

Safety Standards

of the
Nuclear Safety Standards Commission (KTA)

KTA 2201.4 (2012-11)

**Design of Nuclear Power Plants against Seismic Events;
Part 4: Components**

**(Auslegung von Kernkraftwerken gegen seismische
Einwirkungen; Teil 4: Anlagenteile)**

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

If there is any doubt regarding the information contained in this translation, the German wording shall apply.

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KTA SAFETY STANDARD

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Design of Nuclear Power Plants against Seismic Events; Part 4: Components

KTA 2201.4

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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 the Bundesanzeiger (BAnz) of January, 23th, 2013. 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 AtG 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 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 that is relevant with respect to radiological effects on the environment. The basic requirements of these preventive measures are dealt with in the safety standard series KTA 2201.

(3) The present safety standard KTA 2201.4 – as part of the series KTA 2201 entitled "Design of nuclear power plants against seismic events" – deals with the components. The series KTA 2201 is comprised of the following six parts:

Part 1: Principles,

Part 2: Subsoil,

Part 3: Design of structural components (*civil structures*),

Part 4: Components (*the present safety standard*),

Part 5: Seismic instrumentation,

Part 6: Post-seismic measures.

(4) In safety standard KTA 2201.4 the verifications required for the mechanical and electrical components including their support structures are broken down into individual verification steps, i.e.,

- a) Determining the excitation at the place of installation,
- b) Modeling and the determination of parameters,
- c) Analyzing the mechanical behavior,
- d) Verifying the limit conditions.

(5) These verification steps are dealt with for each of the four possible verification methods, i.e.,

- a) Verification by analysis,
- b) Verification by physical experiments,
- c) Verification by analogy considerations,
- d) Verification by plausibility considerations.

The earthquake safety of a component may be verified on the basis of an individual verification method or on the basis of a combination of various verification methods.

(6) Safety standard KTA 2201.4 presents the basis for fulfilling the requirements regarding the verification of the site-specific earthquake safety of components. With regard to analyzing the mechanical behavior of the individual components and verifying the fulfillment of their safety-related tasks, additionally, the respective component-specific KTA safety standards need to be consulted.

1 Scope

(1) This safety standard applies to nuclear power plants with light water reactors. It applies to the design of components against seismic forces in order that they meet the protective goals of

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

(2) The present safety standard specifies the requirements with respect to verifying the earthquake safety of components. The task-specific and safety-related requirements that must be specified separately for each component – e.g., load-carrying capacity (stability), integrity and functional capability (cf. Section 3.1) – are not dealt with in this safety standard.

(3) In this safety standard, the term mechanical components refers to components such as vessels, heat exchangers, pumps, valves, lifting gear and pipe lines including their support structures in as far as these components are not considered to be civil structures in accordance with safety standard KTA 2201.3. Liners, crane runways, platforms and scaffoldings are not considered as being part of these mechanical components.

(4) In this safety standard, the term electrical components refers to the combination of electrical devices including all electrical connections and their support structures (e.g., cabinets, frames, consoles, brackets, suspensions or supports).

2 Definitions

(1) The application of the present safety standard relies on definitions of

- a) the general terms as defined in KTA 2201.1,
- b) the terms action (permanent, temporary and accidental), types of actions, combinations of actions, design situations, partial safety factor, ultimate limit state and serviceability limit state as defined in DIN EN 1990,
- c) the terms primary stress, secondary stress and peak stress as well as service limit level as defined in safety standard KTA 3204,
- d) the different requirement categories as defined in KTA-GS-78,

and on the following definitions.

(2) Required response spectrum

The required response spectrum is a response spectrum that is obtained by multiplying the design response spectrum by safety factors and test-signal specific magnification factors. Required response spectra may also be created as an enveloping curve of the response spectra at the various places of installation.

(3) Excitation, single-frequency

A single-frequency excitation has a time history in which at every point in time only a single excitation frequency (e.g., sine sweep, fixed frequency) occurs.

(4) Design spectrum

The design spectrum is an enveloping, widened and smoothed response spectrum that is used as the basis for the seismic design. In this context, it is differentiated between ground acceleration response spectrum (primary spectrum), building response spectrum (secondary spectrum) and component response spectrum (tertiary spectrum).

(5) Damping, modal

Modal damping for mechanical systems is the damping ratio of the respective natural vibration.

(6) Ductility

Ductility is the quotient of the maximum elasto-plastic displacement and the purely elastic displacement (displacement ductility).

(7) Limit frequency, lower

The lower limit frequency of mechanical components is that frequency below which no significant seismic response would occur.

Note :

The lower limit frequency may be specified as one half of the lowest eigenfrequency of the system.

(8) Major system

The major system is a heavy structure that supports one or more lighter-weight subsystems (cf. Definition (12)).

(8) Nonlinearity, geometric or physical

A geometric nonlinearity is the nonlinear relationship between the force values and displacement quantities resulting from the equilibrium and kinematic analyses of a deformed system. A physical nonlinearity is the nonlinear relationship between stresses and distortions resulting from a nonlinear material behavior.

(10) Test response spectrum

A test response spectrum is a response spectrum determined based on the actual motion of the shaking table.

(11) Center of gravity, dynamic

The dynamic center of gravity is that point on the approximated model of a structure that reduces the structure to one degree of freedom, at which point the acceleration is identical to the respective value of the response spectrum.

(12) Subsystem

A subsystem is a lighter-weight partial system that is supported by a heavy major system (cf. Definition (8)).

(13) Behavior coefficient

The behavior coefficient, q , is a reduction coefficient applied to the force values determined by linear analysis of earthquake events. This coefficient takes the dissipative effects into account that arise from the materials used, from the support structure and from the structural design.

3 General Requirements**3.1 Basics**

(1) The general design requirements for components are specified in safety standard KTA 2201.1, Sec. 4.1. They include classification of the components, i.e., their assignment to Class I, Class IIa and Class IIb, as well as the general requirements regarding the verification of their earthquake safety.

(2) It shall be verified for all Class I components that they are able to fulfill their safety-related tasks in the case of seismic events. The safety-related tasks shall be specified for each component. Typical safety related tasks are:

a) Load-carrying capacity (stability)

The load-carrying capacity is the capability of components to withstand the actions to be assumed on account of their strength, stability and secure positioning (e.g., their protection against falling over, against dropping down, against impermissible slipping).

The load-carrying capacity shall be verified for the component and its support. The building structure interaction loads shall be specified.

b) Integrity

Integrity is the capability of a component above and beyond its load-carrying capacity to meet the respective requirements regarding leak tightness and deformation restrictions.

The integrity of the components shall be verified based on requirements in accordance with the component-specific standards.

c) Functional capability

Functional capability is the capacity of a system or component above and beyond its load-carrying capacity to fulfill the designated tasks by way of its respective mechanical or electrical function.

In this context, it shall be differentiated between whether the functional capability of the component must be achieved

- after the earthquake or
- during and after the earthquake.

Furthermore, it shall be differentiated between active and passive functional capabilities.

An active functional capability of a component ensures that the specified movements (relative movements between individual parts) can be performed (closing of clearances, creating or changing of friction forces) and that the electrical functions are maintained.

A passive functional capability of a component means that permissible deformations and movements are not exceeded.

(3) For all Class IIa components it is required to be verified that on account of earthquakes they will not detrimentally affect the Class I components and civil structures in a way that these would not anymore be able to fulfill their safety-related tasks. In this context, it is generally sufficient to verify the load-carrying capacity. In certain cases it may be necessary to verify that limit deformations are not exceeded or that integrity (risk of flooding) is upheld.

(4) Ageing effects that might influence the verification objective shall be taken into account.

Note :

Details regarding ageing effects are dealt with in safety standard KTA 1403.

3.2 Verification Procedure

(1) The individual procedural steps of the verification procedure are shown in **Figure 3-1**.

(2) Depending on the verification objective, individual steps of the verification procedure may be combined, provided, the detailing of the model so allows. Intermediate results do not need to be determined.

(3) The site excitation parameters to be applied shall be the seismo-engineering parameters of the design basis earthquake in accordance with safety standard KTA 2201.1, Sec. 3.5, (i.e., ground acceleration response spectrum, reference horizon, directional components, strong-motion duration)..

(4) The modeling principles in accordance with safety standard KTA 2201.1, Sec. 4.3.2, shall be applied. Additional requirements dependent on the respective verification methods are specified below in Sections 4 through 7.

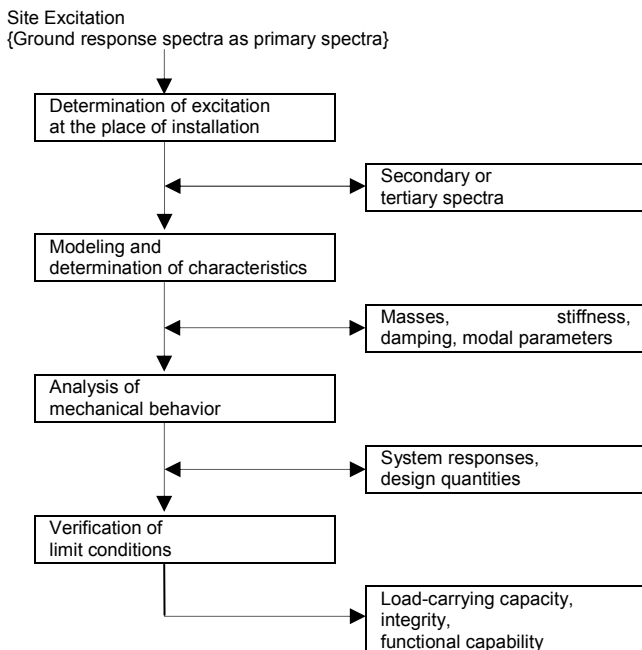


Figure 3-1: Procedural steps of the verification procedure

(5) In case of a linear system behavior, the mechanical behavior may be analyzed separately for the seismic actions and for the other continuous and non-continuous actions. The design quantities shall then be determined by superposition.

(6) In case of a non-linear determination of the system behavior, the entire action collective with safety margins and combination factors shall be analyzed simultaneously.

(7) For the verification of the limit conditions, the determined design quantities for the loads shall be correlated with the corresponding permissible strains.

3.3 Verification Methods

(1) The following verification methods are permissible either individually or in combination with each other:

- Verification by analysis (cf. Section 4),
- Verification by physical experiments (cf. Section 5),
- Verification by analogy (cf. Section 6),
- Verification by plausibility considerations (cf. Section 7).

(2) The verification methods to be applied shall be specified for each component with regard to its respective task.

Note:

In case of the verification of the functional capability of electro-technical components (e.g., contactors, relays, circuit breakers), preference is given to experimental verification methods.

4 Verification by Analysis

4.1 Summary

(1) The basic requirements regarding verification by analysis are specified in safety standard KTA 2201.1, Sec. 4.3. This concerns the combination of excitation directions, the modeling, the determination and application of the acceleration time histories as well as superordinate aspects of the analysis methods.

(2) The dynamic analysis procedures specified under Section 4.4.1 shall be applied to the verification by analysis. In well substantiated cases, simplified procedures are permissible. In the case of pipes, it is permissible to alternatively apply the respective guidelines for laying of pipes, provided, their technical basis includes the load case earthquake.

4.2 Excitation at the Place of Installation

4.2.1 Basics

(1) The excitation at the place of installation shall be determined by one of the following methods:

- as response time histories of the structural components or building response spectra (secondary responses in accordance with safety standard KTA 2201.3),
- as response time histories or response spectra of the component (tertiary responses as specified under Section 4.2.3.1),
- as artificial time histories which, in accordance with safety standard KTA 2201.1, Sec. 4.3.3, must be compatible with the response spectra of the building structure or component.
- as response spectra for tertiary responses with the substitution method, cf. Section 4.2.3.2.

(2) Suitable excitations shall be selected for each direction at the place of installation where the response spectra will cover the secondary design response spectra in the essential frequency range of the component or its substructure. The selected excitations shall be well substantiated.

(3) From the selected registered or artificial time histories suitable stress conditions shall be created under consideration of the assigned direction of excitation at the component (or at the building structure with the component). The creation of stress conditions shall be well substantiated.

Note:

Three stress conditions are sufficient in the case of a linear analysis of the component. A non-linear analysis will require in the order of 5 stress conditions if based on registered time histories and in the order of 7 stress conditions if based on artificial time histories.

(4) Alternatively, the components may be integrated into the model of the building structure and, thus, may be analyzed within the overall model.

(5) Aside from the methods involving time histories or the substitution method for determining the excitation at the place of installation, other mathematical procedures may be applied if they offer equivalent results.

4.2.2 Secondary responses

(1) The responses of the building structure – i.e., the (secondary) response time histories and the (secondary) response spectra – shall be determined within the framework of analyzing the structural components in accordance with safety standard KTA 2201.3.

(2) The mathematical engineering model provided for the structural components in accordance with safety standard KTA 2201.3 shall be expanded by the component as specified in Section 4.3 if the responses of this component must be determined directly as a secondary response and not as a tertiary response.

(3) The determined response time histories shall be provided in their digital form and the determined design spectra both in their graphical and digital form.

4.2.3 Tertiary responses

4.2.3.1 Time history procedure

- (1) The component responses specified in Section 4.2.2 shall be used as the excitation for the component's substructures.
- (2) The components shall be represented by suitable mathematical engineering models as specified in Section 4.3.
- (3) The determined response time histories and the resulting stress conditions shall be provided in their digital form. The response spectra shall be converted into design spectra as specified in Section 4.2.4

4.2.3.2 Substitution method

- (1) In the case of sufficiently homogeneous major systems without any significantly oscillating partial systems, the response spectra (design spectra) for the place of installation of the subsystem may be determined by the substitution method presented below.

Notes:

- (1) The major system is the component or it is the building with the component, and the subsystem is the built-in part of the component.
- (2) A vibrating subsystem is a subsystem that is tuned to the dominant eigenfrequency of the major system and, therefore, has the tendency to produce resonance-type vibration responses in this frequency range.
- (2) The shape of the response spectrum shall be determined as shown in **Figure 4-1**. The spectrum amplification factor with respect to the acceleration of the major system at the place of installation of the subsystem (here: the acceleration of the component) shall be determined as shown in **Figure 4-2**.

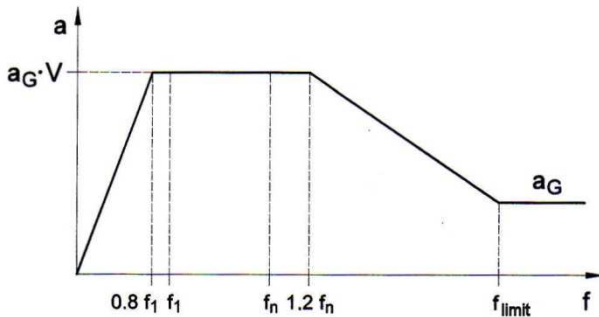


Figure 4-1: Determination of the shape of the response spectrum

Nomenclature:

- f frequency; the x-axis should be logarithmic
- f_1 lowest decisive eigenfrequency of the major system at the lower limit value in the variation range of the system parameters, however, not higher than the rightmost corner frequency of the highest plateau of the associated response spectrum
- f_n highest decisive eigenfrequency of the major system for the upper limit value in the variation range of the component parameters, however, not higher than the rightmost corner frequency of the highest plateau of the associated response spectrum
- f_{limit} upper limit frequency of the response spectrum of the major system
- a acceleration
- a_G acceleration of the major system (component) at the place of installation of the subsystem (built-in part)
- V spectra amplification factor as shown in **Figure 4-2**

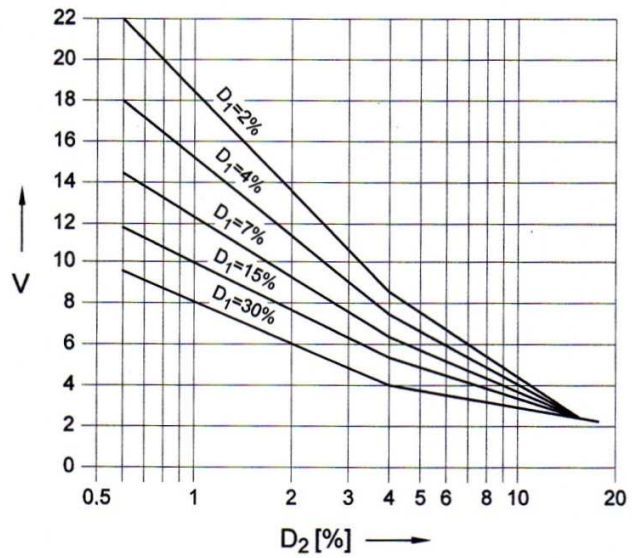


Figure 4-2: Determination of the spectrum amplification factor

Nomenclature:

- D_1 damping ratio of the major system in percent of critical damping
- D_2 damping ratio of the subsystem in percent of critical damping

- (3) The acceleration of the major system (component) shall be determined as specified in Section 4.4.
- (4) The damping level, D_1 , of the major system may be assumed as equal to the modal damping of the major system at its dominant natural vibration. In this context, the damping level of the component shall be applied within the framework of energy weighting as listed in column A of **Table A-1**. These values are considered to be on the safe side and may, therefore, be applied instead of the modal damping.
- (5) The damping ratio, D_2 , of the subsystem (built-in part) shall be applied as listed in column A of **Table A-1**.
- (6) A conversion of this procedure for inhomogeneous systems in individual cases shall be well substantiated.

Note:

The substitution method is a good approximation if the response of the major system is dominated by a single natural vibration. If more natural vibrations are significant contributors then this procedure is increasingly on the safe side.

4.2.4 Design spectra

- (1) Analytically determined tertiary response spectra for the respective place of installation of the components shall be converted to a smoothed design spectra in their respective direction that will ensure a robust design of the components, i.e., one that is insensitive to imprecisions of the parameters.
- (2) Creating the design spectra from analytically determined response spectra shall comprise the following steps:
 - a) Evaluation of the imprecisions of the substructure model. If necessary, these imprecisions shall be accounted for within the framework of item d).
 - b) Creating mean values of the results from the various time histories.
 - c) Cutting-off spectrum peaks that are no wider than 15 % of the respective center frequency.

- d) Smoothing of the resulting response spectra by applying simplified polygon contours.

Note:

The requirement under item d) is, generally, met if spectrum valleys with a base width of less than 20 % of the respective center frequency are surrounded by a plateau originating from the lower peak.

- e) Presentation of the response spectra in graphical form for visual inspection (quality assurance) and their provision in digital form for further processing.

(3) The substitution method provides the design spectra as immediate result..

4.2.5 Non-linear spectra of Class IIa components

(1) If Class IIa components are analyzed by the simplified linear procedure specified in Section 4.4.6, non-linear spectra may be used. These are determined from the design spectra with the aid of the behavior coefficient, q, further detailed in Section 4.4.6. This is shown in **Figure 4-3**.

(2) The amplitudes of the design spectra shall be divided by the behavior coefficient, q, specified in Section 4.4.6. Above the upper limit frequency, f_{limit} , the behavior coefficient $q = 1$. From the right corner frequency of the last plateau outward to the limit frequency, the behavior coefficient shall be linearly reduced to the value $q = 1$ at the upper limit frequency.

4.2.6 Excitation directions

Parallel oriented responses of different excitation directions shall be superposed in accordance with safety standard KTA 2201.1, Sec. 4.3.1.

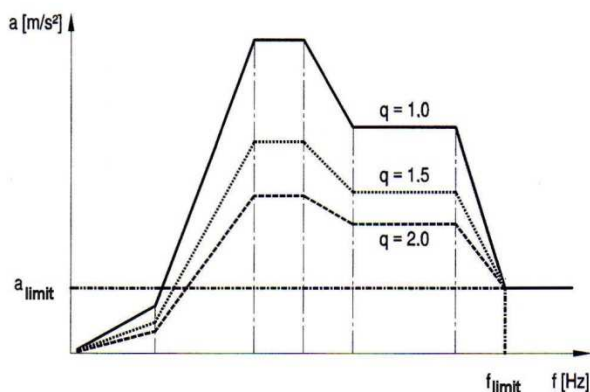


Figure 4-3: Creation of non-linear spectra for Class IIa components

4.3 Modeling

4.3.1 System characteristics

(1) In order to be able to analyze its mechanical behavior, the component shall be projected onto a suitable mathematical model. This model must allow describing the essential natural vibrations up to the upper limit frequency of the excitation spectra.

Note:

The results of complex models should be checked on the basis of global observations or simplified calculations.

(2) The stiffness values should preferably be determined on the assumption of a linear-elastic material behavior. As alternative in well substantiated cases, it is permissible to take advantage of the non-linear material behavior.

(3) With regard to system behavior, the non-linearity due to geometry or mechanical design shall be taken into account.

(4) In well substantiated cases, non-linearities may be linearized.

(5) The mass of the individual component to be applied is the mass corresponding to the analyzed operating condition. In accordance with safety standard KTA 2201.1, Sec. 4.3.2, short-term masses or masses rarely occurring during operation do not need to be applied.

(6) The damping ratios – in per cent of critical damping – needed for verifying the load-carrying capacity and integrity and for determining the tertiary spectra that may be applied shall be as listed in column A of **Table 4-1**. In the case of mechanically active components for which the functional capability is verified by a deformation analysis, the damping ratios to be applied shall be as listed in column B of **Table 4-1**.

(7) Larger damping ratios than the ones listed in **Table 4-1** may be applied, provided, they are verified.

(8) In the case of non-linear analyses with hysteresis effects, the viscous damping ratios to be applied shall also be as listed in column B of **Table 4-1**.

(9) Factors due to modeling of the components that have an influence on the results of the analysis shall be evaluated.

Note:

Usually, influences from the modeling of the components are covered by a variation of the excitation and by the ensuing determination of the effects of the model of the primary structures (building structure, subsoil)

Components	Damping Ratios	
	A	B
Pipes	4	2
Steel with welded connections and welded components (e.g., vessels, valves, pumps, motors, ventilators) ¹⁾	4	2
Steel with SL or SLP bolt connections (SL - structural bolt connection with a borehole tolerance ≤ 2 mm; SLP - fitted bolt connection with a borehole tolerance ≤ 0.3 mm)	7	4
Steel with SLV(P) or GV(P) bolt connections (SLV(P) - preloaded fitted bolt connection; GV(P) - fitted friction-grip bolt connection)	4	2
Cable support structures	10 ²⁾	7
Fluid media	0.5	0.5

¹⁾ If, on account of the design, deformations are possible only in small regions of the structure (low structural damping), the values as listed shall be halved (special cases).

²⁾ In well substantiated cases, the damping ratio may be increased up to 15 %.

Table 4-1: Damping ratios (in percent of critical damping) Column A: non-reduced values Column B: reduced values

4.3.2 Subdivision of structures

(1) Structures may be subdivided if the interaction between the substructures is taken into account or if neither the oscillation behavior nor the loads are inadmissibly modified. This is the case if one of the following conditions is met:

- a) The relevant design quantities calculated for the subdivided system shall not be more than 10 % lower than the respective values before its subdivision. A larger decrease is permissible if special reasons prevail (e.g., low utilization factor).
- b) The significant eigenfrequencies calculated for the subdivided system shall not deviate by more than 10 % from the respective eigenfrequencies of the complete (i.e. undivided) system. A larger deviation is permissible if special reasons prevail (e.g., low utilization factor).

Note:

If the (decoupled) eigenfrequencies of the major system and the subsystem are apart by less than 15 % (resonance tuning) then, in the case of a mass ratio subsystem-to-major-system larger than 0.01, a decoupling would lead to non realistically conservative results. In this case, realistic results can only be achieved by a coupled analysis.

(2) If a decoupling is possible, then as first approximation, the resonating masses of the subsystem can be neglected in the model of the major system in case of a low frequency tuning of the subsystem, but they shall be added to the model of the major system in case of a high frequency tuning.

(3) Pipe systems may be subdivided by the method of overlapping. The overlapping pipe region shall cover at least one axial stop and two radial bearings in the two perpendicular directions.

Note:

The method of overlapping is a way of modeling pipe systems where partial systems to be decoupled are included in the model of the pipe system to be analyzed to such an extent that their impact on the pipe system to be analyzed is sufficiently accounted for.

(4) In the case of pipe system the secondary pipe lines may be decoupled if Equation 4-1 applies.

$$\frac{I_N}{I_H} \leq 0.01 \quad (4-1)$$

Nomenclature:

- I_N planar moment of inertia of the secondary pipe line to be decoupled
- I_H planar moment of inertia of the major system to be analyzed

4.3.3 Fluids inside components

(1) In the case of components with a variable fluid level, the most unfavorable fluid level existing more than 30 days per annum shall be assumed.

(2) The fluid in a completely filled component may be assumed as being a rigid mass oscillating together with the component.

(3) In the case of partially filled components, the method used may be as follows:

- a) Analysis of the load-carrying capacity assuming that the fluid is a rigid mass oscillating together with the component. The sloshing effects of the fluid on the component and built-in components shall be evaluated separately.
- b) Application of the method of substitute masses for horizontal oscillations to account for oscillations of the fluid relative to the component (sloshing). In this method, the mass of the fluid may be subdivided into the "mass at rest" that is rigidly coupled to the component and a "sloshing mass" that can swing freely relative to the component. The damping ratio to be applied for the fluid oscillations shall be as listed in **Table 4-1**.
- c) Components with geometries for which no simple solutions are available may be projected onto equivalent sub-

stitute geometries. In the case of a cylindrical vessel oscillating in the horizontal direction, the fluid mass may be regarded as a rigid pendulum mass.

(4) For the vertical direction of oscillation, the liquid may always be assumed as a rigid mass together with the oscillating component.

(5) As alternative to the approximations under paras. (2), (3) and (4), the procedure in accordance with Appendix A of DIN EN 1998-4 may be followed or the more detailed procedures of fluid dynamics or of accounting for a fluid-structure interaction (e.g., method of finite elements) may be applied.

4.4 Analysis of Mechanical Behavior and Load Determination

4.4.1 Analysis methods

(1) In the case of a linear analysis, the mechanical behavior may be analyzed based on one of the following methods:

- a) Response spectrum method specified under Section 4.4.2,
- b) Time history method specified under Section 4.4.3, or
- c) Quasi-static method specified under Section 4.4.4.

(2) Other methods may be applied, provided, they produce similar results.

(3) In case of a non-linear system behavior (cf. Section 4.4.5), a non-linear analysis by the time-history method shall be applied unless an adequate and sufficiently accurate linearization is available and well substantiated.

(4) As alternative to the non-linear analysis by the time-history method, non-linear static methods may be applied. This must be well substantiated.

Note:

In these kinds of analyses, e.g., non-linear statically determined capacity curves are compared to the requirement spectra and are evaluated with respect to the available ductility (capacity spectrum method).

(5) In the case of Class IIa components, a quasi-non-linear design with the behavior coefficient, q , as detailed in Section 4.4.6 is permissible.

(6) Parallel responses of various models shall always be enveloped. Parallel responses from various stress conditions may be averaged when performing linear analyses of the component and shall be enveloped when performing non-linear analyses of the component.

4.4.2 Response spectrum method

(1) In the case of components that can be modeled as a system with one degree of freedom, the response spectrum directly produces the maximum response values.

(2) In the case of components that are modeled as a system with more than one degree of freedom, the maximum response values to the individual natural vibrations (e.g., stress resultants, accelerations, deformations) shall be superposed. In this context, the method of the complete quadratic combination (CQC) in accordance with Equations (4-2) shall be applied.

$$E = \sqrt{\sum_{L=1, K=1}^M E_L \times E_K \times \rho_{LK}} \quad (4-2)$$

For a constant damping ratio, D , the interaction factor, ρ_{LK} , is given by

$$\rho_{LK} = \frac{8 \cdot D^2 \times (1 + r_{LK}) \times r_{LK}^{1.5}}{(1 - r_{LK}^2)^2 + 4 \times D^2 \times r_{LK} \times (1 + r_{LK})^2} \quad (4-3)$$

where

$$r_{LK} = \frac{f_L}{f_K} \quad (4-4)$$

Nomenclature:

D	damping ratio
E	resultant seismic response quantity as the sum of all modal contributions in the respective direction
E_L, E_K	modal contribution of the L^{th} or K^{th} natural vibration in the respective direction of the seismic response quantity to be determined
ρ_{LK}	interaction factor of the natural vibrations as a function of the modal damping ratios and frequency spacing (frequency ratio, r_{LK}) of the individual eigenfrequencies, f_L and f_K
M	number of natural vibrations up to the upper limit frequency
f_L, f_K	eigenfrequency of the L^{th} or K^{th} natural vibration

Note:

In case of unequal damping ratios, $D_L \neq D_K$, an expanded Equation (4-3) is used.

(3) If all eigenfrequencies are sufficiently widely spaced ($r_{LK} < 0.80$ or $r_{LK} > 1.20$), the modal contributions may be superposed by the square root of the sum of squares as shown by Equation (4-5). Different methods of superposition need to be well substantiated.

$$E = \sqrt{\sum_{L=1}^M E_L^2} \quad (4-5)$$

Note:

As the space between eigenfrequencies increases ($r_{LK} \ll 1$ or $r_{LK} \gg 1$), Equation (4-2) becomes identical to Equation (4-5).

(4) The relative contributions of natural vibrations above the limit frequency shall be adequately taken into account. This requirement is met in case of homogeneous systems if the modal masses of all natural vibrations accounted for sums up to at least 90 % of the total mass of the component in each of the three orthogonal directions. If the sum of the modal masses is less than 90 % of the total mass or if the system is significantly inhomogeneous, then the sum of modal contributions calculated according to Equation (4-2) or Equation (4-5) must be expanded by the rigid-body contribution. Equation (4-6) shows this expansion by the rigid-body contribution for Equation (4-2).

$$E = \sqrt{\sum_{L=1, K=1}^M E_L \times E_K \times \rho_{LK} + \left(E_{St}^0 - \sum_{L=1}^M E_L^0 \right)^2} \quad (4-6)$$

Nomenclature – in addition to that of Equation (4-2):

E_L^0	modal contribution of the L^{th} natural vibration multiplied by the rigid-body acceleration of the seismic response quantity to be determined. Here, the modal contributions are added arithmetically.
E_{St}^0	response of a static load case, assuming a rigid-body acceleration in the respective direction

(5) To account for the rigid-body contribution with a good margin of safety, the expanded Equations (4-7) or (4-8) may

be applied as expansions of Equations (4-2) or (4-5), respectively.

$$E = \sqrt{\sum_{L=1, K=1}^M E_L \times E_K \times \rho_{LK} + \left(E_{St}^0 \right)^2} \quad (4-7)$$

$$E = \sqrt{\sum_{L=1}^M E_L^2 + \left(E_{St}^0 \right)^2} \quad (4-8)$$

Nomenclature:

see above

(6) In the case of various points of excitation with different response spectra, the multi-support-excitation method may be applied. In this procedure the individual spectra are weighted by corresponding influence functions. Paras. (4) or (5) shall be applied to the rigid-body contribution.

(7) Section 4.2.6 shall be applied to the superposition of the responses from various excitation directions and Section 4.4.7 to the possible shares from relative displacements.

4.4.3 Time history method

(1) An analysis by the time history method may be performed by a modal time history method or by direct integration. The rigid-body contribution shall be taken into account analogously to the response spectrum method (cf. Section 4.4.2).

(2) In accordance with safety standard KTA 2201.1, Sec. 4.3.3 para. (6), the applied excitations may be based on those acceleration-response time histories from the analysis of the building structures that cover the design spectrum at the place of installation of the component. Alternatively, artificial acceleration time histories may be applied that, in analogy to safety standard KTA 2201.1, Sec. 4.3.3, are compatible with the design spectra.

(3) The time increments of the calculation shall not exceed 0.1 times the vibration period at the upper limit frequency of the associated response spectrum.

(4) Section 4.2.6 shall be applied to the superposition of the responses from various excitation directions and Section 4.4.7 to the possible shares from relative displacements.

(5) In the case of non-linear calculations, Section 4.4.5 shall be taken into consideration.

4.4.4 Quasi-static method

(1) The quasi-static method may be used for systems with a homogeneous distribution of stiffness and mass.

(2) Secondary spectra shall be applied to the design of the support structures of subsystems. The subsystem (supported system) itself shall be designed based on tertiary spectra.

(3) The system responses (stress quantities) may be calculated by a static analysis. In this context, substitute accelerations shall be defined that result in quasi-static actions in proportion to the mass distribution. The substitute accelerations shall be calculated as follows:

$$a_{E,i} = e_i \times S_{a,i} \quad (4-9)$$

Nomenclature:

$a_{E,i}$: substitute acceleration for the direction i

e_i : factor accounting for the relative contributions of higher natural vibrations for the direction i , cf. paras. (6), (7) and (8)

$S_{a,i}$: reading value from the response spectrum for direction i , cf. paras. (4) and (5)

(4) The reading value, $S_{a,i}$, shall be assumed as the largest value of the response spectrum for eigenfrequencies that are larger or equal to the first significant eigenfrequency of the component. If the eigenfrequency is not known, $S_{a,i}$ shall be assumed as the maximum value of the response spectrum. The respective damping and direction shall be taken into account.

(5) In the case of spatially coupled systems – provided, more exacting investigations are not performed – all three values, $S_{a,i}$, shall be set equal to the largest of the three reading values determined.

(6) The values of the factor e_i shall be assumed as listed in **Table 4-2**. In this context, it shall be well substantiated that an idealization of the component conforming to **Table 4-2** is possible. Other values assumed shall be well substantiated. Lower values may also be applied, provided, their permissibility is verified.

(7) In the case of dynamically stiff components (i.e., the fundamental frequency is higher or equal to the upper limit frequency), the factor e_i shall be set equal to 1.0.

(8) When determining the support reaction, the factor e_i may be set equal to 1.0 independently of the type of system.

(9) Any effects that the modeling of the component may have on the analysis results shall be evaluated.

Note :

Generally, the effects of modeling the component are covered by varying the excitation and by the supporting analysis of the effects of modeling the primary structures (building structure, subsoil).

Modeling	e_i
Continuous beam with equal span width	1.0
Over-hanging beam	1.0
Straight beam with any kind of support	1.0 *)
Planar systems (e.g., framework structures, girder grillages, horizontal-plane pipe systems)	1.2
Systems with a spatial oscillation behavior	1.5
*) The largest stress resultants (forces, moments) shall be applied at every cross-section.	

Table 4-2: Values of factor e_i for Equation (4-9)

4.4.5 Non-linear analysis

(1) As alternative to the linear analyses specified in Sections 4.4.2, 4.4.3 and 4.4.4, the components may be verified on the basis of a non-linear time history analysis (i.e., the direct integration of the equations of motion). Well substantiated approximation methods are permissible.

(2) The material equations may be approximated by polygonal and, in the simplest cases, by bilinear characteristic curves. The limits of these characteristic curves shall be set by the available limit ductility.

(3) The parameters of the non-linear analysis model shall be evaluated in accordance with safety standard KTA 2201.1, Sec. 4.3.4 para. (4), with regard to their range of uncertainty and to the uncertainty of the results. If necessary, sensitivity analyses shall be performed.

(4) The non-linear analyses of the components shall be performed for the selected stress conditions specified in Section 4.2.1.

(5) The time histories of the different excitation directions shall be applied simultaneously and together with all other simultaneously occurring actions.

(6) If the damping ratios of Column B of **Table 4-1** are approximated by proportional damping (Rayleigh damping), when selecting the support points it be taken into consideration that the damping effects remain low enough and, thus, on the safe side.

4.4.6 Quasi-non-linear design of Class IIa components

(1) In the case of those Class IIa components in which lasting deformations would be compatible with the protective goals, it is permissible – unless more accurate non-linear calculations are performed as specified under Section 4.4.5 – to verify the load-carrying capacity based on non-linear spectra as specified under Section 4.2.5.

(2) The analysis may be performed linearly by the response spectrum method as specified under Section 4.4.2 where the spectra are reduced by the behavior coefficient, q .

(3) The behavior coefficient for the creation of the non-linear spectra for verifying structures may be assumed as $q = 1.5$ without further verification. Higher values shall be well substantiated.

Note :

In this context, further details are specified in, e.g., DIN EN 1998-1.

(4) The deformations calculated on the basis of paras. (2) and (3) shall be increased by the assumed behavior coefficient, q .

(5) The anchor points of components including the anchoring devices shall be verified as $q = 1.0$ in order to ensure that the anchoring does not fail before the ductility of the component has fully developed. Likewise, the behavior coefficient of the building-structure interaction load shall be determined for a $q = 1.0$.

4.4.7 Relative displacement

(1) In addition to the acceleration-induced loads of the components that can be determined, e.g., by response spectra or acceleration time histories, additional loads caused by earthquake-induced displacements at the connection points must be taken into account if they amount to more than 10 % of the acceleration-induced loads (e.g., stress of pipes due to the deformation of long, slim vessels or due to the relative displacement between two parts of a building structure).

(2) The movements or stress quantities resulting from the relative displacements may be superimposed with the acceleration-induced loads by applying Equation (4-10), i.e., by the square root of the sum of the squares.

$$E = \sqrt{E_a^2 + \sum_{k=1}^n \sum_{i=1}^6 (E_{vik})^2} \tag{4-10}$$

Nomenclature :

E : resulting response value from accelerations and relative displacements

E_a : resulting response value from all acceleration actions

E_{vik} : response value of the statically to be applied i^{th} earthquake-induced displacement component (up to 6 components at each connection point) at the k^{th} connection point (usually one or two, generally, n connection points)

n : number of connection points

4.5 Verification of the Limit Conditions

4.5.1 Basics

(1) The loads (e.g., stress resultants, stresses, deformations, accelerations) determined for seismic actions together with other actions as specified under Section 4.4 shall be correlated with the respective permissible strains. The permissible strains result from the limit conditions of

- a) load-carrying capacity,
- b) integrity, and
- c) functional capability.

(2) The limit conditions may be determined linearly or non-linearly from the stress quantities or from the displacement quantities.

(3) The verification of action combinations for the design basis earthquake shall be based on Requirement Category A3 in accordance with KTA-GS-78 unless deviating requirements are specified below.

(4) The correlation of the Requirement Categories in accordance with KTA-GS-78 with the loading levels of steel engineering, i.e., the design limits of structural engineering and, in particular, the service limit levels of plant engineering, is presented in **Table 4-3**. Depending on the individual case, a more conservative categorization is permissible.

(5) The verifications may be carried out by the partial safety concept specified under Section 4.5.2 or by the global safety concept (stress analysis) specified under Section 4.5.3. In the case of stability problems, the verification shall be carried out as specified under Section 4.5.2.

Designation: Source	Classification			
Service Limit Levels of mechanical engineering: KTA 3201.2 KTA 3211.2	A	B	C	D
Loading Levels: KTA 3205.1 KTA 3205.2	H	HZ	HS1	HS2/3
Design load situations: DIN EN 1990 DIN EN 1993	permanent and variable		accidental	
Requirement Categories: KTA-GS-78	A1		A2	A3

Table 4-3: Classification of the requirement categories

(6) The verifications shall be differentiated according to

- a) Rod and bar structures (e.g., support structures of components), and
- b) Shell and plate structures of components with or without pressurization (e.g., vessel walls, support skirts, pipes, fittings).

(7) The verification of action combinations with the design basis earthquakes shall only be performed for primary stresses unless deviating requirements are specified below.

Note:

Secondary and peak stresses are specified in component-specific standards.

(8) In the case of components consisting of brittle materials (e.g., cast iron, ceramics) or of unfavorably constructed components (e.g., with fillet welds), the total stress shall be taken into account in addition to the primary stresses. In this context, the secondary stresses and peak stresses shall either be treated as primary stresses or shall, in addition to the primary stresses, be evaluated with regard to their respective failure mode.

(9) If the mechanical design does not ensure a sufficient deformation capacity (ductility) of the component or its support structure, then the design basis earthquake shall be categorized in Requirement Category A2.

(10) With regard to load-carrying capacity (and, if danger of flooding exists, also with regard to integrity), the Class IIa components shall be verified in the same way as Class I components if their loading from seismic actions were determined as specified in Section 4.4.6 (quasi-nonlinear design). Special attention shall be given to paras. (3), (4) and (5) of Section 4.4.6.

(11) The mathematical analysis of the active and passive functional capability shall be performed by verifying the deformation as specified under para. (12) or by the stress analysis as specified under para. (13).

(12) The deformation verification shall prove that the determined deformations do not adversely affect the required functionality. In this context, it shall be differentiated between:

- a) Functional capability is required only after the earthquake. The verification shall be based on the resulting permanent deformations.
- b) Functional capability is required also during the earthquake. The verification shall be based on the resulting total deformations (elastic plus permanent deformations).

(13) If the verification by way of stress analysis is chosen, it shall be based on more stringent limit values as follows:

- a) If an active functional capability is required only after an earthquake or if only a passive functional capability is required, it is sufficient to assume Service Limit Level C for the design basis earthquake.
- b) If an active functional capability is also required during an earthquake, Service Limit Level B shall be assumed for the design basis earthquake.
- c) With regard to ensuring the flow in passive components (e.g., pipes, heat exchangers), it is sufficient to assume Service Limit Level D, provided, an elastic analysis is basis for the verification of the component.

Note:

Details are specified in component-specific standards. The verification of functional capability by stress analysis specified under this para. (13) covers the verification of the load-carrying capacities for the respective regions.

4.5.2 Verification by the partial safety concept

(1) In accordance with DIN EN 1990, the following actions shall be taken into account:

- a) Permanent actions, G_k , (characteristic value),
- b) Variable actions, Q_k , (characteristic value),
- c) Actions from the design basis earthquake, A_{Ed} (design basis earthquake in accordance with safety standard KTA 2201.1).

