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Design of nuclear power plants against seismic events —

Part 1: Principles

Conception parasismique des installations nucléaires —

Partie 1: Principes

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Foreword

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A list of all parts in the ISO 4917 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

In accordance with IAEA Safety Standards Series No. SSR-2/1, protective measures against seismic events are required, provided earthquakes are taken into consideration.

Earthquakes comprise that group of design basis external events that requires taking preventive plant engineering measures against damage and which are relevant with respect to radiological effects on the environment.

This document will be applied under the presumption that the geology and tectonics of the plant site have been investigated with special emphasis on the existence of active geological faults and lasting geological ground displacements, and that the site has been deemed suitable for a nuclear installation.

Design of nuclear power plants against seismic events —

Part 1:
Principles

1 Scope

This document applies to nuclear power plants with water cooled reactors and, in particular, to the design of components and civil structures against seismic events in order to meet the safety objectives. For other nuclear facilities the applicability of the document is checked in advance, before it might be applied correspondingly. Seismic isolation is not adressed in the series of ISO 4917.

The following safety objectives are defined in order to ensure the protection of people and the environment against radiation risks:

a) controlling reactivity;

b) cooling fuel assemblies;

c) confining radioactive substances;

d) limiting radiation exposure.

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.

IAEA Safety Standards Series No., SSG-67*, Seismic Design for Nuclear Installations*, INTERNATIONAL ATOMIC ENERGY AGENCY VIENNA, (2021)

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
action
impact of an external force (e.g. seismic action)

3.2
action effect
internal force inside a structure (e.g. force, moment)

3.3
active geological fault
fault showing evidence of past movements (e.g. recent seismicity or geological evidence) within such a period that it is reasonable to assume that further movements can occur

Note 1 to entry: For areas of low seismicity evidence of last movements in the Quaternary (until ≈ $2,6 \cdot 10^6$ a) or including Pliocene (until ≈ $5,3 \cdot 10^6$ a) can be appropriate to consider. For higher seismic areas shorter periods can be considered.

Note 2 to entry: A geological fault need also to be considered active if a structural relationship with a known active geological fault is demonstrated or likely. In this case the movement of one fault can cause the movement of the other.

Note 3 to entry: The definition is equivalent to “capable fault” in IAEA Glossary (2018)[5].

3.4
beyond design basis earthquake
decisive level of ground motion which exceeds the design basis earthquake

3.5
civil structure
building structure that is connected to the ground and consists of structural and non-structural elements (building materials and structural members)

Note 1 to entry: It may be necessary to perform the verification of earthquake safety for “civil structures” in their entirety as well as for the individual parts (“structural members”).

3.6
complete quadratic combination
CQC
stochastically based superposition relationship for oscillating systems in order to take account of the coupling of eigenmodes in modal analyses

3.7
component
electrical, instrumentation and control, and mechanical equipment that ensures the operation of the nuclear facility, including distribution systems and their support structures

Note 1 to entry: This definition is necessary for the differentiation between “plant component” and “*civil structures* (3.5) or building structures”. In mechanical engineering, a component is one that is manufactured from product forms and represents the smallest part of a subassembly.

3.8
correlation coefficient
ρ_{xy}
coefficient of two seismic time histories, x(t) and y(t), defined by the covariance σ_{xy} of $x(t)$ and $y(t)$ divided by the product of the related standard deviations s_x and s_y of the two time histories

3.9
damping ratio
D
dimensionless characteristic value of a (velocity proportional) damped oscillating single-degree-of-freedom system, in percentage of critical damping

3.10
deaggregation
quantification of the relative contributions from earthquakes of different sizes and at different distances to the seismic hazard at a site

Note 1 to entry: Usually calculated for discrete ground motion levels from the probabilistic seismic hazard analysis (PSHA) and for intervals of *magnitude* (3.24) and distance or for seismic sources.

3.11
design basis earthquake
decisive level of ground motion for the design against seismic events

Note 1 to entry: The design basis earthquake (DBE) is equivalent to SL-2 earthquake as per IAEA SSG-67 or safe shutdown earthquake (SSE) in some national guidelines. It represents the seismic impact at the site, at least expressed in terms of *ground acceleration response spectra* (3.17) and *strong motion duration* (3.38).

3.12
epistemic uncertainty
aleatoric variability
epistemic uncertainty, based on uncertainty of the state of knowledge, (e.g. regarding models or parameters) and aleatoric variability, inherently connected with stochastic phenomena or processes (e.g. decrease of acceleration amplitudes with increasing distance)

Note 1 to entry: Epistemic uncertainties can be reduced by additional data, information or improved modeling (e.g. uncertainty in specifying the source region). Aleatoric variabilities usually cannot be reduced.

Note 2 to entry: Epistemic uncertainty and aleatoric variability is equivalent to "Epistemic uncertainty" and "aleatoric uncertainty" in IAEA Glossary (2018)[5].

3.13
external event
event unconnected with the operation of a facility or the conduct of an activity that could have an effect on the safety of the facility or activity

Note 1 to entry: These events having either natural causes (e.g. high water, earthquake) or civilizational causes (e.g. aircraft crash, pressure wave from explosions).

3.14
focal depth
depth of the hypocenter beneath the surface of the earth

3.15
free field
location at or near the surface, where vibratory ground motion is not affected by structures and facilities

3.16
functionality
ability of a system or *component* (3.7) to fulfill its designated safety functions during and after the seismic event

Note 1 to entry: This definition is specific to components. In the case of *civil structures* (3.5), the adequate term would be "serviceability".

3.17
ground acceleration response spectrum
response spectrum derived from a ground motion related to *free field* (3.15) or a reference horizon at depth

3.18
ground motion prediction equation
GMPE
function (typically empirical) for the prediction of ground motion

Note 1 to entry: Input parameters are *magnitude* (3.24), source to site distance, local site conditions and other parameters.

3.19
inspection level earthquake
level of ground motion that, if exceeded, causes a plant inspection

3.20
integrity
ability of a plant *component* (3.7) to fulfill its functions with regard to leak tightness or deformation restrictions

3.21
(macroseismic) intensity
classification of the strength of ground motion, based on the observed effects within a limited area, e.g. a village

Note 1 to entry: Basis for determining the intensity are phenomenological descriptions of the effects on humans, objects, buildings and the earths surface. The intensity is a robust measure for strength classification; the corresponding macroseismic classification scales (e.g. EMS 98[11]) define twelve intensity levels.

3.22
internal event
event or group of events that result from failures of systems, structures or *components* (3.7) (SSC) or human failures originating within a nuclear power plant that cause an initiating event directly or indirectly and may challenge safety functions to achieve its safety objectives

Note 1 to entry: These are exceptional events caused by plant internal incidents (e.g. differential pressures, jet impingement and reaction forces, plant internal flooding due to breakage or leakage of pressurized components, load crash)

3.23
load-bearing capacity
ability of *components* (3.7) and *civil structures* (3.5), based on their material strength, stability and secure positioning, to withstand the impact from events

3.24
magnitude
measure of the size of an earthquake, approximately related to the energy released in the form of seismic waves

Note 1 to entry: The classic definition of seismic magnitude is the logarithm of the maximum amplitude of recorded seismograms taking the distance to the hypocenter (seismic focus center) into account. Different types of seismic magnitudes are, e.g. local magnitude, body wave magnitude, surface wave magnitude and moment magnitude.

3.25
operating basis earthquake
decisive level of ground motion that is likely to occur and affect the plant during its operating lifetime

3.26
paleoseismology
method used to search for indications of prehistoric earthquakes in geological sediments and rock formations and includes estimation of their *magnitude* (3.24) and of the age of the deformations due to earthquakes

Note 1 to entry: Paleoseismology serves to extend earthquake findings into the younger geological times. Paleoseismology is generally restricted to geological terrains of continuous sedimentation of the past ten thousands of years.

3.27
peak ground acceleration
maximum amplitude (absolute value) of the horizontal or vertical ground acceleration *components* (3.7) of the earthquake time history (accelerogram)

Note 1 to entry: It corresponds to the rigid-body acceleration of the *ground acceleration response spectrum* (3.17).

3.28
probability of exceedance
probability that a certain ground motion (e.g. peak acceleration, spectral value of acceleration) is reached or exceeded at a site within a specified time period (usually one year)

Note 1 to entry: The reciprocal of the annual probability of exceedance is often termed as average return period.

3.29
response spectrum
largest oscillation amplitudes (values) of a damped single-degree-of-freedom oscillator (accelerations, velocities, displacements) with various eigenfrequencies and a constant *damping ratio* (3.9) in response to an excitation described by a time history at the base point

Note 1 to entry: Unless indicated otherwise, the response spectrum in this document relates to acceleration (spectral acceleration) and relates to an elastic oscillator that includes no effects from ductile deformations.

3.30
rigid-body acceleration
value of the *response spectrum* (3.29) in the high frequency range where the seismic response shows no further significant increase (corresponding to maximum absolute amplitude of the acceleration time history)

3.31
seismic-engineering parameter
parameter, such as *response spectrum* (3.29), *strong motion duration* (3.38) and further parameters characterizing the ground motion at the site

3.32
seismic hazard curve
graphic representation of the per annum probability that a specific parameter of the earthquake ground motion is reached or exceeded at the plant site

Note 1 to entry: Seismic hazard curves are determined by the probabilistic seismic hazard analysis (PSHA), usually expressed in spectral accelerations and *peak ground acceleration* (3.27).

3.33
seismic source region
zone (area of diffuse seismicity) or line (associated with a fault) on which a uniformly distributed seismicity is assumed

Note 1 to entry: Zoning of seismic source regions (seismic source zones) are established mainly based on seismicity, geologic and tectonic development and, in particular, regarding neotectonic conditions.

3.34
seismogram
graphic display (or digital data) of the ground motion (proportional to displacement, velocity or acceleration) at a certain location during the earthquake

Note 1 to entry: It is also called earthquake record or earthquake time history and is usually recorded in three orthogonal directions, two of these in the horizontal plane.

Note 2 to entry: An earthquake record proportional to the ground acceleration is called an accelerogram.

3.35
serviceability
ability of *civil structures* (3.5) to enable the designated use even under the impact of events that are assumed to occur

3.36
soil
loose or firm ground material

3.37
spectral matched time history
recorded time history, adjusted by the spectral machting technique to be compatible to the site *response spectrum* (3.29)

3.38
strong motion duration
length of time of the seismic strong ground motion at a site, calculated by a certain definition

Note 1 to entry: Strong motion duration may be defined as the time interval between the 95th and 5th percentiles of the integral of the mean square value of the acceleration or other definition; a consistent definition of duration should be used throughout the evaluation.

3.39
structural member
structural part of the *civil structure* (3.5)

Note 1 to entry: Some documents use the term "building structures" instead of "civil structures".

3.40
subsoil
layers of weathered material below the earth surface

3.41
tectonics
science of the structure, forces, motions and deformations of the earth's crust and parts of the earth's mantle

Note 1 to entry: Tectonics considers global, regional and local aspects. Neotectonics considers the tectonics of the more recent geological past (Quaternary period).

3.42
time history envelope function
typical average envelope over the relevant time span of *seismograms* (3.34)

Note 1 to entry: It is characterized by its increasing phase, its strong ground motion phase and its decreasing phase; it is used for generating artificial seismograms that are compatible with a ground response spectrum.

Note 2 to entry: The *strong motion duration* (3.38) is the total duration of the increasing phase, the strong ground motion phase and the decreasing phase of the time history envelope function.

3.43
time history set
set of three acceleration time histories, for each of the three orthogonal directions of motion, that act simultaneously

3.44
uniform hazard response spectrum
response spectrum (3.29) from a probabilistic seismic hazard assessment with an equal *probability of exceedance* (3.28) for each of its spectral ordinates

4 General seismic design concept

In this document the following seismic events (seismic levels) are considered:

— Design basis earthquake (DBE), equivalent to SL-2 earthquake as per IAEA SSG-67 or safe shutdown earthquake (SSE) in some national guidelines;

— Inspection level earthquake, if exceeded a plant shutdown inspection shall be performed, and the plant shall be shut down (see ISO 4917-6);

— Operating basis earthquake (OBE), equivalent to SL-1 earthquake in IAEA SSG-67;

— Beyond design basis earthquake, according to IAEA SSG 67.

NOTE Details of the beyond design earthquake could be specified country specific and are not covered by this standard.

5 Determining the design basis earthquake

5.1 General requirements

The design basis earthquake (DBE) is described by the seismic action at the location of the site that is characterized by ground motions. The design basis earthquake shall be specified by evaluating probabilistic and/or deterministic analyses. The analyses should be performed in accordance with IAEA SSG-9. However, it is recommended to perform probabilistic and deterministic analyses to the extent reasonable. The design basis earthquake is equivalent to the SL-2 earthquake in IAEA SSG-67. The considered surrounding area of the site shall be large enough to incorporate all seismic sources that could affect the nuclear installation. Examples of typical areas in km are given in Annex A. Seismic sources (e.g. seismic source region) shall not be cut by the defined radius. The design basis earthquake is the basis for the specification of the seismic-engineering parameters. The design basis earthquake may be understood either as being a combination of a number of decisive earthquakes (e.g. deterministic scenarios) or as being the governing ground motions at the site of the facility (e.g. expressed as a uniform hazard response spectrum).

An operating basis earthquake (OBE) can be defined in addition to ensure the possibility of continued operation in the event of less severe, but more probable, earthquakes. The operating basis earthquake is equivalent to the SL-1 earthquake in IAEA SSG-67. It shall be based on a defined annual probability of exceedance and a corresponding hazard fractile or mean hazard value. Alternatively, its acceleration response spectra can be calculated from the design basis earthquake by a constant factor. Annex A contains criteria for the definition of the operating basis earthquake.

The deterministic approach to specify the design basis earthquake shall be based on historic and recent earthquakes and magnitude estimations for active geological faults. The approach considers the largest credible seismic action at the site using current scientific knowledge.

The probabilistic approach to specify the design basis earthquake shall be based on a defined annual probability of exceedance and a corresponding hazard fractile or mean hazard value. Recommended design values can be found in the Annex A.

The design basis earthquake shall be specified with a minimum horizontal peak ground acceleration value of 0,1 g.

If anthropogenic impacts (e.g. induced seismicity) may cause significant ground motion at the site, their impacts shall be assessed.

5.2 Deterministic determination of the design basis earthquake

The strongest earthquakes that may occur within the surrounding area of the site, up to the radius specified in 5.1, shall form the basis for the deterministic determination of the design basis earthquake. The location of geological structures, in particular those which can be considered as active geological faults, shall be examined. Findings from paleoseismology shall be taken into account. Seismic sources are represented by areal seismic zones with diffuse seismicity and active geological faults. In accordance with IAEA SSG-9, the following principles apply to determine the vibratory ground motion hazard at the site:

a) For each active geological fault, it shall be assumed that an earthquake with the potential maximum magnitude occurs closest to the site, considering the physical dimensions of the fault. If the fault is within the site vicinity and its location and extent cannot be determined with sufficient accuracy, the earthquake shall be assumed to occur beneath the site. It shall be ensured that active geological faults shall not fall within the site area.

b) For seismic source regions that do not include the site, the associated potential maximum magnitude earthquake shall be assumed to occur at the point of the region closest to the site.

c) For the seismic source region that includes the site, the potential maximum magnitude earthquake shall be assumed to occur at some identified specific horizontal and vertical distance from the site (typically less than 10 km). Within this distance, the absence of active geological faults faulting shall be ensured. Otherwiese, the earthquake shall be assumed to occur beneath the site.

NOTE The strength of historic earthquakes can be described by their respective (macroseismic) intensities and magnitude estimations. Regarding particularly relevant historic earthquakes and a correspondingly uncertain database, it may be necessary to perform additional investigations. When determining the design basis earthquake, the epistemic uncertainties and the aleatoric variabilities of the data, parameters and models used, and the incompleteness and limitations of the earthquake catalog, shall be considered by appropriate margins.

5.3 Probabilistic determination of the design basis earthquake

The annual probabilities of exceeding the seismic activity at the site, as well as the uncertainties of these values, shall be determined by a probabilistic seismic hazard analysis (PSHA).

All elements of the PSHA shall be properly described and documented. Specifically, the earthquake catalogs used, the seismic source regions and active geological faults with their characteristic parameters, the ground motion prediction equations (GMPE), local site response and the applied procedures and methods.

Epistemic uncertainties and aleatoric variabilities of the applied data, used parameters and models shall be taken into account. Their influence on the results shall be evaluated. Epistemic input parameters and models shall be justified.

Seismic hazard curves including their tolerance range, shall be calculated for exceedance probabilities between 10^{-2} and 10^{-6} (or 10^{-7}) per annum. Mean and median values and at least fractiles of 5 %, 16 %, 84 % and 95 % shall be calculated.

A deaggregation shall be performed. This requires determining and specifying the effects of the various earthquake magnitudes, and of the various distances and seismic sources on the overall hazard, in particular for the determined probability of exceedance specified in 5.1. Deaggregation plots for at least three frequencies (low, middle and high) shall be drawn for discrete magnitude and distance bins and it shall be given the contributions of the ground motion deviates from the expected mean (typically given as factor ε of the standard deviation). For a better comparison of the findings from the deterministic and probabilistic methods in 5.4, it is recommended to select the deaggregation distances with respect to the distances of the relevant seismic sources.

5.4 Specification of the design basis earthquake

Results should be compared if deterministic and probabilistic evaluations are performed as recommended. Particular emphasis shall be placed on the comparison of the seismic-engineering parameters resulting from the respective evaluation methods.

The plausibility and reliability of the findings from the deterministic and probabilistic methods should be evaluated.

The design basis earthquake should be specified by the probabilistic assessment and verified by the deterministic assessment as a plausibility check. Recommendations for the comparison of probabilistic and deterministic assessments are given in Annex A.

NOTE The design basis earthquake can be based on a standard (generic) ground motion spectrum which covers multiple site conditions if this standard design spectrum envelopes the site-specific ground motion from the seismic hazard analysis for all frequencies of interest.

5.5 Seismic-engineering parameters of the design basis earthquake

With regard to the verification of the earthquake safety of components and civil structures, the seismic action of the design basis earthquake shall be described by seismic-engineering parameters, in particular, by the ground response spectra (e.g. scenario-based response spectra, uniform hazard response spectrum) with the corresponding rigid-body accelerations (at peak ground acceleration) and the strong-motion duration.

Ground motion prediction equations (GMPE) and the use of earthquake records based on at least magnitude, distance and site conditions, can be applied for the determination of the seismic-engineering parameters. Alternatively, ground motion simulations based on fault rupture modeling may be applied in well founded cases (e.g. to model near-field ground motions). Detailed information about ground motion simulation based on fault rupture modelling can be found in IAEA Safety Report Series No. 85.

The site-specific ground acceleration response spectra shall be specified for free field conditions and for soil sites for a reference horizon at depth (control point). The reference horizon at depth can be a geological layer boundary of a stiff ground layer or a rock surface. The control point at depth is the input level for soil dynamic calculations. The associated ground profile from the free field to the reference horizon at depth and information about deeper geological layers shall be considered together with the dynamic soil characteristics and their tolerances. At least for soil sites with associated shear wave velocities below a certain value (e.g. 1 000 m/s), the influence of site response shall be evaluated by soil dynamic calculations. If site response analyses are performed, it shall be ensured that the seismic loads applied for the design are consistent to the hazard calculation output (e.g. no double counting of uncertainties due to soil variability).

At least two ground acceleration response spectra shall be specified, one for the two horizontal components (usually assumed to be equal) and the other for the vertical component of the ground motion. The vertical component shall be assessed from seismic hazard analysis using ground motion prediction equations for the vertical direction or an evaluation of a frequency dependant vertical to horizontal ground motion ratio (v/h ratio). Alternatively, the vertical component can be calculated, assuming a frequency independent v/h ratio, given in Annex A. Both horizontal components and the vertical component shall be assumed to be simultaneously effective, but their maxima should be considered as statistically independent.

The ground response spectra shall be specified for a frequency range starting at a specified lower bound frequency f_{lb} up to an upper bound frequency, i.e., at which the rigid-body acceleration begins. Both frequency bounds are strongly dependent on the energy contents of ground motion and on the soil conditions at the site.

The ground response spectra shall be specified at least for 5 % of critical damping. The 5 % spectrum (D = 0,05) may be converted to spectra with other damping D, by multiplying the peak spectral range of the spectrum (spectrum plateau) by the factor f_D. For higher frequencies (above the upper corner frequency of the spectrum plateau), f_D gradually decreases until 1 as it merges into the rigid-body acceleration. Annex A includes an example for f_D. If the selected GMPE in the seismic hazard analysis provide also values for other than 5 % damping, the response spectrum should be calculated also for some of these damping values.

NOTE 1 The seismic analysis of building structures differentiates between the ground or free field response spectra (primary spectra), the building response spectra (secondary spectra) and the component response spectra (tertiary spectra). In their smoothed, broadened or enveloping form, they are used as basis for the design.

The strong motion duration of the design basis earthquake shall be specified in accordance with the assumed duration criterion and time history envelope function, which serves as the basis for determining artificial seismograms.

If recorded acceleration time histories are used for determining the seismic-engineering parameters, they shall be fully documented. The same applies for spectral matched acceleration time histories.

With regard to structural analyses, recorded acceleration time histories should be specified whose characteristic parameters, i.e., response spectrum, strong-motion duration and energy content, are similar to those of the design basis earthquake.

NOTE 2 The energy content can be expressed, for example, in terms of Arias Intensity or CAV (cumulative absolute velocity). The energy content may be evaluated under consideration of relevant magnitudes and distances (from the deaggregation analysis) and the duration of the design earthquake.

NOTE 3 If recorded time histories are used, it is permissible to scale them by multiplication factors from about 0,5 to 2,0.

6 General design requirements

6.1 Design basis

6.1.1 Classification

6.1.1.1 General

Regarding their seismic design, the individual components and civil structures shall be assigned to one of the following three seismic categories:

6.1.1.2 Seismic category 1

Components and civil structures that are required to fulfill the safety objectives given in Clause 1, including limiting radiation exposure.

6.1.1.3 Seismic category 2

Components and civil structures not belonging to seismic category 1 and which, due to their own damage and the sequential effects possibly caused by an earthquake, could adversely affect the safety related functions of seismic category 1 components and civil structures.

6.1.1.4 Seismic category 3

All other components and civil structures.

6.1.2 Verification of design basis earthquake safety

For seismic category 1 components it shall be verified that, with regard to their

a) load-bearing capacity,

b) integrity, and

c) functionality,

they will be able to fulfill their respective safety related functions in case of a design basis earthquake.

For seismic category 1 civil structures it shall be verified that, with regard to their

— load-bearing capacity,

— serviceability

they will be able to fulfill their respective safety related functions in case of a design basis earthquake.

NOTE 1 In order to meet this requirement for civil structures, additional verifications (e.g. of the limitation of deformations and crack widths) might be necessary.

For seismic category 2 components and civil structures it shall be verified that they will not impair seismic category 1 components and civil structures during a design basis earthquake in such a way that they would not be able to fulfill their safety related functions (see IAEA SSG-67 for further information).

Seismic category 3 components and civil structures do not need to be designed for the design basis earthquake specified in accordance with this document.

NOTE 2 Design specification may require that components and civil structures are designed to withstand operating basis earthquake (see 5.1).

6.2 Combinations of seismic action with other actions

The verification of the design basis earthquake safety of components and civil structures shall combine seismic action with the permanent and variable actions in accordance with the plant specific design requirements and relevant engineering standards.

Earthquake related consequential effects shall be taken into account.

Combinations of seismic action with other independent external or internal events is only required if their simultaneous occurrence is probable. The value of this probability should be defined at an early planning stage (e.g. Preliminary Safety Analysis Report: PSAR).

6.3 Verification procedures

6.3.1 General requirements

The design basis earthquake safety of components and civil structures shall be verified analytically or experimentally or by analogy or plausibility considerations.

The excitation in the three orthogonal directions shall be assumed as occurring simultaneously, but their maxima should be considered as statistically independent.

Components of seismic actions effects from different excitation directions may be superposed by the square root of the sum of their squares. Alternatively, all three of the following combinations may be applied in calculating the resulting load combinations with a combination factor f_{xyz}:

a) $1{,}0\ E_x \oplus f_{xyz}\ E_y \oplus \mathrm{f}_{xyz}\ E_z$

b) $f_{xyz}\ E_x \oplus 1{,}0\ E_y \oplus \mathrm{f}_{xyz}\ E_z$

c) $f_{xyz}\ E_x \oplus f_{xyz}\ E_y \oplus 1{,}0\ E_z$

Here, the symbol $\oplus$ indicates “to combine with” and E_x, E_y and E_z are the respective load combinations from design basis earthquake action effects in the directions x, y and z. Typical values for f_{xyz} are given in the Annex A. The value f_{xyz} shall not be less than 0,3.

The loads resulting from the combinations of seismic action effects with other actions effects specified in 6.2 shall be evaluated with regard to the corresponding limit conditions of load-bearing capacity, integrity and functionality.

NOTE More details can be found in ISO 4917-3 and ISO 4917-4.

6.3.2 Modeling

With regard to the dynamic analysis, the building structures including subsoil as well as the components with their supporting structures shall be transposed into mathematical engineering models that shall be able to describe the structural behavior for the decisive frequency range excited by earthquakes.

The parameters and boundary conditions required for the modeling process (e.g. stiffness, mass and damping ratio D) shall be chosen depending on the design objectives.

NOTE 1 Detailed requirements for civil structures can be found in ISO 4917-3 and for components in ISO 4917-4.

A dimensional shell structural model of a building with sufficiently detailed configuration of all relevant individual structural members shall pay special attention to the decoupling criteria between structural members or components. Decoupling criteria are given in Annex A.

Structures may be subdivided or considered as uncoupled from each other, provided, the interaction between the partial structures is taken into account or this does not essentially change the vibration behavior and the action effects.

The condition of normal operation shall be used as the basis for assembling the masses for analytic models for the dynamic analysis of components and building structures. In the case of the global structural analysis, the masses from variable actions may be accounted for with ¼ of their actual value unless more detailed requirements have been specified.

NOTE 2 Details can be found e.g. in ISO 4917-3.

If other operating conditions exist with significantly different mass distributions that occur more than 30 days per year, the influence of these different mass distributions shall be evaluated. As far as necessary, variations of the model shall be investigated and the envelope of the results determined.

The influence of the interactions between building structures and soil (soil-structure interaction) shall be determined.

The soil characteristics shall be varied within a reasonable range. Soft, average and hard soil stiffnesses should be defined based on field tests and shear velocity variations. If not specified otherwise by a geotechnical report, the average value of the soil stiffnesses may be multiplied and divided by a variation factor f_{var} to cover the uncertainties of soil parameters. A recommended value for f_{var} is given in Annex A. The incoherency of seismic motion for a mat foundation of a building can be neglegted.

The envelope of the analytic results of the soft (average multiplied by f_{var}), average and hard (average multiplied by f_{var}) soil stiffnesses shall be determined.

Regarding the calculation of the damping of structures, viscous damping (i.e., velocity proportional damping) may be assumed. The damping ratios D to be applied for the verification of the earthquake safety of components and buildings and civil structures and for the calculation of building response spectra, shall be assumed in accordance with the individual application.

NOTE 3 Damping ratios can be found in ISO 4917-3 and ISO 4917-4.

6.3.3 Acceleration time histories

Each time history set shall be applied for simultaneously excitation of the three orthogonal directions of ground motion.

The artificial acceleration time histories or spectral matched time histories or recorded acceleration time histories, usually used in time history related analyses, shall be compatible with the ground acceleration response spectrum specified in 5.5. Recorded acceleration time histories shall be compatible at least in the frequency range decisive for the analyzed structure. Time histories can be considered compatible if they meet the conditions in Annex A. The necessary number of statistically independent acceleration time histories, its maximum correlation coefficient and the use of the calculation results can be found in Annex A.

In the case of linear analyses of components and civil structures these should be based on at least three time history sets of statistically independent acceleration time histories (each set representing three orthogonal directions of ground motion). At least three load situations (each with three sets of acceleration time histories) should be formed and applied to the individual structure. The results should be averaged. The total amount of independent acceleration time histories may be reduced by interchanging time histories to compile new sets.

NOTE Depending on national requirements, a single set of statistically independent acceleration time histories may be sufficient, if the response spectra of these time histories envelope the design spectrum by a certain margin.

In the case of non-linear analyses of components and civil structures these should be based on at least five sets of statistically independent time histories. The results may be conservatively enveloped. Alternatively, the procedure described in A.6 may be used.

Components may be analyzed by applying the response time histories determined from the transient analysis of the building structures.

6.3.4 Analysis methods

Dynamic analysis methods (i.e., spectral methods, linear and non-linear time history methods, frequency response methods) shall basically be used. Simplified methods (e.g. quasi-static methods) are permissible.

If linear modal analysis methods are used, the phase position of the superposed modal fractions shall be taken into account. In the case of modal spectral methods, the phase positions shall basically be taken into account by applying the complete quadratic combination (CQC). However, it is permissible that other types of superpositions (e.g. square root of the sum of squares) are applied (see ISO 4917-3 and ISO 4917-4). Floor response spectra shall be determined taking 6.3.2 into account. Details regarding the frequency increment are given in Annex A.

The analysis results shall be evaluated with regard to the influence of uncertain input data. If necessary, this might involve performing sensitivity analyses. This applies, especially, to non-linear analyses.

7 Seismic instrumentation and inspection level

A seismic instrumentation shall be installed that it will display the exceedance of any acceleration limit values related to the inspection level of the plant. Furthermore, the seismic instrumentation shall be designed such that it allows comparing the response spectra derived from the recorded earthquake time histories with the underlying response spectrum of the inspection level.

The inspection level of the plant corresponds to f_i times the design basis earthquake. A typical factor for f_i is given in Annex A.

NOTE Details regarding seismic instrumentation can be found in ISO 4917-5 and regarding the inspection level in ISO 4917-6.

8 Post seismic measures

When an earthquake is recorded by the site instrumentation, depending on the level of this recorded earthquake, specific actions shall be set in place. The detail of these actions, together with the associated earthquake level are described in Part 6.

9 Secondary seismic effects and ground displacements

The effects of the design basis earthquake on the soil and on the direct vicinity of the site shall be investigated. Any changes of the soil (e.g. soil liquefaction, landslides, subsidences), of the surroundings (e.g. dam breaks, destruction of supply or disposal pipelines) or of ground displacements caused by earthquakes shall not adversely affect the fulfillment of safety related safety-objectives in an inadmissible manner.

NOTE Details regarding changes of the soil can be found in ISO 4917-3.

10 Considerations for beyond design basis events

In order to provide adequate seismic margins for the most important system, structures and components (seismic category 1) and to avoid cliff edge effects, the considerations for beyond design basis according to IAEA SSG-67 shall be applied. The beyond design basis earthquake shall be defined in accordance with national regulations.