A Criterion for Determining Exceedance of the Operating Basis Earthquake

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ABSTRACT

A criterion is recommended for determining whether the Operating Basis Earthquake (OBE) has been exceeded after the occurrence of a seismic event at a nuclear power plant. The technical procedure provides a fast and effective means for assessing the damage potential of any "felt" earthquake in the first few hours after occurrence. For OBE exceedance to occur, the recommended criterion requires exceedance of both a response spectrum parameter and a second damage parameter, referred to as the Cumulative Absolute Velocity (CAV).

INTRODUCTION

Recently there have been several small-magnitude earthquake ground motions which have exceeded the Operating Basis Earthquake (OBE) design response spectrum at high frequencies at newly-constructed nuclear power plants. Although no damage occurred a great deal of effort was required, after the fact, to prove this to be true. It is probable that there will be more earthquakes with predominately high-frequency, low-energy ground motions occurring in the eastern U.S. in the future. However, experience has shown that these types of earthquake motions are non-damaging to buildings of good design and construction, and especially to nuclear power plant structures and equipment, which have a high level of seismic capacity.

In recognition of the need to develop a rational criterion for determining when the OBE has been exceeded, the Electric Power Research Institute (EPRI) formed the OBE Exceedance Working Panel (the Panel). The Panel consisted of industry consultants and nuclear utility and NRC representatives, who developed the recommended two-level criterion for determining OBE exceedance which is presented in this paper [1].

PROJECT BACKGROUND AND APPROACH

The Panel focused its efforts first on determining what constitutes a potentially damaging earthquake motion and second on developing a conservative criterion for determining OBE exceedance. The emphasis here is on potentially damaging earthquake motions. The Panel studied the large amount of general earthquake experience data for structures and equipment which have been collected over the years including the most recent earthquake data for conventional power plants and heavy industrial facilities. This data has formed the primary basis for determining ruggedness of equipment in nuclear power plants [2]. Both this data, and the broad professional experience of the Panel were employed to develop a conservative but realistic criterion for determining whether the OBE has been exceeded.

The Panel defines an earthquake motion which is potentially damaging to nuclear power plants (i.e., an earthquake motion at the site which exceeds the OBE) as a ground motion at the site that not only exceeds the OBE response spectrum but also is potentially damaging to buildings of good design and construction. This comparison introduces an inherent conservatism, because most earthquake damage data are available for only conventional buildings. Since nuclear power plants are designed and constructed to a higher seismic standard than buildings of good design or construction, which may or may not have been seismically designed, the criterion is conservative.

The issue of earthquake-induced relay chatter has not been explicitly addressed by the Panel in establishing the OBE exceedance criterion. However, the Panel believes that relay chatter, while an important issue to resolve, is not a concern important to the determination of OBE exceedance, and it was not considered further in developing the OBE exceedance criterion given herein. In addition, there is the possibility that the plant may shut down even though the OBE exceedance criterion indicates that the OBE was not exceeded. For example, the turbine may trip due to the actuation of protective relays, damage may occur to transmission lines or ceramic insulators in the switchyard, offsite power may be lost, or there may be voluntary action by the plant operators. Under these conditions the plant should be allowed to start-up under normal operating procedures after a plant walkdown and systems status check. The subject of plant restart following an earthquake is being addressed in a current EPRI study (EPRI project 2848-21).

The Panel has defined that an earthquake motion at a site has exceeded the OBE if its response spectrum exceeds the OBE design response spectrum at frequencies between 2 and 10 Hz, and the earthquake motion is potentially damaging to buildings of good design and construction¹, which are conservative surrogates for the seismic capacity of nuclear power facilities.

The basis for the criterion is supported from three perspectives. First, a study of selected engineering parameters was performed by analyzing recorded earthquake time histories and associated damage. As discussed below a study which related the parameters to the MMI scale and also directly to damage descriptions was performed. Next, a review of earthquake experience of equipment at conventional power and heavy industrial facilities was conducted. Finally, the use of blast and equipment vibration data to determine potential for damage due to high-frequency, short-duration earthquakes and code requirements for cyclic high-frequency loading were investigated.

OBE EXCEEDANCE CRITERION

Based on the engineering characteristics of ground motion and the investigation of earthquake records and associated damage as discussed in this paper, the Panel recommended the following two-level criterion for conservatively determining when an earthquake motion at the site has exceeded the OBE at a nuclear power plant. A more detailed definition of the OBE exceedance criterion, which can be directly implemented at nuclear power plants, is given in Reference 1.

The OBE is considered to have been exceeded if:

¹This term is taken from the description given in the MMI scale and refers to buildings which have reasonable earthquake protection, but have not necessarily been designed by an engineer (e.g., block and brick walls reinforced with steel, and wood-framed houses which are anchored to their foundations).

1. Response Spectrum Check: The 5 percent-damped ground response spectrum for the earthquake motion at the site at frequencies between 2 and 10 hz, exceeds the corresponding OBE design response spectrum or 0.20 g, whichever is greater,
and
2. CAV Check: The computed CAV value from the earthquake record is greater than 0.30 g-sec.

The first check relies on processed ground response spectra obtained from instrumentation commonly installed at nuclear power plants. The second check may require that additional processing equipment be available.

The new parameter introduced is referred to as the Cumulative Absolute Velocity (CAV). This parameter conservatively defines the threshold of damage for nuclear power plant structures and equipment. It is an optional second check when the response spectrum check leads to an exceedance. The CAV is defined as follows:

$$CAV = \int_0^{t_{max}} |a(t)| dt$$

where:

$a(t)$ = acceleration time history

t_{max} = duration of record

This parameter is the absolute area under the accelerogram and is sensitive to potentially damaging low-frequency motions but less sensitive to high-frequency motions which are non-damaging.

Thus, if either the recorded response spectrum or CAV value is less than the corresponding threshold limit (e.g., 0.20 g for a 5 percent-damped ground response spectrum comparison or 0.30 g-sec for the CAV comparison) the OBE has not been exceeded. The response spectrum check is usually more conservative than the CAV check since it might indicate exceedance if localized spectral peaks exist, even though the total energy of ground motion was insufficient to cause damage. Therefore, computing the CAV value may indicate that the OBE has not been exceeded even though the response spectrum check indicates exceedance, thereby avoiding an unnecessary shutdown. Figure 1 summarizes the recommended general requirements for OBE exceedance. Detailed implementation requirements and the engineering basis for the criterion are given in Reference 1.

Notwithstanding the conservatism of this criterion, the Panel recommends as a matter of prudence that a walkdown of the normally accessible areas and a systems check of the plant be conducted after any felt earthquake motion at the site as an added assurance that no damage has occurred. The extent of such a walkdown and systems check should be consistent with the felt conditions at the plant. The details of the walkdown and systems status check will be addressed in EPRI project RP2848-21.

Finally, the Panel does not recommend an automatic immediate plant shutdown if the criterion is exceeded. Plant operating conditions must also be considered.

ENGINEERING BASIS FOR OBE EXCEEDANCE CRITERIA

The Panel reviewed the various parameters which have been used in the past to assess the damage potential of earthquake ground motions. The following

Figure 1. General Requirements for OBE Exceedance.

parameters were ultimately pursued: (1) Arias Intensity, (2) CAV, (3) PGA, (4) Peak Spectral Acceleration, and (5) Averaged Spectral acceleration.

A total of 263 time histories were selected and analyzed. The following steps were performed in the investigation of each of the parameters selected for study:

- a. Compute the parameter value for each earthquake record.
- b. Pair each computed parameter value with the corresponding MMI intensity for the station at which the record was obtained.
- c. Find the record with the lowest parameter value (this value is the parameter threshold) for which the intensity is greater than MMI VI (i.e., MMI equal to VII).
- d. Count the number of earthquake records with MMI VI or less which have parameter values above the threshold (these records represent those cases for which the parameter would erroneously, but conservatively, predict potential damage to buildings of good design and construction).

The objective of the analysis was to find those parameters for which the number of records with MMI VI or less, above the threshold, was a minimum.

The Panel selected MMI VI as a conservative measure of damage to buildings of good design and construction at which there is reasonable engineering assurance that no damage will occur to nuclear power plant structures or equipment. The

MMI damage descriptions for structures taken from the 1931 unabridged MMI scale were studied, and it was concluded that MMI VI is conservative and at least two MMI units less than the earthquake intensity required to potentially damage buildings of good design and construction (i.e., failure requires at least MMI VIII). Based on a detailed review of earthquake response at conventional power and heavy industrial facilities damage to these facilities does not even begin until MMI VIII.

In summary, based on the analysis of earthquake records and correlation with MMI data, the CAV was found to be the best parameter for determining the damage threshold of earthquakes. The CAV has a threshold value of 0.30 g-sec (i.e., value below which no events have damage greater than MMI VI). Arias intensity, based on filtered records, is a close second with a threshold value of 0.007 g-sec². The spectral acceleration parameter was retained because of past experience and usage.

There was concern for the uncertainty associated with calculated or inferred intensities, and therefore they should not be used as a basis for the threshold values. In view of this, the Panel assessed the available seismic records and identified those records where there was well-documented damage to buildings and structures in the vicinity of the recording stations. This approach eliminates the need to depend on MMI values, which are subjectively determined and subject to some interpretation.

There were 90 records for which the Panel feels confident of the correlation between ground motion and damage. If only these records are considered, both the threshold response spectrum and the CAV parameter values, established using all the records, are shown to be conservative for determining potentially damaging earthquakes. That is, there were no earthquake records for which damage was observed, that had response spectrum or CAV values below the corresponding threshold values. All other records reviewed, which included many calculated or inferred intensities, were also compared with the response spectrum and CAV parameters and in all cases were consistent with the established thresholds. Consequently, the criterion can be justified solely from comparison with well-documented damage from known ground motions. As discussed above, this conclusion was also substantiated for earthquakes with calculated or inferred intensities.

The following three damage data categories were defined for direct correlation with damage (or non-damage):

<u>Damage Data Category</u>	<u>Description</u>
0	Category 0 is for industrial or power facilities which contain engineered structures and equipment. Written description (or detailed verbal description) of damage (or lack of damage) is available in order to determine whether damage (D) or non-damage (N) had occurred.
1	Category 1 is for buildings of good design and construction, which have not necessarily been designed by an engineer. Similar to Category 0 direct information is available to determine whether damage (D) or non-damage (N) had occurred.

- 2 Category 2 is for situations where adequate description of damage (non-damage) is not available for determining which damage class (i.e., D or N) to use. However, the Panel based on their experience in studying the recorded time history was able to state whether the earthquake was potentially damaging to buildings of good design and construction.

Note that, in general, the damage determination was made based on structures close to the station where the earthquake records were obtained. In several cases it was known that structures in a more severe damage data category (i.e., for a better engineered structure), at a lower ground motion (i.e., farther from the epicenter) had been damaged. For those cases the damage data category was upgraded. For example, the Pacoima Dam record was assigned a OD classification since industrial facilities farther from the epicenter were damaged.

It was found that cases of non-damage are spread over a wide range of parameter values. For damaging events for categories 0, 1 and 2 the parameter values are relatively high compared to the criterion threshold values. The lowest parameter values for damaging events are as follows:

<u>Damage Data</u> <u>Category/Classification</u>	<u>CAV</u> <u>(g)</u>	<u>SA5%</u> <u>(g-sec)</u>
OD	.867	.962
1D	.510	.435
2D	.889	.373

From these results it is seen that the ground motion levels required to cause damage to buildings of good design and construction are a factor of at least 1.5 greater than the criterion threshold values. This indicates that adequate conservatism is included in the OBE exceedance criterion.

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REFERENCES

- [1] A Criterion for Determining Exceedance of the Operating Basis Earthquake. Palo Alto, California: Electric Power Research Institute, prepared by Jack R. Benjamin and Associates, Inc., July, 1988, NP-5930.
- [2] Use of Seismic Experience Data to Show Ruggedness of Equipment in Nuclear Power Plants. Senior Seismic Review and Advisory Panel, Prepared for Seismic Qualification Utility Group in cooperation with U. S. Nuclear Regulatory Commission, Washington, D. C., October 14, 1987 (DRAFT).