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Seismo-engineering parameters for sites of interim storages for spent nuclear fuel at German nuclear power plants

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Abstract

Within the scope of the licensing procedure for 12 interim storage facilities for spent nuclear fuel at nuclear power plants (NPP) and one for the dismantling of a NPP in Germany, site-specific expert reports were carried out to determine seismo-engineering design parameters. Our work was based on the German nuclear safety standard KTA 2201 part 1 "Design of Nuclear Power Plants against Seismic Events" which requires the derivation of the design earthquake in terms of (macroseismic) intensity. The intensity of the particular design earthquake was evaluated by the deterministic method stipulated in KTA 2201 part 1. According to the current state-of-the-art of science and technology supplementary to the deterministic approach, probabilistic evaluations were done setting a probability of exceedance for the occurrence of the design earthquake of $10^{-5}\,\text{year}^{-1}$. Geological development and neotectonic conditions of the site surrounding areas were included in the evaluations. For 13 interim storage facility sites, soil-dependent design spectra and corresponding strong-motion duration values were determined.

For sites with low seismic hazard site-specific design spectra from the literature were used. In the case of sites with higher seismic hazard (design earthquake ⩾ VII 1/2 MSK) strong-motion registrations representative for the site were selected from world wide data and subsequently evaluated to derive site-specific design spectra.

Keywords: Design earthquake; Nuclear power plant; Response spectrum; Seismic hazard; Seismo-engineering parameters

1. Introduction

The Federal Institute for Geosciences and Natural Resources (BGR) on behalf of the licensing authority, the Federal Office for Radiation Protection (BfS), carried out expert reports including seismo-engineering parameters for 12 interim storage facility sites for spent nuclear fuel at German nuclear power plants (NPP). During the licensing procedure, the applicant or NPP owner, respectively, submitted its expert report which were reviewed by BGR and compared with its own analyses. One expert report carried out on the request of a Technical Inspection Association was done for the dismantling of the NPP at stade. Our work was based on the German nuclear safety standard KTA 2201 part 1 "Design of Nuclear Power Plants against Seismic Events" of the Nuclear Safety Standards Commission. In KTA 2201 part 1 the determination of the design earthquake is required in unities of (macroseismic) intensity. For each of the 13 interim storage facilities, site-specific analyses were done including seismic hazard assessment and evaluation of design spectra. The intensity of the particular design earthquake was evaluated by the deterministic method stipulated in KTA 2201 part 1. As long as the earthquake data enabled a sufficiently reliable interpretation supplementary to the deterministic approach the design earthquake was estimated by a probabilistic hazard assessment setting a probability of exceedance for the occurrence of the design earthquake of $10^{-5}\,\text{year}^{-1}$.

A probabilistic seismic hazard assessment is not claimed in KTA 2201 part 1 which is the mandatory basis for

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earthquake design of nuclear installations since the year 1990. However, performing probabilistic seismic hazard assessment has become international practice and state-of-the-art technology. It is standard for example in Great Britain, Sweden, Switzerland and USA. The value for the probability of exceedance of the design earthquake differs among these countries, 10^{-4} or $10^{-5}\,\text{year}^{-1}$. In the recommendations for the revision of the KTA 2201 part 1, formulated by a working group of the Reactor Safety Commission [1], both values are considered to be suitable, however, in combination with different levels of the response spectrum: using $10^{-4}\,\text{year}^{-1}$, the 84% percentile of the response spectrum has to be taken; using $10^{-5}\,\text{year}^{-1}$, the spectrum corresponding to the 50% percentile has to be used. We chose the 50% percentile spectrum in combination with a recurrence period of the design earthquake of $10^{-5}\,\text{year}^{-1}$.

2. Procedure to determine the design earthquake

The objective of the independent expert review performed by BGR was to examine and to give an assessment of the site-specific expert report submitted by the applicant. Therefore, an own expert report for each interim storage facility site was carried out, followed by a comparison of the results of both reports including an evaluation.

Carrying out seismo-engineering expert reports for sites of nuclear installations in Germany are not stipulated in great detail. The Nuclear Safety Standard KTA 2201 part 1 in its latest version of 1990 gives only principle guidance concerning the procedure and content of the corresponding reports. The licensing authority, BfS, and the authorized expert organization, BGR, have to ensure conjointly that the independent expert reviews correspond to the current state-of-the-art of science and technology. Furthermore, analyses have to be carried out with sufficient detail and transparency, input data must be proved, arguments and conclusions must be plausible.

The independent expert analyses performed by BGR are based on the earthquake catalogue for the Federal Republic of Germany [2] in its continuously updated version and the seismotectonic regions of Leydecker and Aichele [3] shown in Fig. 1. We subdivided the Upper Rhine Graben according to the proposal of Leydecker and Aichele [3]. For a division into seismotectonic regions, geological development, tectonic conditions and seismicity were taken into account. A homogenous distribution of future epicenters is assumed in each seismotectonic region.

2.1. Deterministic assessment of the design earthquake

KTA 2201 part 1 [4] includes the following requirement for the determination of the design earthquake: ‘‘The design earthquake is the earthquake of the highest intensity at the site that can occur according to scientific knowledge, taking into consideration an area of about 200 km around the site.’’ For earthquakes having occurred in the seismotectonic region of the site, it has to be assumed that such earthquakes can occur nearby the site. The logical interpretation of this requirement means to assume a quake at the nearest ‘‘active’’ fault in relation to the site. We regard faults to be ‘‘active’’ when their last movement took place within the last 2 million years, i.e. since the end of tertiary and in the quaternary.

Earthquakes from surrounding regions have to be assumed to occur at the border of their seismotectonic region at the closest distance to the site and their impacts on the site have to be estimated. The intensity at the site was calculated with the intensity attenuation law of Kövesligethy [5] (see Ref. [6]), which is commonly regarded as a suitable relation corresponding to the attenuation properties of the subsoil structure in Germany:

$$I_S = I_0 - 3\,\log\left(\frac{r}{h}\right) - 1.3\alpha(r-h), \tag{1}$$

where I_S is the site intensity (MSK) (for MSK: see Ref. [7]); I_0 is the epicentral intensity (MSK); r is the hypocentral distance (km); h is the focal depth (km); α is the absorption coefficient of the subsoil (km^{-1}) (here $0.002\,\text{km}^{-1}$).

For each region, a characteristic seismogenic depth was assumed. This depth describes the crustal part of the maximum released energy. Some regions show two characteristic seismogenic depths. In these cases, the greater depth was used conservatively to calculate the impact at the site.

As already mentioned, KTA 2201 part 1 [4] requires the determination of the design earthquake assuming an earthquake of the greatest intensity at the site that can occur according to the present state-of-the-art of science, i.e. not the impact of the maximum observed earthquake of a seismotectonic region has to be assumed for the evaluation of the design earthquake, but the maximum credible or possible earthquake of a region. As a rule, this requires an intensity increase with respect to the maximum observed earthquake, which takes into account that the maximum credible earthquake of the regarded seismotectonic region did not take place during the historically observed time period. The amount of the maximum credible intensity, i.e. the intensity increase, was chosen in dependence of the following criteria:

- amount of the maximum observed intensity (because of the nonlinearity of the macroseismic scale);
- extent and reliability of the documents with regard to the historical earthquakes;
- observed time period and completeness of the earthquake catalogue;
- size of the seismotectonic region and its seismicity;
- number of earthquakes with the highest observed intensity in a seismotectonic region.

The last point is accounted for with the fact that in some regions the greatest observed intensity occurred relatively often during a long time period. Therefore,