Safety Standards

of the

Nuclear Safety Standards Commission (KTA)

KTA 2201.1 (2011-11)

**Design of Nuclear Power Plants against Seismic Events;
Part 1: Principles**

(Auslegung von Kernkraftwerken gegen seismische Einwirkungen;
Teil 1: Grundsätze)

The previous version of this safety
standard was issued in 1990-06

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KTA SAFETY STANDARD

November 2011	**Design of Nuclear Power Plants against Seismic Events; Part 1: Principles**	KTA 2201.1

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PLEASE NOTE: Only the original German version of this safety standard represents the joint resolution of the 50-member Nuclear Safety Standards Commission (Kerntechnischer Ausschuss, KTA). The German version was made public in Bundesanzeiger BAnz No. 11 of January 19, 2012. Copies may be ordered through the Carl Heymanns Verlag KG, Luxemburger Str. 449, 50939 Koeln, Germany (Telefax +49-221-94373603).

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Comments by the Editor:

Taking into account the meaning and usage of auxiliary verbs in the German language, in this translation the following agreements are effective:

shall	indicates a mandatory requirement,
shall basically	is used in the case of mandatory requirements to which specific exceptions (and only those!) are permitted. It is a requirement of the KTA that these exceptions - other than those in the case of **shall normally** - are specified in the text of the safety standard,
shall normally	indicates a requirement to which exceptions are allowed. However, exceptions used shall be substantiated during the licensing procedure,
should	indicates a recommendation or an example of good practice,
may	indicates an acceptable or permissible method within the scope of this safety standard.

Basic Principles

(1) The safety standards of the Nuclear Safety Standards Commission (KTA) have the task of specifying those safety-related requirements which shall be met with regard to precautions to be taken in accordance with the state of science and technology against damage arising from the construction and operation of the plant (Sec. 7 para. 2 subpara. 3 Atomic Energy Act – AtG) in order to attain the protective goals specified in the Atomic Energy Act and the Radiological Protection Ordinance (StrlSchV) and further detailed in the "Safety Criteria" and in the "Design Basis Accident Guidelines".

(2) In accordance with Criterion 2.6 of the Safety Criteria, protective measures against the seismic events are required, provided earthquakes must be taken into consideration. Table I of the Design Basis Accident Guidelines classifies earthquakes as belonging to that group of design basis accidents that requires taking preventive plant engineering measures against damage and which are relevant with respect to radiological effects on the environment. The basic requirements of these preventive measures are dealt with in safety standard series KTA 2201.

(3) Safety standard KTA 2201.1 – as part of the series KTA 2201 entitled "Design of nuclear power plants against seismic events" – deals with the principles governing the seismic design of nuclear power plants. The series KTA 2201 is comprised of the following six parts:

Part 1: Principles (*the present safety standard*)

Part 2: Subsoil

Part 3: Civil structures

Part 4: Components

Part 5: Seismic instrumentation

Part 6: Post-seismic measures

(4) The present safety standard will be applied under the presumption that the geology and tectonics of the plant site has been investigated with special emphasis on the existence of active geological faults and lasting geological ground displacements.

1 Scope

This safety standard applies to nuclear power plants with light water reactors and, in particular, to the design of components and civil structures against seismic events in order to meet the protective goals of

a) controlling reactivity,
b) cooling fuel assemblies,
c) confining radioactive substances, and
d) limiting radiation exposure.

2 Definitions

(1) Components

Components are electrical and mechanical systems and equipment that make it possible to operate the nuclear facility.

N o t e :

This definition is necessary for the differentiation between "plant component" and "civil structures or building structures".

(2) Response spectrum

The response spectrum is the graphical representation of the largest oscillation amplitudes (values) of a dampened single-degree-of-freedom oscillator (accelerations, velocities, displacements) with various eigenfrequencies and a constant damping ratio in response to an excitation described by a time history at the base point. Unless indicated otherwise, the response spectrum relates to the acceleration (spectral acceleration). In this safety standard, the response spectrum is considered to be that of an elastic oscillator that shows no effects from ductile deformations.

N o t e :

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.

(3) Civil structures

Civil structures or building structures are such structures that connect to the ground and are manufactured from construction products (building materials and structural members).

N o t e :

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").

(4) Structural member

In structural engineering, a structural member is a component part of the civil structures or building structures.
In mechanical engineering a structural component is one that is manufactured from product forms and represents the smallest component of a subassembly.

(5) Building response spectrum

The building response spectrum is the response spectrum at a specific point or level of the building structures (it corresponds to floor response spectrum).

(6) Design basis earthquake

The design basis earthquake is the decisive earthquake for the design against seismic events. The design basis earthquake is the basis for the specification of the seismo-engineering parameters. The design basis earthquake may also be understood as being a combination of a number of decisive earthquakes or as being the design-decisive ground motions at the site of the facility.

(7) Ground acceleration response spectrum

The ground acceleration response spectrum is the response spectrum derived from a ground motion relative to a reference horizon in the ground profile.

(8) Damping ratio

The damping ratio, D (also: Lehr's damping ratio), is a dimensionless characteristic value for a (velocity proportional) damped oscillating single-degree-of-freedom system. The damping ratio is defined by Equations 2-1 and 2-2.

$$D = \frac{c}{c_{critical}} \tag{2-1}$$

$$c_{critical} = 2 \cdot \sqrt{k \cdot m} \tag{2-2}$$

Nomenclature:

c :	damping constant
$c_{critical}$:	critical damping constant
k :	stiffness
m :	mass

The case D = 1 characterizes the aperiodic limit case and is called critical damping. Analogously, D = 0.05 is denoted as 5 % of critical damping.

(9) Deaggregation

Deaggregation is the determination – to be performed within the **p**robabilistic **s**eismic **h**azard **a**nalysis (PSHA) in discrete intervals of the epicentral intensity or of the magnitude or distance – of the proportions contributed by earthquakes to the overall hazard at a site.

(10) Actions

For the purpose of this safety standard, actions are mechanical effects. Actions are forces and deformations influencing components and civil structures. These actions may be permanent (e.g., dead weights), variable (e.g., imposed loads, live loads, wind) or exceptional (e.g., high water, earthquake).

(11) External events

External events are exceptional events having either natural causes (e.g., high water, earthquake) or civilizational causes (e.g., air craft crash, pressure wave from explosions).

(11) Internal events

Internal events 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).

(12) Energy content

The energy content of the earthquake time history is defined as the integral of the squared accelerations over the duration of the earthquake.

(14) Energy criterion

The 90 %-energy criterion is understood to be the duration of the ground motion between reaching 5 % and 95 % of the energy content. Correspondingly, the 70 %-energy-criterion refers to the duration between 5 % and 75 % of the energy content.

(15) Epicentral intensity

The epicentral intensity is the intensity of the earthquake at the epicenter.

(16) Epicenter

The epicenter is the vertical projection of the location of the initial fault rupture of an earthquake (hypocenter) upward to the surface of the Earth and is identified by the corresponding geographic coordinates.

(17) Free field response spectrum

The free field response spectrum (also: response spectrum of the design basis earthquake) is the ground acceleration response spectrum for a reference horizon in the subsoil the oscillation properties of which are not influenced by building structures.

(18) Functional capability

Functional capability is the ability of a system or component, above and beyond its load-carrying capacity and physical integrity, to fulfill its designated task by corresponding mechanical or electrical functions.

Note:

This definition is specific to components. In the case of civil structures, the adequate term would be “serviceability”.

(19) Serviceability

Serviceability is the ability of civil structures to enable the designated use even under the actions of events that must be assumed to occur.

Note:

This definition is specific to civil structures. In the case of components, the adequate term would be “integrity” or “functional capability”.

(20) Seismic hazard curve

A seismic hazard curve is the graphic representation of the per annum probability that a specific parameter of the seismic event is exceeded at the plant site. Seismic hazard curves are determined by the PSHA. The parameters used are macro seismic intensities of the ground motion (spectral accelerations, maximum accelerations).

(21) Limit frequency, upper

The upper limit frequency is that frequency above which the seismic response shows no further significant increase (rigid-body acceleration). At the upper limit frequency, the acceleration response spectra will asymptotically reach the maximum acceleration of the corresponding time history.

Note:

In practice, the upper limit frequency is that frequency above which the acceleration response spectrum will not exceed the level of 1.1 times the rigid-body acceleration.

(22) Focal depth

The focal depth of an earthquake is the depth of the hypocenter beneath the surface of the earth.

(23) Hypocenter

The hypocenter is that point on the rupture surface of an earthquake where the rupture process begins; its location is described by the coordinates of the earthquake’s epicenter and its focal depth.

(24) Seismo-engineering parameters

The seismo-engineering parameters are the response spectrum, strong ground motion duration and further parameters characterizing the ground motion at the site.

(25) Integrity, physical

Physical integrity is the ability of a plant component, above and beyond its load-carrying capacity, to fulfill its requirements with regard to leak tightness or deformation restrictions.

Note:

This definition is specific to components. In the case of civil structures, the adequate term would be “serviceability”.

(26) Intensity

Intensity is the classification of the strength of ground motions based on the observed effects within a limited area, e.g., a village. Basis for determining the intensity are phenomenological descriptions of the effects on humans, objects and building structures. The intensity is a robust measure for strength classification; the corresponding macroseismic classification scales (e.g., MSK-64, EMS-98) define twelve intensity levels.

(27) Correlation coefficient

The correlation coefficient, ρ_{xy}, of two seismic time histories, x(t) and y(t), is defined as a covariance, σ_{xy}, related to the standard deviations of the two time histories, s_x and s_y:

$$\rho_{xy} = \frac{\sigma_{xy}}{\{s_x \cdot s_y\}} \qquad (2\text{-}3)$$

The correlation coefficient can assume values between -1 and +1. It is equal to zero if there is no linear connection between x(t) and y(t).

(28) Magnitude

Magnitude, a term introduced by Charles Richter in 1935, is a quantitative measure for determining the strength of earthquakes. The classic definition of seismic magnitude is the logarithm of the maximum amplitude of registered 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.

(29) Peak ground acceleration

The **p**eak **g**round **a**cceleration (PGA) is defined as the maximum amplitude (absolute value) of the horizontal or vertical acceleration components of the earthquake time history (seismogram). It corresponds to the rigid-body acceleration of the ground acceleration response spectrum (“adjustment value”).

(30) Paleoseismology

Paleoseismology is a method used to search for indications of prehistoric quakes in geological sediments and rock formations and includes estimation of their magnitude and of the age of the deformations due to earthquakes. Paleoseismology serves to extend earthquake findings into the younger geological times.

Note:

Paleoseismology is generally restricted to geological terrains of continuous sedimentation of the past ten thousands of years.

(31) Earthquake source region

Earthquake source region is an area or line on which a uniform distribution of seismicity is assumed. Borderlines between seismic source regions are established on the basis of the geologic and tectonic development and on the basis of the seismicity.

(32) Seismogram

A seismogram is the graphic display of the ground motion (proportional to displacement, velocity or acceleration) at a certain location during the earthquake. It is also called earthquake registration or earthquake time history and is usually recorded in three orthogonal directions, two of these in the horizontal plane.

(33) Seismotectonic unit
(also: seismotectonic region)

A seismotectonic unit is a region for which uniformity is assumed regarding seismic activity, geological structure and development and, in particular, regarding neotectonic conditions. A seismotectonic unit may also be an earthquake source region.

(34) Strong ground motion duration
(also: duration of strong ground motion phase)

The strong ground motion duration is defined by the length of time it takes for the energy content at a site to reach a certain percentage (e.g., the 90 %-energy criterion).

(35) Rigid-body acceleration

The rigid-body acceleration is the maximum amplitude (absolute value) of the acceleration time series on which the acceleration time history is based; it corresponds to the value of the response spectrum in the high frequency range.

(36) Tectonics

Tectonics is the science of the structure, forces, motions and deformations of the Earth's crust and parts of the Earth's mantle. Tectonics considers global, regional and local aspects. Neotectonics considers the tectonics of the more recent geological past (Quaternary period).

(37) Load-carrying capacity
(also: stability)

Load-carrying capacity is the ability of components and civil structures, based on their material strength, stability and secure positioning, to withstand the actions from events that must be assumed to occur.

(38) Probability of exceedance

The probability of exceedance is the probability that a certain ground motion (e.g., peak acceleration, spectral value of acceleration) or intensity is reached or exceeded at a site within a specified time period (usually one year). The reciprocal of the annual probability of exceedance is often termed as average return period. The graphic display of the probability of exceedance is the seismic hazard curve.

(39) Uncertainties

Two types of uncertainties are considered in the present safety standard: epistemic and aleatoric uncertainties. An epistemic uncertainty is one where the uncertainty is based on uncertainties of the state of knowledge, e.g., regarding models or parameters. Epistemic uncertainties can be reduced by additional data, information or improved modeling (e.g., uncertainty in specifying the source region). An aleatoric uncertainty is one where the uncertainty is inherently connected with stochastic phenomena or processes (e.g., decrease of acceleration amplitudes with increasing distance). Aleatoric uncertainties cannot be reduced.

(40) Complete quadratic combination

A **c**omplete **q**uadratic **c**ombination (CQC) is a stochastically based superposition relationship for oscillating systems in order to take account of the coupling of eigenmodes.

(41) Time history envelope function

The time history envelope function describes typical average envelopes over the relevant time span of seismograms. It is characterized by its increasing phase, its strong ground motion phase (cf. strong ground motion duration) and its decreasing phase; it is used for generating artificial seismograms that are compatible with the actions of seismic events.

3 Determining the Design Basis Earthquake

3.1 General Requirements

(1) The design basis earthquake is described by the seismic actions at the location of the site that are characterized, essentially, by the intensity and ground motions. The design basis earthquake shall be determined and specified based on deterministic and probabilistic analyses. The surrounding area of the site out to a radius of at least 200 km shall be taken into account; however, it shall be examined whether data is available that would make it necessary to consider even larger radii from the site in the analyses.

(2) The deterministic approach to specifying the design basis earthquake shall be based on historic earthquakes, taking the earthquake with the largest seismic actions into consideration that would have to be assumed at the site in light of current scientific knowledge.

(3) The probabilistic approach to specifying the characteristics of the design basis earthquake shall be based on a probability of exceedance of 10^{-5} per annum.

(4) The design basis earthquake shall be specified by evaluating the deterministic and the probabilistic analyses. The corresponding seismic actions may be specified for the 50 %-fractile value, provided, the probability of exceedance of the characteristics of the design basis earthquake is in the order of 10^{-5} per annum.

(5) The design basis earthquake shall be specified with an intensity of at least VI.

3.2 Deterministic Determination of the Design Basis Earthquake

(1) Basis for the deterministic determination of the design basis earthquake are the strongest earthquakes that have occurred within the surrounding area of the site up to the radius specified in Section 3.1 para. 1. Paleoseismic findings shall be taken into account.

Note:

The strength of historic earthquakes is usually described by their respective intensities. With regard to particularly relevant historic earthquakes and a correspondingly insecure data base it may be necessary to perform additional investigations.

(2) The design basis earthquake shall be determined deterministically under consideration of the geologic and tectonic conditions and, substantiating the seismotectonic units used, as follows:

a) If the epicenter of the decisive earthquake in accordance with para. 1 lies in the same seismotectonic unit as the site, then it shall be assumed that this earthquake will occur in the vicinity of the site within a maximum epicentral radius of 10 km and with the same intensity at the site.

b) If the epicenter of the decisive earthquake in accordance with para. 1 lies in another seismotectonic unit than that of the site, then it shall be assumed that the epicenter of a similar earthquake would occur at a point closest to the site directly on the borderline of the tectonic unit in which it had originally occurred.

(3) When determining the design basis earthquake, the uncertainties of the data and models used and the incompleteness and limitations of the earthquake catalog shall be taken into account.

Note:

This is usually achieved by adding a certain value to the strength of the earthquakes that have occurred in the past.

3.3 Probabilistic Determination of the Design Basis Earthquake

(1) The per annum exceedance probabilities of seismic actions at the site as well as the uncertainties of these values shall be determined using the probabilistic seismic hazard analysis (PSHA).

(2) All elements of the PSHA shall be properly described and documented. The elements of the PSHA are, specifically, the earthquake catalogs used, the seismic source regions with their characteristic parameters, the damping functions as well as the influences from the local geological subsoil, and the applied procedures and methods.

(3) The uncertainties of the applied data, models and methods shall be taken into account. Their influence on the results shall be determined and evaluated.

(4) Seismic hazard curves including their tolerance range shall be established for exceedance probabilities between 10^{-2} and 10^{-6} per annum.

(5) A deaggregation shall be performed. This requires determining and specifying the effects of the various earthquake strengths (magnitudes, epicentral intensities), and of the various distances and seismic source regions on the overall hazard, in particular for the probability of exceedance of 10^{-5} per annum.

3.4 Specification of the Design Basis Earthquake

(1) The results from the deterministic and the probabilistic determinations shall be compared. Particular emphasis shall be placed on the comparison of the seismo-engineering parameters resulting from the respective determination methods.

(2) The plausibility and reliability of the findings from the deterministic and probabilistic determination methods shall be evaluated.

(3) The design basis earthquake shall be specified and justified on the basis of the evaluation of the plausible and reliable findings from the deterministic and probabilistic determination methods.

(4) Specification of the design basis earthquake shall include its intensity and, in accordance with the corresponding seismotectonic conditions, also the decisive ranges of magnitude, distance and focal depth that are needed for determining of the seismo-engineering parameters.

3.5 Seismo-Engineering Parameters of the Design Basis Earthquake

(1) With regard to the verification of the earthquake safety of components and civil structures, the actions of the earthquake shall be described by seismo-engineering parameters, in particular, by the ground response spectra with the corresponding rigid-body accelerations (at peak ground acceleration) and the strong-motion duration.

(2) Magnitude-based and distance-based earthquake registers or empirical relations may be applied for the determination of the seismo-engineering parameters.

(3) The ground response spectra shall be specified as free field response spectra for the site-specific uniform reference horizon of the subsoil. The associated ground profile of the geological subsoil and that of the subsoil shall be taken into account together with the dynamic soil characteristics and their tolerances.

Note:

The reference horizon is usually the ground level; however, in well founded cases, the geological layer boundary of a sufficiently stiff ground layer or the bedrock surface may be used as reference horizon.

(4) Two ground acceleration response spectra shall be specified, one for the two horizontal components assumed to be equal and the other for the vertical component of the earthquake excitation. The response spectrum for the resultant horizontal earthquake excitation may be specified by multiplying the response spectrum for one horizontal component by the factor of 1.2. If no seismological data are available for the vertical component, it shall be assumed to be 2/3 of the horizontal component. Both of the horizontal components and the vertical component shall be assumed to be simultaneously effective.

(5) The ground response spectra shall be specified for a frequency range starting at 0.2 Hz up to an upper limit frequency, i.e., at which the rigid-body acceleration begins, which is strongly dependent on the subsoil conditions at the site.

(6) The ground response spectra shall be specified for 5 % of critical damping. The 5 % spectrum (D = 0.05) may be converted to spectra with other damping levels, D, and increasing spectral ranges by beginning at low frequencies and multiplying the peak spectral range of the spectrum by the factor $\sqrt{7/(2 + D \cdot 100)}$ until it gradually reaches the factor 1 as it merges into the rigid-body acceleration range.

(7) The strong ground motion duration of the design basis earthquake shall be specified together with the assumed energy criterion and time history envelope function; this serves as the basis for determining synthetic seismograms.

(8) If registered acceleration time histories are used for determining the seismo-engineering parameters, they shall be fully documented.

(9) With regard to structural analyses, registered acceleration time histories shall 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:

It is permissible that the time histories are scaled by multiplication factors from about 0.5 to 2.0.

4 General Requirements Regarding Verification

Note:

In this section the term “earthquake” is used in short for “design basis earthquake”.

4.1 Design Requirements

4.1.1 Classification

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

Class I

Components and civil structures that are required to fulfill the protective goals cited in Section 1, including limiting radiation exposure.

Class IIa

Components and civil structures that do not belong to Class I and which, due to their own damage and the sequential effects possibly caused by an earthquake, could detrimentally affect the safety related functions of Class I components and civil structures.

Class IIb

All other components and civil structures.

4.1.2 Verification of earthquake safety

(1) For Class I components and civil structures it shall be verified that, with regard to their

a) load-carrying capacity,

b) integrity, and

c) functional capability,

they will be able to fulfill their respective safety related tasks in case of an earthquake.

Note:

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

(2) For Class IIa components and civil structures it shall be verified that they will not impair Class I components and civil structures during an earthquake in such a way that they would not be able to fulfill their safety related functions.

(3) Class IIb components and civil structures do not need to be designed for the design basis earthquake specified in accordance with this safety standard.

4.2 Combinations of Actions

(1) The verification of the earthquake safety of components and civil structures shall combine actions from earthquakes with the permanent and variable actions in accordance with the plant specific design requirements and relevant engineering standards.

(2) Earthquake related sequential actions shall be taken into account.

(3) Combinations of actions from earthquakes with other independent external or internal events is only required if their simultaneous occurrence must be assumed on the grounds of probability considerations.

Note:

Combinations of actions from earthquakes with high-water events are dealt with in safety standard KTA 2207 and with fire events in KTA 2101.1.

4.3 Verification Procedures

4.3.1 General requirements

(1) The earthquake safety of components and civil structures shall be verified analytically, or experimentally, or by analogy or plausibility considerations.

(2) The vibration impulses in the three orthogonal directions shall be assumed either as occurring simultaneously or as occurring independently of each other; also permissible is to apply a horizontally resultant and the vertical vibration impulse.

(3) Parallel loading parameters 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 loading parameters:

a) $1.0\ E_x \oplus 0.3\ E_y \oplus 0.3\ E_z$

b) $0.3\ E_x \oplus 1.0\ E_y \oplus 0.3\ E_z$

c) $0.3\ E_x \oplus 0.3\ E_y \oplus 1.0\ E_z$

Here, the symbol $\oplus$ indicates “to combine with” and E_x, E_y and E_z are the respective loading parameters from earthquake actions in the directions x, y and z.

(4) The loads resulting from the combinations of actions specified under Section 4.2 shall be evaluated with regard to the corresponding limit conditions of load-carrying capacity, integrity and functional capability.

Note:

Details in this respect are specified in safety standards KTA 2201.3 and KTA 2201.4 as well as in the plant component specific KTA safety standards.

4.3.2 Modeling

(1) 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.

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

Note:

Corresponding requirements for civil structures are specified in safety standard KTA 2201.3 and for components in safety standard KTA 2201.4.

(3) Any modeling by equivalent beams subjected to axial and torsional loads shall take the decisive influence from torsion and eccentricities between the centers of gravity and the centers of stiffness into account. Furthermore, existing deformabilities of individual building elements not accounted for in the beam model that would, however, have a relevant influence on their structural behavior or that of connected components shall be taken into account in verifying the earthquake safety of components and buildings and civil structures.

(4) A three-dimensional plate and shell structure model of a building structure with sufficiently detailed configuration of all relevant building components shall pay special attention to the uncoupling criteria between building component and plant component.

Note:

Details in this respect are specified in safety standard KTA 2201.3.

(5) 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 loadings.

(6) The condition of normal operation shall be used as the basis for assembling the masses for analytic models designed 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:

Details in this respect are specified, e.g., in safety standard KTA 2201.3.

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.

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

(8) The soil characteristics shall be varied within a reasonable range. If no data is available, the average value of the subsoil stiffness shall normally be multiplied by 1.5 and divided by 1.5 in order to cover the tolerances of soil characteristics. The envelope of the analytic results of the low, average and high subsoil stiffness shall be determined.

Note:

A variation by the factor 1.5 usually covers also the mutual subsoil interaction of neighboring buildings (structure-soil-structure interaction). Details in this respect are specified in safety standards KTA 2201.2 and KTA 2201.3.

(9) With regard to calculating 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:

Damping ratios are specified in safety standards KTA 2201.3 and KTA 2201.4.

4.3.3 Acceleration time histories

(1) The artificial acceleration time histories normally used in time history related analyses shall be compatible with the ground acceleration response spectrum detailed in Section 3.5. Alternatively, the registered acceleration time histories as specified in Section 3.5 para. 8 may be used.

(2) Time histories shall be considered as compatible with the ground acceleration response spectrum detailed in Section 3.5 if the amplitudes of no more than 10 % of the control frequencies of the response spectrum calculated for a damping ratio of D = 0.05 are lower than 10 % of the amplitudes of the goal spectrum.

(3) In the case of linear analyses of components and civil structures these shall be based on at least 3 statistically independent acceleration time histories. By interchanging the results of these analyses, at least 3 load situations shall be formed and applied to the individual structure. The results of these analytical procedures may be averaged.

(4) In the case of non-linear analyses of components and civil structures these shall be based on at least 7 statistically independent time histories and their combinations. A smaller number of combinations is permissible in well founded cases. An enveloping curve shall be found for the results of these analytical procedures.

(5) Artificial time histories may be assumed as being statistically independent if the absolute value of the correlation coefficient of each of two time series is smaller than 0.3 and the mean absolute value of all correlation coefficients is smaller than 0.2.

(6) Components may be analyzed by applying the response time histories from the analysis of the building structures.

(7) The registered acceleration time histories specified in Section 3.5 para. 8 may be used as alternative to the artificial time histories; however, at least 5 time series shall be applied. The response spectra from these time histories shall normally be compatible with the ground acceleration response spectrum in the frequency range decisive for the analyzed structure. In the case of linear analyses, the averaged results of these analytical procedures may be applied.

4.3.4 Analytic methods

(1) Dynamic analytic 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.

(2) If linear modal analytic 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 **c**omplete **q**uadratic **c**ombination (CQC). However, it is permissible in well-founded cases that other types of superpositions (e.g., square root of the sum of squares) are applied.

(3) Floor response spectra shall be determined taking Section 4.3.2 into account. The frequency increment in each octave shall normally be no larger than 1/50 of the lower limit of the octave, however, no smaller than 0.02 Hz.

(4) The analytic 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.

5 Seismic Instrumentation and Inspection Level

(1) 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 registered earthquake time histories with the underlying response spectrum of the inspection level.

(2) The inspection level of the plant corresponds to 0.4 times the rigid-body accelerations and it corresponds to the ground or building response spectra of the design basis earthquake scaled down by factor 0.4. A higher limit value of the inspection level is permissible, provided, it is verified that specified normal operation of the plant is still possible even after the occurrence of an earthquake of this higher level.

Note:

Details regarding seismic instrumentation are specified in safety standard KTA 2201.5 and regarding the inspection level in safety standard KTA 2201.6.

6 Post Seismic Measures

Whenever the seismic instrumentation registers an earthquake in the plant, a plant inspection shall be carried out. Whenever the acceleration limit values of the inspection level are exceeded, the loadings caused shall be investigated more extensively to help evaluate the earthquake effects with regard to a continuation of plant operation. In case the inspection level is decisively exceeded or the plant is not anymore in a specified normal condition, then the plant shall be shut down.

Note:

Details regarding post seismic measures are specified in safety standard KTA 2201.6.

7 Seismic Effects at the Site

The effects of the design basis earthquake on the subsoil and on the direct vicinity of the site shall be investigated. Any changes of the subsoil (e.g., soil liquefaction, landslides, subsidences), of the direct environs (e.g., dam breaks, destruction of supply or disposal pipe lines) or of ground displacements caused by earthquakes shall not detrimentally affect the fulfillment of safety related protective goals in an inadmissible manner.

Note:

Details regarding changes of the subsoil are specified in safety standard KTA 2201.2.

Appendix A

Regulations Referred to in this Safety Standard

(Regulations referred to in this safety standard are only valid in the version cited below. Regulations which are referred to within these regulations are valid only in the version that was valid when the later regulations were established or issued.)

AtG		Act on the peaceful utilization of atomic energy and the protection against its hazards (Atomic Energy Act – AtG) of December 23, 1959, revised version of July 15, 1985 (BGBl. I, p. 1565), most recently changed by Article 1 of the Act of July 31, 2011 (BGBl. I, p. 1704)
StrlSchV		Ordinance on the protection from damage by ionizing radiation (Radiological Protection Ordinance – StrlSchV) of July 20, 2001 (BGBl. I 2001, p. 1714; 2002, p. 1459), most recently changed by Article 1 of the Ordinance of October 4, 2011 (BGBl. I, p. 2000)
Safety Criteria	(1977-10)	Safety criteria for nuclear power plants of October 21, 1977 (BAnz. No. 206 of November 3, 1977)
Design Basis Accident Guidelines	(1983-10)	Guidelines for the assessment of the design of nuclear power plants with pressurized water reactors against design basis accidents as defined in Sec. 28, para. 3 StrlSchV (Design Basis Accident Guidelines) of October 18, 1983 (Addendum to BAnz. No. 245 of December 31, 1983)