart.

Phasing of the input motion should be random and the amplitude chosen so the RRS is fulfilled. When the time histories to be used for biaxial testing, tri-axial testing, or analysis are generated

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it's important that the frequencies of the corresponding waveform in each orthogonal direction differ slightly, otherwise the coherence between the time histories will be high. For example, if sinusoids at 1/12 octave frequencies are used a frequency shift of 1/24 octave between the corresponding sine waves in the different time histories will decrease the coherence dramatically.

9.6.3.3 Time history test

A test may be performed by applying to the equipment a specified time history that has been synthesized to simulate the seismic input. It shall be demonstrated that the actual motion of the shake table is as severe as, or more severe than, the required motion. This can be accomplished by a direct comparison of the table-motion time history with the specified motion by means of an oscilloscope or oscillograph trace. A comparison can further be made through the use of response spectra of the required motion and the table motion. In the latter method, a response spectrum of the specified motion (RRS) is developed for the appropriate critical damping given in 5.7. Subsequently, a table motion is developed so that its TRS envelops the RRS according to the general criteria of 9.6.3.2.

It should be recognized that these two comparison methods may have significantly different degrees of sensitivity and, hence, differing adequacy for testing different physical effects. For example, when very low frequencies are important, direct comparisons of displacement time histories are useful. On the other hand, if intermediate-to-high frequencies are important, then comparison of accelerations or a computation of response spectra is more useful.

9.6.3.4 Random-motion test

A test may be performed by applying to the equipment a random excitation, the amplitude of which is adjusted either manually or automatically in multiple-frequency bands. The method of input can take various analog and digital forms. The exact bandwidth of individual bands employed is left to the discretion of the test engineer. Typically, 1/3 octave or narrower bands are considered for analog synthesis equipment. Digital synthesis equipment may require narrower bands or intervals. However, the use of wider bands may be adequate in some cases where unfiltered ground-level motion is intended. On the other hand, use of very narrow (that is, 1/6 octave or less) bands may be necessary when filtering by building resonances is intended in the input motion. In any event, the process involves use of an aggregate of multiple narrowband signals that is input to the shake table, with each band adjusted until the TRS envelops the RRS according to the criteria given in 9.6.3.2. For an analog signal synthesis system, the multiple-band frequency source may be either a random noise generator and multiple-channel filter combination or multiple signals taped on individual channels of an analog tape recorder. A third practical signal synthesis system is a digital computer programme that has the capability of computing the inverse of the shaker system transfer function and applying it to the desired table-motion time history. For all types of signal sources, a gradual buildup, hold, and decay of the signals provide a realistic simulation of an actual seismic event.

9.6.3.5 Complex-motion tests

9.6.3.5.1 General

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 narrowbands associated with each building resonance. For these cases, the use of a random motion test (even with narrow individual bandwidth resolution) 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, according to the criteria of 9.6.3.2, without introducing excessive ZPA levels. Several typical methods of synthesizing complex signals are described in 9.6.3.5.2 through 9.6.3.5.6. For each of these test methods, the criteria of 9.6.3.2 shall be met. Success in the use of any one of these methods will depend on the type of

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synthesis equipment available, the exact shape of the RRS, and the experience of the test engineer. The following methods have been utilized sufficiently to warrant special mention. However, further combinations of these and other signal components may be used as necessary to produce the required table motion.

9.6.3.5.2 Random motion with sine dwells

To meet an RRS that includes a moderately high peak random excitation may require an unreasonably high peak value of the input. In this case, a broadband random motion is first synthesized similar to the description given in 9.6.3.4. The levels of individual frequency bands are adjusted until as much of the RRS, or the lower level broadband portion of the RRS, is enveloped by the TRS using a peak input acceleration that is at least equal to, but not substantially greater than, the required ZPA. Then a sine dwell is added at each frequency corresponding to a sharp peak of the RRS until this TRS envelops the RRS according to the criteria given in 9.6.3.2. The duration of the sine dwell is made equal to the total test duration. When more than one sine-dwell frequency is required, all shall be initiated simultaneously and continue for the duration of the test run. (For the case of artificially broadened spectra, 9.6.1.2 may apply. In this case, a series of tests, each with a different sine-dwell frequency, may be performed to cover the broadened area.) This technique generally affords the maximum amount of amplification possible for a given narrowband RRS.

9.6.3.5.3 Random motion with sine beats

This motion is similar to that of 9.6.3.5.2 except that sine beats are used in place of sine dwells. The same criteria of motion synthesis, test duration, and simultaneous initiation of sine beats are applicable in this type of test. (For the case of artificially broadened spectra, 9.6.1.2 may apply, in which case a series of tests, each with a different sine-beat frequency, may be performed to cover the broadened area. See Figure 3.) Multiple applications of sine beats, spaced throughout the duration of the test, are applied for each required frequency. The number of cycles per beat becomes an additional parameter that can be adjusted for best results to meet the enveloping criteria of 9.6.3.2. The optimum number of cycles per beat may be determined from Figure 4, which gives resonance amplifications of sine beats for different cycles per beat and damping values.

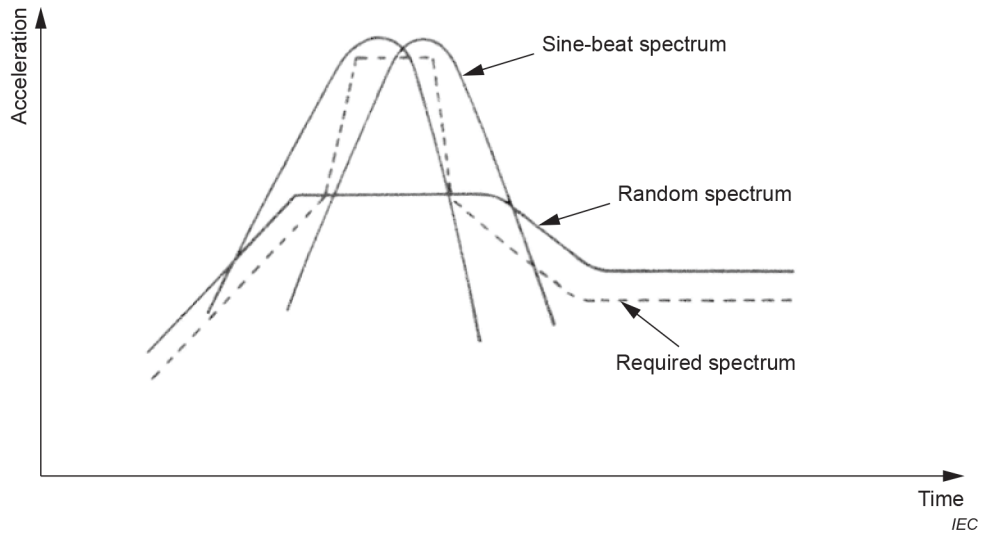

Figure 3 – Random spectrum with superimposed sine beats

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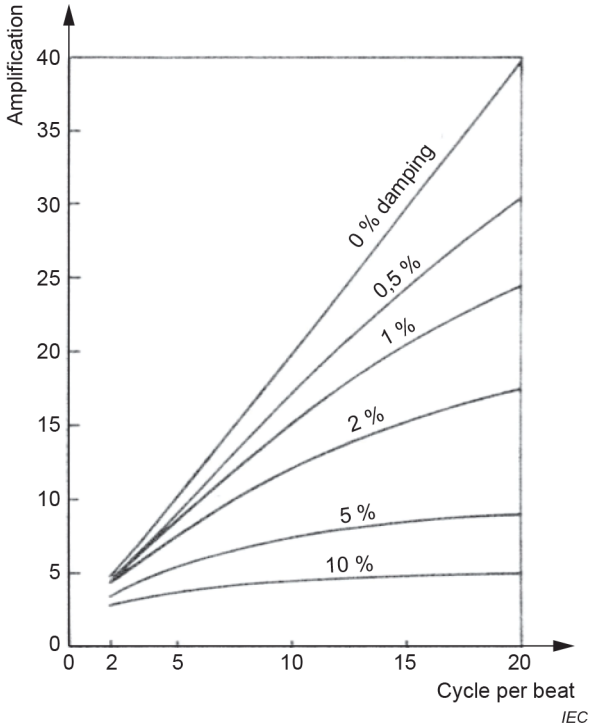

Figure 4 – Resonant amplification versus cycles per beat

9.6.3.5.4 Combination of multiple sinusoids

This motion consists of the summation of multiple sine waves (sinusoids) with distinct frequencies that include the resonant frequencies of the equipment up to the cutoff frequency. The frequencies of the sinusoids are typically spaced at 1/3 octave intervals, or narrower, to meet the enveloping criteria of 9.6.3.2. All sinusoids shall be initiated simultaneously and continue for the duration of the test run. Each frequency shall have individual amplitude and phase controls. When many distinct frequency sinusoids are combined, the result approaches broadband random motion. This method can be readily used in digital synthesis of required table motion.

9.6.3.5.5 Combination of multiple sine beats

This motion is similar to that of 9.6.3.5.4 except that a series of sine beats at each distinct frequency is used in place of the sinusoids. The same criteria of 9.6.3.5.4 for the test frequencies, octave spacing, simultaneous initiation of the sine beats, and continuously repeated and test duration are applicable in this type of test. As in 9.6.3.5.3, the number of cycles per beat can be adjusted for best results to meet the enveloping criteria of 9.6.3.2. As with the combination of multiple sinusoids, if many distinct frequency sine beats are combined, the result approaches broadband random motion.

9.6.3.5.6 Combination of decaying sinusoids

A complex wave comprising the aggregate of multiple decaying sinusoids can sometimes be used to produce a medium bandwidth TRS with a reasonably low ZPA. The frequencies of the component signals should be spaced typically at 1/3 octave or narrower intervals to meet the enveloping criteria of 9.6.3.2. The decaying sinusoids should have individual decay rate controls over the damping range from 0,5 % to 10 %. Each frequency shall have individual amplitude and phase controls. All frequencies shall be initiated simultaneously and continuously reinitiated for the duration of the test run. It is desirable to vary the decay rate and the amplitude of each frequency to optimize the fit of the TRS to the RRS. The resulting motion shall be justifiable as representative of the strong motion portion of the SSE/S2.

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9.6.4 Other tests

When there are vibration tests other than those described in 9.6.2 and 9.6.3 that are equally justifiable and that conservatively simulate the expected seismic environment, they may be used instead.

The following factors shall be considered to justify the test method employed to qualify equipment:

a) Bandwidth of the RRS compared to that of the TRS and equipment characteristics and responses;
b) Duration of the test compared to the defined seismic event;
c) Peak acceleration of the test input and the magnification observed (that is, the indicated frequency distribution of the input);
d) Natural modes and vibration frequencies of the equipment;
e) Typical equipment damping;
f) Fragility levels;
g) Low-cycle fatigue potential.

In any case, the TRS shall envelop the RRS according to the criteria of 9.6.3.2.

9.6.5 Test duration and low-cycle fatigue potential

To properly account for vibration buildup and low-cycle fatigue effects, it is necessary to specify the duration and the fatigue-inducing properties of the input test waveform.

The duration of the strong motion portion of each test shall be at least equivalent to the strong motion portion of the original time history used to obtain the RRS and shall be defined in the test specification. If the strong motion duration is not defined then the duration of strong motion for seismic testing should be a minimum of 15 s. For multiple-frequency tests, the stationary part of the test defines the strong motion portion of one multiple-frequency waveform employed. For single-frequency tests, the duration is the sum of the individual durations of all tests at all different single frequencies (exclusive of the pause between beats). Note that the individual test duration at any single frequency should be sufficient to produce a TRS acceleration in accordance with the criteria of 9.6.2.2.

The fatigue-inducing potential of the test waveform should be at least equivalent to the strong motion portion of the earthquake response motion at the mounting of the equipment. This equivalence may be confirmed for multiple-frequency testing by showing that the test waveform has a stationarity similar to that of the earthquake response motion or that the test waveform generates a similar number of equivalent maximum peak-stress cycles when exciting a given structural resonant frequency. To simulate fatigue at a lower level, a number of peak stress cycles above the required threshold may be used provided other test criteria have been met.

See Annex E for further discussion of test duration and equivalent number of maximum peak-stress cycles. Other justifiable methods, besides that identified in Annex E, may be adequate to verify low-cycle fatigue capability.

9.6.6 Multi-axis tests

9.6.6.1 General

Seismic ground motion occurs simultaneously in all directions in a random fashion. However, for test purposes, single-axis, biaxial, and triaxial tests are allowed. If single-axis or biaxial tests are used to simulate the 3D environment, they should be applied in a conservative manner to account for the absence of input motion in the other orthogonal direction(s). One factor to be considered is the 3D characteristics of the input motion. Other factors are the dynamic characteristics of the equipment, flexible or rigid, and the degree of spatial cross-coupling

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response. Single and biaxial tests should be applied to produce adequate levels of excitation to equipment where cross coupling is significant and yet minimize the level of over-testing where the cross coupling is not significant. To expose potential failure modes, single-axis and biaxial tests shall be performed in a number of directions as described in 9.6.6.2 and 9.6.6.3. In terms of total duration and fatigue induced, these tests are intended to be conservative. For equipment mounted to the building structure, biaxial testing or triaxial test methods are recommended.

Multi-axis shake table designs/installations require special consideration and test controls in place to verify that the shake table has insignificant pitch and roll actions during seismic testing. If these actions are ignored, they may impact the results of testing due to the coupling between the equipment and the shake table (e.g., shifts in equipment frequency response and damping, enveloping criteria not met).

9.6.6.2 Single-axis tests

Single-axis tests should conservatively reflect the seismic event at the equipment mounting locations and thereby account for the absence of motion in the other orthogonal directions. Single-axis tests are justified when the input motion can be shown to be essentially unidirectional or when the equipment being tested can be shown to respond independently in each of the three orthogonal axes. The former is the case when a device is normally mounted on a panel that amplifies motion in one direction, when it is restrained to motion in one direction, or its response in one direction does not produce stresses at the same location as a response in any other orthogonal direction. The latter is the case when an equipment has very low cross coupling among all axes or when other justification can be given.

For single-axis tests, it is permissible to perform the required OBEs/S1s followed by the SSE/S2 in each axis in sequence or any other justifiable method whereby adequate OBE/S1 ageing can be demonstrated.

9.6.6.3 Biaxial tests

Biaxial tests should conservatively simulate the seismic event at the equipment mounting location. They should account for the absence of motion in one orthogonal direction for independent input motions in the other two orthogonal axes or for the absence of motion in two orthogonal directions if dependent inputs are used. The factors to be considered include the directional nature of the input motion and the cross coupling of the equipment. Biaxial testing should be performed with simultaneous inputs in a horizontal and vertical axis. If cross-coupling exists an amplification factor (safety factor) should be applied. It can be either the square root of the sum of the squares (SRSS) of the two-principal horizontal direction response spectrum or a factor of $\sqrt{2}$ if both horizontal response spectra are the same. The selection of the horizontal axis may include the principal axes or some other direction selected to expose potential failure modes by testing the equipment in its most vulnerable direction.

Independent random inputs are preferred, and when used, the test shall be performed in two steps with the equipment rotated 90° about the vertical axis for the second step. To provide statistically independent simulated motions, the table time histories should have coherence values of less than 0,5 when computed with at least 12 data samples. Alternatively, an absolute value of less than 0,3 correlation coefficient for all time delays may be used (see Annex F for further explanation). It is permissible to perform the required OBEs/S1s followed by the SSE/S2 in the first step, followed by the same sequence in the second step, or any other justifiable method whereby adequate OBE/S1 ageing can be demonstrated.

When independent random inputs are not used, four tests should be run with the following:

a) The inputs in phase;

b) One input 180° out of phase;

c) The equipment rotated 90° about the vertical axis and the inputs in phase;

d) The same equipment orientation as item c) but with one input 180° out of phase.

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It is permissible to perform the required OBEs/S1s followed by the SSE/S2 in item a) followed by the same sequence in items b), c), and d), or any other justifiable method whereby adequate OBE/S1 ageing can be demonstrated.

9.6.6.4 Triaxial tests

Triaxial tests, when performed, shall be done with a simulator capable of independent motions in all three orthogonal directions. To provide statistically independent simulated motions, the table time histories should have coherence values of less than 0,5 when computed with at least 12 data samples. Alternatively, an absolute value of less than 0,3 correlation coefficient for all time delays may be used (see Annex F for further explanation).

9.6.7 Line-mounted equipment

When the seismic ground motion has been filtered due to one predominant structural mode, the resulting floor or line-mounted equipment motion may consist of one predominant frequency. In this case, a short duration steady-state vibration can be a conservative input excitation to the equipment. Further, single-frequency testing may be used to determine (or verify) the resonant frequencies and damping of equipment. If it can be shown that the equipment has no resonances, only one resonance, widely spaced resonances that do not interact, or if otherwise justified, single-frequency testing may be used to fully test the equipment.

The seismic qualification of line-mounted items of equipment, such as instrumentation and control components, devices, HVAC damper actuators, and valve actuators and their attached functional accessories for which operability shall be demonstrated, requires special consideration. In establishing a seismic qualification programme for such equipment, it shall be recognized that the most critical seismic loading condition for line-mounted components will occur as a result of the response of the line (e.g., piping or duct system) in which the component is located. The seismic loading on the equipment/component at the electrical and piping/tubing connections due to attachment to electrical conduit and piping/tubing shall be addressed up to the first mounting support. This most critical condition provides an input motion to the component that is predominantly single frequency, that is, the natural frequency of the line in the vicinity of the component.

The following test method has been used to envelop the SSE/S2 seismic qualification requirements for power-plant line-mounted equipment.

The line-mounted equipment should be exposed to a series of single-frequency tests at equipment resonant frequencies and 1/3 octave frequency increments throughout the range of 2 Hz through 32 Hz, or higher, if hydrodynamic loads are to be considered. When testing to frequencies higher than 32 Hz is required for hard rock regions of the Central and Eastern U.S. and other parts of the world, the octave spacing at frequencies higher than 32 Hz shall be narrowed to 1/6 octave or less up to the cutoff frequency. At each test frequency, the input amplitude should correspond to the levels specified by the system designers. This amplitude may be independent of direction. Therefore, the motion should be applied at the same frequencies and accelerations in each of the three orthogonal axes separately. It shall be shown that the test amplitude is due only to the frequency of interest. Typical methods that can be employed include the use of bandpass or tracking filters. The test duration at each frequency should be the period of time required to establish full operability of the equipment; the duration shall be established considering the site-specific requirements and defined in the test programme. If strong motion duration is not specified then the duration of strong motion for seismic testing should be a minimum of 15 seconds.

The test procedure shall be supplemented by an evaluation of any applicable pipe reaction nozzle loads imposed on the equipment. The definition of procedures for nozzle loads evaluation is considered to be beyond the scope of this standard and is, therefore, not discussed further.

Further clarification and guidance may be obtained from IEEE Std 382™.

Documents
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Full document details: IEC IEEE 60980-344-2020

9.6.8 Additional tests

After earthquake/seismic testing, exploratory testing may be performed to determine the survivability of equipment to specific additional loads. It may be used to determine the ultimate residual capability of equipment. Fragility level is the highest level of input excitation, expressed as a function of input frequency, acceleration and test duration, under which equipment is able to fulfill its performance requirements. Due to the fact these tests are destructive and are considered as an additional proof of mechanical equipment robustness, they are generally conducted on the initiative of the supplier after the earthquake test. Testing is performed at elevated SSE/S2 response spectrum levels or around natural frequencies of equipment that have been verified after SSE/S2 tests. This approach permits the user to gain confidence on functional robustness of the equipment. Moreover, it can permit in some cases to better characterize the failure modes of equipment and to enhance their design accordingly.

9.7 Test documentation

See Clause 13 for test documentation requirements.

10 Qualification by similarity

10.1 General

Where qualification of an equipment item is achieved by extrapolation of previous qualification results with margin based on test, analysis, or combination thereof the extrapolation shall be based on similarity and shall consider excitation, physical system, and safety function. The similarly analysis shall provide evidence that the equipment being analyzed will perform its intended safety function(s) and deemed to be equivalent to the reference equipment.

10.2 Excitation

Similarity of excitation constitutes likeness of the following parameters: spectral characteristics, duration, directions of excitation axes, and location of measured response, for the motions relative to the equipment mounting. These parameters should be as alike as is practical or conservative by comparison for excitations whose similarity is to be established.

10.3 Physical systems

Equipment similarity shall be established for an equipment assembly, or a device, or both, or subassembly (including mounting), depending on the configuration of the new equipment to be qualified. For a complete assembly, similarity may be demonstrated through comparison of make, model and serial numbers, and consideration of dynamic properties and construction.

Since the end objective of qualification by the similarity method includes a consideration of the expected dynamic response, a rational approach can be used to establish similarity of dynamic structural properties by an investigation of physical parameters of equipment systems. This can be done by comparing the predominant resonant frequencies and mode shapes. These dynamic characteristics are dependent on parameters such as the following:

a) Equipment physical dimensions;

b) Equipment weight, its distribution, and center of gravity;

c) Equipment structural load transferring characteristics and stiffness to resist seismic excitation;

d) Equipment base anchorage strength and stiffness to ensure structural integrity and adequate boundary conditions;

e) Equipment interfaces with adjacent items or connecting accessories such as cables and conduits.

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