Transactions of the **13th International Conference on Structural Mechanics in Reactor Technology** (SMiRT 13), Escola de Engenharia - Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil, August 13-18, 1995

Selection of seismic margin criteria for Spanish nuclear power plants

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ABSTRACT: As part of the Individual Plant Examination of External Events (IPEEE) for the operating plants in Spain, the IPE Grupo comprising of utilities that own these plants decided to conduct seismic margin assessments. A comprehensive and consistent analysis of the seismic hazard at these plant sites and their plant design bases was performed in order to bin them into one or more Review Level Earthquake (RLE) bins for seismic margin assessment. Five plants were placed in the focused scope bin whereas two plants were put in the reduced scope bin.

1 INTRODUCTION

Individual Plant Examination of External Events (IPEEE) for operating nuclear power plants in Spain has just started. The Spanish utilities that operate the seven nuclear power plants formed a industry group called IPE Grupo to develop consistent approaches for all the plants in the performance of both IPE and IPEEE. For seismic events, the IPE Grupo recommended that all utilities perform a seismic margin assessment (SMA). As a first step in the SMA, a review level earthquake (RLE) should be selected. Following the practice in the United States, seismic hazard analysis of all the plant sites was conducted. The appropriate RLE was selected for each plant based on the site specific hazard and the plant design basis. IPE Grupo commissioned Westinghouse Energy Systems Europe, EQE International, and Geomatrix Consultants to perform this study of hazard evaluation and review level earthquake selection for all the Spanish nuclear power plants. Expert seismological input was provided to the team by Professor M. Arenillas and Professor A. Samartin.

The objectives of the IPEEE seismic hazard study for Spain were

- To develop site specific seismic hazard curves in a consistent manner for each of the seven nuclear power plants in Spain.
- To perform a comprehensive and consistent analysis of the seismic hazard at these sites and their plant design bases in order to bin them into one or more Review Level Earthquake bins for seismic margin assessment.

This paper describes the methodology used and the results of binning in terms of the seismic margin criteria for each of the nuclear power plants in Spain.

2 SEISMIC HAZARD ANALYSIS

A site specific seismic hazard analysis was performed for each of the seven nuclear power plant sites. The basic seismic hazard analysis formulation used in this study is the same as that used in the EPRI and LLNL studies and is based on the mathematical formulation first proposed by Cornell (1968). An emphasis was place on explicitly incorporating uncertainty in assessing the seismic potential and wave propagation characteristics of the region into the analysis. The LLNL and EPRI studies accomplished this by utilizing the assessments of multiple experts, individually in the case of the LLNL study, or formed into six teams in the case of the EPRI study. Each expert/team was encouraged to represent its input in terms of distributions rather than a single estimate. The present study has been conducted by a single team composed of seismologists, geologists and earthquake engineers which can be considered analogous to a single EPRI team. The team has however attempted to incorporate the range of scientific opinions concerning seismic hazards in Spain through alternative representations of the major components of the seismic hazard model. These alternatives represent differing interpretations of the available data made by the team, as well as consideration of the diversity of opinions expressed in the literature.

The uncertainty in characterizing the seismic hazard at the plant sites in Spain was modeled using the logic tree methodology that was used in the EPRI study. Following the approach used in the EPRI study, detailed documentation of the basis for the assessments of the various input parameters has been done to facilitate scientific review.

The development of the seismic hazard model for the study region followed the general approach used in the EPRI study, which emphasized the use of tectonics and geologic structure to define seismic sources and utilized improved statistical techniques for estimating seismicity parameters. The assessment focused on development of a seismic source model encompassing the entire region significant to seismic hazards at the seven nuclear power plant sites.

Figure 1 shows the mean seismic hazard curves for the sites studied.

3 SEISMIC MARGIN CRITERIA

Appropriateness of Bins

Seismic margin methods in the U.S. have been developed for the light water reactor plants designed and operated over the last thirty years. Comparing the design bases, system design and vintage of the Spanish plants with the U.S. plants, we concluded that the review level earthquake bins established in the U.S. could be used for seismic margin studies of Spanish plants. These bins are:

Review Level Earthquake of 0.5g pga
Full Scope Review at 0.3g pga
Focused Scope Review at 0.3g pga
Reduced Scope Review

Binning Based on Seismic Hazard at Different Sites

<u>Comparison of Hazard at Different Sites</u>. The first step in the binning was to develop the composite hazard of exceeding the NUREG/CR-0098 median spectrum anchored to 0.3g pga for each site. Following the methodology used in the U.S., we calculated these hazards as mean and median probability values. (Table 1)

The binning of U.S. plants was accomplished by grouping based on nine different criteria developed to include the EPRI and LLNL seismic hazard studies and the different measures of hazard as the mean, median and 85 percentile values; the grouping was initially done by ranking the sites on the basis of hazard of exceeding the 0.3g NUREG/CR-0098 spectrum. The binning was further refined using the composite hazard of exceeding the SSE ground motion spectrum at each site. This binning procedure was successful because of the large number of sites involved (69 sites). On the contrary, there are only 7 sites in Spain; grouping by relative ranking of hazard alone is difficult.

In the EPRI and LLNL seismic hazard studies, the median and mean hazard estimates differed significantly stemming from the diverse opinion of experts. For some sites, the mean estimate was larger than the 85 percentile value. Therefore, the mean was also used as an indicator of the uncertainty in the hazard estimate. Such difference does not exist between the median and mean hazard estimates developed in this study. Since the difference between the mean and median hazard estimates for Spanish plants is not significant, we make use of the mean hazard estimates in the binning evaluations; note also that to some extent, mean hazard has incorporated the uncertainty is the hazard in its evaluation.

Quantitative Criteria. NUREG-1407 does not specifically define quantitative criteria for binning the plants. But a careful reading of NUREG-1407 would lead us to infer such quantitative criteria. It states "it was considered appropriate that a site belonged in the 0.5g bin if a hypothetical nuclear power plant at that site was assumed to have a HCLPF of 0.3g and the mean annual core damage frequency associated with that hypothetical plant was 10^{-5} or higher. The work cited in NUREG/CR-5501 showed that the mean annual core damage frequency was roughly an order of magnitude lower than the mean annual likelihood of exceeding the plant HCLPF and very roughly equal to the median annual likelihood of exceeding the plant HCLPF".

We therefore infer that a plant could be placed in the 0.3g bin if

- the mean annual probability of exceeding the 0.3g NUREG/CR-0098 spectrum is less than $1x10^{-4}$ or
- the mean annual frequency of core damage is less than $1x10^{-5}$.

A conservative extension of this criteria would result in placing a plant in the reduced scope bin

- if the mean annual probability of exceeding the SSE spectrum is less than $1x10^{-4}$ AND
- the mean annual frequency of core damage is calculated to be less than $1x10^{-5}$ per year.

Assignment of RLE Bins Based on Hazard. A review of the seismic hazard results shown in Figure 2 indicates that:

- The criterion of mean hazard of exceeding the 0.3g NUREG/CR-0098 median spectrum is met by all the sites.
- The ranking of the sites by the hazard is not altered whether the mean or median hazard estimates are used.
- The mean hazard at SSE for the first two plants is less than $1x10^{-4}$ per year; further examination will be done to ascertain whether these plants could be placed in the reduced scope bin based on seismic core damage frequency.

Binning Based on Seismic Core Damage Frequency

Estimation of core damage frequency requires

- Seismic hazard
- Seismic fragilities of structures and equipment
- Cutsets or Boolean equations for core damage sequences

Seismic hazard analysis has been performed in detail for each site. Seismic fragility of structures and equipment could be estimated by detailed review, walkdown and analysis. For the purposes of binning, such detailed assessment is not necessary. Even if the seismic fragilities are known, the cutsets or Boolean equations for core damage sequences are needed to estimate the core damage frequency. This could only be done by an extensive systems analysis. In the absence of complete information on fragilities and system Boolean equations, we had to make some generic assumptions and develop some guidance for binning.

Past published seismic PRAs on PWR and BWR plants in the U.S. have shown that the plant HCLPF capacity is about 1.2 to 2.0 times the SSE (Ravindra and Nafday, 1989; Sewell, et al 1990) with an average value of 1.7 times the SSE. A convenient way to characterize the plant is by means of the core damage fragility curve family. Following the traditional PRA approach, the fragility family may be represented by the familiar lognormal parameters A_m, β_R and β_U. An examination of published seismic PRAs conducted in the U.S. showed that the values of β_R and β_U varied little from plant-to-plant. The results of plant-level values of β_R and β_U as derived from six PRA studies for eight reactor units indicate plant-to-plant averages of 0.22 and 0.24 respectively (Sewell, et al 1990).

For modern plants designed to current USNRC criteria, the plant level median capacity ranges from 4 to 8 times the SSE. For older plants not designed to current USNRC criteria, a representative plant level median capacity is 5 times the SSE. There are, however, some limitations on the use of these median capacity estimates.

Using the generic plant level fragility curves and site specific seismic hazard curves, the mean core damage frequency was estimated. The median capacity of the plant is calculated as follows:

$$A_m = \text{HCLPF} \exp[\, 1.65\,(\beta_R + \beta_U\,)]$$

With this A_m and $\beta_R = 0.22$ and $\beta_U = 0.24$, the full family of fragility curves can be obtained. This fragility family is then convolved with the seismic hazard curves for different plants to obtain the mean core damage frequency (CDF) from seismic events for each estimated HCLPF. For the two plants candidate to the reduced scope bin, a pessimistic estimate of the plant level HCLPF capacity could be equal to SSE. In such a case, only one plant has an estimated median CDF close to the target for placing the plant into the reduced scope bin.

However, review of published seismic PRAs as explained above has shown that the plant level HCLPF capacity ranges from 1.2 to 2.0 times the SSE with an average value of 1.7 SSE. If we use the lower bound value of 1.2 SSE, a second plant meets the MCDF target of 1.0×10^{-5} per year. For the average value of 1.7 SSE, the mean CDF is estimated as 4.4×10^{-6} per year for that second plant. Therefore, it is expected that mean CDF would be acceptably low and the plant could be placed in the reduced scope bin for seismic margin study conditional on demonstrating that the seismic margin is at least 1.2 over the SSE.

The mean CDF for each plant is calculated assuming the best estimate of the seismic capacity based on our experience in performing the seismic PRAs of U.S. plants. Pessimistic and best estimate mean CDF values are shown in Table 2 for all plants.

This table shows that the best estimate of mean CDF for all plants are less than the target of $1x10^{-5}$ per year and the placing of the remaining five plants into focused scope bin is justified.

RLE Ground Spectrum

In the U.S., the seismic margin evaluation is done using the NUREG/CR-0098 median spectrum shape. The screening table given in NUREG/CR-4334 is in terms of the peak ground acceleration values. The EPRI screening limit for 0.3g RLE bin is higher than the NUREG/CR-0098 spectrum anchored to 0.3g pga at all frequencies. It was observed that the NUREG/CR-0098 envelops the design SSE and the 10,000-year uniform hazard spectrum for all the seven Spanish nuclear power plant sites. The 10,000-year uniform hazard spectrum shape could be used for developing the median response and calculating the HCLPF capacities of the components and the plant. However, final HCLPF capacities should be presented in terms of the NUREG/CR-0098 spectrum to be consistent with the use of screening tables.

4 CONCLUSIONS

In conclusion, the study recommended to use the RLE bins from NUREG-1407 and to place the Spanish plants into the following categories:

0.5g - Bin:	None
0.3g - Full scope bin:	None
0.3g - Focused Scope Bin:	5 plants
Reduced Scope Bin:	2 plants (one conditional on demonstrating a sufficient margin on seismic core damage frequency)

5 REFERENCES

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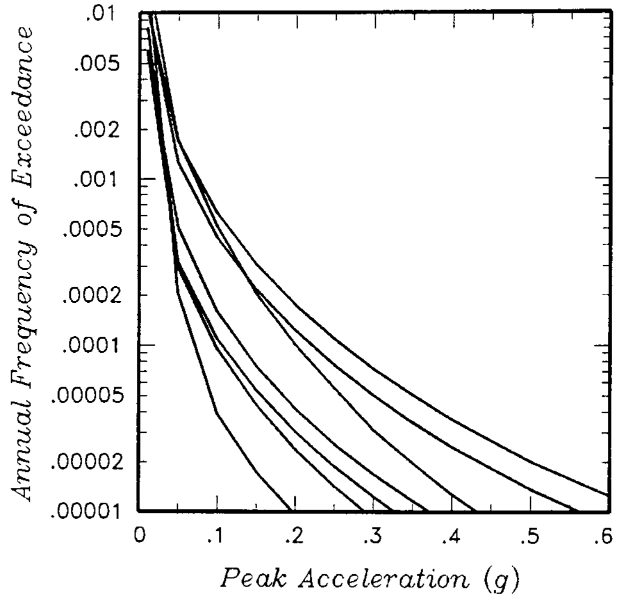

Figure 1: Seismic Hazard Curves for Spanish Nuclear Power Plant Sites

Table 1

Annual Frequency of Exceeding the 0.3g NUREG/CR-0098 Spectrum

Plant	Median Frequency	Mean Frequence
1	4.1×10^{-6}	4.8×10^{-6}
2	4.8×10^{-5}	6.5×10^{-5}
3	3.8×10^{-5}	4.6×10^{-5}
4	0.5×10^{-5}	2.2×10^{-5}
5	9.7×10^{-6}	1.2×10^{-5}
6	7.0×10^{-5}	9.4×10^{-5}
7	1.1×10^{-5}	1.6×10^{-5}

Table 2

Seismic Core Damage Frequency Estimates for Spanish Plants

Plant	Best Estimate Mean CDF	Pessimistic Estimate Mean CDF
1	1.2×10^{-6}	1.1×10^{-5}
2	8.6×10^{-6}	7.0×10^{-5}
3	3.6×10^{-6}	2.8×10^{-5}
4	5.7×10^{-6}	4.6×10^{-5}
5	1.4×10^{-6}	1.6×10^{-5}
6	6.5×10^{-6}	3.7×10^{-5}
7	6.0×10^{-6}	2.0×10^{-5}