

## Principles of Earthquake Design for Nuclear Power Plants in the FRG — Historical Development and a Critical Review

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### Summary:

The principles of earthquake design for NPP in the FRG are recorded in the German nuclear safety standard KTA 2201.1 "Design of NPP's against Seismic Events, Part 1: Basic Principles", prepared in 1971 and 1972 and issued in 1975. The regulations of KTA 2201.1 are based on the US-regulation App. A 10 CFR 100 "Seismic and Geologic Siting Criteria for NPP's". The principles are therefore basically the same in the States as in the FRG.

This results at least in an overestimation of the earthquake risk in Germany.

One of the important reasons for unrealistic design procedures and therefore uneconomic soft- and hardware consequences is bound to the requirement for a double earthquake design, namely the design against the SSE and the OBE. Because of the identical physical consequences of these two earthquake at least for most of the known plant sites, where fatigue due to the smaller but more frequent earthquake (OBE) has no technical relevance, there is no reason for an OBE.

Therefore the present regulatory standpoint should be revised.

On the basis of this knowledge a group of German experts has drafted a new proposal for KTA 2201.1, including the following basic modifications:

- The calculations for the "Design Earthquake" will be deleted
- design for a single maximum earthquake, the "Safety Earthquake"
- definition of a smaller earthquake, with the requirement to inspect and if necessary to shut down the plant in the case that such a defined earthquake occurs.
- possibility of using site-specific seismic input data instead of standard response spectra.
- no need for any calculations in the case of site intensity  $I \leq 6$

## 1. Introduction

The principles of earthquake design of NPP in the FRG are recorded in the German nuclear safety standard KTA 2201.1 "Design of Nuclear Power Plant Against Seismic Events; Part 1 Basic Principles", issued in 1975. This safety standard goes back to first drafts, written in the years 1971 and 1972 and is based on the 1971-published US-regulation App. A 10 CFR 100 "Seismic and Geologic Siting Criteria for Nuclear Power Plants".

The principles are therefore basically the same, that means there is the formal necessity for a double earthquake design in the U.S. as well as in the FRG.

The App. A 10 CFR 100 defines two different earthquakes for which the safety related structures and components have to be designed, first the "Safe-Shutdown Earthquake" (SSE) and second the "Operating Basis Earthquake (OBE)".

The Safe Shutdown Earthquake <sup>1)</sup> is that earthquake which is based upon an evaluation of the maximum earthquake potential considering the regional and local geology and seismology and specific characteristics of local subsurface material. It is that earthquake which produces the maximum vibratory ground motion for which certain structures, systems, and components are designed to remain functional. These structures, systems and components are those necessary to assure the following:

- (1) The integrity of the reactor coolant pressure boundary,
- (2) The capability to shut down the reactor and maintain it in a safe shutdown condition, or
- (3) The capability to prevent or mitigate the consequences of accidents which could result in potential off-site exposures comparable to the guideline exposure of this part".

The "Operating Basis Earthquake" <sup>2)</sup> is that earthquake which, considering the regional and local geology and seismology and specific characteristics of local sub-surface material, could reasonably be expected to affect the plant site during the operating life of the plant; it is that earthquake which produces the vibratory ground motion for which those features of the nuclear power plant necessary for continued operation without undue risk to the health and safety of the public are designed to remain functional".

The maximum vibratory accelerations of the Safe Shutdown Earthquake at the foundations of the nuclear plant shall be taken at least equal to 0,1 g.

"The Operating Basis Earthquake shall be specified by the applicant after considering the seismology and geology of the region surrounding the site. If vibratory ground motion exceeding that of the Operating Basis Earthquake occurs, shutdown of the nuclear power plant will be required. Prior to resuming operations the licensee will be required to demonstrate to the

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- 1) The "Safe Shutdown Earthquake" until this time in Safety Analysis Reports also had been identified as the "Maximum Hypothetical Earthquake" or the "Design Basis Earthquake".
  - 2) The "Operating Basis Earthquake" until this time in Safety Analysis Reports had also been identified as the "Maximum Credible Earthquake" and the "Design Basis Earthquake" when the "Maximum Hypothetical Earthquake" designation was used for the larger earthquake.

Commission that no functional damage has occurred to those features necessary for continued operation without undue risk to the health and safety of the public. The maximum vibratory ground acceleration of the Operating Basis Earthquake shall be at least one-half of the maximum vibratory ground acceleration of the Safe Shutdown Earthquake".

It is apparent that the Operating Basis Earthquake (OBE) has a triple definition. It is described as an earthquake (1) for which the features necessary for continued operating of the plant are designed to remain functional; (2) to have design value at least one-half of the SSE; and (3) to be specified by the applicant. As is well known, there are several plants for which the OBE is either greater or less than one half of the SSE, but for the most part the OBE has been taken to be half of the SSE.

The nuclear safety concerns associated with the OBE in general have not been clearly identified in the Federal Regulation. For instance, from definition (1) in the Federal Regulation, it is clear that features necessary for continued operation (in the event of an earthquake up to the selected OBE level) must be designed to remain functional. However, there is no nuclear safety requirement that the plant must continue to operate at or beyond the OBE or any other earthquake level. Presumably if the plant was designed to be shut down for inspection and safety evaluation in the event of an earthquake beyond a selected level, there should be no safety requirements to design for continued operating above that level.

From the standpoint of the owner/operator he should have the option of selecting seismic design level considered necessary to protect his financial investment as indicated in definition (3) of the Federal Regulation. The design requirement to safety shutdown the plant up to the SSE level would seem sufficient to assure nuclear safety.

This context, it seems to be very important to point out that the original intention of the NRC was not to apply both the SSE and the OBE criteria for safety related plant components. The specification of two different earthquakes in the U.S. was essentially meant to reflect the concept of designing safety-related components to withstand the SSE and all other plant components to withstand an operating basis earthquake (OBE) that would avoid unnecessary loss of plant availability. Since, however, the American NPP industry saw in this an unjustified attempt by the NRC to extend its field of competence, protests were raised. In respect to this, the NRC decided to cater for this protest by refraining from making any pronouncements concerning conventional plant component, while at the same time requiring safety-related plant components to be qualified for both OBE and SSE.

Based on the SSE/OBE requirements and not recognizing the original intention of the NRC the German KTA 2201.1 also defines two earthquakes for the analyses of safety related structures and components, supposing that an analysis for a maximum event would be necessary to ensure stability, integrity and operability of the components and an additional analysis for a smaller event would be necessary to avoid failure caused by fatigue.

This led firstly to the "Design Earthquake" (AEB) as that earthquake of maximum intensity that in the past has occurred within the same seismic unit, up to a distance of no more than about 50 km from the site, and second to the "Safety Earthquake" (SEB) as that earthquake of

maximum intensity that, according to scientific knowledge, might occur at the site taking into consideration a radius of about 200 km from the site. In this way in both countries earthquake-concepts have been established not only for safety reasons, but with regard to the availability.

## 2. Critical Review

Regarding the definitions of U.S. "Operating Basis Earthquake" and the German "Design Earthquake" it is obvious that the German "Design Earthquake" could result in an important influence on the design of npp components and structures because of the fact that there was no statement in KTA 2201.1 - that this earthquake should be defined as an earthquake which "could reasonably be expected to affect the plant during its operating life".

A probabilistic evaluation of the "Design Earthquake", specified for German NPP sites, expresses that these earthquakes are events with occurrence probabilities of less than  $10^{-3}/a$  and that therefore the "Design Earthquake", so far specified by the seismologists can not be an event relevant for the power operation, as e.g. an event with return periods of about 100 - 200 years.

The two regulations, the App. A 10 CFR 100 and the safety standard KTA 2201.1 published or drafted in the early seventies, possess formal validity even today, although there is now a great amount of knowledge in the field of seismology and the influence of seismic loads on the behaviour of structures and equipment even for the special equipment of power plants. The adverse influence of the double earthquake design, which is described in the 6<sup>th</sup> SMiRT presentation K 1/4 "A Critical Review of the Philosophy of Seismic Design, Specially Regarding the Design Basis Earthquake and the Safe Shutdown Earthquake" by M. Hintergräber, was already discussed within the NRC in 1979 and the discussions resulted in the same critical distance to the current seismic design concept as in Germany.

One of the NRC-staff-conclusions summarizes that a design for a single limiting event (the SSE) and inspection and evaluation for earthquakes in excess of some specified limit (the OBE) when and if they occur, may be the most sound regulatory approach.

In the U.S. the OBE is specified by the applicant after the SSE is determined by the NRC and - although there is the regulation that the OBE shall be at least one half the maximum vibratory ground acceleration of the SSE - there are several plants with license on the basis of OBE/SSE up to 1/3 and 1/4.

In the FRG both, the "Design Earthquake" (AEB) and the "Safety Earthquake" (SSE) are defined by the authorities, neglecting the statement of the experts that there is no argument for the definition and the analysis of a "Design Earthquake", especially because of German seismicity.

It can be seen from figure 1 that the German licensing attitude differs also in the items of OBE/SSE-ratio although there is no special requirement in the safety standard, and differs too in the chronological sequence for the definition of earthquake load postulates. Another example for the overestimation of the German seismicity and the overall conservatism of German earthquake design-loadings is the shape of the obligatory "design response

spectrum" laid down by the authorized seismologists and which is based on and therefore nearly identical to the U.S. Reg. Guide 1.60 response spectrum. Knowing that about 50 % of the American earthquakes which led to the "Reg. Guide-spectrum" had magnitudes greater than those ever occurred or possible in the FRG, it is obvious that the German design procedure for seismic events is too conservative and has no reflection to reality.

As already mentioned the former argument for an analysis for the "Design Earthquake" was the idea that the smaller earthquake is so frequent that the influence of fatigue has to be considered in the design. Now it is obvious that this is practically not the case, at least not for German plant-sites and therefore there is no reason for a smaller earthquake, the "Design Earthquake" respectively the "Operating Basis Earthquake". The maximum credible seismicity in Germany can be characterized by intensities of  $I \leq 8$  (see figure 2), magnitudes of about 6.5 and probabilities of occurrence of about  $10^{-5}/a$  to  $10^{-6}/a$ .

### 3. A Realistic Approach

Based on the understanding mentioned so far, a group of German experts consisting of seismologists, mechanical and structural engineers, has drafted a new proposal for KTA 2201.1 in order to make a first step on the long way to correlate the real and analytical earthquake-behaviour of structural and mechanical equipment of npp.

In the first instance this is indeed a national activity to revise the earthquake design concept, but it is generally known, that in the U.S. the NRC-Staff intends to revise their App. A 10 CFR 100. It seems to be likely that there can be a similar revision in the U.S. as described in the following.

- (1) The definition of and the analysis for the "Design Earthquake" will be deleted. This is justified because of the fact that the "Safety Earthquake" and the smaller "Design Earthquake" cause the same physical effects on the components. There is no effect of fatigue. Therefore there is neither a safety related nor another argument for a "Design-Earthquake"-analysis if the plant is designed for the "Safety Earthquake".
- (2) The "Safety Earthquake" is the only earthquake to ensure the safety related functions of npp-components, the so-called class 1-components, and governs therefore the design. It can be defined in probabilistic manner with a recurrence period of about 10.000 years. There will be no necessity for defining seismic engineering parameters for the "Safety Earthquake" for sites with intensities of  $I \leq 6$ . In this instance the seismic safety of structures and components will be ensured by only structural provisions, laid down in special safety standards.
- (3) There will be the definition of a so-called "Combination-Earthquake", which must be taken into account for the combination of earthquake and earthquake-independent plant-internal fires and external floods necessary for some special - but not class 1-equipment. The "Combination Earthquake" has to be defined as a small event which can reasonably be expected during life-time of the plant, that means it can be probabilistically defined

with a recurrence period of about 100 - 200 years.

This earthquake will be used for the design of fire protection and flood-protection-systems, if these systems are necessary for the operability of class 1-equipment in the case of internal fire or external flood.

Class 1-equipment will not be designed for those combinations of small earthquakes and independent fires and floods.

There will be no definition of "Combination Earthquake" for sites with an intensity of  $I \leq 6$  for the "Safety Earthquake".

- (4) Based on the site specific design of class 1-equipment a so-called "Earthquake-Inspection Level" will be defined by the applicant as a ratio of the maximum "Safety-Earthquake" acceleration.

It has to be defined on such a level that after an earthquake no relevant deformations in the class 1-equipment are possible. If the inspection-level is defined as not exceeding 50 % of the amplitudes of the pertinent "Safety Earthquake", the deformations can be considered as not being relevant.

If an earthquake occurs which has amplitudes greater than those described with the "inspection-level" the plant must be shut down and the class 1-equipment must be inspected.

- (5) Regarding the definition of the site-specific-intensities, the seismologist will be allowed to take into account the decrease of intensity with distance from the epicentre, if there is enough information about identified and possible sources, the subsurface characteristics and correlation between intensity-decrease and distance from the epicentre.

- (6) The use of the in respect to the German seismicity extremely conservative "Reg. Guide 1.60 Spectrum" or the use of similar spectra will be restricted to sites with a lack of information about the specific geologic and seismologic conditions.

In all other cases the seismologist will be allowed to define a site-specific-seismic-input instead of standard response spectra scaled by means of deterministically or probabilistically defined maximum accelerations. For example the seismologist will be allowed to specify the seismic input based on the use of Fourier-Amplitude-Spectra derived from source parameters.

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|--------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>1) Definitions</p>                                                                            | <p>OBE: An earthquake which could reasonably be expected during the service life of the power plant.</p> <p>SSE: An earthquake whose intensity corresponds at least to the maximum earthquake intensity measured in the past in the vicinity of the power plant.</p> | <p>AEB: An earthquake whose intensity corresponds to the maximum seismic intensity measured in the past in the vicinity of the power plant site.</p> <p>SEB: An earthquake which has never occurred in the past, but which is hypothetically possible on the basis of present scientific knowledge.</p> |
| <p>2) Official specifications for the ratios of OBE/SSE or AEB/SSE</p>                           | <p>The OBE should not be smaller than 1/2 SSE; probability studies may justify lower ratios.</p>                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                         |
| <p>3) Current licensing practice for OBE/SSE or DBE/SSE ratios</p>                               | <p>1/3 to 1/4</p>                                                                                                                                                                                                                                                    | <p>1/2</p>                                                                                                                                                                                                                                                                                              |
| <p>4) Chronological sequence/responsibility for the definition of earthquake load postulates</p> | <p>1.) SSE by NRC (safety report) then OBE by applicant (economic consideration)<br/>i.e. OBE is produced by reducing SSE</p>                                                                                                                                        | <p>1.) AEB, then<br/>2.) SEB, both by licensing authority (safety report)<br/>i.e. SEB is produced by increasing AEB</p>                                                                                                                                                                                |

figure 1: Comparison of licensing items

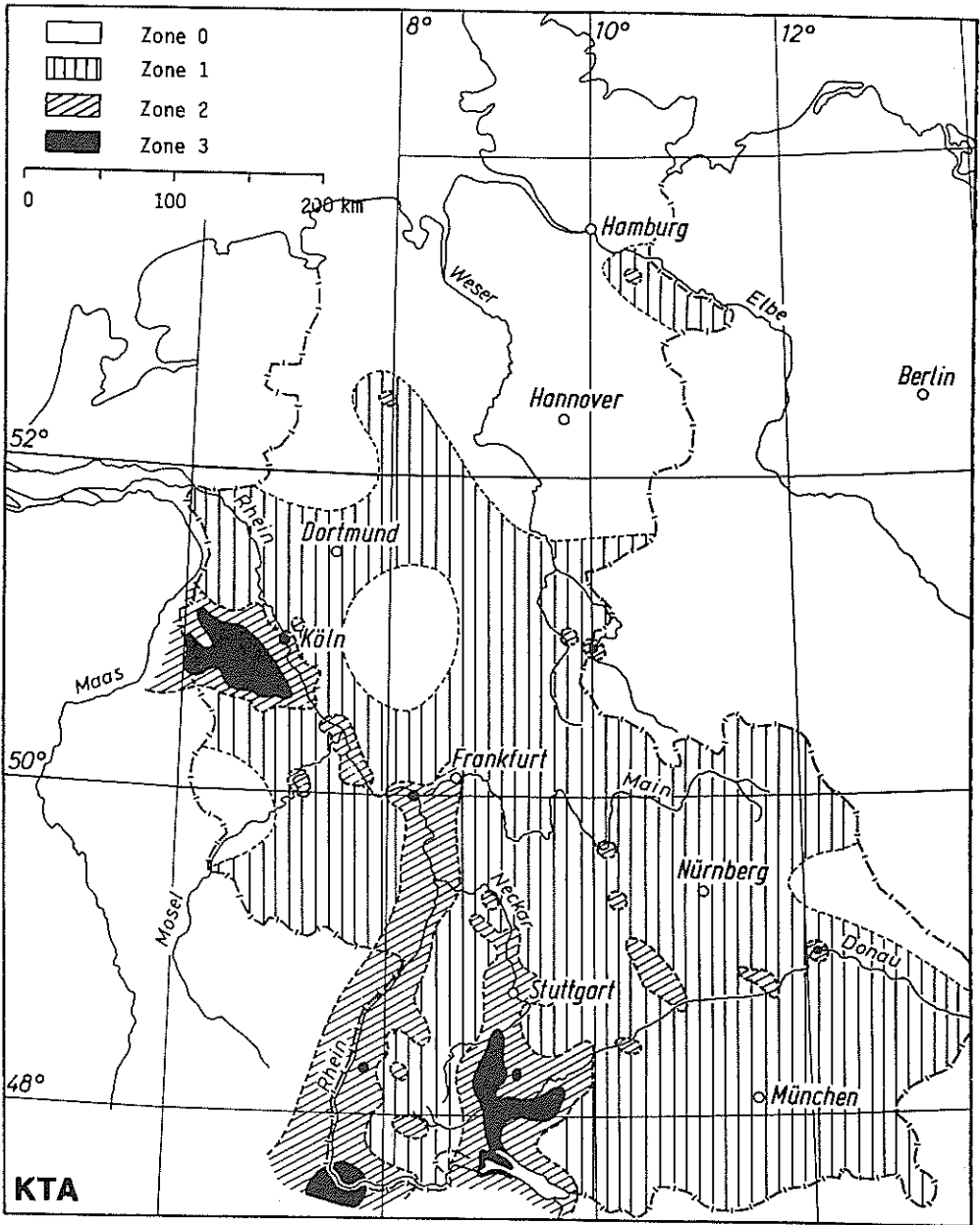


figure 2: Earthquake zones in the FRG

- Zone 0 : no intensity greater 5 has ever occurred
- Zone 1 : intensity 6 either has occurred or can be expected
- Zone 2 : intensity 7 either has occurred or can be expected
- Zone 3 : intensity 8 either has occurred or can be expected