KTA 2201 — SEISMIC DESIGN STANDARDS IN THE FEDERAL REPUBLIC OF GERMANY

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Summary

To ensure a uniform and high level of safety with respect to the seismic event for all nulear power plants in the Federal Republic of Germany, the Nuclear Safety Standards Commission (KTA) initiated work on the nuclear safety standard KTA 2201, Design of Nuclear Power Plants against Seismic Events" in six separate parts.

This paper will restrict itself, as far as possible, to a treatment of those aspects of Part 2 "Characteristics of Seismic Events" and Part 3 "Design of Structural Components", where substantial progress has been made in recent months.

Part 2 deals in detail with the seismic and soil input parameters, and lays down the requirements for defining the Design and Safety Earthquakes at a site. The basic paramter used in defining the seismic event is the macroseismic intensity. The standard will prescribe a method to obtain a reasonable relationship between the Design and Safety Earthquakes: the Design Earthquake is first determined, and the Safety Earthquake is then derived, and this is usually about one Intensity larger. The maximum horizontal acceleration for the site is then arrived at using a fixed intensity-acceleration correlation. For the standard design response spectrum (the response spectrum method is one of the methods suggested), a modified version of the USNRC Spectrum is used.

Part 3 sets out the requirements for the detailed design of the structural components. These include the analytical methods, the damping factors without consideration of stress levels, and the permissible stresses for concrete, steel and masonry.

1. Introduction

In comparison with the sites of a large majority of the nuclear power plants in the world, the nuclear power plant sites in the Federal Republic of Germany are situated in areas of relatively low seismic activity. It was quite apparent that a direct application of the standards developed for other countries would not suffice because of the special seismic condition in the Federal Republic of Germany. So, in order to ensure a uniform and high level of safety against the earthquake event for all nuclear power plants in the Federel Republic of Germany, the Nuclear Safety Standards Commission (KTA) initiated work on the nuclear safety standard KTA 2201, Design of Nuclear Power Plants against Seismic Events. This safety standard, which is developed based on the experience gained from the licensing procedures, consists of the following six parts: 1. Basic Principles, 2. Characteristics of Seismic Events, 3. Design of Structural Components, 4. Design of Electrical and Mechanical Components, 5. Seismic Instrumentation, 6. Measures Subsequent to Earthquakes.

Parts 1 and 5 have been completed [1,2] and the results of work on Part 5 were presented at the 4th SMiRT Conference. This paper will try and restrict itself to a treatment of Parts 2 and 3, the preliminary reports on which have already been issued [3, 4, 5]. As the drafts on these parts are still under development, only some special aspects will be discussed in the following.

2. KTA 2201.2 - Characteristics of Seismic Events

2.1 Scope and Pupose

This part of the safety standard is primarily meant for stationary nuclear power plants, but it is also expected to be used for other nuclear facilities as appropriate. Its purpose is to set out the requirements for the determination and the employment of the seismological and soil input parameters which can then be used in Parts 3 and 4 for the design of the structures, systems and components of the nuclear facility. These parameters include the maximum acceleration, and the shear modulus, the damping and the poissons ratio for the soil.

2.2 Seismological Parameters

The ground motion values for the prospective site, i.e., the maximum accelerations for the Design and Safety Earthquakes are determined on the basis of an Intensity method. To obtain the Intensities for the site, a seismotectonic investigation of the area needs to be carried out. This is done by identifying all seismotectonic provinces within a radius of about 200 km around the site and determining past earthquake activities associated with them. A map of the region is used to plot the epicenters of all historical earthquakes

a) with a Magnitude $\geq$ 3 or an Intensity $\geq$ 5 which have occurred within a radius of 50 km from the site

b) with a Magnitude $\geq$ 4 or an Intensity $\geq$ 6 which have occurred in the annular ring between 50 km and 200 km radius from the site.

On the basis of this plot, the maximum earthquake intensity for the Design Earthquake at the site can now be determined: if the historic earthquakes are located in the same seimotectonic province as the site, then these earthquakes are assumed to occur either in the vicinity of the site or at the site itself depending on whether this can be associated with a seismically active structure or not. If, however, the historic earthquakes are located in a seismotectonic province other than that of the site, then, for the calculation, this earthquake is assumed to occur at that point in the boundary of this province which is closest to the site. The Intensities referred to are based on the Medvedev-Karnik-Sponheuer Scale (MSK 1964). The Safety Earthquake is then determined considering the uncertainties in the determination of the Intensity for the site and the probability of occurrence; this is usually one Intensity larger.

Once the Intensity values have been arrived at, the ground motion values, i.e., the maximum acceleration values are determined from Intensity-acceleration relationships. An appropriate relationship will be given in the draft standard and this will correspond with the range of accelerations for each Intensity value as given in the safety standard KTA 2201.1 (Tab.I). This relationship will also be consistent with the probability values used so far: 10^{-2} to 10^{-4} for the Design Earthquake and 10^{-4} to 10^{-6} for the Safety Earthquake. The emphasis, however, is on the so called deterministic (i.e. seismotectonic) rather then on the so called probabilistic approach; the probability values are only used in trying to further improve the design values.

The acceleration values determined in this manner are used as the scaling values for the standard response spectrum. (The response spectrum method is one of the methods suggested).

The standard response spectrum proposed for the Federal Republic of Germany is a modified version of the USNRC Regulatory Guide 1.60 spectrum. The modification is in the lower frequency ranges to account for the lower magnitudes of the earthquakes in the Federal Republic of Germany as compared with the United States. The unlimited use of the standard response sepctrum method is restricted to the "normal" cases. In the cases where

- geological anomalies like local soft soil conditions, or
- seismological anomalies, especially proximity of the site to the epicenter of a tectonic or non-tectonic earthquake

exist, the use of this spectrum needs to be carefully considered. In some cases, special spectra may need to be developed to suit the case.

The alternative method suggested is the Time History Method. In this case, the frequency content and the duration needs to be specified based on the seismotectonic and geological conditions of the site. Since, however, actual time histories are not available for the sites in the Federal Republic of Germany, artificial time histories need to be generated. One or several time histories can be used for this and the requirement is that these envelope the standard response spectrum either as a whole or together in parts.

2.3 Soil Parameters

The parameters to be determined are the shear modulus, the damping and the Poissons ratio, which are used in the analyses to take the soilstructure interaction into account. They are determined for each site as a function of the soil depth and of the shear strain. They are usually required to be supplied in terms of a range of values rather than an absolute value.

The damping is determined on the basis of laboratory methods alone as, for example, dynamic shear tests, dynamic torsion tests and resonance tests. The Poisson's ratio is determined in-situ from the propagation velocity of the longitudinal and transverse waves, and, in the laboratory, on the basis of deformations resulting from dynamic loads.

It must also be demonstrated for the sites that no loss of shear strength can take place as a result of the dynamic influences. A special method for determining the soil liquefaction potential will be dealt with in the final paper.

3. KTA 2201.3 - Design of Structural Components

3.1 Scope and Purpose

This part of the safety standard is also meant primarily for stationary nuclear power plants, but is also expected to be used for other nuclear plants in order to ensure their stability. The structural components treated in this part of the standard are the reinforced concrete, pre-stressed concrete, steel and masonry components.

3.2 Dynamic Analysis

Linear elastic behaviour of the structures is usually assumed in the analysis. The dynamic analyses is carried out using either the Response Spectrum or Time History Methods. The mathematical model of the structure must ensure that the frequency range of interest can be considered in the design and also that the soil-structure interaction can be suitably considered. Viscous velocity damping may be considered in the analyses. The permissible values for the structures where ductile behaviour is ensured can be seen from Table II.

According to Part 1 of the safety standard, it must be demonstrated that other structures do not endanger Class I structures through their failure. The method applicable for such a demonstration is still under discussion and results will be presented in the final paper.

3.3 Design of Reinforced Concrete

3.3.1 General Remarks

All structures and structural components which are important to safety are required to be designed such that they can withstand the most severe earthquake expected at the site without loss of function. In practice, these structures and structural components are designed such that they can safely withstand the Design Earthquake several times without loss of stability and without the elastic limits being exceeded. In the case of the Safety Earthquake, these limits may be exceeded and there may be permanent deformation, but the important criterion is that the safety related structural components retain their safety functions. Basically, the normal building codes apply for the design, but larger permissible stresses or lower factors of safety are allowed by the earthquake standard. The case of reinforced concrete is used to illustrate this.

3.3.2 Permissible Stresses and Factors of Safety

Basically, the design is carried out in accordance with the Building Code DIN 1045 [6] which applies to structures under static loading. But, there are important deviations e.g.:

Design Earthquake:

a) Bending, Bending with axial force and axial force alone: The factors of safety have been reduced to
   ν = 1.4 for tensile failure
   ν = 1.7 for compressive failure

b) Shear force: The permissible shear stresses for beams and slabs have been correspondingly increased (Table III)

c) Limitation of crack width: No proofs are necessary

Safety Earthquake:

a) Bending, Bending with axial force and axial force alone: Table IV shows the permissible values of β_R which is based on 0.9 β_{WN}. The safety factor can be assumed to be ν = 1.0. For bending with a small axial force, an additional demonstration must be carried out.

b) Safety against buckling: For slenderness ratios $\lambda > 70$, the deformations must be considered in the dynamic design.

c) Shear forces: The permissible shear stresses for beams and slabs are shown in Table V.
   The permissible values for the principal compressive stresses are shown in Table VI.

3.3.3 Reinforcement Limits

In case the damping values mentioned in 3.2 are chosen, a ductile behaviour of the structures and components must be ensured. This is done by setting limits on the amount of reinforcement. The minimum limit is governed by the yield strength of steel (Table VII).

$$\min \mu_o = \frac{\min A_s}{b \cdot d} = 0.2 \, \frac{\beta_{bz}}{\beta_s} \cdot k_d \cdot k_n \qquad \text{eq. (1)}$$

$$\text{with } k_d = 1.0 \text{ for } d \leq 0.50 \text{ m} \quad \text{or}$$

$$k_d = 0.8 \text{ for } d \geq 4.50 \text{ m}$$

$$k_n = 1 + \frac{n}{\frac{\beta_{bz}\, k_d}{\beta_R} - n} \leq 4$$

$$n = \frac{N}{b\, d\, \beta_R}$$

The maximum limit is governed by the assumption of plastic deformation due to bending.

$$\max \mu_o = \mu_o' + \frac{\beta_R}{\beta_s} (0.23 + n) \leq 0.5 \frac{\beta_R}{\beta_s} \qquad \text{eq. (2)}$$

$$\text{with } n = \frac{N}{\beta_R \cdot b \cdot d}$$

3.4 Pre-stressed Concrete, Steel and Masonry Structural Components

In each of these cases, the design is governed by the relevant building code for the design and construction of normal strutures. However, just as for reinforced concrete, there are important deviations considering the special aspects of earthquake loading. These deviations manifest themselves again in the way of higher permissible stresses or lower factors of safety. This enables the materials to be used to the fullest extent possible when considering the relatively short duration loads caused by earthquakes. This is especially true for the safety earthquake where the safety functions are required to remain intact but the stresses can extend well above the elastic limits.

References

[1] KTA 2201.1, "Auslegung von Kernkraftwerken gegen seismische Einwirkungen, Teil 1: Grundsätze", Sicherheitstechnische Regel des KTA, Fassung 6/75

[2] KTA 2201.5, "Auslegung von Kernkraftwerken gegen seismische Einwirkungen, Teil 5: Seismische Instrumentierung", Sicherheitstechnische Regel des KTA, Fassung 6/77

[3] Vorbericht an den KTA, "Auslegung von Kernkraftwerken gegen seismische Einwirkungen, Teil 2.1: Kenndaten seismischer Erregung; Seismologische Kenndaten", September 1977 (not published)

[4] Vorbericht an den KTA, "Auslegung von Kernkraftwerken gegen seismische Einwirkungen, Teil 2.2: Kenndaten seismischer Erregung; Baugrunddynamische Kenndaten", August 1976 (not published)

[5] Vorbericht an den KTA, "Auslegung von Kernkraftwerken gegen seismische Einwirkungen, Teil 3: Auslegung der baulichen Anlagen", Januar 1976 (not published)

[6] DIN 1045, Beton und Stahlbeton, Bemessung und Ausführung (Dez. 1978)

Table I: Range of acceleration values [m/sec²] corresponding to each value of Intensity I_{MSK}

Intensity	6	7	8	9
Acceleration	0.3-0.9	0.7-2.2	1.5-3.0	3.0-7.0

Table II: Damping Values expressed as % of Critical Damping

	Reinforced Concrete	Pre-stressed Concrete	Steel, welded	Steel, bolted	Masonry
Design Earthquake	4	2	2	4	4
Safety Earthquake	7	5	4	7	7

Table III: Permissible shear shesses in MN/m² for slabs and beams for loading combinations with the Design Earthquake

	Concrete Strength Classes			
Shear ranges	B 25	B 35	B 45	B 55
1 τ_{01}	0,9	1,2	1,3	1,5
2 τ_{02}	2,2	2,9	3,2	3,6
3 τ_{03}	3,6	4,8	5,4	6,0

Table IV: Compressive strength $\beta_R = 0.9\ \beta_{WN}$ in MN/m² for loading combinations with the Safety Earthquake

Concrete Strength Classes	B 25	B 35	B 45	B 55
Compressive Strength β_R	22,5	31,5	40,5	49,5

Table V: Permissible shear Stresses in MN/m² for slabs and beams for loading combinations with the Safety Earthquake

	Concrete strength Classes			
Shear ranges	B 25	B 35	B 45	B 55
1 τ_{01}	1,4	1,8	2,0	2,2
2 τ_{02}	2,2	2,9	3,2	3,6

Table VI: Principal compressive stresses $\sigma_{II}^{(II)}$ in MN/m² for the calculated ultimate load

Concrete Strength Classes	B 25	B 35	B 45	B 55
$\sigma_{II}^{(II)}$	17,5	24,5	31,5	38,5

Table VII: Concrete tensile strength in MN/m² for calculating the minimum reinforcement

	Concrete strength Classes			
Concrete tensile strength	B 25	B 35	B 45	B 55
β_{bz}	3,5	3,7	4,0	4,2