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Research Article

Using Safety Margins for a German Seis

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Abstract

The German regulatory guide demands the performance of a pro
events. In 2005, a new methodology guideline (Methodenband) ba
was released to provide the analyst with a set of suitable tools an
In the case of earthquake, a multilevel verification procedure is su
used depends on the seismic risk at the site of the plant. For site
only a reduced analysis is proposed. This paper describes the ev
components and systems for plants at sites with high seismic
guideline. The seismic PRA results in an estimation of core damag
the described approach can also be adapted for the usage in a red
Westinghouse has wide experience in performing seismic PRA fo
uses the documented set of seismic design analyses dating from
as a basis for a seismic PRA, which means that usually no costly
performed.

1. Verification Procedure of the German Methodolog

In the case of earthquakes, a multilevel verification procedure is su
(Methodenband) [1] which requires a probabilistic analysis only f

intensity $I_{DBE}(MSK) > 6$ on the site (DBE: Design Basis Earth
comparable with the European macroseismic scale (EMS)). For
reduced analysis is possible by demonstrating sufficient safety
intensity of $I = I_{DBE} + 1$. For earthquake intensities I_{DBE} above 7 a
buildings, structures, mechanical, and electrical components is ma

2. Seismic Hazard Analysis

Basis for a seismic PRA is a probabilistic seismic hazard analysis
earthquakes to exceed a certain intensity as shown in Figure 1. Ir
earthquakes will be used as initial values for the initiating event
buildings, structures, and components to estimate core damage fre

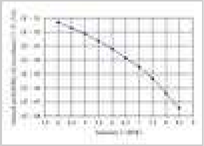

Figure 1: Hazard curve of seismic risk at plant

While the annual probability of exceedance is given as a function
ground acceleration of the design basis earthquake is used as bas
and components. Therefore, a mapping associating peak ground
established. Figure 2 shows pairs of variates for some Germa
guideline. This guideline suggests also a doubling of the peak gr
known as Cancani correlation, with respect to the design basis
approximation can be improved by the usage of site specific res
earthquakes and for different intensities, respectively. Site specific
sites in Germany. Calculation of site specific response spectra res
values as a function of the earthquake intensity. Typically, con
applied for earthquake calculations during the construction phase
specific response spectra can provide quite large safety margins in

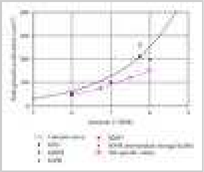

Figure 2: Classification of earthquake inter
Cancani. Site specific spectra provide a h
improvements.

3. Identifying the Plant Specific Scope of the Analys

To perform a seismic PRA, it has to be identified which plant s
directly to core damage sequences, and which design-basis accide
buildings, structures, and components have to be identified w
accidents. Furthermore, it has to be identified which are the seism
the corresponding safety systems needed to cope the design-b
accidents are a collapse of the reactor building, breakdown of the
piping as well as a structural failure or loss of the integrity of the
design-basis accidents loss of offsite power, loss of main heat s
(LOCAs) and an interaction with flooding of safety related systems

For the identified structures and components a screening proced reduce the amount of detailed investigation based on the calculat curves.

4. Assumptions to Simplify the Analysis

To reduce the scope of the analysis some conservative assumptio which the analysis is done, a loss of offsite power is directly assur main feed water, so that the amount of structures and compon those structures and components whose seismic-induced failure ca all parts of the plant which are not designed to withstand the relatively robust against seismic loads, the failure of single pipes can be added to the beyond design-basis accidents which lead dir operator procedures which require human actions outside the co rooms may not be accessible after an earthquake. An exception t removal from the fuel storage pool under the condition that its inte

5. Screening

All components needed to cope with design-basis accidents as mo a seismic evaluation. Additionally, all relevant passive components their corresponding hangers and supports) have to be added. To values for seismic rugged components from the literature, for ex used. The usage of the generic values for typical plant components

6. Plant Walkdowns

Plant walkdowns are an essential part of the seismic PRA to verify as mentioned in the previous chapter and also to support the estin stress analyses. Further goals of plant walkdowns are the identif seismic loads and the identification of components where only a related components or structures have to be identified which ca seismic failure, for example, through collision or falling.

Prior to the walkdowns, a detailed planning with identification of th be done, including the preparation of record sheets with com walkdowns are performed by seismic qualification and system exp A detailed recording of the plant walkdowns is mandatory. The d the summary of the record and the preparation of a photo docume

7. Calculation of Safety Factors and Fragility Curves

Westinghouse uses safety margins in the existing stress calculati curves as a function of the peak ground acceleration as describ components can be calculated by

$$F_{\text{Failure}}(A, Q) = \Phi\left[\frac{\ln(A/\breve{A})+}{}\right.$$

F_{Failure} describes the probability of failure during an earthquake v
level Q. Φ and Φ^{-1} are the distribution function of the standardiz
function. β_U and β_R describe the uncertainty and the scattering o
factor $\bar{F}_{\text{SR}}$ is a product of all individual safety factors $\bar{F}_i$ describec
ground acceleration with the failure probability of 50% (Median):

$$\bar{A} = A_{\text{DBE}} \cdot \bar{F}_{\text{SR}} = A_{\text{DBI}}$$

A_{DBE} is given by the acceleration of the plant design basis earthq
the strength factor with 1.5, the factor for hardening of concret
absorption with 1.4, the factor for broadening of the response sp
intensity with depth of the building in ground with 1.1. These f
approximately larger than 3. Figure 3 shows the corresponding fra

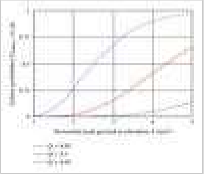

Figure 3: Example of a fragility curve for a bu

The fragility curve, shown in Figure 3 for three different confidenc
as a function of the horizontal peak ground acceleration. To ca
damage frequencies the median curve with a confidence level of
existing documents of the seismic design analyses, the constructio

Examples for safety factors of a component, here a pipe, are the fa
spectra with 1.1 and 1.6, the factor for the attenuation of intensit
strength factor with 1.3, the three hinge factor with 1.2, the fact
factor for damping of the floor response spectra with 1.2. These
approximately larger than 7 for the example of a pipe. The corresp

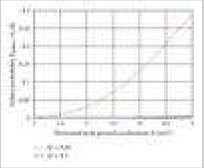

Figure 4: Example of a fragility curve for com

Because of the high resistivity of a pipe against seismic loads only
Q of 95% is visible, whereas the median fragility curve coincides n

The procedure for using safety margins to calculate safety factors
guideline.

8. Modeling and Quantification

In the last step of the full analysis within the scope of a seismic
damage frequencies are calculated for individual intensity intervals
The relevant intensity area reaches from a reasonable minimum i
anticipated for earthquakes with lower intensities to a maximum v

earthquake becomes negligible. According to the German method
(see Section 2) for plants with intensity 6 or less for the design
was used in the example shown in Figure 5.

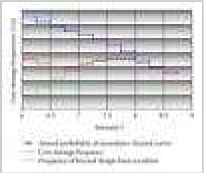

Figure 5: Core damage frequencies for di
corresponding annual probability of exceeda
design-basis accidents are shown. Values on th

In order to estimate core damage frequencies, the existing Level
individual intensity interval. As frequency for the initiating even
offsite power), the annual probability of earthquakes to exceed t
used. The seismic-related failures and unavailabilities of building
fragility curves, are superposed with the corresponding stochastic

For beyond design-basis accidents which cannot be coped wit
frequencies correspond directly to the annual probability of earth
of the seismic-induced failure of buildings, structures, and co
accidents. For design-basis accidents the core damage frequencie
the assumed probability that such an accident is caused by an
related failure probabilities of the relevant buildings, structures
accident. As described before, loss of offsite power is assumed alr

Figure 5 shows an example of calculated core damage frequencie
German nuclear power plant. With increasing intensity, the initial
In the last intensity interval, the remaining probability of earthqua
damage frequencies. At low earthquake intensities the anticipa
stochastic unavailabilities of components dominates the result.
approximately 40% to the overall result. Seismic-related unavaila
assumption that no earthquakes with intensities below 6 are to
result is dominated by the seismic-induced failure of buildings
accidents. This region contributes with approximately 60% to the
site specific response spectra, as described in Section 2, lead to a
also to a reduction of the contribution of the high-intensity region
from the failure of buildings and structures. The failure of compone

9. Reduced Analysis

As described before, a reduced analysis is possible for plants at sit
lower than 7. The procedure for this purpose is a considerably red
The verification of resistivity against seismic loads from an ear
intensity of the design basis earthquake is done by fragility
components, which contribute by experience in a decisive way to
buildings, structures and components, which have a dominant
previous PRAs, generic values for seismic-rugged components,
resistivity against seismic loads as well as the existing seismic an
from later updates, if done, can be used.

10. Summary and Experiences

Westinghouse used the procedure described by the new German r
seismic PRA for a German BWR. Also a corresponding seismic PRA

Due to the high core damage frequencies at low earthquake inten
offsite power in association with the stochastic unavailabilities c
systems is needed. The seismic-related unavailabilities of compo
most important part. Normally, all documents needed for the ana
phase, so that no costly new calculations have to be perforn
construction company should be consulted. The described screenir
number of components to be analyzed and of fragility curves to be
two weeks. An important safety factor results from realistic site sp
conservative response spectra used for the design phase. For a fu
for buildings and structures and approximately 30 fragility curves
The overall conclusion for the development of a German seismic I
described in the German methodology guideline is feasible and rea

Acknowledgments

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new German procedure guideline.

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