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Division VII

Principles governing the Seismic Design of Nuclear Power Plants with regard to the revised German Safety Standard Series KTA 2201

Björn Elsche[1], Fritz-Otto Henkel[2] and Rüdiger Meiswinkel[3]

[1] Civil engineering specialist, E.ON Kernkraft GmbH, Hannover, Germany
[2] Managing Director, Woelfel Beratende Ingenieure GmbH + Co. KG, Hoechberg, Germany
[3] Representing Professor, TU Kaiserslautern, Kaiserslautern, Germany

ABSTRACT

As a part of the German safety standard series KTA 2201 the safety standard KTA 2201.1 deals with the principles governing the seismic design of nuclear power plants. This safety standard defines the demands on determining the design basis earthquake for a nuclear power plant site regarding deterministic hazard analysis (DSHA) as well as probabilistic seismic hazard analysis (PSHA). Furthermore in view of the other parts of the series KTA 2201 fundamental requirements will be established, especially general design requirements for building structures and components which have to be considered in the parts KTA 2201.3 and KTA 2201.4.

INTRODUCTION

Earthquakes belong to that group of design basis accidents that requires preventive plant engineering measures against damage. The basic requirements of these preventive measures are dealt with in safety standard series KTA 2201 entitled "Design of nuclear power plants against seismic events". The series KTA 2201 is comprised of six parts shown in Figure 1.

KTA 2201
Design of Nuclear Power Plants against Seismic Events

KTA 2201.1	Principles
KTA 2201.2	Subsoil
KTA 2201.3	Building structures
KTA 2201.4	Components
KTA 2201.5	Seismic instrumentation
KTA 2201.6	Post-seismic measures

Figure 1. The safety standard series KTA 2201.

Due to further developments in the range of seismic hazard assessments and seismic design a revision of these standard series became necessary which was started in 2005. So in 2011 the revised KTA 2201.1 was published. This part of the series KTA 2201 deals with the principles governing the seismic design of nuclear power plants as a basis for the other parts KTA 2201.2, KTA 2201.3, KTA 2201.4, KTA 2201.5 and KTA 2201.6.

In this revised KTA 2201.1 the chapters "determining the design basis earthquake" and "general requirements regarding verification" occupy a central position. The other chapters like "seismic instrumentation and inspection level" and "post-seismic measures" only comprise fundamental requirements which represent the basis for the parts 5 and 6 of the series KTA 2201.

SEISMIC ACTIONS

Strength of Earthquakes

The effects of earthquakes (tectonic earthquakes), which induce seismic effects, manifest themselves in considerable amounts of energy being released, due to the rock strata shifting. From the hypocenter, shock waves spread out at different speeds and amplitudes. The earthquakes themselves which trigger these waves can be defined and/or quantified either by their magnitude or intensity (see Figure 2).

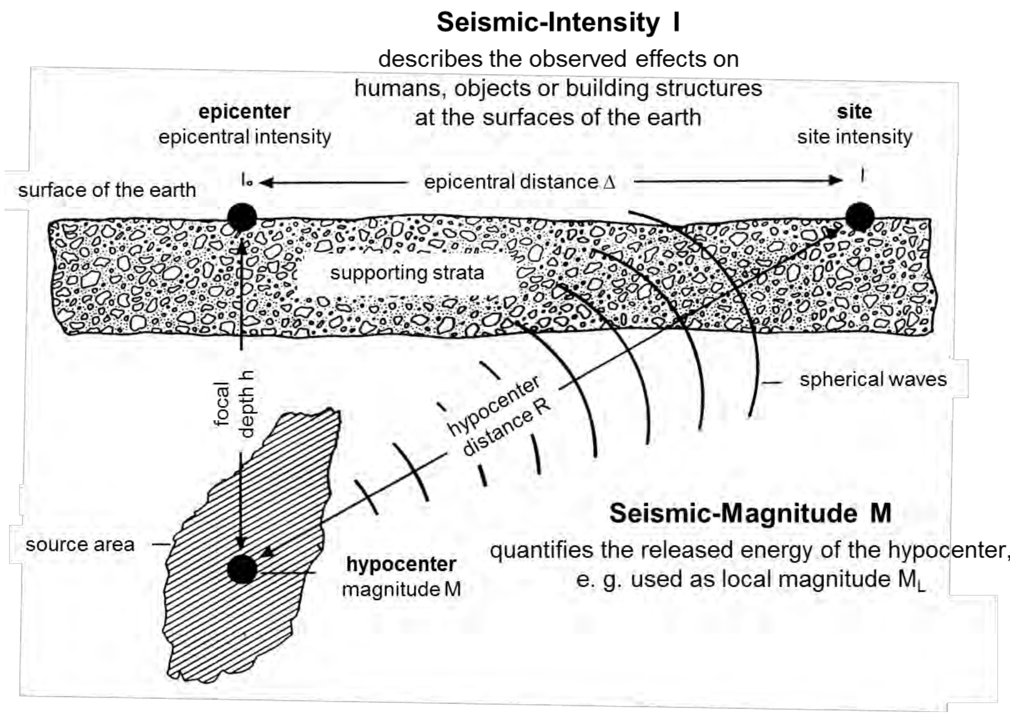


Figure 2. Classification of the strength of earthquakes.

Magnitude, which is normally used as local or close quake magnitude (M_L) , measures the energy released to the hypocenter of the earthquake underground. Regarding the magnitude at a given hypocenter depth the impact of an earthquake at a given location on the surface of the earth (normally a land surface) can be defined as intensities. Intensity is a measure of the impact of seismic waves and dislocations at the surface of the earth on people, objects and building structures. The strength of these effects is classified in qualitative terms based on the effects observed in a limited area. Intensity is divided into 12 degrees, which are defined as macroseismic scales, such as MSK or EMS (see Table 1).

In KTA 2201.1 the intensity will be used as a characteristic size for the design basis earthquake because in opposite to the magnitude intensity represents a robust measure for the expected seismic actions. Moreover the alternative of using intensities is justified by the excellent database for European countries, especially for Germany.

Table 1: European Macroseismic Scale (EMS)

Earthquake - Intensity
(EMS)

EMS is similar to
MSK: Medvedev-Sponheuer-Karink-scale

intensity	definition	obseravtions
I	Not felt	Not felt by anyone.
II	Scarcely felt	Vibration is felt only by individual people at rest in houses, especially on upper floors of buildings.
III	Weak	The vibration is weak and is felt indoors by a few people.
IV	Largely observed	The earthquake is felt indoors by many people, outdoors by few. Windows, doors and dishes rattle.
V	Strong	Many sleeping people awake. Entire sections of all buildings tremple.
VI	Slightly damaging	Slight damage to buildings.
VII	Damaging	Many buildings suffer slight to moderate damage.
VIII	Heavily damaging	Many to most building suffer damage.
IX	Destructive	Many ordinary buildings partially collaps and a few collapse completely.
X	Very destructive	Many buildings collapse. Cracks and landsline can be seen.
XI	Devastating	Most buildings collapse.
XII	Completely devastating	All structures are destroyed. The ground changes.

Design Basis Earthquake

For the determination of the design basis earthquake (DBE) the macro-seismic intensity is the leading parameter. In line with this local intensity (site intensity), with its associated ground movements (accelerations, velocities, displacements), a ground response spectrum must be defined as the basis for the further design of building structures or components. Such a response spectrum, in the form of an acceleration spectrum, represents the maximum acceleration amplitudes of a damped single-degree-of freedom oscillator with various eigenfrequencies and a constant damping ratio in response to a non-stationary excitation.

Based on intensities the design basis earthquake shall be specified by evaluating deterministic seismic hazard assessment (DSHA) as well as probabilistic seismic hazard assessment (PSHA). DSHA and PSHA result in the site specific intensity with the corresponding ground acceleration response spectrum (Figure 3).

For the deterministic determination the design basis earthquake is the earthquake of maximum intensity at a specific site which, according to scientific knowledge, may occur at the site or within a larger radius of the site (up to approx. 200 km from the site). So based on historical earthquake records with the consideration of geologic and tectonic conditions the design basis earthquake shall be determined as follows (see Figure 4):

- If epicenters or areas of maximum intensity of earthquakes are located in the same tectonic unit as the site, these earthquakes shall be assumed to occur in the vicinity of the site.
- If epicenters or areas of maximum intensity of earthquakes are located in another tectonic unit than that of the site, then it shall be assumed that the epicenters or areas of maximum

intensity of these earthquakes are located at a point closest to the site directly on the borderline of their tectonic unit.

The probabilistic approach to specifying the design basis earthquake is based on a probability of exceedance of 10^{-5} per annum (10^{-5}/a) regarding seismic actions which may be specified for the 50 %-fractile value (median values). Uncertainties of the applied data, models and methods have to be considered. Furthermore a deaggregation will be performed to identify the contributions of different magnitude intervals and distance ranges.

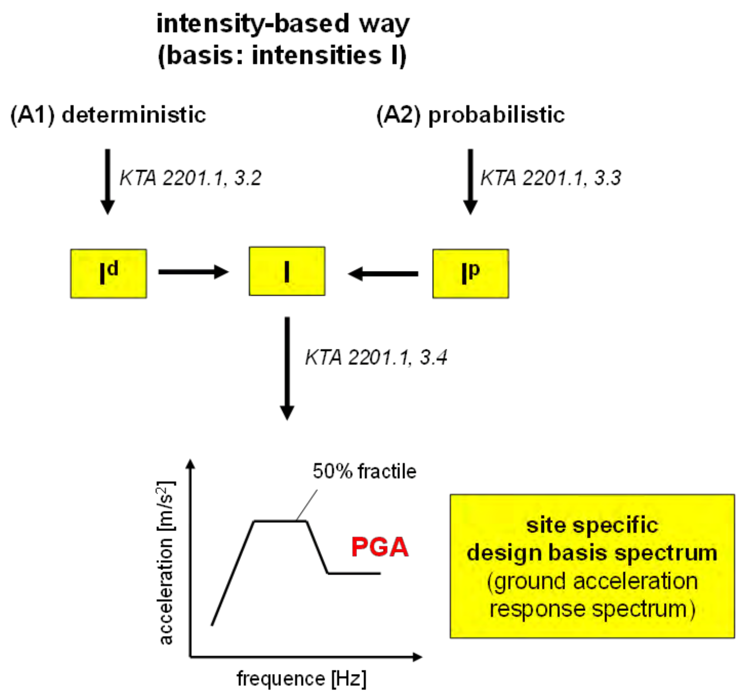


Figure 3. Determining the design basis earthquake according to KTA 2201.1.

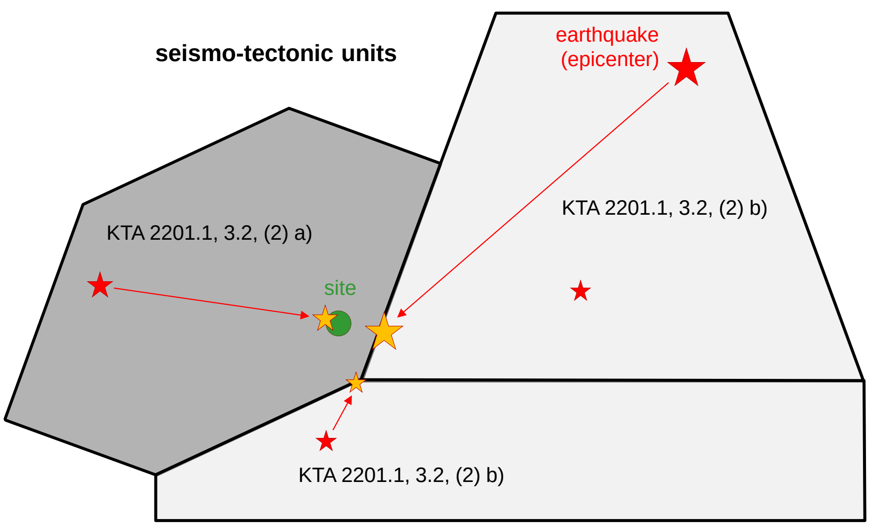
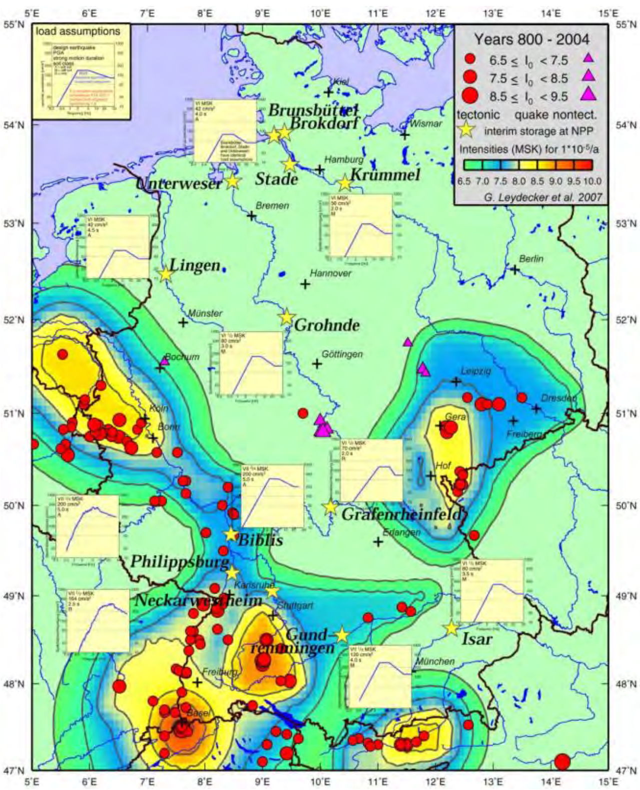


Figure 4: Deterministic analysis (DSHA) according to KTA 2201.1

As a result of the deterministic and the probabilistic determinations the actions of the earthquake can be described by seismo-engineering parameters, in particular, by the ground response spectra with the corresponding rigid-body accelerations (PGA: peak ground acceleration) and the strong-motion duration. Figure 5 shows typical results for the German nuclear power plant sites, determined by Leydecker et al. (2004) for the erection of the German interim storage facilities.



Dec. 2004 G. Leydecker et al.

NPP site	I (DE) [MSK]	PGA [cm/s²]	T_{70} [s]	SC
Brunsbüttel Brokdorf Stade Unterweser	VI	42	4.0	A
Krümmel	VI	56	2.0	M
Lingen	VI	42	4.5	A
Grohnde	VI ½	80	3.0	M
Grafenrheinfeld	VI ½	70	2.0	R
Biblis	VII ¾	**200**	5.0	A
Philippsburg	VII ¾	**200**	5.0	A
Neckarwestheim	VII ½	**164**	2.5	R
Isar	VI ½	80	3.5	M
Gundremmingen	VII ¼	**120**	4.0	M

I (DE): intensity MSK of the Design Earthquake,
PGA: peak ground acceleration (horizontal component),
T_{70}: strong-motion duration (70% of acceleration energy is released; between 5% and 75% percentile),
SC: soil class (A: loose sediments, M: firm sediments, R:rock)

Figure 5. Seismic design data of German nuclear power plant sites, see Leydecker(2004).

The ground response spectra will be specified as free field response spectra for the site-specific uniform reference horizon of the subsoil (usually the ground level). This ground response spectra relates to the two horizontal components assumed to be equal. If no seismological data are available for the vertical component, it shall be assumed to be 2/3 of the horizontal component.

Minimum design requirement

As a benchmark for the minimum design, essentially intensity I or peak ground acceleration PGA can be considered. Commonly a so-called magnitude based way will be applied to determine the design basis earthquake. Using such an approach magnitudes directly result in PGA values of standardized response spectra (uniform hazard spectra). So with the regard to the minimum design the IAEA safety guide SSG-9 recommends that, generically, a horizontal free field standardized response spectrum anchored to PGA value of 0.1g should be considered. SSG-9 is drafted to be applicable in any region, also where information on regional seismicity is limited. So deliberately deviations from min PGA = 0.1 g are possible if for example more detailed information about seismicity is available.

Because the target of minimum design is a basic protection against seismic impacts, a parameter should be chosen for this, which is a good measure for the effects to be expected due to an earthquake. This requirement does not fulfill the ground acceleration according to current knowledge. The only single parameter, which satisfies this requirement, is the intensity. For this reason and due to the fact that the knowledge of earthquake activity and shock effects (as a data base) in Germany primarily relates to the intensity, the working group of KTA 2201.1 has decided to set a minimum intensity of VI.

GENERAL REQUIREMENTS REGARDING VERIFICATION

Design Requirements

In view of the verifications in KTA 2201.1 fundamental requirements for the parts 3 and 4 of the series KTA 2201 are given. So KTA 2201.1 defines three classes of building structures and components:

- Class I: Components and building structures that are required to fulfill the protective goals (controlling reactivity, cooling fuel assemblies, confining radioactive substances and limiting radiation exposure), including limiting radiation exposure.
- Class IIa: Components and building structures that do not belong to Class I and which, due to their own damage and the sequential effects possibly caused by an earthquake, could detrimentally affect the safety related functions of Class I components and building structures.
- Class IIb: All other components and building structures

Depending on these classes different verification demands are formulated. So Class I components and building structures have to be verified, with regard to their load bearing capacity, integrity and functional capability, in such a way that they will be able to fulfill their respective safety related tasks for seismic events. For Class IIa components and building structures verifications shall demonstrate that the safety related functions of Class I components and building structures will not be affected detrimentally. For Class IIb components and building structures no seismic safety according to KTA 2201.1 is required, but possibly conventional seismic design requirements have to be considered.

With regard to the verification of the earthquake the design basis earthquake and its possible sequential consequences have to be taken into account. Possible sequential consequences could include the failure of high energy containers, not designed to withstand earthquakes, such as feed water tanks in the turbine hall of a PWR (pressurized water reactor). Combined effects of earthquakes and other extraordinary actions are not generically taken into account as they are extremely rare.

Verification Requirements

According to KTA 2201.1 the earthquake safety of components and building structures can be verified analytically, or experimentally, or by analogy (similarity) or plausibility (experience based) considerations. So in KTA 2201.4 all these four alternatives are provided (see Henkel et al. (2013)). But generally analytical verification procedures will be applied which require adequate structural models and analytical methods.

For structural analysis purposes, earthquake effects are to be set as the ground response spectra for the design basis earthquake or compatible recorded acceleration time histories in each case, recording the simultaneous excitation in both horizontal and the vertical direction. The subsequent superposition of parallel loading parameters can be taken either as the root of the sum of the squares or the superposition rules as in DIN EN 1998 (2010).

Structural modeling is subject to particular requirements, due to the dynamic effects and to the influence of the subsoil at the site in particular. In principle, the structural models to be used for the building structure, including the subsoil for the plant components with their support structures are those which are able to describe the structural behavior for the decisive frequency range excited by earthquakes.

Depending on the purpose of verification involved, it must be decided whether structural modeling requires a spatial beam model or even a spatial shell model, allowing for possible decoupling between the building structure as a whole and part structures or decoupling criteria between the building structure as a whole and components.

With regard to the dynamic behavior of the structure, the influence of the interaction between building structure and subsoil (soil–structure interaction) must be taken into account, varying the soil characteristics in a reasonable range represented by lower, medium and upper soil stiffness. The envelope of the analytical results with different soil stiffnesses must then be determined.

The structural analyses can be carried out using the usual dynamic analytic methods like the response spectrum methods, linear and non-linear time history methods or frequency response methods. Also the quasi-static method as a simplified method can be applied.

The resulting method to be used in conducting structural analyses and verifications of building structures and components with a view to using the different parts of KTA 2201 is shown in Figure 6. In the parts KTA 2201.3 and KTA 2201.4 detailed information is given for the verification procedure including the characteristics of the dynamic analytic methods (see Henkel et al. (2013)).

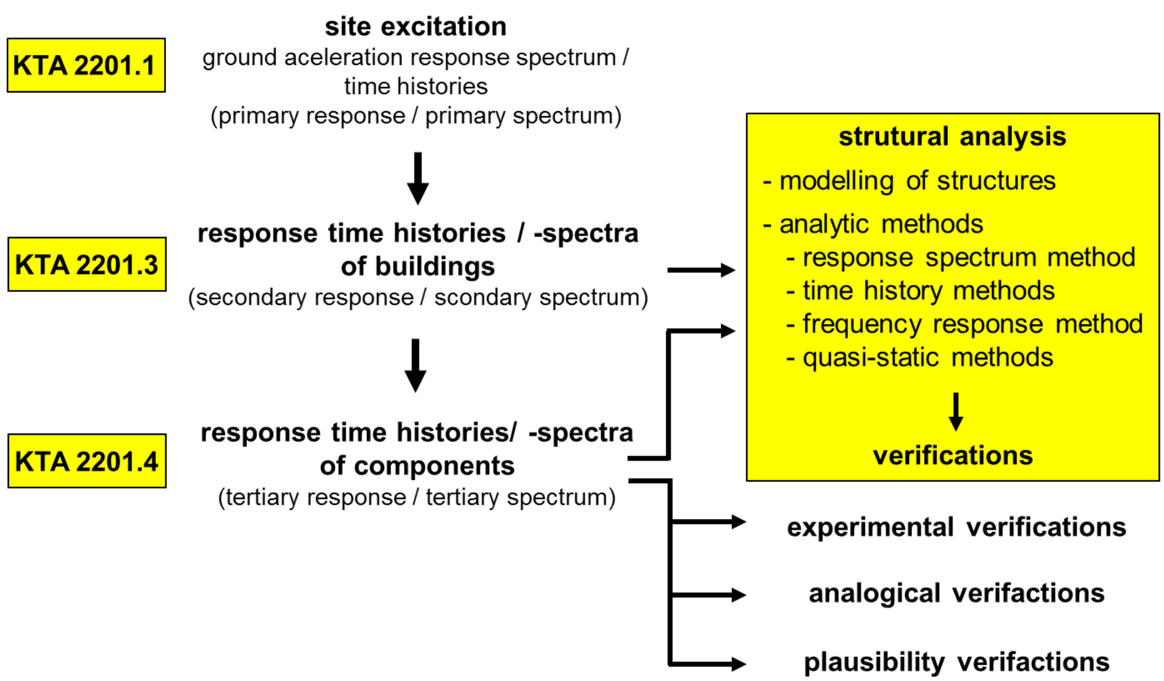


Figure 6. Earthquake analysis and verifications according to KTA 2201.1.

SEISMIC INSTRUMENTATION AND POST SEISMIC MEASURES

KTA 2201.1 provides fundamental requirements for the seismic instrumentation and post seismic measures. Thus a seismic instrumentation must be installed in each nuclear power plant regarding the inspection level. The inspection level of the plant corresponds to 0.4 times the response spectrum of the design basis earthquake. So the seismic instrumentation shall display the exceedance of any acceleration limit values related to the inspection level of the plant and register the earthquake time histories for a further comparison with design values.

After registration of an earthquake a plant inspection shall be carried out. Especially after exceedance of the acceleration of the limit values of the inspection level detailed investigations will be necessary. As a possible consequence the plant shall be shut down.

More detailed information about the seismic instrumentation and post seismic measures is provided in KTA 2201.5 and KTA 2201.6.

CONCLUSION

The German safety standard series KTA 2201 entitled "Design of nuclear power plants against seismic events" comprises six parts which have been revised since 2005 with regard to the today's state of science and technology. The revision of KTA 2201.1 – as the fundamental part of the standard series KTA 2201 – was published at end of 2011.

This safety standard KTA 2201.1 deals with the demands on determining the design basis earthquake for a nuclear power plant site. The seismic actions at the location of the site are characterized, essentially, by the intensity and ground motions. So the macroseimic intensity as a robust measure for the expected seismic actions represents the leading parameter. Furthermore for intensities an excellent database for European countries, especially for Germany, is available.

Based on intensities deterministic hazard analysis (DSHA) and probabilistic seismic hazard analysis (PSHA) can be carried out and result in the ground acceleration response spectrum of the design basis earthquake. Such a site specific design spectrum and the fundamental design requirements of KTA 2201.1 can be applied for the design of building constructions and components in order to meet the protective goals of controlling reactivity, cooling fuel assemblies, confining radioactive substances and limiting radiation exposure.

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