Seismic Loading for Evaluation of Temporary Conditions in Nuclear Power Plants

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SEISMIC LOADING FOR EVALUATION OF TEMPORARY CONDITIONS IN NUCLEAR POWER PLANTS

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ABSTRACT

A quantitative procedure for using available site-specific annual seismic hazard curves to determine the acceleration level for evaluation of a temporary condition of known short duration (several days or months in a year) is described. The results are relatively insensitive to the choice of hazard curves for sites in the eastern United States since the procedure depends on the shape of the curves rather than on the probability values. The use of the procedure for determining a short duration limit for not considering seismic effects as a load case is also described and the results obtained for a site are presented and discussed.

Introduction

Nuclear power plants are designed for two levels of seismic load: Operating Basis Earthquake (OBE) and Safe Shutdown Earthquake (SSE). The design-basis qualification of components and structures considers resulting seismic effects in various combinations with other significant parameters, such as dead load, operation effects, and accident effects. Conditions of predicable short duration (several days or months) often require evaluation to support maintenance activities or modifications during refueling cycles. Examples are temporary rigging loads, placement of lead blankets on components for temporary radiation shielding, and modification of boundary conditions for testing and repair as in a steam generator snubber removal. Detailed structural analysis for full seismic effects on structures, systems, or components for temporary conditions can result in costly modification work. In order to properly account for such conditions, it is appropriate to include the duration effect on seismic load when structures and components are evaluated for a temporary condition.

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This paper discusses a quantitative procedure for considering the duration effect of short-term loads when seismic loading is being considered. The procedure uses available annual seismic hazard curves to obtain the acceleration level applicable to a prescribed load duration. The derived acceleration, expressed as a fraction of design-basis SSE or OBE acceleration, is relatively insensitive to the specific hazard curve, from among those available for use in this type of calculation. Approach and reasoning are also provided to determine a very short duration limit for not considering seismic as a load case. The implementation issues related to the procedure are also discussed.

Duration-Dependent Site Acceleration

The calculation of site acceleration as a function of a prescribed short duration utilizes site-specific annual hazard curves (plots of the probability of exceedance per year against peak horizontal ground acceleration). The availability of annual hazard curves for nuclear plant sites, the distribution function of site acceleration, and selection of an acceleration level from the distribution function are described below.

Availability of Annual Hazard Curves

Most nuclear plant sites in the United States have recently developed annual hazard curves available either because of studies related to their response to Individual Plant Examination for External Events (IPEEE) or because of resolution of the eastern seismicity issue related to the Charleston Earthquake. For sites east of the Rocky Mountains, the annual hazard curves are available from two sources:

- Lawrence Livermore National Laboratory (LLNL) Study (Bernreuter et al., 1989)
- Electric Power Research Institute (EPRI)/Seismic Owners Group (SOG) Study (McGuire et al., 1989)

Three items are noteworthy regarding the LLNL and EPRI/SOG hazard curves relative to this paper: (1) these curves were developed through extensive studies involving groups of seismicity and ground motion experts, and formal procedures for considering the experts' judgement; (2) both procedures used a Poisson process for the occurrence of earthquakes in each seismic zone; and (3) the hazard curves from these studies were used by the United States Nuclear Regulator Commission (USNRC) and the industry to formulate solutions to seismic issues in nuclear power plants (e.g., the USNRC used LLNL and EPRI/SOG curves to put 69 plants in the eastern United States into two seismic bins for the purpose of addressing the seismic portion of IPEEE).

Figure 1 shows seismic hazard curves for a specific site from LLNL and EPRI/SOG studies. It is well-known that for the same acceleration value, the probability of exceedance from the curves of the two studies vary widely. The procedure to be discussed depends on the shape of hazard curves rather than on absolute probability values. For this reason, the results tend to be less sensitive to the source of the hazard curve that is used in the calculation.

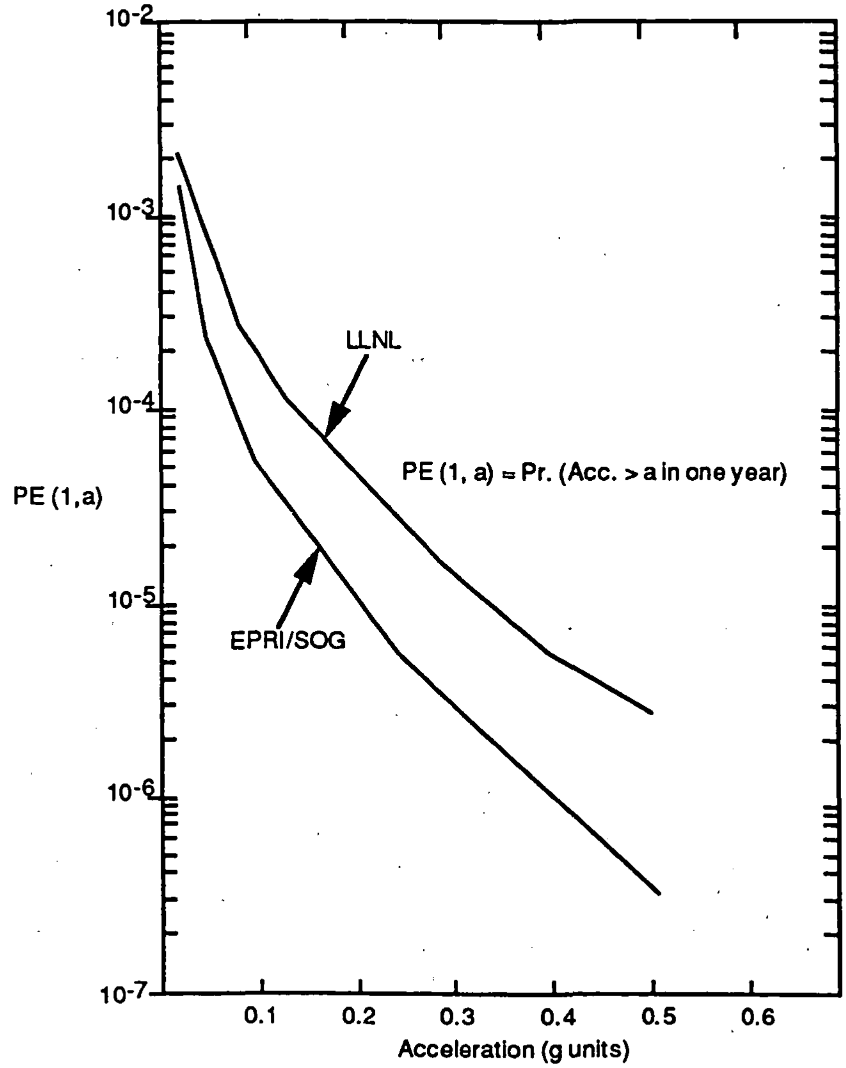

Figure 1. Sample median annual hazard curves for a site.

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Distribution Function of Site Acceleration in t_d

Consider a short duration t_d (fraction of a year), and adopt the following assumptions:

1. Seismic acceleration at the site has a probability distribution function

$$F_A(a) = \text{Pr.}[A \leq a] \tag{1}$$

where A = random site peak horizontal acceleration, a = a specific value of acceleration, and Pr. [.] denotes the probability of the event described within the bracket.

2. The earthquakes at the site occur in accordance with a stationary Poisson process at a yearly rate ν (average number of earthquakes per year).

Define duration-dependent hazard curve (PE) as

$$PE\,(t_d,a) = Pr.\,[A_{max} > a \text{ within } t_d]$$
$$= 1 - Pr.\,[A_{max} \leq a \text{ within } t_d] \quad (2)$$

where A_{max} = maximum site acceleration during t_d. Based on assumptions 1 and 2, the hazard function is (Cornell, 1968)

$$PE\,(t_d,a) = 1 - e^{-\nu t_d[1 - F_A(a)]} \quad (3)$$

Since νt_d = average number of earthquakes affecting the site in duration t_d (Cornell, 1968), it is usually much smaller than unity. Also since $F_A(a)$ is a probability distribution function, $1 - F_A(a)$ is smaller than unity. It follows that

$$PE\,(t_d,a) \approx t_d \nu\,[1 - F_A(a)] \quad (4)$$

Equation 4 implies

$$PE\,(t_d,a) = t_d\,PE\,(1,a) \quad (5)$$

where PE (1,a) = annual hazard curve. Consequently, by specifying a short duration t_d as a fraction of a year, the duration-dependent hazard curve can be constructed by scaling the annual hazard curve according to Equation 5. Figure 2 shows hazard curves constructed from the EPRI/SOG curve of Figure 1 for t_d = 0.5 (6 months), 0.333 (4 months), 0.167 (2 months), and 0.083 (1 month).

Site Acceleration for t_d

The specification of an acceptable probability level for selecting an acceleration from the hazard function and the choice of a unique hazard curve given this selected probability are controversial. In order to circumvent these difficulties, plant design basis accelerations [i.e., $a_{SSE}(1)$ = for SSE peak ground acceleration and $a_{OBE}(1)$ = for OBE peak ground acceleration] and their corresponding annual probabilities are used.

Consider $a_{SSE}(1)$, for example. Given a specific annual hazard curve, the ordinate at this acceleration, i.e., PE $(1,a_{SSE})$, yields the probability of exceeding this acceleration. Since the

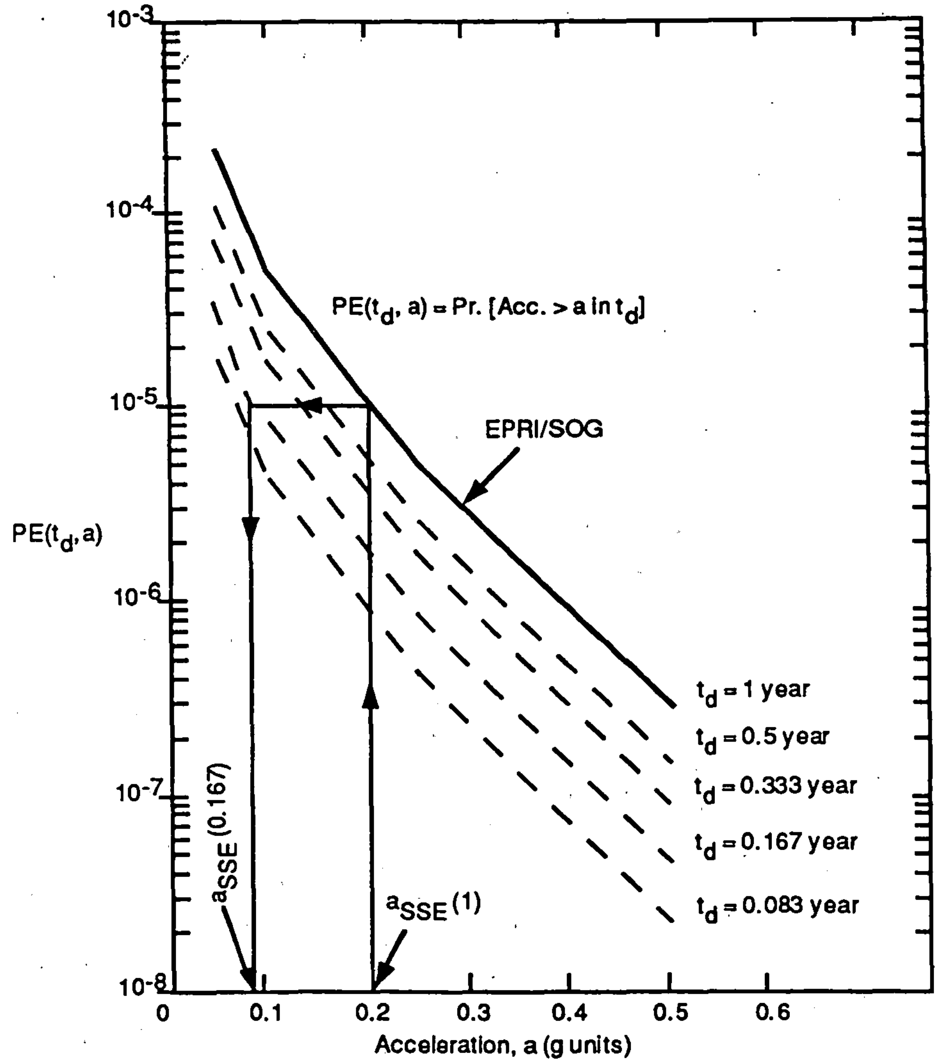

Figure 2. Duration-dependent hazard curves for EPRI/SOG curve in Figure 1 and construction of a_{SSE} (t_d) using a_{SSE} (1).

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plant is *deterministically* designed for $a_{SSE}(1)$, it is logical to treat $PE(1, a_{SSE})$ as an acceptable probability of exceedance. This probability is used to determine $a_{SSE}(t_d)$ from the associated duration-dependent hazard curve. The construction for $t_d = 0.167$ is shown in Figure 2, assuming $a_{SSE}(1) = 0.2$ g. The value of $a_{(SSE)}$ (0.167) is read as 0.09 g.

In summary, the acceleration value corresponding to short duration t_d (for SSE or OBE evaluation) is the acceleration value that will have the same probability of being exceeded during t_d as the design value [$a_{SSE}(1)$ or $a_{OBE}(1)$] has in one year. Note that a year is used as a base period because of the way hazard curves are now available to the plants. Any duration other than a year could be used for the base period. A more directly relevant value would be the duration of a refueling cycle. Any such choice is not expected to affect the results significantly.

Table 1 summarizes the ratio of SSE acceleration for t_d, $a_{SSE}(t_d)$, to SSE acceleration for one year, $a_{SSE}(1)$, for the two site hazard curves of Figure 1. For this comparison $a_{SSE}(1) = 0.2$ g. Considering the appreciable difference in the ordinates of the two hazard curves in Figure 1, the acceleration ratios in Table 1 from the LLNL and EPRI/SOG are very close. This table shows the relative insensitivity of the procedure to the choice of LLNL or EPRI/SOG hazard curves.

Table 1. Ratio SSE acceleration for t_d to design-basis SSE acceleration for hazard curves in Figure 1.

	$a_{SSE}(t_d)/a_{SSE}(1)$	
Duration t_d	LLNL	EPRI/SOG
1 year	1.00	1.00
6 months	0.72	0.77
4 months	0.58	0.64
2 months	0.42	0.46
1 month	0.29	0.33

After the ratio $a_{SSE}(t_d)/a_{SSE}(1)$ is determined for a prescribed short duration, the effective accelerations for component evaluation can be calculated using the floor spectra reduced by the above ratio. The SSE allowables will be utilized to complete the evaluation for SSE. If necessary, a similar calculation can be performed on the component with $a_{OBE}(t_d)/a_{OBE}(1)$ ratio and the corresponding OBE allowables.

Duration for Not Considering Seismic as a Load Case

The value of site acceleration decreases as the corresponding duration becomes smaller, as shown in Table 1. It is of practical interest to calculate a duration corresponding to each hazard curve, such that, for durations smaller than this value, seismic effects do not have to be considered as a load case. A practical approach to this is to specify an acceleration threshold that is acceptably small so as not to require a specific seismic evaluation.

A site acceleration of 0.02 g may be considered a reasonable threshold under which detailed seismic evaluation is not required, as described later. Let t_d (0.02) denote the duration for a 0.02-g acceleration. Applying Equation 1 and using $PE(1,a_{SSE})$ as the acceptable probability level, t_d (0.02) is given by

$$t_d(0.02) = \frac{PE(1,a_{SSE})}{PE(1,0.02\ g)} \quad \text{(in years)} \tag{6a}$$

$$= \frac{8760\ PE(1,a_{SSE})}{PE(1,0.02\ g)} \quad \text{(in hours)} \tag{6b}$$

When Equation 6b is evaluated using $a_{SSE}(1) = 0.2$ g and the annual hazard curves in Figure 1, the resulting values of $t_d(0.02)$ are 69 hours for EPRI/SOG hazard curves and 206 hours for LLNL curves. The application of this procedure to the curves of several stations shows the following:

- The shortest duration is always calculated from the median hazard curves of EPRI/SOG.
- The calculated duration t_d (0.02) always exceeds 24 hours, which implies that a 24-hour duration is conservatively short enough so as not to require evaluation of seismic effects; duration longer than 24 hours may be acceptable at specific sites.

Justification for 0.02 g

Two generic justifications that support 0.02 g as being a low enough acceleration not to require a seismic evaluation are provided below.

Reference to Correlation of MM Intensity with Peak Ground Acceleration

Figure 3 shows correlation of Modified Mercalli (MM) intensities with peak horizontal ground accelerations provided by a number of investigators (Murphy and O'Brien, 1977). For intensity V, acceleration varies from 0.012 g to 0.07 g. For intensity VI, the corresponding acceleration range is from 0.024 g to 0.12 g. The 0.02-g ground acceleration is near the low end of acceleration for intensity V, and it is less than the low point acceleration for intensity VI. Recalling that intensity V shaking is felt and small unstable objects get displaced, but damage to structures or movement of large objects does not occur, it follows that 0.02-g acceleration is sufficiently low enough as to not require a specific seismic calculation to show acceptability.

Reference to Threshold of Damage from Construction Vibrations

Wiss provides information on the threshold of possible damage to buildings caused by construction activities (Wiss, 1981). In terms of peak ground velocity, this threshold for residential buildings is 2 in./sec. The velocity threshold for commercial buildings is higher (4 in./sec). Values to correlate peak ground velocity to peak ground acceleration for seismic motions are 48 in./sec/g for competent soil and 36 in./sec/g for rock (Newmark and Rosenblueth, 1971). Combining this information to obtain a lower bound for damaging acceleration level yields

$$a_{\text{lower bound}} = (2 \text{ in./sec}) \div (48 \text{ in./sec/g}) = 0.042 \text{ g} \tag{7}$$

This lower bound value justifies using 0.02 g as the acceleration level that requires no specific seismic qualification.

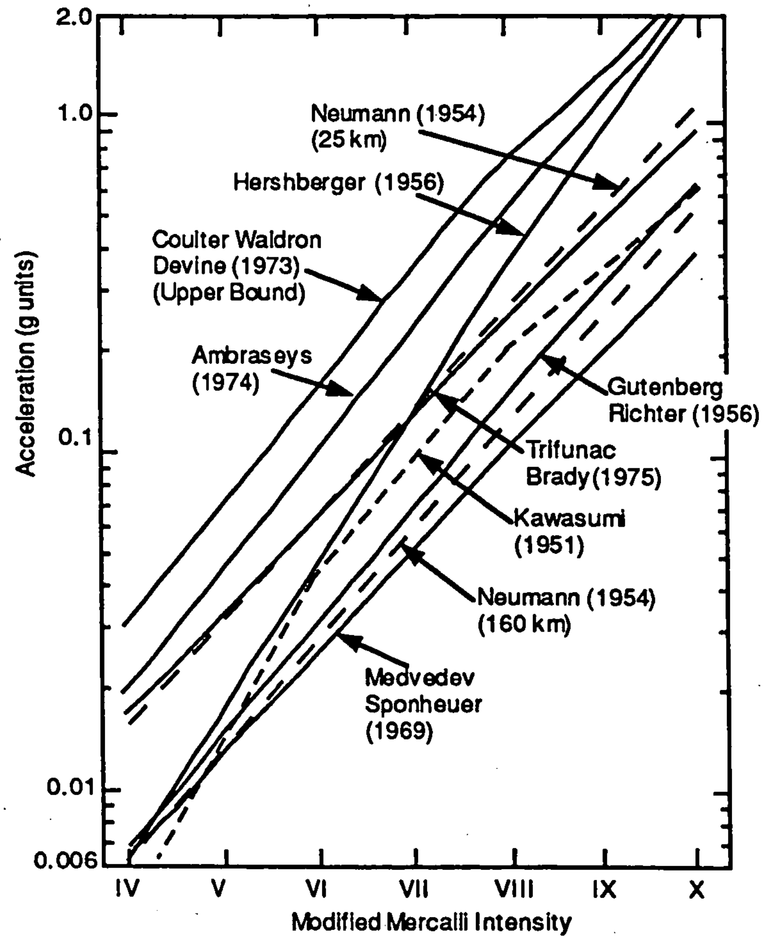

Figure 3. Selected intensity/acceleration correlations from (Murphy and O'Brien, 1977).

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Implementation Issues

The following two issues are of particular interest when the described procedure is applied to the evaluation of a specific temporary condition.

Duration, t_d, and Start Time

A conservative duration (t_d) for each temporary condition should be estimated to preclude future reevaluation, should the anticipated duration of the activity be exceeded; this t_d should be used to determine the applicable acceleration for making the necessary evaluations. The start time of this duration can be any time in a given year or in a refueling cycle. Because the procedure is based on the Poisson process for occurrence of earthquakes and since the Poisson process is a memoryless process, if in a given application (due to unforeseen factors) the estimated duration expires before the work is completed, the evaluation remains valid for a subsequent duration equal to t_d. However, this Poisson assumption should not be misused by underestimating the duration t_d when the work is being planned.

Applicability of Poisson Assumption

As noted earlier in this paper, modern site-specific annual seismic hazard curves are determined by utilizing considerable expert studies and judgment. These studies all use the Poisson assumption as a suitable and convenient tool to provide data for engineering evaluations. The resulting hazard curves are considered to provide stable estimates of site seismicity. On this basis, using the annual hazard curves to consider duration-dependent acceleration seems to be reasonable without becoming concerned with the invalidity of the Poisson assumption during foreshocks and aftershocks of a main seismic event. It is presumed that significant changes in seismicity will be appropriately incorporated in the future seismic hazard curves.

Summary and Conclusions

This paper discusses a quantitative procedure for using available site-specific annual seismic hazard curves to determine an acceleration level for evaluating a temporary condition of known short duration (several days or months in a year). The plant design basis SSE or OBE acceleration is used to determine the acceleration for a short duration from the annual hazard curves. The results depend on the shape of the hazard curves rather than on absolute probabilities. The results are insensitive to the choice of hazard curves from LLNL and EPRI/SOG studies for sites in the eastern United States.

The specific results for a given site presented in the paper show that for the SSE conditions and durations of 6 months and 1 month in a year, the corresponding acceleration values are 0.77 and 0.33 times the SSE ground acceleration, respectively.

Given an acceleration level that is low enough as not to require a specific seismic evaluation, the use of the procedure is described to determine short-duration limits such that durations less than this limit do not require considering seismic effects as a load case. Generic information is presented to consider 0.02 g as a reasonable threshold under which detailed seismic evaluation is not required. For the example worked here, the "no seismic limit" duration is calculated as 69 hours. Studies with seismic hazard curves for several sites show that a 24-hour duration is a conservative duration for which seismic effects need not be considered as a load case.

Finally, two items of interest for implementing the procedure are discussed and recommendations for each are provided.

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