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Mr. Eugene V. Imbro
Chief, Mechanical and Civil Engineering Branch
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: New Plant Seismic Design Activities

PROJECT NUMBER: 689

Dear Mr. Imbro:

This letter is in response to requests made by the NRC staff in the May 11-12, 2006, meetings between the NRC staff and the industry on new plant seismic design activities.

Enclosure 1 provides an industry's recommendation on a quantitative target for annual probability of unacceptable performance to be used with the performance-based approach for determining seismic ground motion described in the ASCE/SEI 43-05 Standard. The definition of unacceptable performance for Seismic Design Category, SDC-5D is the *Frequency of the Onset of Significant Inelastic Deformation* (FOSID). In the industry-NRC discussions over the past 18 months, it is clear that there are other equivalent target criteria, such as seismic core damage frequency, that may be proposed by an applicant on a case by case basis.

Enclosure 2 provides the response to the April 27, 2006, NRC request for additional information relating to the first question on the G1.2 project report, *Use of Minimum CAV in Determining Effects of Small Magnitude Earthquakes on Seismic Hazard Analysis*. The question was on the use of the Cumulative Absolute Velocity (CAV) threshold as a damage parameter (the CAV threshold level is 0.16 g-sec) in the G1.2 project to filter non-damaging earthquakes from a seismic hazard analysis. This topic was discussed in the May 11-12, 2006 meetings.

The final reports on the determination of seismic ground motion, the G-Tasks, and the first draft of the integrated report for use in the development of a NRC regulatory guide will be forwarded to you by July 15, 2006. These reports will incorporate comments from peer reviews and the EPRI Seismic Technical Review

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and Advisory Groups. Responses to NRC RAIs will be incorporated in the text or as an appendix.
We are continuing to work on the high frequency tasks with an emphasis on Task S2.1, *Effect of Seismic Wave Incoherence.* As we have informed you earlier, Task S2.2, *Effect of Limited Inelastic Behavior on High Frequency Response* is considered a lower priority. We will continue to work task S2.2, including the development of responses to the NRC questions that have been raised in the 18-months of constructive interaction on improving the seismic response spectra and design for new nuclear power plants.

We are developing high frequency screening criteria for components that may be affected by high frequency seismic motions. We estimate that we will be in a position to discuss these screening criteria with the NRC staff in August 2006.

If you have any questions on this letter or its enclosures please contact me at (202) 739-8094; aph@nei.org.

Sincerely,

Adrian P. Heymer

Enclosures

c: Dr. William D. Beckner, NRC
Dr. Anthony H. Hsia, NRC
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Document Control Desk

Approach for Defining the Safe Shutdown Earthquake (SSE) Design Response Spectrum (DRS)

It is proposed that the Safe Shutdown Earthquake (SSE) Design Response Spectrum (DRS) for future nuclear power plants can be established by following the Risk (Performance-Goal) Based Approach defined in ASCE Standard 43-05 (Ref. 1) for the most stringent Seismic Design Category, SDC-5D. For SDC-5D, the quantitative target annual probability of unacceptable performance P_{FT} is:

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The qualitative description of acceptable performance for SDC-5D is to not exceed Limit State D, which is defined in the ASCE Standard as "Essentially Elastic Behavior." Thus, the definition of unacceptable performance for SDC-5D is the "onset of significant inelastic deformation" and P_{FT} represents the target frequency for the onset of significant inelastic deformation (FOSID).

The basis for selecting a quantitative target performance goal P_{FT} of mean $1x10^{-5}$/yr is that this mean represents slightly lower than the average Seismic-Induced Core Damage Frequency (SCDF) reported for 25 nuclear power plants that have performed seismic probabilistic risk assessments (SPRAs) as reported in NUREG 1742 (Ref. 2). The reported mean SCDFs have a median value of $1.2x10^{-5}$/yr and a mean value of $2.5x10^{-5}$/yr.

Additionally, a conservative bias is introduced by choosing the onset of significant inelastic deformation as the qualitative performance goal. This performance goal corresponds to significantly less damage than would be required to reach core damage. Therefore, holding the FOSID to a target of mean $1x10^{-5}$ /yr insures that the SCDF will be below mean $1x10^{-5}$/yr.

For new standard plant designs, the NRC (SECY 93-087) has advised that the Seismic Core Damage HCLPF margin factor should be at least 1.67 times the design response spectra. With this HCLPF seismic margin for Seismic Core Damage, Reference 3 demonstrates that for 28 sites with the design response spectra defined by the ASCE Standard 43-05 approach for SDC-5D, the achieved SCDF lies in the range of $0.6x10^{-6}$/yr to $5.4x10^{-6}$/yr with a median value of approximately $3x10^{-6}$/yr.

Thus, the achieved SCDF for new plants will be substantially less than the average SCDF reported for existing plants.

References

1. *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities*, ASCE/SEI 43-05, American Society of Civil Engineers, 2005

2. *Perspective Gained From the Individual Plant Examination of External Events (IPEEE) Program,* NUREG-1742, Volumes 1 and 2, U.S. NRC, Sept. 2001

3. *Performance-Based Seismic Design Spectra,* Program on Technology Innovation: Assessment of a Performance-Based Approach for Determining Seismic Ground Motions for New Plant Sites, Vol. 1, TR-1012045, EPRI, September 2005

Response to NRC Request for Information on Cumulative Absolute Velocity (CAV) Damage Threshold

This document provides a response to a NRC information request on the acceptability of the CAV value of 0.16 g-sec as a conservative exceedance threshold for developing a conditional probability function that allows non-damaging earthquakes to be filtered from a seismic hazard analysis using a smooth transition function.

Introduction

The NRC issued 14 RAIs to NEI on April 27, 2006, related to the G1.2 project report, *Use of Minimum CAV in Determining Effects of Small Magnitude Earthquakes on Seismic Hazard Analysis*. The first RAI in the NRC April 27, 2006, letter was on the use of the CAV threshold as a damage parameter (the CAV threshold level is 0.16 g-sec) in the G1.2 project to filter non-damaging earthquakes from a seismic hazard analysis. The RAIs were reissued, with some clarifications, on June 1, 2006. The partial text of the two-part CAV threshold request is as follows:

a) …"Please provide the basis for selecting the 0.16 g-sec threshold as a quantitative measure of no damage to structures, in view of the qualitative nature of assigning an MMI to a site"…and
"also please justify the limitation imposed by simplifying the complexity of ground motions into a single parameter of CAV."
b) "In view of the significant increase of strong motion earthquake recordings near industrial sites since 1980, please justify the continued usage of 0.16 g-sec as a conservative threshold for damage by providing examples from recent strong motion recordings…"

These two requests were discussed at the May 11-12, 2006 new plant seismic issues meeting at the NRC. The industry presented the position that the use of the CAV parameter and the selection of the 0.16 g-sec CAV threshold level were chosen in the G1.2 project specifically to eliminate the potential for discussion on: (1) what parameter should be used to best characterize the threshold of damage for NPP equipment/structures, and (2) what level of that parameter conservatively defines the value of that threshold.

EPRI research projects (Reference 1 and 2) conducted in the late 1980's and early 1990's provide the necessary information for the response to part a) of the request above. Reference 1 describes a variety of damage parameters considered in the study, and the basis for selecting the CAV as the parameter with the best correlation to potential damage. Reference 2 describes the process for computing the CAV and the basis for the 0.16 g-sec threshold. The NRC participated in the

review of this project and endorsed its results in RG 1.166 as part of the OBE exceedance criteria.

Regarding part b) of the RAI, the industry presented its position in the May meeting that there is no known earthquake occurrence/data that contradicts the basis for the CAV threshold criterion of RG 1.166. The use of the CAV parameter, along with the 0.16 g-sec threshold remains valid. The requested additional research to study the implications of strong motion recordings near industrial sites since 1980 is considered to be unwarranted from a technical standpoint (the CAV threshold was set at a very conservative level). At the conclusion of the May 11-12, 2006 meetings, the NRC requested that the industry describe its position together with a brief summary to address the request associated with describing the basis for selecting the 0.16 g-sec CAV (RAI (a) above). In addition, the NRC commented that they would research the question relating to the new earthquake effects on the CAV value to determine if there was a more specific basis for requesting a detailed assessment of this issue. The following information represents the response to request a) above.

Selection of the CAV Threshold Damage Value

The CAV concept was developed in Reference 1, which concluded that the CAV was the best single parameter for determining the damage threshold of earthquake ground motion. The procedure for determining the CAV was further refined in Reference 2, which standardized the computational algorithm to be used to determine the CAV value associated with a given free-field acceleration time-history record. The CAV is the integration of the absolute value of ground acceleration over successive one-second intervals of a free-field acceleration time-history for which the absolute value of the recorded acceleration exceeds 0.025 g. Over 177 seismic records were used in the study (Reference 2) along with a Modified Mercalli Intensity (MMI) value assigned to each record site.

In general, the assignment of the MMI intensity associated with each record site was based on published isoseismic maps for a given earthquake event. In some cases, the MMI intensity associated with a given record site was based on actual damage noted in the vicinity of the site. Reference 1 provides full documentation of the sources used for determination of MMI intensity for the record sites. The CAV value was computed for each site record and then correlated with the assigned site intensity value. The threshold of damage potential was chosen conservatively as MMI intensity VII for which there is "negligible damage to buildings of good design and construction" (see Reference 1 for definition). Reference 2 determined that the threshold CAV value associated with MMI VII was 0.16 g-sec. This value was chosen as the lowest CAV value associated with site MMI intensity VII, which is the

record associated with (i.e., closest to) the Pasadena Power Plant in the 1987 Whittier earthquake. The plant had no damage due to the earthquake.

Figure 1 shows the entire set of 177 CAV values from Reference 2 plotted against the assigned site MMI intensity. Note that CAV values as high as 3 occur for sites with MMI site intensity VII. The goal of the studies documented in References 1 and 2 was to establish a screening value which could be used as justification for continued nuclear plant operation following an earthquake, given that the threshold CAV determined from site (free-field) records was not exceeded.

Reference 2 identifies the records associated with the El Centro Steam Plant during the 1979 Imperial Valley earthquake as having the lowest CAV values (0.77 - 0.94) associated with minor damage to a power plant facility. The site intensity was identified as MMI VIII. There were four horizontal strong motion records associated with the plant site 1) two records from the USGS Differential Array (2400 ft. from Unit 4 of the plant) and 2) two records from the USGS El Centro Array No. 8 (4000 ft. from Unit 4 of the plant). The noted plant damage was structural only, being minor concrete cracks and buckling of the boiler frame braces. The plant operating units were fully functional following the earthquake.

The El Centro Steam Plant is one of the reference data sites used by the Seismic Qualification Utility Group (SQUG) to establish the Unresolved Safety Issue (USI) A-46 resolution. The minimum CAV value for this plant is identified in Figure 1 as the lowest value for power plant structural damage (EC Array No. 8, CAV = 0.77 & 0.82; Diff. Array, CAV = 0.91 & 0.94). The other lower CAV values indicated in Figure 1 for MMI VIII are for commercial building structures with minor structural damage (CAV > 0.54).

Reference 1 concluded that power plants and other heavy industrial facilities can sustain ground motion levels associated with MMI VIII site intensities and remain functional. The threshold CAV value determined in Reference 2 was purposely chosen to be a conservatively low value associated with MMI VII records representing a non-damaging level to be used as a screening value for continued operation of a nuclear plant following an earthquake.

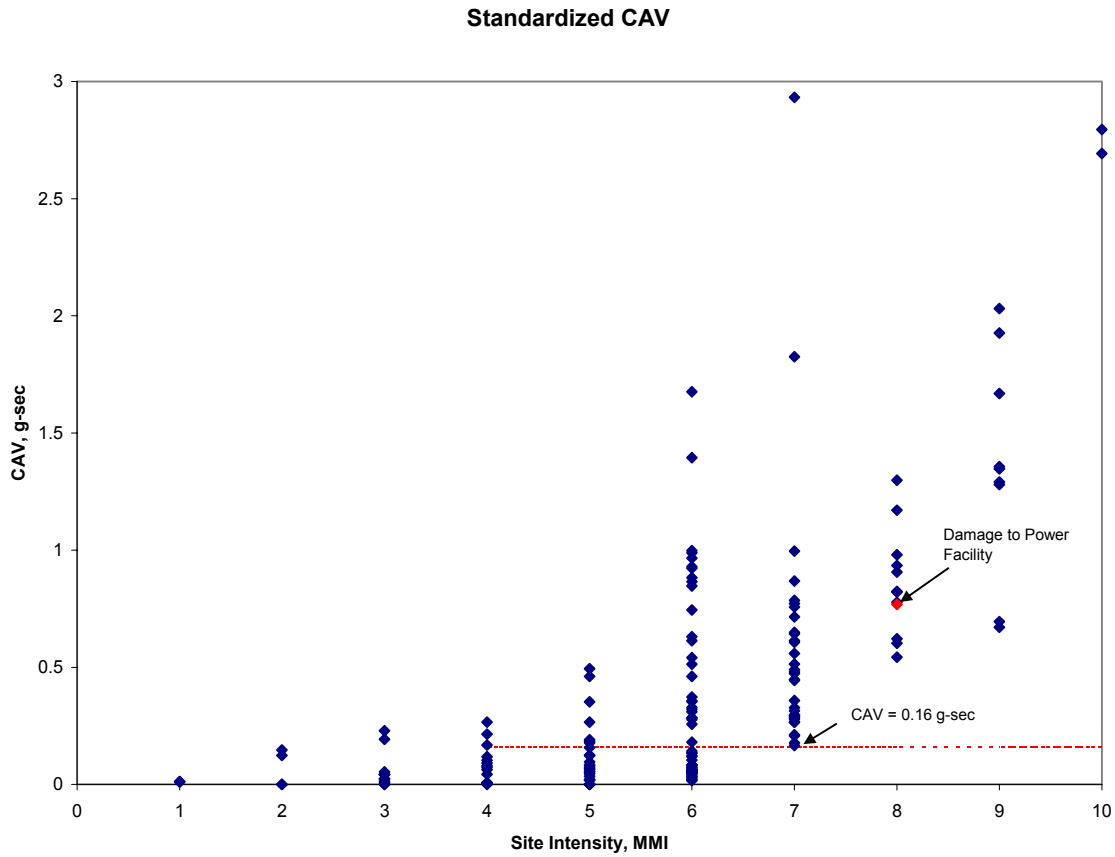
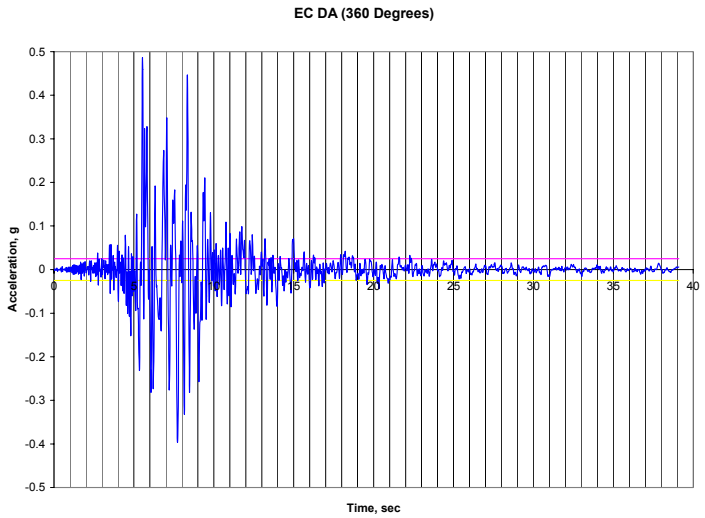


Figure 1. Plot of CAV vs. Site MMI Intensity for 177 Records (Reference 2)

In general, the CAV is a function of the duration of the strong motion portion of the time-history record. If the cumulative value of the CAV is plotted as a function of time using the equation:
CAV(t) =**Error! Objects cannot be created from editing field codes.** where S_i= 0 for $|a| < 0.025g$ and W_i=1 for $|a| \geq 0.025g$ and

zero otherwise, the generation of the total CAV value may be compared to the acceleration time-history. For this calculation, the integration limits, t_i, are taken as integer values of time in seconds. Figure 2 shows a cumulative CAV function plot corresponding to the closest free-field acceleration records associated with the El Centro Steam Plant. This type of presentation indicates that the strong motion portion of each time-history record yields a region where the CAV value accumulates at an approximate constant rate.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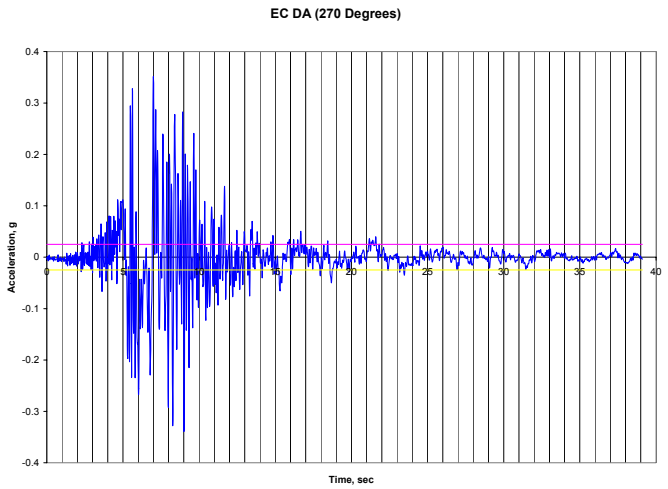
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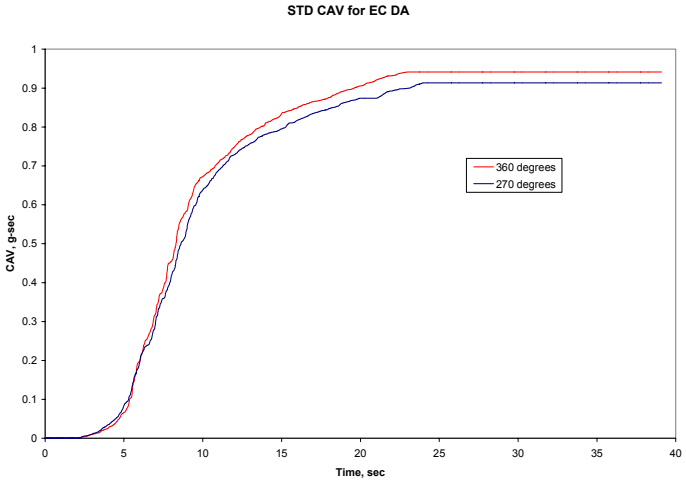
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Figure 2. Time-History Records and Computed CAV Values Associated with the El Centro Steam Plant (Differential Array, 1979 Imperial Valley, CA Earthquake; closest record to plant)

As can be noted in Figure 2, the CAV for the El Centro Steam Plant includes the strong motion portion (5-10 sec) that contributes approximately 60% of the total CAV value. The remaining portion of the CAV value is due to the initial 2-5 sec rise time and the 10-23 sec decay time of the records. Thus, the computed CAV value is always larger than the strong motion contribution resulting in a conservative damage measure when used as a low bound exclusion criterion.

The damage threshold CAV value of 0.16 g-sec, selected in Reference 2, was based on the observed negligible structural damage associated with MMI VII for buildings of good design and construction. Since power plants have been subjected to earthquake motions with observed MMI VIII levels and have remained functional, the selected threshold CAV value of 0.16 g-sec which is associated with MMI VII can also be interpreted as a conservative measure of threshold functional damage.

If a motion, either a design time-history or an actual acceleration record, is associated with a given power plant site, then we can state, with high confidence, that no functional damage should occur to components within that plant (given the primary caveats are satisfied, i.e. adequate anchorage, sufficient restraint, lack of spatial interaction, etc.). This is the underlying basis for the CAV threshold criteria included in Regulatory Guide 1.166 as an optional method for determining Operating Basis Earthquake exceedance in the case of a seismic event occurring in the vicinity of an operating nuclear power plant.

Conclusion

The CAV threshold value of 0.16 g-sec, included in RG 1.166 and based on the documented EPRI studies, represents a very conservative value for use as threshold in developing a conditional probability function that filters non-damaging earthquakes (i.e., low Magnitude events) from the seismic hazard analysis.

References:

1. "A Criterion for Determining Exceedance of the Operating Basis Earthquake", EPRI NP-5930, July 1988.
2. "Standardization of the Cumulative Absolute Velocity", EPRI TR-100082, December 1991.