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BSI Standards Publication

High-voltage switchgear and controlgear

Part 210: Seismic qualification for metal enclosed and solid-insulation enclosed switchgear and controlgear assemblies for rated voltages above 1 kV and up to and including 52 kV

National foreword

This Published Document is the UK implementation of IEC/TS 62271-210:2013.

The UK participation in its preparation was entrusted by Technical Committee PEL/17, Switchgear, controlgear, and HV-LV co-ordination, to Subcommittee PEL/17/1, High-voltage switchgear and controlgear.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Appareillage à haute tension – Partie 210: Qualification sismique pour ensembles d'appareillage sous enveloppe métallique pour tensions assignées supérieures à 1 kV et inférieures ou égales à 52 kV

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a technical specification when

- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 62271-210, which is a technical specification, has been prepared by subcommittee 17C: High-voltage switchgear and controlgear assemblies, of IEC technical committee 17: Switchgear and controlgear.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
17C/515/DTS	17C/548/RVC

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

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

A list of all the parts in the IEC 62271 series, under the general title *High-voltage switchgear and controlgear*, can be found on the IEC website.

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

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

Part 210: Seismic qualification for metal enclosed and solid-insulation enclosed switchgear and controlgear assemblies for rated voltages above 1 kV and up to and including 52 kV

1 General

1.1 Scope

This part of IEC 62271 applies to metal enclosed switchgear and controlgear assemblies complying with IEC 62271-200 for metal enclosed and IEC 62271-201 for solid-insulation enclosed, ground or floor mounted, intended to be used under seismic conditions.

The seismic qualification of the switchgear and controlgear assemblies takes into account any auxiliary and the control equipment mounted directly on the assembly.

It will specify seismic severity levels, acceptance levels, and give a choice of methods that may be applied to demonstrate the performance of high-voltage switchgear and controlgear assemblies for which seismic qualification is required.

The seismic qualification of the switchgear and controlgear assemblies is only performed upon request.

1.2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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 60068-2-57:1999, *Environmental testing – Part 2-57: Tests – Test Ff: Vibration – Time-history method*

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

IEC 60068-3-3:1991, *Environmental testing – Part 3: Guidance – Seismic test methods for equipment*

IEC 62271-1:2007, *High-voltage switchgear and controlgear – Part 1: Common specifications*

IEC 62271-200, *High-voltage switchgear and controlgear – Part 200: AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV*

IEC 62271-201, *High-voltage switchgear and controlgear – Part 201: AC insulation-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV*

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

2 Normal and special service conditions

(void)

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60068-3-3, IEC 62271-1, IEC 62271-200, IEC 62271-201 and ISO 2041 apply.

4 Seismic qualification requirements

4.1 General

The seismic qualification shall demonstrate the ability of the switchgear and controlgear assemblies to withstand seismic stresses.

Basis of seismic qualification is the test, because only that allows a verification of functionality of the equipment during and after the seismic events. The test is also a necessary input for setup of numerical model used for analysis.

A combination of test and analysis is needed because not each type of switchgear arrangement can be tested.

4.2 Preliminary analysis

4.2.1 Selection of the representative test sample

Due to practical reasons concerned with the available experimental facilities, the seismic qualification of switchgear and controlgear assemblies requires the choice of proper test samples which reasonably represent the whole system for the purpose of structural and functional checks.

Such test samples shall include the switching devices with their relevant operating mechanism and control equipment, and their electrical and mechanical interfaces.

These test samples shall demonstrate the worst cases, such as those with heaviest mass and highest centre of gravity. In case of functional units with different masses, the heaviest panel shall be placed at one end of the test arrangement. Simulation can be used to determine the test sample, which satisfies the above criteria.

4.2.2 Mathematical model of the test sample

If qualification by combined test and numerical analysis, according to Clause 6, is foreseen, a three-dimensional mathematical model of the test sample shall be created on the basis of technical information concerning the design characteristics.

Such a model shall take into consideration the presence of switching and control devices, compartments and of their supporting structures, and shall have sufficient sensitivity to describe the dynamic behaviour of the test sample in the frequency range being studied.

The validity of the model shall be established by comparison between simulation results and actual tests results, as stated in 7.3.

4.3 Severities

4.3.1 General

In earthquake zone 4 (risk of very strong earthquakes) the measured peak ground acceleration in many cases is approximately 0,5 g. In a few cases the measured peak ground acceleration is around 1 g (see also Annex D).

Due to the wide range of ground motions, site conditions, switchgear installations in buildings, two severity levels are defined for seismic qualification in order to avoid designing or testing always to the highest levels.

The shape of the Required Response Spectra (RRS) (severity levels 1 and 2) is a broadband response spectrum to cover many site conditions (magnitude, depth and distance to epicentre, rock or soft soil) and super elevation due to the floor level installation.

For qualification, one of the following severity levels shall be chosen:

The severity level 1 is recommended for peak ground / floor accelerations up to 0,5 g.

The severity level 2 is recommended for peak ground / floor accelerations up to 1,0 g.

The Required Response Spectra are given in Figures 1 and 2 for the different seismic qualification levels. The curves relate to 2 %, 5 % and 10 % damping ratio of the switchgear and controlgear assemblies. For testing and if the exact damping behaviour is unknown 5 % damping ratio is recommended.

Severity Level 1 is recommended for equipments mounted at the ground level for zones 0 to 4 or at upper floor levels combined with earthquake zones 0 to 3 (see Annex D). For Zone 0, it is not necessary to perform any seismic qualification.

Severity Level 2 is only recommended for equipments mounted at upper floor levels combined with earthquake zone 4 (see Annex D).

If site-specific conditions are known the user may develop a site-specific response spectrum which envelops the shape of the severity level 1 and/or severity level 2.

NOTE The severity level 1 is equivalent to the moderate performance level according to IEEE 693:2005.

The severity level 2 is equivalent to the high performance level according to IEEE 693:2005.

4.3.2 Severity level 1

The RRS is described by the following equations:

Horizontal spectral accelerations S_a (m/s²) for frequencies f (Hz):

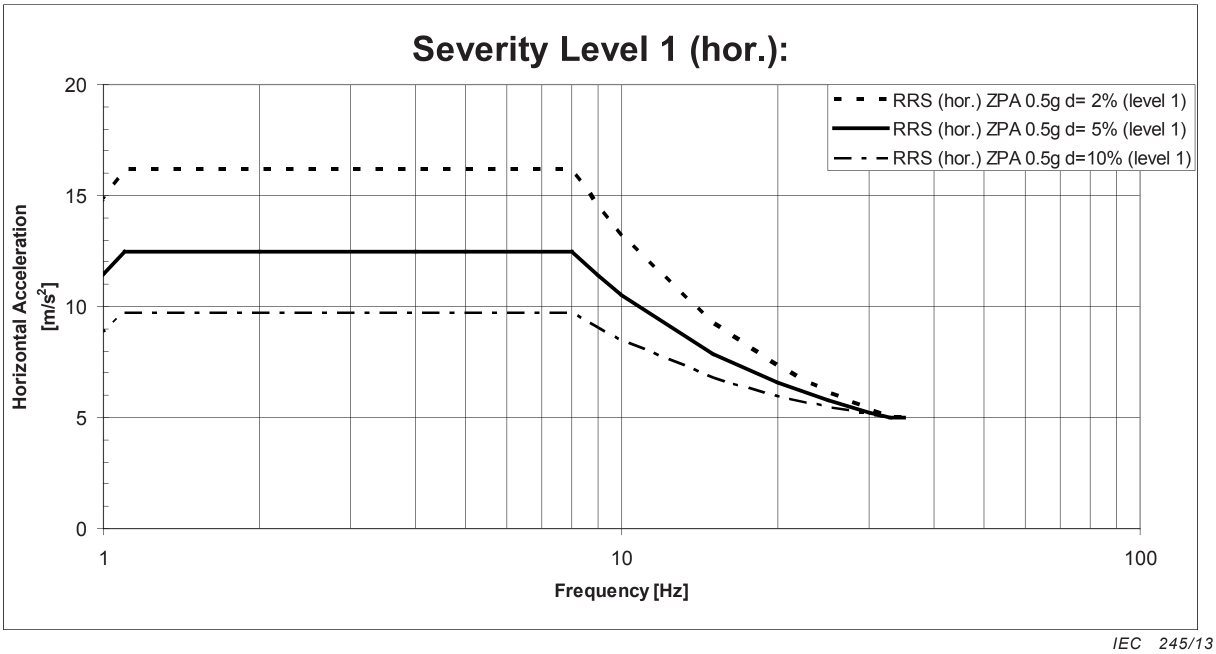
- $S_a = 1{,}144 \times \beta \times f \times g$ for $0{,}0 \leq f \leq 1{,}1$
- $S_a = 1{,}250 \times \beta \times g$ for $1{,}1 \leq f \leq 8{,}0$
- $S_a = 2 \times ((6{,}62 \times \beta - 2{,}64) / f - 0{,}2 \times \beta + 0{,}33)) \times g$ for $8{,}0 \leq f \leq 33$
- $S_a = 0{,}5 \times g$ for $f \geq 33$

$\beta = (3{,}21 - 0{,}68 \ln(d)) / 2{,}115\,6$, where d is the percent damping (2, 5, 10 etc.) and $d \leq 20$ %.
$g = 10$ m/s^2

For qualification the RRS is limited to a frequency range starting at 1,0 Hz (see 5.3.2).

For vertical spectral accelerations the conversion factor is 0,8.

NOTE The conversion factor is 0,8 in order to harmonize the values settle by IEEE and IEC standards.



SOURCE: Reproduced from IEEE Std 693:2005, *IEEE Recommended Practice For Seismic Design of Substations* with the permission of IEEE.

Figure 1 – Severity level 1 (horizontal) – Zero period acceleration (ZPA) = 0,5 g

4.3.3 Severity level 2

The RRS is described by the following equations:

Horizontal spectral accelerations S_a (m/s²) for frequencies f (Hz):

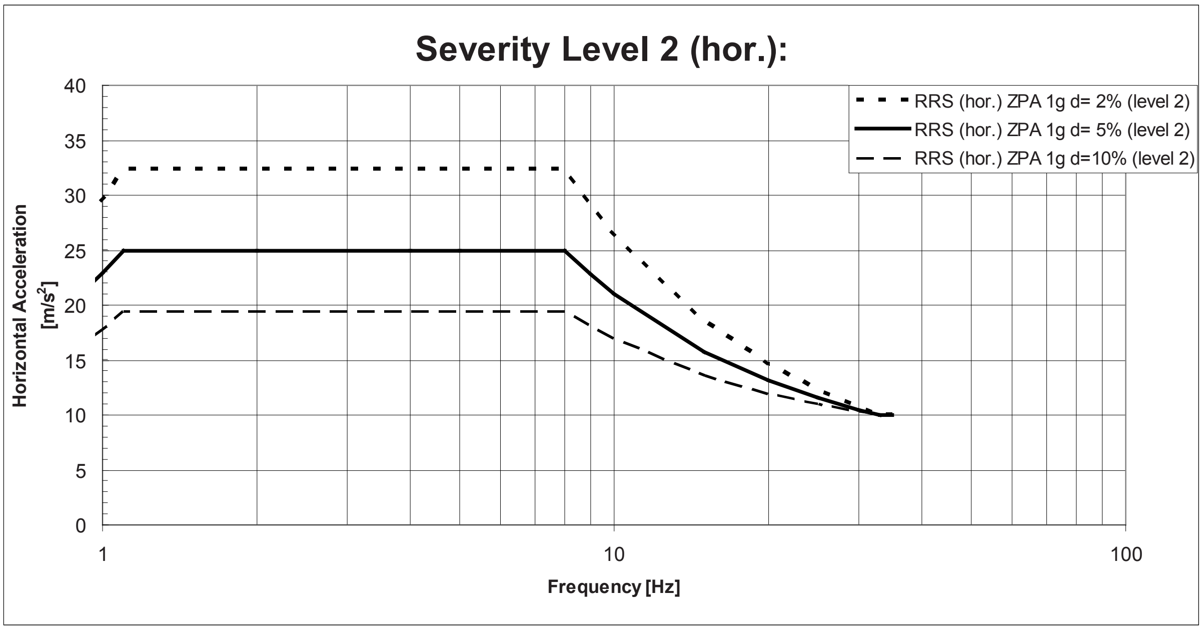
- $S_a = 2{,}288 \times \beta \times f \times g$ for $0{,}0 \leq f \leq 1{,}1$
- $S_a = 2{,}5 \times \beta \times g$ for $1{,}1 \leq f \leq 8{,}0$
- $S_a = 2 \times ((13{,}2 \times \beta - 5{,}28)/f - 0{,}4 \times \beta + 0{,}66)) \times g$ for $8{,}0 \leq f \leq 33$
- $S_a = 1 \times g$ for $f \geq 33$

$\beta = (3{,}21 - 0{,}68 \ln(d)) / 2{,}115\,6$, where d is the percent damping (2, 5, 10 etc.) and $d \leq 20$ %.
$g = 10$ m/s^2

For qualification the RRS is limited to a frequency range starting at 1,0 Hz (see 5.3.2).

For vertical spectral accelerations the conversion factor is 0,8.

NOTE The conversion factor is 0,8 in order to harmonize the values settle by IEEE and IEC standards.



SOURCE: Reproduced from IEEE Std 693:2005, *IEEE Recommended Practice For Seismic Design of Substations* with the permission of IEEE.

Figure 2 – Severity level 2 (horizontal) – Zero period acceleration (ZPA) = 1 g

4.4 Acceptance classes

Two acceptance classes for equipment are defined:

For class 1, the equipment has to maintain its functionality during and after the earthquake. After the seismic event maintenance and partial replacement might be necessary to ensure long term operation.

For class 2, the equipment has to maintain its functionality during and after the earthquake. After the seismic event no maintenance is required.

5 Qualification by test

5.1 General

The test procedure shall be in accordance with IEC 60068-3-3 with the modification that the time history test method in accordance with IEC 60068-2-57 shall be applied. The time history test method more closely simulates actual conditions, because the behaviour of the test sample is always not linear.

The seismic test should demonstrate the ability of the switchgear and controlgear assemblies to perform its required functions during and after seismic loads in form of Test Response Spectrum (TRS) that envelopes the RRS. The demonstration shall be performed as it is settled in 5.4.1 and 5.4.3.

If a test sample cannot be tested with its supporting structure (e.g., due to its size), the dynamic contribution of the structure shall be determined by analysis and accounted for in the test.

5.2 Mounting

The test sample shall be mounted as in service condition including dampers (if any).

If exact service conditions are unknown, a rigid base frame shall be used between the equipment and the shaking table.

The horizontal orientation of the test sample shall be in the direction of excitation acting along its two main orthogonal axes.

Any fixtures or connections required only for testing shall not affect the dynamic behaviour of the test sample.

The method of mounting of the test sample shall be documented and shall include a description of any interposing fixtures and connections (see IEC 60068-2-47).

5.3 Test parameters

5.3.1 Measurements

The measurements should be in accordance with 5.2 of IEC 60068-3-3:1991.

At least the following signals shall be recorded:

- acceleration at the shake-table;
- acceleration at significant places within the test object:
  - at least one measurement point, directly connected to the main structure (usually on top of switchgear),
  - near to the centre of gravity (if accessible),
  - at critical components (e.g. heavy masses).

5.3.2 Frequency range

The frequency range shall be from 1 Hz to at least 35 Hz in accordance with the Annex B of IEC 60068-2-57:1999 because in earthquakes the predominant frequencies are in between this range. The frequency range is applied to the resonant frequency search test and the generation of artificial earthquake wave.

The first resonant frequency for a typical test setup in horizontal directions is in the range of 5 Hz to 10 Hz, therefore test frequencies below 1 Hz are not relevant.

Due to the limitation of some shake-tables it is not required to envelop the RRS below frequencies of 70 % of the lowest resonant frequency of the equipment.

5.3.3 Parameters for resonant frequency search

The resonant frequency search test shall be carried out according to 10.1 of IEC 60068-3-3:1991.

The recommended acceleration during the resonant frequency search is 0,1 g. The search shall be conducted successively by sine sweeps in the three main axes at a maximum rate of 1 octave/min.

5.3.4 Parameters for time history test (seismic load test)

The test directions shall be chosen according to IEC 60068-3-3:1991, Clause 15.

Tri-axial testing is recommended.

The severity level shall be chosen according to 4.3.

The total duration of the time-history shall be 30 s at least and the strong part duration shall be not less than 20 s.

5.4 Testing procedure

5.4.1 General

The test sequence shall be as follows:

- functional checks before testing;
- resonant frequency search (required to determine critical frequencies and damping ratios and/or for analysis);
- time-history test (seismic load test);
- resonant-frequency search;
- functional checks after testing.

5.4.2 Inspection and functional checks

Before and after the tests, the following operating characteristics or settings shall be recorded or evaluated (when applicable) at the rated supply voltage and operating pressure:

a) visual inspection;

b) operation of any switching device;

c) closing time of any fast-closing switching device;

d) opening time of any fast-opening switching device;

e) operation of any withdrawable or removable part;

f) gas and/or liquid tightness where relevant;

g) resistance measurement of the main circuit;

h) power-frequency withstand voltage test as condition check of the main circuit (all switching devices in closed position) phase to phase and phase to earth, according 6.2.11 of IEC 62271-1:2007;

i) power-frequency withstand voltage test as condition check of the switching devices in opened position, according 6.2.11 of IEC 62271-1:2007.

These functional tests can be performed at the laboratory of the manufacturer.

5.4.3 Resonant frequency search

The resonant frequency search test shall be carried out according to 10.1 of IEC 60068-3-3:1991.

5.4.4 Time history test (seismic load test)

The time history test shall be performed once according to IEC 60068-2-57 with the parameters as defined in 5.3.4.

During the seismic test the following parameters shall be recorded in addition to 5.3.1:

- electrical continuity of the main circuit (if applicable);
- electrical continuity of the auxiliary and control circuit (representative NO/NC contacts).

During the test the control circuits shall be energized at the rated voltage.

One test run is required, at the beginning all switching devices shall be in closed position; the test condition depends on the switching devices and their ability to perform operations during the strong motion part of the time history:

- during this operational test each circuit-breaker shall perform at least one operating sequence (recommendation: O-5s-C-5s-O within the middle of total test duration and therefore within the strong part of motion);
- other switching devices shall operate as specified (e.g. open operation for load break switches);
- switching devices unable to operate during seismic loads shall perform the test in closed position without operation.

NOTE 1 Circuit-breakers ensure the switching capability even during seismic events. Other switching devices give evidence only for the functionality specified by the manufacturer.

NOTE 2 A further test run can be performed optionally, with all switching devices in closed position without operation. This leads to a qualification valid for this standard and for the IEEE 693.

Criteria for assessing the test validity and the test results are provided in 7.1 and 7.2.

If the test is intended to be used as a basis for numerical analysis, then further recordings shall be performed in order to provide relevant data. Further test parameters are:

- deflection of components where significant displacements are expected;
- strains on critical elements (e.g. bushings, flanges, enclosures and support structures);
- acceleration on relevant locations on the test sample.

6 Qualification by combination of test and analysis

6.1 General

Analysis alone cannot be applied because metal-enclosed switchgear and controlgear assemblies are complex devices and functional operability can not be verified by analysis techniques alone.

Analysis may be used:

- in validating switchgear and controlgear assemblies already tested in the same configuration under different seismic conditions;
- in validating switchgear and controlgear assemblies similar to the ones already tested under the same seismic conditions but which include modifications influencing the dynamic behaviour (e.g. change in the arrangement of the switchgear and controlgear assemblies, or in the mass of components);
- in validating switchgear and controlgear assemblies which cannot be qualified by testing alone (e.g. because of their size and/or complexity).

The methodology comprises the analysis of the structural part and the testing of the functionality separately.

The structural part consists principally of the structure including braces, frames, struts and attachments that transmit all seismic loads between the equipment and the floor. The dynamic behaviour of the equipment or assembly depends on the structural part.

Two or more assemblies can be considered structurally similar when they have the same structural scheme and the same connections types; they can be different by the mass distribution and/or the dimensions.

The functional part consists of components which are considered as logical sub-grouping of equipment functions typically organized and arranged as physical devices, modules or subassemblies that can be detached from the equipment and can be mounted to a test fixture using the same mechanical and electrical interfaces and tested as standalone units.

Two methods may be used to perform the mechanical validation:

- numerical analysis,
- analysis based on similarity.

6.2 Numerical analysis

6.2.1 General

Numerical analysis shall only be used to demonstrate the structural integrity. Additional accelerations at the fixing points of equipment may be calculated.

The functional operability shall be demonstrated from experience data (see 6.3).

Numerical analysis is performed with a numerical model which shall be calibrated by using static and / or dynamic data following the numerical method adopted (see Annex C).

6.2.2 Static data (stiffness)

The stiffness of the structure in horizontal direction could be obtained by applying a static force at the top of it.

If the structure is not axial-symmetric, at least two different orthogonal static forces shall be required.

6.2.3 Dynamic data

Dynamic data (damping ratios, critical frequencies, modal shapes, responses in acceleration on different points of the structure) for numerical analysis shall be obtained by a dynamic test of a similar test sample (see Annex A).

If during the test a nonlinear behaviour of the structure is detected, the analysis shall be reassessed taking into account the test results by using equivalent elastic stiffness and damping.

NOTE The nonlinearity is mainly on the damping, which can be quite different and higher than that measured at low levels, and on the stiffness, which can change with increasing loads, and consequently can change the resonant frequencies.

6.2.4 Numerical model

The general procedure is as follows:

a) set up of the finite element (FE) model by identifying the parts which act as structure (and therefore shall be modelled using structural FE) and the parts which act as masses (and therefore can be modelled using inertial FE);
b) calibration of the FE model by using experimental data in 6.2.2 and / or in 6.2.3 according to the computed method used;
c) considering the modularity of switchgear and controlgear assemblies, the numerical model calibrated for the test sample can be extended to a complete set of assemblies, all having the similar structure;
d) determination of the response, in the frequency range stated in 5.3.2, using the methods described in the following subclauses (see 6.2.5);

e) conclusion on the seismic mechanical behaviour according to the acceptance criteria given in subclause 7.4.

6.2.5 Computation methods

6.2.5.1 Static coefficient analysis

This method is based on the assumption that the complete assembly is subjected to the same acceleration. It allows a simpler technique to estimate the structural integrity with higher conservatism.

It should be used only when the accelerations on the components or on their anchorage points are expected to be equal or lower in comparison with the corresponding measured values on the tested assembly.

If the first natural frequency is unknown, the acceleration to take into account shall be the peak of the required response spectrum at a damping of 5 % (in case of unknown damping value).

If the first natural frequency is known, the acceleration to take into account shall be the spectral acceleration at this frequency and for a damping of 5 % (in case of unknown damping value).

In the both cases a coefficient of 1,5 shall be applied to take into account the effect of higher frequency modes.

Therefore, the seismic forces on each component of the switchgear and controlgear assemblies are obtained by multiplying the values of its mass, concentrated at its centre of gravity, by this acceleration.

6.2.5.2 Response spectrum dynamic analysis

For equipment having the first natural frequency below 35 Hz, the response spectrum dynamic analysis is recommended.

In comparison with the static coefficient analysis (see 6.2.5.1), this method allows the computation of the distribution of the maximal acceleration on the assembly.

In comparison with the time history analysis (see 6.2.5.3), this method allows to use directly the required response spectrum.

The response of interest, deflection, stress or acceleration, is determined by combining each modal response considering all significant modes (see Annex C for recommended combination procedure).

6.2.5.3 Time history dynamic analysis

Time history dynamic analysis is the most careful dynamic computation technique, involving time-step simulation of dynamic phenomena. It is based on a proper definition of the time histories which shall comply with the required response spectrum. In this case, the method can give the most detailed results. But it is not recommended because for the seismic qualification these levels of detail are not necessary.

The procedure of the time history dynamic analysis is described in Annex C.

6.3 Analysis by experience or similarity

In addition to the numerical analysis, analysis by experience may be another way to achieve the seismic qualification. It requires data from equipments of similar design that has successfully operated under previous qualification tests.

Each structural modification, which proves that the stiffness is not deteriorated, is acceptable. In these conditions, analysis by experience has to demonstrate that modifications do not generate stresses higher than obtained during the qualification test on the similar equipment.

For example: a mass moved from the top to the bottom produces a decrease of the bending moment on the anchorage points of the base.

If there is equivalence between the components to be qualified and the components previously tested the functionality shall be demonstrated. This means there is a high degree of similarity of the components and the local severity on the component shall be equal or less severe than this encountered during the qualification tests.

If there is no equivalence or in case of new components, the functionality shall be demonstrated with dynamic tests representative of the local environmental conditions and severity on the component.

7 Evaluation of the seismic qualification

7.1 Validity criteria of the seismic test

The seismic simulation waveform shall produce a test response spectrum which envelopes the required response spectrum (calculated at the same damping ratio) and have a peak acceleration equal to or greater than the zero period acceleration. Details on the validity criteria for the seismic tests are given in IEC 60068-2-57.

7.2 Acceptance criteria of the test results

For acceptance class 1, it shall be checked that:

a) the dielectric strength, switching capability and current carrying capability of the switchgear shall not be impaired, evidence is given by comparison of the functional check recordings before and after the test (according to 5.4.1). No significant change shall occur; all measured values shall be within the relevant tolerances given by the manufacturer;
b) during a seismic test run without mechanical operation of switching devices the main contacts shall remain in open or closed position;
c) during a seismic test run with mechanical operation of switching devices the main contacts shall reach the intended positions;
d) during the seismic test, chatter of relays shall not cause the switching devices to operate.

For acceptance class 2, all the acceptance criteria of class 1 have to be fulfilled plus the following criteria:

- the resonant frequencies shall not change by more than 20 % after the test;
- cracks on main parts are not acceptable (e.g. primary structural elements and insulating parts);
- deformations are allowed as long as the long term functionality is not affected;
- the condition of fixing devices of the equipment shall be maintained;
- any withdrawable or removable part shall operate correctly;
- auxiliary and control circuits shall not provide wrong information of the status of the switchgear and controlgear assemblies (position, alarm signals).

NOTE 1 Normally, chatter less than 2 ms is considered to be acceptable.

NOTE 2 Resetting of monitoring equipment is considered to be acceptable if the overall performance of the switchgear and controlgear assemblies is not affected.

7.3 Criteria of model acceptance

The model is considered consistent if the calculated accelerations of the devices which are part of the assembly are equal to or greater than the measured values during the test.

Natural frequencies and vibration modes shall be compared in order to verify the consistency of the model.

7.4 Acceptance criteria of the numerical analysis results

When a material is ductile, the Von Mises equivalent stresses of each component shall not exceed 100 % of yield strength of the material.

When a material is brittle, the Von Mises equivalent stresses shall not exceed 100 % of the minimal stress guaranteed in flexion.

NOTE 1 A material is ductile if it experiences a considerable plastic deformation before fracture.

NOTE 2 A material is brittle if it experiences a limited or no plastic deformation before fracture.

7.5 Acceptance criteria of the analysis results by similarity

The expected mechanical stresses on the equipment to be qualified shall be equal to or smaller than the stresses, in the same points, previously measured on a similar successfully tested equipment.

8 Documentation

8.1 Information for seismic qualification

The following information is required for either analysis or testing of the switchgear and controlgear assemblies:

a) severity level (see 4.3);
b) acceptance class (see 4.4);
c) details of structure and mounting (see 5.1 and 5.2);
d) number and relative position of testing axes (see 5.2).

8.2 Test report

The test report shall contain the following items:

a) severity:
   – severity level;
   – acceptance class;
b) switchgear and controlgear assemblies identification file including structure and mounting details:
   – one drawing of the complete test objects including weights, centre of gravity and measuring points;
c) test facility:
   – location;
   – test equipment description and calibration;

d) test method and procedures:
   – number and relative position of testing axes;
   – number and conditions of test runs;
e) test data including functional data:
   – resonant frequencies and damping, including records of the resonant frequency search;
   – response spectra including comparison of RRS and TRS for each axis;
   – time histories of the test for each axis;
   – list of any anomalies, documentation of any marks for distress respectively damage;
   – data of the functional checks, measured before and after the test including comparison;
   – some diagrams of the contact supervision during the time-history test;
   – photos of test set-up and measuring points;
f) results and conclusions.

The cover sheet of the test report shall contain at least the following information:

- type and designation of test object;
- severity level;
- acceptance class;
- number and conditions of test runs.

8.3 Analysis report when analysis is a numerical analysis

The report shall include the following:

a) identification and description of equipment to be qualified;
b) switchgear seismic test references and relevant test data;
c) justification of the choice of the computation method;
d) identification of the computer software and validation references;
e) model description (type of elements, size of meshing, assumptions,..);
f) list of natural frequency modes in the 1 Hz to 35 Hz range (except for static method);
g) model validity and justification statement;
h) equipment response for the Required Response Spectra (RRS) specified;
i) mounting-reaction forces;
j) calculated deflections of connections, attachments and clearances;
k) performance of each device, component, and accessory in terms of mechanical behaviour and operability under seismic conditions;
l) results, conclusions, and qualification statement;
m) signatures (as required) and date.

8.4 Analysis report when analysis is performed by similarity

The report shall include the following:

a) identification and description of equipment to be qualified;
b) identification and description of reference equipment;
c) justification of the similarity;
d) comparison of the equipment to be qualified versus reference equipment: stiffness, dimensions, arrangement, mass distribution, seismic severity;

e) performance of each device, component, and accessory in terms of mechanical behaviour and operability under seismic conditions;
f) results, conclusions, and qualification statement;
g) signatures (as required) and date.

Annex A
(normative)

Characterization of the test sample for analysis

A.1 Low-level excitation

A.1.1 General

The method exploits the application of a low-level excitation of the test sample for the determination of its natural response.

A.1.2 Test method

There are different test methods:

- resonance search with a slowly swept sinusoidal vibration test according to IEC 60068-2-6,

  See ISO 7626-2.

NOTE When portable exciter is used, experimenters pay attention to the influence of the weight of portable exciters. With the test sample mounted to simulate the recommended service mounting conditions, a number of portable exciters are attached at the points on the test sample which will best excite its various modes of vibration.

- measurement of the transfer functions at critical points of the structure by using an impact test,

  See ISO 7626-5.

- measurement of response at critical points of the structure by using a broadband random input signal according to IEC 60068-2-64.

The data obtained from the monitoring instruments placed on the test sample are used to analyse its dynamic performance.

A.1.3 Analysis

The frequency responses obtained from the test are used to determine the modal frequencies and damping ratios which shall be used in the numerical analysis of the test sample stated in 6.2.

A.2 (Void)

Annex B
(informative)

Criteria for seismic adequacy of enclosed switchgear and controlgear assemblies

B.1 General

B.1.1 Combination of stresses

The probability of an earthquake of the recommended seismic qualification level occurring during the life-time of the switchgear and controlgear assemblies is low, whilst the maximum seismic load in a natural earthquake would only occur if the switchgear and controlgear assemblies were excited at their critical frequencies with maximum acceleration. As this will last only a few seconds, a combination of the utmost electrical and environmental service loads leads to unrealistic conservatism.

The following loads may be considered to occur additionally, if not otherwise specified:

– rated internal pressure;
– permanent loads (dead loads);
– thermal effects.

The combination of loads should be effected by static analysis, applying the forces in the direction they occur.

B.1.2 Floor and building structure interaction

Floor and building structure interaction may be described if it is desirable to calculate the effect of their presence. Measures that may be taken to minimize floor and building structure interaction are as follows:

- lower centre of gravity of equipment;
- lightweight equipment;
- use of monolithic floors or buildings meeting seismic requirements.

B.1.3 Displacement limitations

Considerations that impose displacement limitations on equipment may be described as follows:

- alignment of moving parts;
- leakage of insulating gas;
- impact with adjacent equipment;
- reduction of dielectric spacing and damage to insulation;
- interconnection to equipment on adjoining floors.

B.2 Recommended installation provisions and practices

B.2.1 Floors

It is recommended that, as far as possible, all interconnected equipment be placed on a monolithic floor to reduce differential movements due to the design earthquake. When interconnected equipment is not located on the same floor, then the expected differential motions between equipment due to floor motion should be considered.

Consideration may be given to interaction on underground conduits entering and leaving through the floors. If equipment is rigidly coupled to structural elements, such as walls or adjacent floors, the element response and relative motion may be taken into account.

B.2.2 Methods for anchoring equipment to foundations

It is strongly recommended that large equipment and equipment with large dimensions between anchor locations be anchored to steel members embedded in and firmly attached to structural elements in the concrete. Location and type of fixings may be shown on the manufacturer's drawing. All fixings shall be adequate for forces coming from a design earthquake. Exposed metal fixings shall be protected from corrosion.

If bolts are used to anchor equipment, they shall be either cast in fresh concrete or fixed by means of well-tested chemical anchors for drilled holes in hardened concrete. The use of bolts or anchors that are placed in holes drilled in hardened concrete is not recommended. Bolts of mild, ductile steel are preferred.

Consideration may be given to any unequal distribution of dynamic earthquake loading on the anchor bolts (due to bolt hole tolerance, torque load or non-contact of nut). The torque value to which the anchor bolts are tightened, their size and location, shall be shown on the construction drawings. In addition, the strength and material specifications shall be provided.

All anchor systems shall be designed to accommodate torsion, shear and bending and axial loads and any combination thereof that is experienced during the design earthquake. Shear and tensile strength of that portion of the anchor system within the foundation may be greater than the strength of the bolt attaching to the equipment.

NOTE See [1]. [1]

B.2.3 Interconnection to adjacent equipment

All interconnections between structures shall be adequate to accommodate all large relative motions.

Structurally and dynamically dissimilar structures may experience large relative displacements. Leads and interconnections shall be long and flexible enough to allow these displacements to occur without causing damage. Particular attention shall be paid to brittle non-ductile parts such as ceramic bushings and insulators. In no circumstances shall electrical or structural interconnections abruptly stiffen leading to increased motion and strain. Such nonlinearities develop large impact forces. Consideration shall be given to the resultant change in dynamic characteristics of the equipment as a result of any being used to make interconnections between equipment.

B.2.4 Use of bracings on switchgear structure

Stiffening the equipment may increase some of its natural frequencies, raising them out of the critical range of earthquake energy. Diagonal cross-bracing and axial load-carrying members can be used to stiffen or strengthen equipment. Where bracing is employed, particular attention should be paid to the following aspects:

- bolted joints are recommended throughout the structure so as to increase the effective damping at high force levels;

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1 Figures in square brackets refer to the bibliography.

- information concerning the correct torque for all bolts shall be supplied, thus ensuring the assemblies will behave dynamically as intended;
- if part of the structure is to be supplied by the user, then the manufacturer or user, or both, shall supply the necessary information so that the static and dynamic characteristics and foundation requirements can be easily determined.

The following basic requirements on the bracing should be taken into account:

- the bracing shall be substantially stiffer than the structure it reinforces so as to be effective;
- the bracing shall not buckle or exhibit a sharply nonlinear behaviour. In particular, any abrupt stiffening under any circumstance is to be avoided;
- permanent deformation in the bracing after an earthquake is acceptable provided that it does not impair normal functioning of the assembly.

Annex C
(informative)

Dynamic analysis methods

C.1 General

As a general preliminary remark, it is necessary to check the adequateness of the finite element mesh to the maximum frequency content of the input signal (typically 35 Hz). The mesh size shall be fine enough to be able to reproduce the modal shapes corresponding to the higher frequencies taken into account.

C.2 Response spectrum analysis

For a given earthquake time history, the maximum response of a generic one degree of freedom elastic system, (characterized by a natural frequency f and a critical damping β) can be easily evaluated, so that we can obtain a function of this two parameters (f , β).

We define as Acceleration Response Spectrum of a given earthquake time history, the function $S_a(f\ ,\ \beta)$ which describes the maximum acceleration of the generic one degree of freedom system for a given range of frequencies and damping values. Since the modal representation of a generic finite element elastic model is made by n orthogonal eigenvectors (where n is the number of modes) each one representing a one degree of freedom system, the acceleration response spectrum function provides the maximum acceleration for each eigenvector. By knowing maximum acceleration for each eigenvector (one degree of freedom system), maximum displacements, forces, etc can be computed.

Maximum quantities for the complete model are then computed by combining maximum modal quantities relevant to all computed modes; for this reason the quality of result depends on the computation of a sufficient number of eigenvectors.

To combine the maximum modal spectral responses the following rule is recommended:

$$a_{\max} = \sqrt{\sum_{m-c1-c2-...} a_e^{\ 2} + \left(\sum_{c1} |a_e|\right)^2 + \left(\sum_{c2} |a_e|\right)^2 + \left(\sum_{c3} |a_e|\right)^2 + ...}$$

where

a_{max} is the combination result;

m is the number of computed modes;

a_e is the maximum response of the generic mode;

$c1$, $c2$, etc are mode clusters whose frequencies are within 10 %.

This rule combines all “distant” modes and mode clusters through the Square Root of Sum of Squares (SRSS) rule. Within the generic mode cluster the modal quantities are combined by summing their absolute value.

Sufficient modes (modal mass) should be included to ensure an adequate representation of the structure dynamic response and constraints forces at supports. The suggested criterion for sufficiency in a particular direction shall be that the cumulative participating mass of the modes considered shall be at least 90 % of the actual mass.

If the participant mass does not reach 90 % within the 35 Hz range, it means that the finite element model has several resonant frequencies above 35 Hz and the effects of the orthogonal inputs can be taken into account as follows:

- determine the remaining effective mass in a given direction,
- apply for each component a static force equal to the mass of the component times the percentage of mass missing times the Zero Period Acceleration (ZPA),
- calculate stresses, reactions and so on,
- combine for each direction stresses, reactions and so on from the dynamic analysis with those from the analysis above using the SRSS rule described below.

When base excitation is applied along more than one orthogonal axis (biaxial or triaxial excitation) the responses relevant to different excitation direction shall be also combined. This further combination should be carried out following the SRSS rule.

$$A_{\max} = \sqrt{\sum_{j=1,3} a_{\max}{}^{2}}$$ where j = 1,3 are the excitation directions.

When dynamic results computed by response spectrum analysis have to be combined with static ones (typically dead loads), the following scheme is recommended:

For displacements, velocities, acceleration, forces and moments the resultant should be computed by adding the static quantities to the response spectrum analysis result (signless) multiplied for the sign of the static ones. For stresses, it is required to combine static and response spectrum analysis values of all the stress tensor components, adding each component of the static stress tensor to the corresponding component of response spectrum analysis stress tensor multiplied by the sign of the static one.

C.3 Time history analysis

Time history analysis method involves time-step computation of the model dynamics: equations of motion are solved for each time-step, considering mass, stiffness, damping forces and external applied forces.

This method requires the use of synthetic input time histories compatible with the RRS: if available, those used for the shaking table test can be employed. Since results from a single set of compatible base time histories is not sufficient for qualification scopes, it is required to use at least 3 sets of different compatible base time histories.

Being a dynamic simulation of the structural dynamics, the identification of maximum quantities shall be carried out after the analysis.

Time history analysis for linear elastic models (the only one allowed by the present standard) can be carried out using either the modal transient analysis with "m" modal equations (being m the number of eigenvectors used) or the direct transient analysis with the complete set of "n" equations (being n is the degree of freedom number of the finite element model).

Modal transient analysis uses the same modal representation of the finite element model used by the response spectrum analysis. In analogy with the response spectrum analysis, an important issue is the check of the respect of the minimum participant mass percentage required (90 %) for each excitation direction (see C.2). Damping can be applied as modal damping, selecting a value for each mode.

Direct transient analysis solves directly the "n" equation of motion of the finite element model. Since no modal representation is used, the participant mass check is not an issue. The damping can be defined through the use of a damping matrix proportional to mass and/or stiffness (Rayleigh damping) which corresponds to a percentage damping which is not constant along the frequency range, so that care shall be used.

Annex D
(informative)

Expected peak ground accelerations for different earthquake scales

D.1 Earthquake zones

Earthquake zones are defined in a world-wide map of natural hazards according to the insurance Munich Re group.

In the following Table D.1 different earthquake zones are shown:

Table D.1 – Earthquake zones with earthquake intensity and magnitude scale

Earthquake Zones *	Earthquake Intensity Scales						Earthquake Magnitude Scale	
World Map of Natural Hazards (Munich Re Group)	**MM 1956**	**Descriptive term**	**Acceleration % g** (g = 9.81 m/s²)	**EMS 1992**	**RF 1883**	**JMA 1951**	**Magnitude****	**According to Richter (1956)** $\log_{10} E = 11.8 + 1.5 M$
Zone 0	I	Imperceptible	< 0.1	II	II	I	1.0-3.0	E = energy released (in erg); to be multiplied by 32 for each full M grade M = Richter Magnitude (up to M ~ 9.5)
	II	Very slight	0.1-0.2				3.0-3.9	
	III	Slight	0.2-0.5	III	III			
	IV	Moderate	0.5-1	IV	IV	II	4.0-4.9	In addition to M, effects observed on the surface (-> intensities) depend mainly on the depth of and the distance from the focus, the duration of the earthquake and the prevailing subsoil conditions.
	V	Rather strong	1-2	V	V	III		
Zone 1	VI	Strong	2-5	VI	VI		5.0-5.9	
Zone 2	VII	Very strong	5-10	VII	VII	IV	6.0-6.9	
Zone 3	VIII	Destructive	10-20	VIII	VIII	V		
Zone 4	IX	Devasting	20-50	IX	IX		7.0 and higher	
	X	Annihilating	50-100 (~1g)	X	X	VI		
	XI	Disaster	1-2g	XI				
	XII	Major disaster	>2g	XII		VII		

MM: 1956 Modified Mercalli
EMS: 1992 European Macroseismic Scale (Improvement of Medwedew-Sponheur-Karnik, 1964)
RF: 1883 Rossi-Forel
JMA: 1951 Japan Meteorological Agency

* Probable maximum intensity (MM: Modified Mercalli scale) with an exceedance probability of 10% in 50 years (equivalent to a "return period" of 475 years) for medium subsoil conditions

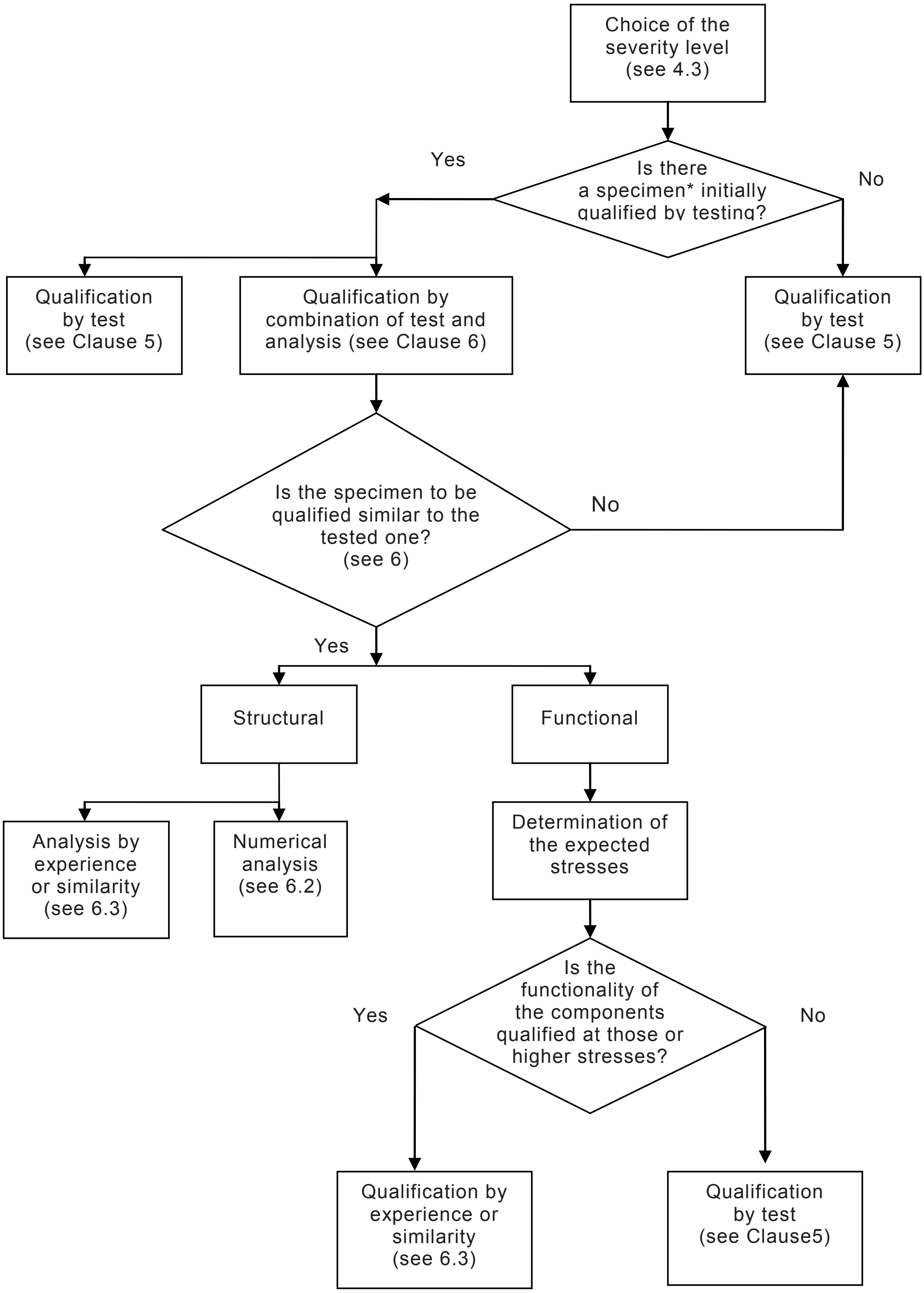
** according USGS - United States Geological Survey

NOTE See [2].

D.2 (Void)

Annex E
(informative)

Qualification process flowchart



* the reference is the specimen initially tested under the seismic loads.

NOTE In any case, the qualification by testing is a possible solution.

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[2] USGS United States Geological Survey, available at

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

[4] ISO 7626-1, *Mechanical vibration and shock – Experimental determination of mechanical mobility – Part 1: Basic terms and definitions, and transducers specifications*

[5] ISO 7626-2, *Vibration and shock – Experimental determination of mechanical mobility – Part 2: Measurements using single-point translation excitation with an attached vibration exciter*

[6] ISO 7626-5, *Vibration and shock – Experimental determination of mechanical mobility – Part 5: Measurements using impact excitation with an exciter which is not attached to the structure*

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