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

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KTA SAFETY STANDARD

November 2012	**Design of Nuclear Power Plants against Seismic Events; Part 4: Components**	KTA 2201.4

Previous versions of this safety standard: 1990-06 (BAnz No. 20a of January 30, 1991; Corrections: BAnz No. 115 of June 25, 1996)

Contents

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 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.

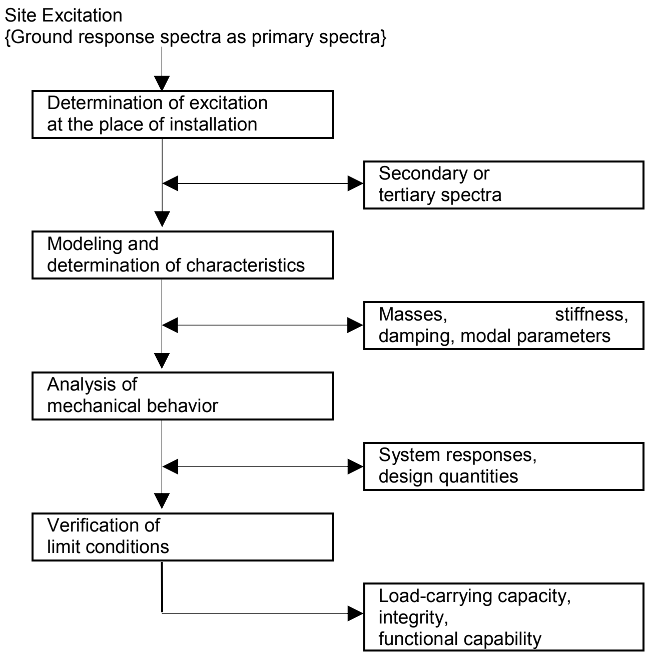

Figure 3-1: Procedural steps of the verification procedure

(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:

a) Verification by analysis (cf. Section 4),

b) Verification by physical experiments (cf. Section 5),

c) Verification by analogy (cf. Section 6),

d) 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 electrotechnical 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:

a) as response time histories of the structural components or building response spectra (secondary responses in accordance with safety standard KTA 2201.3),

b) as response time histories or response spectra of the component (tertiary responses as specified under. Section 4.2.3.1),

c) 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.

d) 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.**

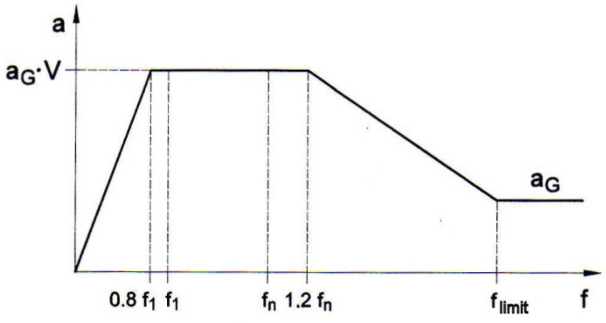

Figure 4-1: Determination of the shape of the response spectrum

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***

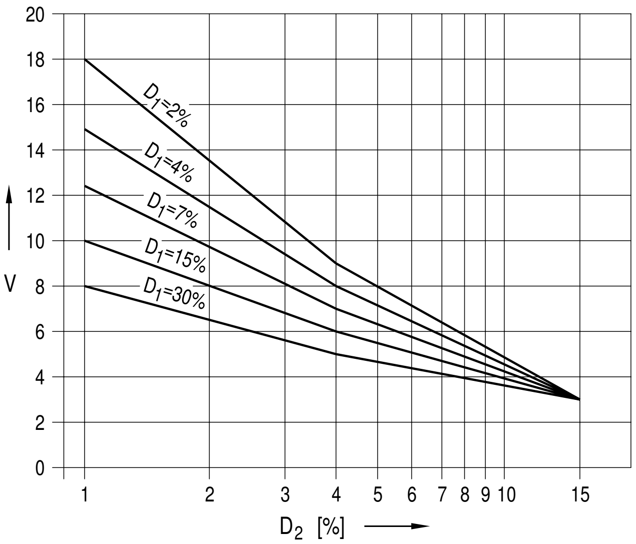

Figure 4-2: Determination of the spectrum amplification factor

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 loweer 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.

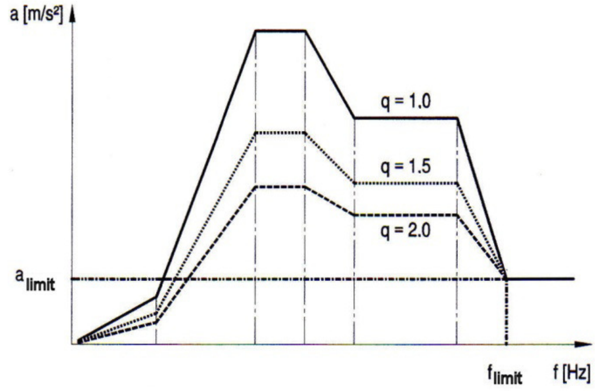

Figure 4-3: Creation of non-linear spectra for Class IIa components

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.

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

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 substitute 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 **c**omplete **q**uadratic **c**ombination (CQC) in accordance with Equations (4-2) shall be applied.

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

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

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

where

$$r_{LK} = \frac{f_L}{f_K} \tag{4-4}$$

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.

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

Note:

As the space between eigenfrequencies increases ($r_{LK} << 1$ or $r_{LK} >> 1$), 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).

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

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.

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

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

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:

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

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.

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

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 nonlinearly 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).

(2) The permanent actions and variable actions shall be assumed as the corresponding characteristic values.

Note:

Actions from earthquakes are design values and implicitly contain a partial safety factor $\gamma_F = 1.0$. In accordance with DIN EN 1990, the design value, A_{Ed}, covers both the weighting factor, γ_1, and the importance factor, γ, for the design basis earthquake in accordance with safety standard KTA 2201.1.

(3) The design value for the earthquake loading shall be calculated by Equation (4-11) in accordance with DIN EN 1990 as the action combination of the limit conditions of the load-carrying capacity and of the serviceability:

$$E_d = E\left\{G_k \oplus A_{Ed} \oplus \sum_{i \geq 1} (\psi_{2,i} \times Q_{k,i})\right\} \qquad (4\text{-}11)$$

Nomenclature:

E_d : *design value for the earthquake loading*

$E\{...\}$: *earthquake loading function*

G_k : *characteristic value of permanent action*

Q_k : *characteristic value of variable action*

A_{Ed} : *actions from design basis earthquake*

ψ_2 : *combination coefficient*

$\oplus$: *indicates "shall be combined with"*

$\sum$: *indicates "combined effect of"*

(4) The combination coefficients, ψ_2, for the variable actions shall be specified such that the product of ψ_2 and Q_K would describe the quasi-permanent value of the respective variable action. Accordingly, the combination coefficients, ψ_2, for the quasi-permanent imposed loads and prior deformation restraints shall be assumed as $\psi_2 = 1.0$.

Note:

The combination coefficients, ψ_2, are defined in DIN EN 1990. Reference values for ψ_2 are specified in safety standard KTA 2201.3.

(5) For the ultimate limit condition it shall be verified that

$$E_d \leq R_d \qquad (4\text{-}12)$$

where

$$R_d = R\{f_k / \gamma_M\} \qquad (4\text{-}13)$$

is the material specific design value of the bearing capacity which in turn is a function of the ratio of the characteristic value of material strength, f_K, and the respective partial safety factor, γ_M. In the case of structural steel, three different partial safety factors, γ_M, shall be considered:

- γ_{M0}: stress analysis of the cross-section,
- γ_{M1}: verification of the stability of components with respect to flexural buckling and torsional buckling,
- γ_{M2}: verification of the tensile strength for the net cross-section.

(6) The partial safety factors γ_{M0} and γ_{M1} shall be assumed as being equal to 1.0. With respect to the tensile-strength-dependent permissible strain, the value of γ_{M2} shall be assumed as being equal to 1.15.

(7) Unless more detailed requirements are specified in the component-specific standards, the design value of the bearing capacity may be determined by Equation (4-14).

$$R_d = \sigma_{zul} \qquad (4\text{-}14)$$

where σ_{zul} is the permissible stress for the respective requirement category in accordance with the corresponding component-specific standards.

(8) Bar-shaped elements of components outside of the scope of the component-specific nuclear standards may be verified in accordance with DIN EN 1993-1-1.

(9) Shell-shaped elements of components outside of the scope of the component-specific nuclear standards may be verified by applying Equation (4-14) in combination with para. (4) of Section 4.5.3.

(10) When verifying the secure positioning (tilting, slipping) of unanchored components for the design basis earthquake, a safety factor equal to 0.95 shall be assumed for stabilizing actions and equal to 1.0 for destabilizing actions.

(11) For the limit condition of the functional capability or of the integrity it shall be verified that

$$E_d \leq C_d \qquad (4\text{-}15)$$

where E_d is the design value of the earthquake loading (e.g., stress, deformation) according to Equation (4-11) and C_d is the design value of the functional capability or of the integrity (e.g., permissible stress or deformation). This latter value shall be specified for the individual component and the individual case.

4.5.3 Verification by the global safety concept

(1) This verification shall be based on the action combinations in accordance with the corresponding component-specific standards.

(2) The permissible strains (e.g., permissible stress, deformations) in accordance with corresponding component-specific standards shall be applied.

(3) A stress analysis shall be performed for the ultimate limit condition and the limit condition of the integrity to verify that

$$\sigma_{vorh} \leq \sigma_{zul} \qquad (4\text{-}16)$$

where σ_{vorh} is the strain for the decisive action combination determined as specified under para. (1) and σ_{zul} is the decisive permissible strain specified under para. (2). The limit condition of the functional capability shall be verified as specified under Section 5 or under Section 4.5.1, para. (11).

Note:

Equation (4-16) applies in a general sense to every kind of loading (e.g., stress, deformation, distortion).

(4) The load-carrying capacity or the integrity of shell-shaped elements of components outside of the scope of the component-specific nuclear standards may be verified based on the primary stresses listed in **Table 4-4**. This limitation to a primary stress analysis is only permissible if the design and the materials are in accordance with safety standard series KTA 3211.

(5) When verifying the secure positioning (tilting, slipping) of unanchored components for the design basis earthquake, a safety factor equal to 0.95 shall be assumed for stabilizing actions and equal to 1.0 for destabilizing actions.

Requirement Category or Service Limit Level	P_m	$P_m + P_b$ or $P_l + P_b$
A3 or D	$0.7 \times R_m$	$\alpha \times 0.7 \times R_m$
A2 or C	$1.0 \times R_{p0.2}$	$\alpha \times 1.0 \times R_{p0.2}$

Nomenclature:

P_m	*general membrane stress from the design value of loading during the earthquake situation*
P_l	*local primary membrane stress from the design value of loading during the earthquake situation*
P_b	*primary bending stress from the design value of loading during the earthquake situation*
R_m	*characteristic value of the tensile strength of the material*
$R_{p0.2}$	*characteristic value of the yield strength or 0.2 % proof stress of the material*
α	*form factor depending on the cross-section (e.g., α = 1.5 for rectangular cross-sections)*

Table 4-4: Limit conditions of the primary stresses of other components

5 Verification by Physical Experiments

5.1 Verification Objective

(1) The verification objective of the test shall be derived from the respective safety-related tasks.

(2) With respect to the requirements derived from the verification objective for the limit values to be observed, it shall be specified whether these limit values must be determined during the test.

5.2 Requirements Regarding the Test Object

(1) Physical experiments for the verification of seismic safety may be performed on components (component or individual devices) – hereinafter generally referred to as ‘test objects’ – either in a test bay or in their installed condition in the nuclear power plant.

(2) These experiments shall be performed on original components or, preferably, on design-identical components. Substitute components may be used if they represent the properties of the original components with respect to the respective verification objective.

(3) If the same test object is used for several partial tests, it shall be ensured that the test object continues to have those properties of the original component that are essential to the respective test.

(4) If the experiment is performed in a test bay, the test object shall be mounted in such a way that the original boundary conditions with respect to the verification objective are represented.

(5) The influence of existing oscillation insulations shall be taken into account. This may be accounted for either in the mounting of the test object or when determining the action quantities.

(6) If a position other than the specified in-plant mounting position of the test object is used in an experiment, the changed influence of gravity shall be taken into consideration.

(7) As far as necessary, connections to neighboring components shall be taken into account.

(8) If necessary with regard to the verification objective, all operating conditions for the test object that must be postulated for the seismic event (e.g., pressure, temperature, voltage, electric current, limit values to be observed) shall be determined. If the operating conditions are only partly or not at all accounted for by the experiment, their effects shall be accounted for by some other means (e.g., by analysis).

5.3 Requirements Regarding Excitation of Oscillation

5.3.1 Basics

(1) The excitation of oscillation for the verification by physical experiments shall be determined under consideration of the type of excitation as specified under Sections 4.2 and 5.5.

(2) The decisive action for the experiment shall be specified for the respective assumptions (e.g. static substitute loads, response spectrum, time history) as well as for the respective test signal in the excitation directions at the place of installation.

(3) The test object shall be excited at its anchor points in such a way that it receives at least the specified actions. Any deviations shall be well substantiated.

(4) The selected excitation shall, basically, be equivalent to the decisive seismic action. In case of an excitation by means of forced oscillations as specified in para. (1) item c) of Section 5.3.6, the equivalency shall preferably be verified by comparing the response spectra. Other verification methods, e.g., by the spectral power density, are permissible.

(5) A deviation from the requirement of equivalency between excitation and seismic action is permissible, provided, it is possible to achieve the verification objective by extrapolation (e.g., for stresses in the linear range).

5.3.2 Comparison of Actions

(1) A comparison of the actions shall be performed in order to ensure that the required actions are achieved by the test.

(2) The actions shall, preferably, be compared based on the response spectra. In the evaluation, the damping of the response spectrum shall be larger than or equal to the corresponding value of the required spectrum.

a) In case of an unknown oscillation behavior of the test object, it shall be ensured that the required response spectra are achieved by the entirety of applied test excitations.

b) If the characteristic frequencies of the test object are known, it is sufficient if the individual test signals envelop the required response spectra in the range of these frequencies. The verification shall be carried out for these characteristic frequencies and, additionally, for frequencies ± 10 % away from the characteristic frequencies. The equivalency shall be verified for reliably determined damping values or for the respective damping value to be applied according to Column A of **Table 4-1**.

(3) When calculating the test response spectrum, the spacing of the support points shall be adjusted to the respective damping ratio in order to detect if the test response spectrum falls below the required response spectrum.

(4) In the case of damping ratios from 1 % to 5 %, the maximum calculation increments shall be 1/12 of an octave and from 5 % to 10 % 1/6 of an octave. Even higher damping ratios would permit increasing the calculation increments up to 1/3 of an octave.

5.3.3 Excitation Axes

(1) Basically, the excitations of the test shall be applied simultaneously in all three spatial directions.

(2) An individualization of the sequence of the individual direction-related loads is permissible, provided,

a) the verification objective allows for the superposition of the corresponding reactions of the test object, or

b) it is shown that the behavior of the test object (eigenfrequencies, stiffness) or that the required response spectra (frequency ranges with large resonance peaks) are independent of each other with respect to the individual axes, or

c) the multi-axial character of the seismic excitation is taken into account by means of a correspondingly higher test excitation (cf. Section 5.5.2).

(3) In the case of multi-axial test excitations with a fixed phase assignment, the in-phase and 180°-phase-offset excitation signals shall normally be combined.

5.3.4 Transverse motions

(1) Movements orthogonal to the respective direction or plane of excitation shall be measured.

(2) If transverse motions occur, it shall be ensured that the required value in the direction of excitation is achieved.

5.3.5 Single-frequency test excitations

(1) In case of single-frequency test excitations, the measured amplitude of the excitation frequency in the specified excitation direction shall not fall below 90 % of the corresponding required value.

(2) The level of background vibrations, d, calculated according to Equation (5-1), should not exceed 100 % in the range up to five times the highest test frequency.

$$d = \frac{1}{a_n} \times \sqrt{a_{ges}^2 - a_n^2} \times 100 \qquad (5\text{-}1)$$

Nomenclature:

d : *level of background vibration in percent*

a_{ges} : *effective value of the acceleration amplitude within the frequency range to be monitored*

a_n : *effective value of the required acceleration amplitude at the excitation frequency*

Note:

A higher level of background vibration has a conservative effect on the results of stress tests and, therefore, is permissible, provided, this is compatible with the verification objective.

5.3.6 Test Excitation Methods

(1) The following test excitation methods are permissible taking the restrictions specified under Sections 5.4, 5.5 and 5.6 into account:

a) Static methods

These include those methods where the values relevant to the verification objective do not change during the test or they change only to such degree that dynamic influences can be neglected (e.g., static deflection tests).

b) Free oscillation methods

These include those methods where, after application of the initial loads, the system is left to itself with respect to its oscillation (e.g. fess vibration tests, snap-back tests).

c) Forced oscillation methods

These include those methods where a time dependent excitation is upheld over the entire duration of the test. In this context, either a single-frequency or a multiple-frequency excitation may be applied.

(2) The single-frequency tests may use, e.g., fixed sine waves, sine sweeps or sine beats as excitation.

(3) The multiple-frequency tests may use, e.g., noise frequencies, spectrum-compatible time histories or the superposition of several individual frequencies as excitation.

5.4 System Characteristics and Parameters

5.4.1 Static parameters

Static parameters (local and global stiffness) shall normally be determined for the decisive stress level. In the case of linear system behavior, they may be determined for lower stresses. In this context, the static methods as specified under Section 5.3.6, para. (1), item a), shall normally be applied. The other methods specified under Section 5.3.6 are also permissible.

5.4.2 Dynamic Parameters

(1) Single-axis excitation shall normally be applied for the determination of the dynamic parameters.

(2) The dynamic parameters (e.g., eigenfrequencies, natural vibration modes) shall be determined before the stress test by the methods specified under Section 5.3.6, para. (1), item b) or item c).

Note:

When applying the method specified under Section 5.3.6, para. (1), item c), dynamic parameters can be determined with a one-axis sine-sweep excitation between 1 m/s² and 2 m/s² and a sweep velocity smaller or equal to one octave per minute.

(3) The dynamic behavior shall be examined up to 1.2 times the upper limit frequency.

(4) The damping ratio shall be determined by applying one of the methods specified under Section 5.3.6 para. (1), item b) or c). A conservative estimate using the method specified under Section 5.3.6, para. (1), item a), (measurement of the static hysteresis) is permissible. In this context, the following restrictions apply:

a) In the case of the methods specified under para. (1), item b) of Section 5.3.6, when determining the damping ratio by means of the free vibration test, it shall be considered that the oscillation fade-out, aside from being influenced by system damping, can also be influenced by the dissipation of energy into adjacent systems.

b) With regard to the method specified under para. (1), item c) of Section 5.3.6 the following applies:

  ba) In the case of single-frequency excitation it shall be observed that the excitation lasts long enough for the condition of a steady state oscillation is reached.

  bb) In the case of a sine-sweep excitation, the frequency sweep rate applied shall basically not exceed one octave per minute. Higher sweep rates shall be well substantiated.

  bc) The damping ratio may be determined from the transfer function at suitable points on the test object. The determination may be based on the half-value width or on the resonance amplification according to item bd).

bd) A lower limit boundary for the damping ratio, D, of the test object may be calculated by Equation (5-2).

$$D = \frac{1}{2 \cdot Q} \cdot 100 \qquad (5\text{-}2)$$

Nomenclature:

D : damping ratio of test object in percent

Q : resonance peak

Note:

Equation (5-2) is exactly true only for an oscillator with one degree of freedom.

5.5 Analysis of Mechanical Behavior and Determination of Stress

5.5.1 Methods

The following methods shall be applied when determining the stresses on the test object:

a) Static methods

If the action quantity is based on an applied deflection force that was determined from the substitute acceleration, $a_{E,i}$, according to Equation (4-9), then the static methods specified under para. (1), item a) of Section 5.3.6 shall normally be applied only to systems with a sufficiently homogeneous distribution of mass. In this context, prerequisite for the determination of $a_{E,i}$ is the knowledge or a conservative estimate of the damping ratio of the test object (e.g., values from Column A of **Table 4-1**).

b) Free oscillation method

It shall be ensured that the required acceleration, $a_{E,i}$, according to Equation (4-9) is applied during at least one cycle of the free oscillations. This method is particularly suited for components with a sufficiently homogeneous distribution of mass.

c) Forced oscillation method

The stress may be determined by applying the method of forced oscillations as specified under para. (1), item c) of Section 5.3.6.

5.5.2 Base excitation

5.5.2.1 General requirements

(1) The excitation of the test object shall basically be measured at the mounting points of the test object. This requirement may be deviated from, provided, the oscillations at the measurement point and at the anchor point are identical with regard to phase and amplitude.

(2) Basically, the damping ratio shall be determined for distinctive low eigenfrequencies. This requirement may deviated from, provided, the values of Column A of **Table 4-1** are applied.

(3) The values of Column A of **Table 4-1** shall be applied as damping ratios for higher eigenfrequencies if the damping cannot be accurately determined by experiments (e.g., from the transfer behavior).

5.5.2.2 Single-frequency excitation in case of unknown eigenfrequencies of the test object

(1) In the case of a single-frequency excitation and unknown eigenfrequencies of the test object, the excitation shall be adjusted such that the test response spectrum envelops the required response spectrum as specified under Section 5.3.2.

(2) The excitation amplitude of the single-frequency excitation in the direction i shall be calculated by Equation (5-3).

$$A_i(f) = k_i \times \frac{a_i(f,D)}{\ddot{U}(f,D)} \qquad (5\text{-}3)$$

Nomenclature:

i :	*index for direction x, y, (horizontal) and z (vertical)*
f :	*excitation frequency in Hz*
D :	*damping ration of the test object*
a_i(f, D) :	*acceleration of the response spectrum in direction i*
Ü(f, D) :	*excitation-specific amplification factor as specified in* ***Figure 5-1*** *or* ***Figure 5-2*** *(depending on the excitation form)*
k_i :	*factor for measuring the relative shares of several natural vibrations if only one natural vibration is excited at a time.* *k_i = 1, if several natural vibrations are excited simultaneously or if only one natural vibration lies in the test frequency range.* *$k_i = \sqrt{2}$, if only one natural vibration is excited at a time and several characteristic modes lie in the test frequency range.*

The excitation shall be applied up to the upper limit frequency of the required response spectrum.

An additional test of the rigid-body acceleration shall be performed with at least one period of a freely selected excitation frequency that shall be unequal to an eigenfrequency and smaller than the upper limit frequency.

$$A_i(f) = k_i \times a_{oi} \qquad (5\text{-}4)$$

where

(additionally)

a_{0i} : rigid-body acceleration (zero-period acceleration) in the direction i

(3) If time histories of the excitation for the place of installation are available, the excitation may be calculated by Equation (5-5).

$$A_i(f) = k_i \times r_{eff} \times a_{oi} \qquad (5\text{-}5)$$

with

$$r_{eff} = \frac{a_{eff}(\text{time history excitation})}{a_{eff}(\text{single frequency excitation})} \leq 1 \qquad (5\text{-}6)$$

Nomenclature

r_{eff} : ratio of the effective values occurring in a time-history excitation and the effective values occurring in a harmonic excitation.

The respective effective value, a_{eff}, shall be determined by Equation (5-7).

$$a_{eff} = \sqrt{\frac{1}{T} \times \int_{t_0}^{t_0+T} a^2(t)dt} \qquad (5\text{-}7)$$

Nomenclature:

a(t) : time-dependent acceleration response function

T : period length

t_0 : starting time

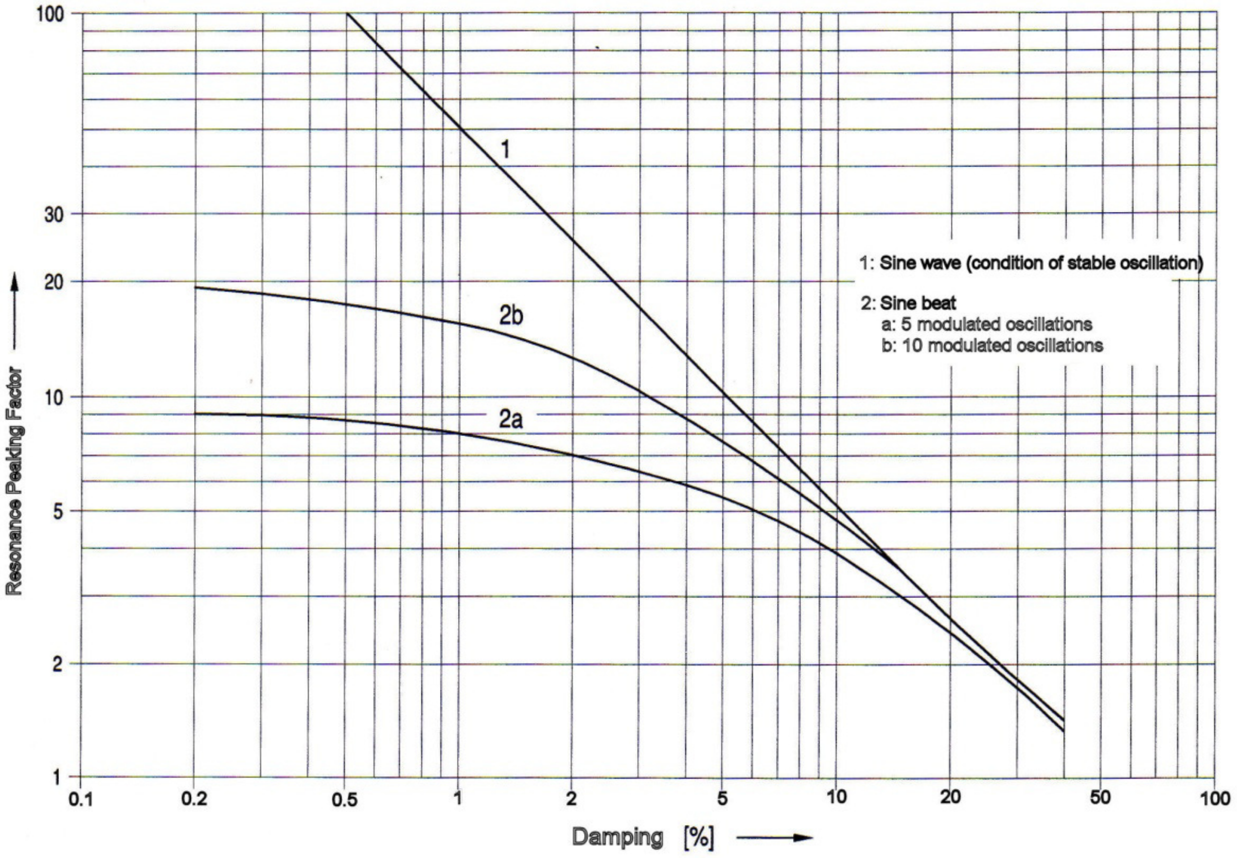

Figure 5-1: Resonance amplification factors for a sine wave excitation and for a sine beat excitation at constant frequency

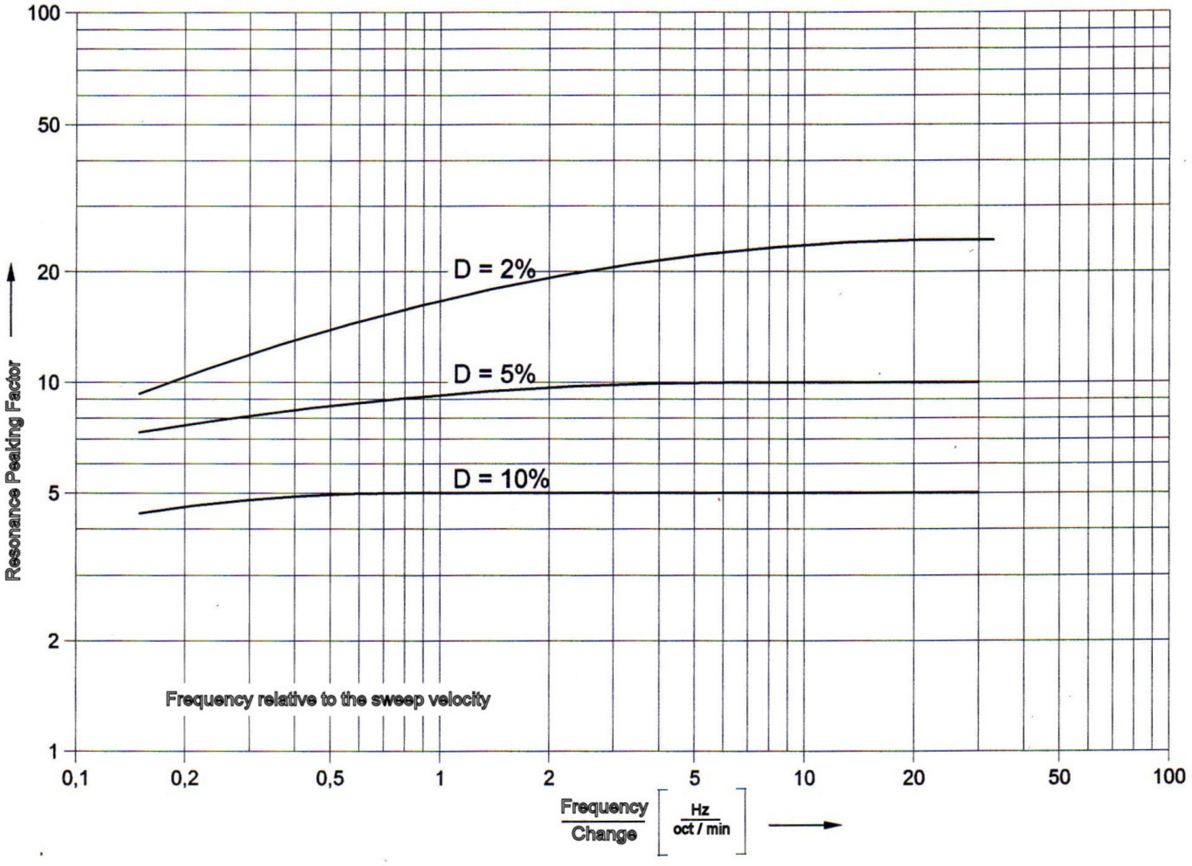

Figure 5-2: Resonance amplification factors for sine sweep excitation

5.5.2.3 Single-frequency excitation in case of known eigenfrequencies of the test object

(1) If the eigenfrequencies of the test object are known and lie within the test frequency range, it is sufficient to perform the test at these eigenfrequencies. In this case, the respective test response spectrum at these locations shall reach or exceed the response spectrum.

(2) In the case of test objects with a rigid-body behavior, it is sufficient to perform the test with a static excitation with the rigid-body acceleration. In case of a dynamic excitation, the rigid-body acceleration may be calculated by Equation (5-4). The excitation may be performed with a freely selected frequency that is lower than or equal to the upper limit frequency, and it shall be applied for a complete period of the excitation frequency.

(3) Depending on the type of excitation at the place of installation, one of the procedures under para. (1) or para. (2) shall be applied to the determination of the acceleration of the response spectrum, $a_i(f,D)$, in the direction i.

5.5.2.4 Multiple-frequency excitation

(1) In case specified time histories are available for the earthquake excitation, these time histories may be applied as test input. The validity of the test time histories shall be established by comparing their response spectra with the specified time history specified under Section 5.3.2

(2) If more than three specified time histories are available, three representative time histories may be selected as test input signals.

(3) If the test is performed with artificial time histories, with noise signals or with multiple-frequency signals, a complete signal shall be used. In this case, one test run is sufficient. A complete signal is considered to be one that envelops the required response spectrum between the upper and lower frequency limits as specified under Section 5.3.2.

(4) The artificial time histories shall be generated on the basis of the response spectra at the place of installation of the test object as specified under Section 5.3.2.

(5) If the test acceleration does not achieve the value of the rigid-body acceleration, an acceleration equal to the rigid-body acceleration shall be applied in an additional test step. This acceleration may be applied statically or dynamically and, independent of the eigenfrequencies, at any frequency less than or equal to the upper frequency limit.

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(5) If the test acceleration does not achieve the value of the rigid-body acceleration, an acceleration equal to the rigid-body acceleration shall be applied in an additional test step. This acceleration may be applied statically or dynamically and, independent of the eigenfrequencies, at any frequency less than or equal to the upper frequency limit.

5.5.2.5 Simultaneity of excitation directions

(1) If the excitation at the place of installation is dominantly two-axial (one horizontal direction, a_h, and the vertical direction, a_v), the test excitation $a_i(f,D)$ and a_{oi} shall be determined as follows:

a) One-axis test excitation

$$a_i(f,D) = \sqrt{a_h^2(f,D) + a_v^2(f,D)} \quad (5\text{-}8)$$

$$a_{oi} = \sqrt{a_{o,h}^2 + a_{o,v}^2} \quad (5\text{-}9)$$

b) Two-axis test excitation or one-axis test excitation, provided, the requirements according to para. (2) item b) of Section 5.3.3 (decoupled axes) are met:

$$a_i(f,D) = a_{h,v}(f,D) \quad (5\text{-}10)$$

$$a_{oi} = a_{oh,v} \quad (5\text{-}11)$$

Nomenclature:

$a_i(f,D)$: spectral value of acceleration in direction i

a_{0i} : rigid-body acceleration (zero period acceleration) in direction i

a_h : horizontal acceleration

a_v : vertical acceleration

(2) If the excitation at the place of installation is three-axial, the test excitation $a_i(f,D)$ and a_{oi} shall be determined as follows:

a) One-axis test excitation:

$$a_i(f,D) = \sqrt{a_x^2(f,D) + a_y^2(f,D) + a_z^2(f,D)} \quad (5\text{-}12)$$

$$a_{oi} = \sqrt{a_{ox}^2 + a_{oy}^2 + a_{oz}^2} \quad (5\text{-}13)$$

b) Two-axis test excitation (vertical and horizontal):

vertical:

$$a_i(f,D) = a_z(f,D) \quad (5\text{-}14)$$

$$a_{oi} = a_{oz} \quad (5\text{-}15)$$

horizontal:

$$a_i(f,D) = \sqrt{a_x^2(f,D) + a_y^2(f,D)} \quad (5\text{-}16)$$

$$a_{oi} = \sqrt{a_{ox}^2 + a_{oy}^2} \quad (5\text{-}17)$$

c) Three-axis test excitation or one- or two-axis test excitation, provided, the requirements according to para. (2) item b) of Section 5.3.3 (decoupled axes) are met:

$$a_i(f,D) = a_{x,y,z}(f,D) \quad (5\text{-}18)$$

$$a_{oi} = a_{ox,y,z} \quad (5\text{-}19)$$

Nomenclature:

cf. para. (1) above

5.5.3 Center-of-gravity excitation

(1) The excitation at the center of gravity (e.g., in the installed condition in the plant) may only be applied in the case of components with a homogeneous distribution of mass.

(2) It shall be ensured that the required substitute accelerations, a_{Ei}, according to Equation (4-9) are applied,

(3) With regard to the test excitation requirements (e.g., test frequencies or test frequency range), the same requirements apply as those specified for the base excitation (cf. Section 5.5.2).

5.6 Verification of Limit Conditions

(1) The experiment-based stress analysis shall verify that the test objects fulfil their safety-related tasks as specified under Section 3.1. In this context, the stresses specified under Section 5.5 shall be determined.

(2) For the verification of permissibility of the stresses, the test excitation methods specified under Section 5.3.6 may be applied, with the following restrictions:

a) With respect to functional capability, the method specified in para. (1), item a) of Section 5.3.6 may only be applied in the case of a deformation-related failure.

b) With respect to functional capability under load, the method specified in para. (1), item b) of Section 5.3.6 may only be applied if the free vibration decay time is longer than the length of the required interval for a safety-related functioning of the test object. In this context, the amplitude decrease shall also be taken into consideration.

(3) The following methods, among others, are permissible for the verification of safety against failure:

a) To verify the load-carrying capacity and the integrity, the proof that the limit conditions specified under Section 4.5 are not exceeded may be performed by stress or strain measurements on significant force-transmitting parts of the test objects.

b) To verify the functional capability, checks may be performed regarding possibly occurring deformations to ensure that no impermissible condition occurs under load.

c) If no stresses or deformations are found, it is permissible to increase the test stress by a safety factor, γ_F. The safety factor, γ_F, shall be calculated as specified by Equation (5-20):

$$\gamma_F = \gamma_{F1} \times \gamma_{F2} \qquad (5\text{-}20)$$

Nomenclature:

γ_{F1} *: safety factor against failure, γ_{F1} = 1.1*

γ_{F2} *: safety factor for the number of test objects between 3 and 1 (transfer factor, cf. Equation (5-21))*

$$1.0 \le \gamma_{F2} \le 1.4 \qquad (5\text{-}21)$$

In well substantiated cases the safety factor γ_{F2} may be reduced. If it can be proven with respect to the verification objective that the most unfavorable test object has been chosen, a safety factor γ_{F2} = 1.0 may be used.

(4) If a verification of safety against failure is possible with the safety factor γ_F specified in para. (3), the verification objective is considered as having been achieved, provided,

a) a limit stress test leads to at least a safety factor γ_F, or

b) a test is carried out with stresses increased by the safety factor γ_F and the verification objective is achieved, or

c) a test with the safety factor γ_F = 1.0 verifies a safety margin for the stresses or deformations, or

d) an extrapolation of a test stress condition lower than the specified earthquake stress condition verifies compliance with the safety against failure as specified under para. (3).

(5) Provided, the verification of load-carrying capacity, integrity or functional capability is not required to comply with certain mechanical stress or strain limits, then the completed test is considered as proof of permissibility.

5.7 Combination of Several Verification Steps.

When combining several verification steps in one test step, the requirements for the contained partial steps need to be considered only to the extent as necessary for the respective verification objectives. Only the respective test objective needs to be verified.

5.8 Documentation

The documentation shall normally include the following information:

a) Regarding the test object:
   - identification marking of the test object,
   - identification of the test object (e.g., type, manufacturer, technical drawing),
   - data sheet (e.g., information on materials, certifications),
   - verification objective.

b) Regarding the layout of the test:
   - description of the equipment for testing, measuring and data collection,
   - test conditions,
   - diagram of measuring points.

c) Regarding the implementation of the test:
   - date of implementation of the test,
   - test laboratory, tester,
   - type of excitation signal,
   - excitation amplitude,
   - frequency range,
   - direction of excitation,
   - specific observations.

6 Verification by Analogy

(1) A verification by analogy shall be based on the following reference results:

a) the results from analytical or experimental verifications as specified under Sections 4 or 5 that were performed on similar, type-identical components,

b) the quantitatively documented results for the respective component with regard to its behavior under other actions, provided, these results are suited to make comparisons.

(2) The available reference results shall be evaluated with regard to transferability of the actions and resistances, and it shall be quantitatively substantiated that this procedure verifies that the respective component can fulfill its safety-related task.

(3) Static system characteristics (global or local stiffness) and parameters (material properties) may be used as reference results, provided, the mechanical design and materials are qualitatively similar. This also applies to a non-linear behavior which must be comparable at the respective stress levels.

(4) The dynamic system characteristics (e.g., eigenfrequencies, natural vibration modes) may be used as reference if the static system characteristics are comparable and any changes with respect to mass distribution are evaluated.

(5) Higher values for the damping ratios than the ones specified under Section 4 may be applied, provided, they are well substantiated for the specific case of application..

(6) If, in limited frequency ranges, the reference excitation is smaller than the required excitation, it shall be verified that this is either negligible for the specific component or that this is covered by the higher excitation level when verifying the limit conditions.

7 Verification by Plausibility Considerations

(1) A verification by plausibility considerations shall be based on factual experience as follows:

a) Experience regarding the behavior of similar, type-identical components in nuclear or non-nuclear facilities during earthquakes that have actually occurred.

b) Experience from earthquake verifications for similar, type-identical components that enable an evaluation of the design planning or mechanical design of other components with regard to earthquake safety.

(2) The factual experience shall be evaluated with regard to transferability of the actions and resistances. On this basis it shall be substantiated in writing that it is plausible that the respective component will be able to fulfill its safety-related task.

(3) To gain factual experience as specified under para. (1), item a), and for evaluating the mechanical design as specified in para. (1), item b), it is necessary

- to peruse the design documents, and
- to perform walk-through inspections of the plant.

The observations made in this context shall be documented in writing.

(4) Walk-through inspections shall normally be performed according to the schematic sequence shown in **Figure 7-1**.

Walk-through inspections shall be performed in the actual power plant. If a CAD model is available, they can also be performed as a virtual walk-through. Prerequisite in the latter context is that the CAD model and all data relevant to the evaluation are current and quality assured.

(5) The evaluation and application of the walk-through inspection results shall be well substantiated. The substantiating criteria shall be based on the requirements that must be met (i.e., load-carrying capacity, integrity, functional capability).

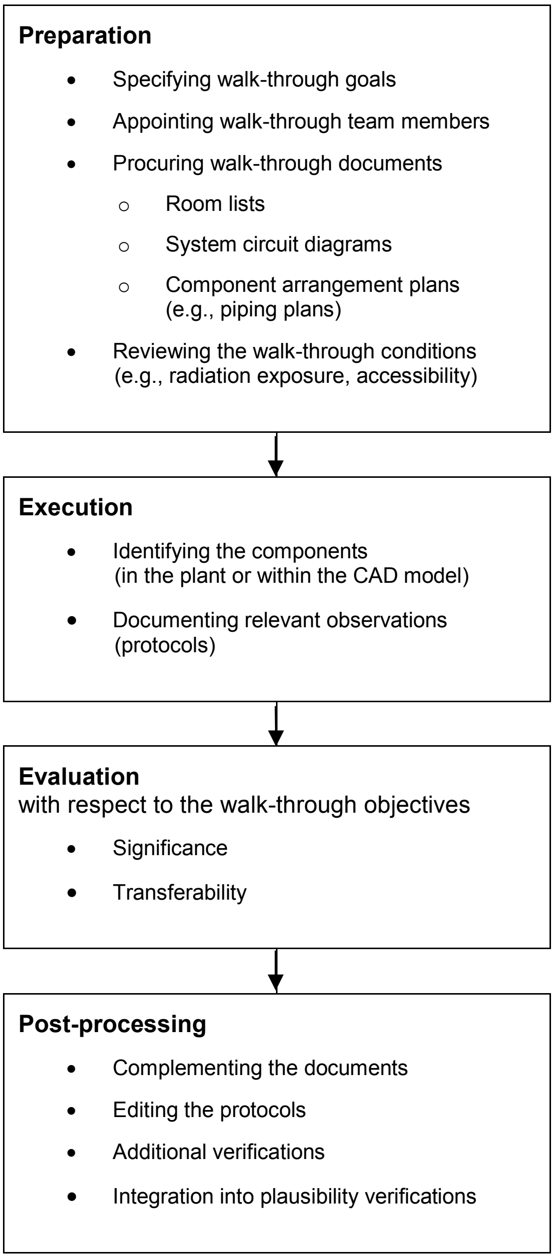

Figure 7-1: Schematic sequence of walk-through inspections

Appendix A

Regulations Referred to in this Safety Standard

(Regulations referred to in this safety standard are valid only in the versions cited below. Regulations which are referred to within these regulations are valid only in the version that was valid when the latter 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 5, Sec. 6 of the Act of February 24, 2012 (BGBl. I, p. 212)
StrlSchV		Ordinance on the protection from damage by ionizing radiation (Radiological Protection Ordinance – StrlSchV) of July 20, 2001 (BGBl. I, p. 1714; 2002 I, p. 1459), most recently changed by Article 5, Sec. 7 of the Act of February 24, 2012 (BGBl. I, p. 212)
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)
KTA 1403	(2010-11)	Ageing-management in nuclear power plants
KTA 2201.1	(2011-11)	Design of nuclear power plants against seismic events; Part 1: Principles
KTA 2201.3	(E 2012-11)	Design of nuclear power plants against seismic events; Part 3: Design of structural components – Draft safety standard
KTA 3201.2	(ÄE 2010-11)	Design of reactor cores of pressurized water and boiling water reactors; Part 2: Neutron-physical requirements for design and operation of the reactor core and adjacent systems – Draft safety standard revision
KTA 3204	(2008-11)	Reactor pressure vessel internals
KTA 3205.1	(2002-06)	Component support structures with non-integral connections Part 1: Component support structures with non-integral connections for components of the reactor coolant pressure boundary of light water reactors
KTA 3205.2	(1990-06)	Component support structures with non-integral connections; Part 2: Component support structures with non-integral connections for pressure and activity-retaining components in systems outside the primary circuit
KTA 3211.1	(2000-06)	Pressure- and activity-retaining components of systems outside the primary circuit Part 1: Materials
KTA 3211.2	(ÄE 2010-11)	Pressure and activity retaining components of systems outside the primary circuit; Part 2: Design and analysis – Draft safety standard revision
KTA-GS-78	(2005-11)	KTA-Status Report, Recommendations regarding the application of KTA safety standards considering current structural engineering standards
DIN EN 1990	(2010-12)	Eurocode: Basis of structural design; German version EN 1990:2002 + A1:2005 + A1:2005/AC:2010
DIN EN 1990/NA	(2010-12)	National Annex - Nationally determined parameters - Eurocode: Basis of structural design
DIN EN 1993-1-1	(2010-12)	Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings; German version EN 1993-1-1:2005 + AC:2009
DIN EN 1993-1-1/NA	(2010-12)	National Annex - Nationally determined parameters - Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings
DIN EN 1998-1	(2010-12)	Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings; German version EN 1998-1:2004 + AC:2009

DIN EN 1998-1/NA	(2011-01)	National Annex - Nationally determined parameters - Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, Seismic actions and rules for buildings
DIN EN 1998-4	(2007-01)	Eurocode 8: Design of structures for earthquake resistance - Part 4: Silos, tanks and pipelines; German version EN 1998-4:2006