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April 1994

DOE STANDARD

NATURAL PHENOMENA HAZARDS DESIGN AND EVALUATION CRITERIA FOR DEPARTMENT OF ENERGY FACILITIES

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Appendix C

Commentary on Earthquake Design and Evaluation Criteria

C.1. Introduction

Earthquake design and evaluation criteria for DOE structures, systems, and components are presented in Chapter 2 of this standard. Commentary on the DOE earthquake design and evaluation provisions is given in this appendix. Specifically, the basic approach employed is discussed in Section C.2 along with meeting of target performance goals, seismic loading is addressed in Section C.3, evaluation of seismic response is discussed in Section C.4, capacities and good seismic design practice are discussed in Section C.5, special considerations for systems and components and for existing facilities are covered in Sections C.6 and C.7, respectively, and quality assurance and peer review are addressed in Section C.8. Alternate seismic mitigation measures are discussed in Section C.9.

These seismic criteria use the target performance goals to assure safe and reliable performance of DOE facilities during future potential earthquakes. It is to be noted that these ar merely target performance goals which need not be proven mathematically or by probabilistic risk assessments. Design of structures, systems, and components to withst and earthquake ground motion without significant damage or loss of function depends on the following considerations:

1. The SSC must have sufficient strength and stiffness to resist the lateral loads induced by earthquake ground shaking. If an SSC is designed for insufficient lateral forces or if deflections are unacceptably large, damage can result, even to well-detailed SSCs.

2. Failures in low ductility modes (e.g., shear behavior) or due to instability that tend to be abrupt and potentially catastrophic must be avoided. SSCs must be detailed in a manner to achieve ductile behavior such that they have greater energy absorption capacity than the energy content of earthquakes.

3. Building structures and equipment which are base supported tend to be more susceptible to earthquake damage (because of inverted pendulum behavior) than distributed systems which are supported by hangers with ductile connections (because of pendulum restoring forces).

4 The behavior of an SSC as it responds to earthquake ground motion must be fully understood by the designer such that a "weak link" that could produce an unexpected failure is not overlooked. Also, the designer must consider both relative displacement and inertia (acceleration) induced seismic failure modes.

5. SSCs must be constructed in the manner specified by the designer. Materials must be of high quality and as strong as specified by the designer. Construction must be of high quality and must conform to the design drawings.

By this standard, probabilistic performance goals are used as a target for formulating deterministic seismic design criteria. Table C-1 defines seismic performance goals for structures, systems, or components (SSCs) assigned to Performance Categories 1 through 4. SSCs are to be assigned to performance categories in accordance with DOE G 420.1-2 (Ref. C-67) and DOE-STD-1021-93 (Ref. C-26) in that hierarchial order. For Performance Category 3, 4 the seismic performance goals are defined in terms of a permissible annual probability of unacceptable performance P_F (i.e., a permissible failure frequency limit). Seismic induced unacceptable performance should have an annual probability less than or approximately equal to these goals.

Table C-1 Structure, System, or Component (SSC) Performance Goals for Various Performance Categories

Performance Category	Performance Goal Description	Seismic Performance Goal Annual Probability of Exceeding Acceptable Behavior Limits, P_F
1	Maintain Occupant Safety	Onset of SSC[1] damage to the extent that occupants are endangered
2.	Occupant Safety, Continued Operation with Minimum Interruption	SSC damage to the extent that the component cannot perform its function
3.	Occupant Safety, Continued Operation, Hazard Confinement	10^{-4} of SSC damage to the extent that the component cannot perform its function
4.	Occupant Safety, Continued Operation, Confidence of Hazard Confinement	10^{-5} of SSC damage to the extent that the component cannot perform its function

(1) SSC refers to structure, distribution system, or component (equipment).

The performance goals shown in Table C-1 include both quantitative probability values and qualitative descriptions of acceptable performance. The qualitative descriptions of expected performance following design/evaluation levels of earthquake ground motions are expanded in Table C-2. These descriptions of acceptable performance are specifically tailored to the needs in many DOE facilities.

The performance goals described above are achieved through the use of DOE seismic design and evaluation provisions which include: (1) lateral force provisions; (2) story drift/damage control provisions; (3) detailing for ductility provisions; and (4) quality assurance provisions. These provisions are comprised of the following four elements taken together: (1) seismic loading; (2) response evaluation methods; (3) permissible response levels; and (4) ductile detailing requirements. Acceptable performance (i.e., achieving performance goals) can only be reached by consistent specification of all design criteria elements as shown in Figure C-1.

Table C-2 Qualitative Seismic Performance Goals

PC	Occupancy Safety	Concrete Barrier	Metal Liner	Component Functionality	Visible Damage
1	No structural collapse, failure of contents not serious enough to cause severe injury or death, or prevent evacuation	Confinement not required.	Confinement not required.	Component will remain anchored, but no assurance it will remain functional or easily repairable.	Building distortion will be limited but visible to the naked eye.
2	No structural collapse, failure of contents not serious enough to cause severe injury or death, or prevent evacuation.	Concrete walls will remain standing but may be extensively cracked; they may not maintain pressure differential with normal HVAC. Cracks will still provide a tortuous path for material release. Don't expect largest cracks greater than 1/2 inch	May not remain leak tight because of excessive distortion of structure.	Component will remain anchored and majority will remain functional after earthquake. Any damaged equipment will be easily repaired.	Building distortion will be limited but visible to the naked eye.
3	No structural collapse, failure of contents not serious enough to cause severe injury or death, or prevent evacuation	Concrete walls cracked; but small enough to maintain pressure differential with normal HVAC. Don't expect largest cracks greater than 1/8 inch.	Metal liner will remain leak tight	Component anchored and functional.	Possibly visible local damage but permanent distortion will not be immediately apparent to the naked eye.
4	No structural collapse, failure of contents not serious enough to cause severe injury or death, or prevent evacuation	Concrete walls cracked; but small enough to maintain pressure differential with normal HVAC. Don't expect largest cracks greater than 1/8 inch.	Metal liner will remain leak tight.	Component anchored and functional.	Possibly visible local damage but permanent distortion will not be immediately apparent to the naked eye.

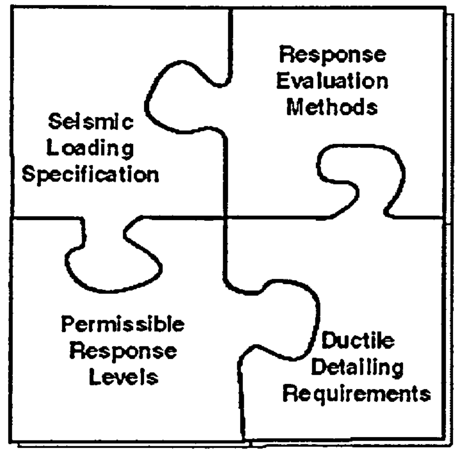

Figure C-1 Consistent Specification of All Seismic Design/Evaluation Criteria Elements

C.2 Basic Approach for Earthquake Design and Evaluation and Meeting Target Performance Goals

C.2.1 Overall Approach for DOE Seismic Criteria

Historical Perspective Since Early Development Using Uniform Building Code Criteria

Structure/component performance is a function of: (1) the likelihood of hazard occurrence and (2) the strength of the structure or equipment item. Consequently, seismic performance depends not only on the earthquake probability used to specify design seismic loading, but also on the degree of conservatism used in the design process as illustrated in Figure C-2. For instance, if one wishes to achieve less than about 10^{-4} annual probability of onset of loss of function, this goal can be achieved by using conservative design or evaluation approaches for a natural phenomena hazard that has a more frequent annual probability of exceedance (such as 10^{-3}), or it can be achieved by using median-centered design or evaluation approaches (i.e., approaches that have no intentional conservative or unconservative bias) coupled with a 10^{-4} hazard definition. At least for the earthquake hazard, the former alternate has been the most traditional. Conservative design or evaluation approaches are well-established, extensively documented, and commonly practiced. Median design or evaluation approaches are currently controversial, not well understood, and seldom practiced. Conservative design and evaluation approaches are utilized for both conventional facilities (similar to DOE PC-1) and for nuclear power plants (similar to DOE PC- 4). For consistency with these other uses, the approach in this standard specifies the use of conservative design and evaluation procedures coupled with a hazard definition consistent with these procedures.

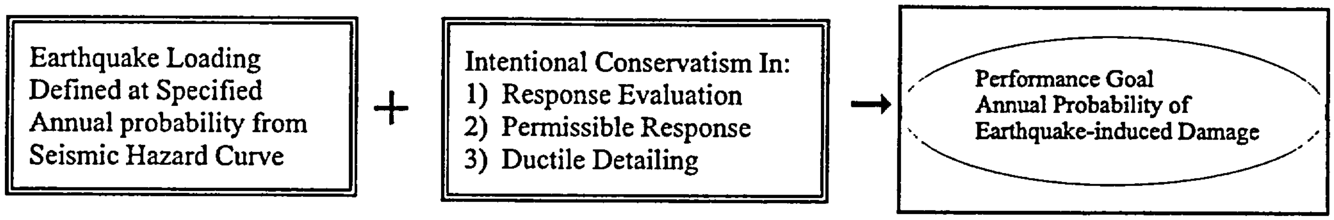

Figure C-2 Performance Goal Achievement

The performance goals for PC-1 SSCs are consistent with goals of model building codes for normal facilities; the performance goals for Performance Category 2 SSCs are slightly more conservative than the goals of model building codes for important or essential facilities. For seismic design and evaluation, model building codes utilize equivalent static force methods except for very unusual or irregular facilities, for which a dynamic analysis method is employed. The performance goals for PC-3 SSC's are consistent with DOE essential facilities and Pu handling facilities. The performance goals for Performance Category 4 SSC's approach those used for nuclear power plants. For these reasons, this standard specifies seismic design and evaluation criteria for PC-1 and PC-2 SSC's corresponding closely to model building codes and seismic design and evaluation criteria for both PC-3 and PC-4 SSC's based on dynamic analysis methods consistent with those used for similar nuclear facilities.

By conceptual development, the DBE is defined at specified hazard probability P_H and the SSC is designed or evaluated for this DBE using an adequately conservative deterministic acceptance criteria. To be adequately conservative, the acceptance criteria must introduce an additional reduction in the risk of unacceptable performance below the annual risk of exceeding the DBE. The ratio of the seismic hazard exceedance probability, P_H to the performance goal probability P_F is defined herein as the risk reduction ratio R_R, given by:

$$R_R = \frac{P_H}{P_F} \qquad \text{(C-1)}$$

Current Status

This concept enunciated above has been carried forward after issuance of IBC 2000. The performance goals achieved with IBC 2000 criteria are better than indicated Appendix B and for intent of this standard are deemed to meet the target performance goals.

In any case, the performance goals given in Appendix B and C for Performance Categories 1 and 2 are for historical purposes from the days of the 1994 Uniform Building

Code and for all intent and purposes the exact numerical values have no practical significance. The numerical values for PC 1 and PC 2 are no longer exact for the seismic provisions of the IBC 2000 which primarily intends to provide uniform margin of collapse for PC 1 SSCs throughout the United States.

The required degree of conservatism in the deterministic acceptance criteria is a function of the specified risk reduction ratio. Table C-3 provides a set of seismic hazard exceedance probabilities, P_H and risk reduction ratios, R_R for Performance Categories 1 through 4 required to achieve the seismic performance goals specified in Table C-1. Note that Table C-3 follows the philosophy of:

1) Annual seismic hazard exceedance of 4×10^{-4} (generally) based on IBC2000 for PC-1 and PC-2, and PC-3 but 1×10^{-4} for PC-4.

2) gradual reduction in hazard annual exceedance probability of other natural phenomena hazards.

3) gradual increase in conservatism of evaluation procedure as one goes from Performance Category 1 to Performance Category 4 (PC 1 to PC 4).

Table C-3 Seismic Performance Goals & Specified Seismic Hazard Probabilities

Performance Category	Target Seismic Performance Goal, P_F	Seismic Hazard Exceedance Probability, P_H	Risk Reduction Ratio, R_R
1	**	*	
2	**	*	
3	$1x10^{-4}$	$4x10^{-4}$* $(1x10^{-3})^1$	4 $(10)^1$
4	$1x10^{5}$	$1x10^{-4}$ $(2x10^{-4})^1$	10 $(20)^1$

* The seismic exceedence probability is based on USGS maps generated in 1997 (and included in IBC 2000) for 2% exceedence probabiity in 50 years. $P_H = 4x10^{-4}$ (Generally). Supplement by deterministic ground motions near very active faults.

** The design methodology of the IBC 2000 for Seismic Use Groups I and III achieves approximately performance goals of PC-1 & PC-2 respectively though it does not meet the relationship shown in equation C-1 for the seismic provisions.

[1] For sites such as LLNL, SNL-Livermore, SLAC, LBNL, and ETEC which are near tectonic plate boundaries.

Different structures, systems, or components may have different specified performance goal probabilities, P_F. It is required that for each structure, system, or component, either: (1) the performance goal category; or (2) the hazard probability (P_H) or the DBE together with the appropriate R_R factor will be specified in a design specification or implementation document that invokes these criteria. As shown in Table C-3, the recommended hazard exceedance probabilities and performance goal exceedance probabilities are different. These differences indicate that conservatism must be introduced in the seismic behavior evaluation approach to achieve the required risk reduction ratio, R_R. In earthquake evaluation, there are many places where conservatism can be introduced, including:

1. Maximum design/evaluation ground acceleration and velocity.
2. Response spectra amplification.
3. Damping.
4. Analysis methods.
5. Specification of material strengths.
6. Estimation of structural capacity.
7. Load or scale factors.
8. Importance factors/multipliers.
9. Limits on inelastic behavior.
10. Soil-structure interaction (except for frequency shifting due to SSI).
11. Effective peak ground motion.
12. Effects of a large foundation or foundation embedment.

For the earthquake evaluation criteria in this standard, conservatism is intentionally introduced and controlled by specifying (1) hazard exceedance probabilities, (2) load or scale factors, (3) importance factors, (4) limits on inelastic behavior, and (5) conservatively specified material strengths and structural capacities. Load factors have been retained for the evaluation of PC-1 and PC-2 SSCs because the IBC approach (which includes these factors) is followed for these categories. These factors are not used for Performance Category 3 and higher SSCs. However, a seismic scale factor SF is used to provide the difference in risk reduction ratio R_R between PC-3 and PC-4. Material strengths and structural capacities specified for Performance Category 3 and higher SSCs correspond to ultimate strength code-type provisions (i.e., ACI 318-99 for reinforced concrete, LRFD, or AISC Chapter N for steel). Material strengths and structural capacities specified for PC-1 and PC-2 SSCs correspond to either ultimate strength or allowable stress code-type provisions. It is recognized that such provisions introduce conservatism. In addition, significant additional conservatism can be achieved if considerations of effective peak ground motion, soil-structure interaction are introduced, and effects of large foundation or foundation embedment are ignored.

The differences in seismic evaluation criteria among categories in terms of load and importance factors, limits on inelastic behavior, and other factors by this standard are summarized below:

1.PC 1 and PC 2	From PC 1 to PC 2, seismic design forces are increased. All other factors are held the same.
2.PC 2 and PC 3	From PC 2 to PC 3, load and importance factors are eliminated, damping is generally increased, and limits on inelastic behavior are significantly reduced. All other factors are essentially the same, although static force evaluation methods are allowed for PC 2 SSCs and dynamic analysis is required for PC 3 SSCs.
3.PC 3 and PC 4	From PC 3 to PC 4, seismic hazard exceedance probability is lowered and a seismic scale factor is used. All other factors are held the same.

The basic intention of the deterministic seismic evaluation and acceptance criteria presented in Chapter 2 is to achieve less than a 10% probability of unacceptable performance for a structure, system, or component (SSC) subjected to a Scaled Design/Evaluation Basis Earthquake (SDBE) defined by:

$$SDBE = (1.5SF)\ (DBE) \qquad \text{(C-2)}$$

where SF is the appropriate seismic scale factor (SF is 0.9 for PC 3 and 1.25 for PC 4). The seismic evaluation and acceptance criteria presented in this standard has intentional and controlled conservatism such that the required risk reduction ratios, R_R, and target performance goals are achieved. The amount of intentional conservatism has been evaluated in Reference C-20 as that there should be less than 10% probability of unacceptable performance at input ground motion defined by a scale factor of 1.5SF times the DBE. Equation C-2 is useful for developing alternative evaluation and acceptance criteria which are also based on the target performance goals.

It is permissible to substitute alternate acceptance criteria for those criteria defined in Chapter 2 so long as these alternate criteria will also reasonably achieve less than about a 10% probability of unacceptable performance for the combination of the SDBE defined by Equation C-2 with the best-estimate of the concurrent non-seismic loads. This relief is permitted to enable one to define more sophisticated alternate acceptance criteria than those presented in Chapter 2 when one has a sufficient basis to develop and defend this alternate criteria.

C.2.2 Influence of Seismic Scale Factor

The target performance goals are the basis of the seismic design and evaluation criteria presented in this standard. For PC 3 and PC 4, target performance goals, P_F, of 1×10^{-4} and 1×10^{-5}, respectively, are met in a more approximate manner as illustrated in this section. The variability in performance goal achievement can be most significantly attributed to the uncertainty in the slopes of seismic hazard curves from which DBE ground motion is determined.

Over any ten-fold difference in exceedance probabilities, seismic hazard curves may be approximated by:

$$H(a) = Ka^{-k_H} \qquad \text{(C-3)}$$

where H(a) is the annual probability of exceedance of ground motion level "a," K is a constant, and k_H is a slope parameter. Slope coefficient, A_R is the ratio of the increase in ground motion corresponding to a ten-fold reduction in exceedance probability. A_R is related to k_H by:

$$k_H = \frac{1}{\log(A_R)} \qquad \text{(C-4)}$$

The Basis for Seismic Provisions of DOE-STD-1020 (Ref. C-20) presents estimates of seismic hazard curve slope ratios A_R for typical U.S. sites over the annual probability range of 10^{-3} to 10^{-5}. For eastern U.S. sites, A_R typically falls within the range of 2 to 4 although A_R values as large as 6 have been estimated. For California and other high seismic sites near tectonic plate boundaries with seismicity dominated by close active faults with high recurrence rates, A_R typically ranges from 1.5 to 2.25. For other western sites with seismicity not dominated by close active faults with high recurrence rates such as INEL, LANL, and Hanford, A_R typically ranges from 1.75 to 3.0. Therefore, seismic design/evaluation criteria should be applicable over the range of A_R from 1.5 to 6 with emphasis on the range from 2 to 4.

DOE seismic design and evaluation criteria presented in Chapter 2 is independent of A_R and, thus, does not reflect its effect on meeting target goals. The performance of structures, systems, and components in terms of annual probability of exceeding acceptable behavior limits can be evaluated by convolution of seismic hazard and seismic fragility curves. Seismic fragility curves describe the probability of unacceptable performance versus ground motion level. The fragility curve is defined as being lognormally distributed and is expressed in terms of two parameters: a median capacity level, C_{50}, and a logarithmic standard deviation, β. β expresses the uncertainty in the capacity level and generally lies within the range of 0.3 to 0.6. For DBE ground motion specified at annual probability, P_H, it is shown in Ref. C-20 that the risk reduction ratio, R_R, between the annual probability of exceeding the DBE and the annual probability of unacceptable performance is given by:

$$R_R = \left(C_{50} / DBE\right)^{k_H} e^{-\frac{1}{2}\left(k_H\beta\right)^2} \qquad \text{(C-5)}$$

where C_{50} and β define the seismic fragility curve and DBE and k_H define the seismic hazard curve.

Using the basic criterion of DOE-STD-1020 that target performance goals are achieved when the minimum required 10% probability of failure capacity, C_{10} is equal to 1.5 times the seismic scale factor, SF, times the DBE ground motion, Equation (C-5) may be rewritten as:

$$R_R = (1.5SF)^{k_H} e^{\left[1.282k_H\beta - \frac{1}{2}\left(k_H\beta\right)^2\right]} \qquad \text{(C-6)}$$

Equation (C-6) demonstrates the risk reduction ratio achieved by DOE seismic criteria as a function of hazard curve slope, uncertainty, and seismic scale factor, SF. Note from Table C-3 that for PC-4 (not near tectonic plate boundaries), the hazard probability is 1×10^{-4} and the performance goal is 1×10^{-5} such that the target risk reduction ratio, R_R is 10 and for PC-3, the hazard probability is 4×10^{-4} and the performance goal is 1×10^{-4} such that the target risk reduction ratio, R_R is 4. The actual risk reduction ratios from Equation (C-6) versus slope coefficient A_R are plotted in Reference C-20 for Performance Categories 3 and 4, respectively. In these figures, SF of 0.9 is used for PC 3 and SF of 1.25 is used for PC 4 and the range of from 0.3 to 0.6 has been considered. For the hazard curves considered by DOE-STD-1023-92 (Ref. C-13), A_R values average about 3.2 in the probability range associated with PC 3 and about 2.4 in the probability range associated with PC 4. More recent seismic hazard studies (Ref. C-6) gives A_R values which average about 3.8 in the probability range associated with PC 3 and about 3.0 in the probability range associated with PC 4.

Figures in Reference C-20 demonstrate that for SF= 0.9 risk reduction ratios between about 3 and 10 are achieved over the A_R range from 2 to 6. These risk reduction ratios support achieving performance goals between about 2×10^{-4} to 5×10^{-5}. In the primary region of interest of A_R between 2.5 and 4, risk reduction ratios from 4 to 6 are achieved as compared to the target level of 4 for PC 3 and sites not near tectonic plate boundaries. Figures in Reference C-20 demonstrate that for SF = 1.25, risk reduction ratios between about 3 and 20 are achieved over the A_R range from 2 to 6. These risk reduction ratios support achieving performance goals between about $3x10^{-5}$ to $5x10^{-6}$. In the primary region of interest of A_R between 2 and 3, risk reduction ratios from about 8 to 17 are achieved as compared to the target level of 10 for PC 4 and sites not near tectonic plate boundaries.

The risk reduction ratio achieved may be improved by using a variable formulation of SF which is a function of A_R. In order to justify use of the variable scale factor approach, the site specific hazard curve must have a rigorous pedigree. Reference C-20 demonstrates that the SF factors shown in Reference C-20 give the best fit of R_R over the A_R range of primary interest from about 2 to about 6. The use of the scale factors given in Figures in Reference C-20 combined with Equation C-6 improves the R_R values compared to target values as shown in Figures in Reference C-20 for PC 3 ($R_R = 4$) and PC 4 ($R_R = 10$), respectively. Figures in Reference C-20 demonstrate that when the variable scale factors are used, risk reduction factors achieved are within about 10% of the target values of 4 and 10, respectively. As a result, target performance goals would be met within about the same 10%.

It is to be noted that the information in Ref. C-20 may need to be adjusted to new P_H value of $4x10^{-4}$ for PC-3 SSCs, with $R_R = 4$. The variable scale Factor is altered from that in Ref. C-20 and becomes, SF = maxium (0.9, $.6A_R{}^{0\,4}$). If the variable scale factor is significantly larger, it should be used instead of 0.9 and 1.25 for PC-3 and PC-4 respectively. This is particularly significant at low seismicity sites.

For sites near tectonic plate boundaries for which A_R is in the range of about 1.5 to 2.25, such as LLNL, SNL-Livermore, SLAC, LBL, and ETEC. Figures in Reference C-20 demonstrate that larger risk reduction ratios are achieved than the target levels of 4 for PC 3 and 10 for PC 4, respectively. Therefore, it is acceptable to use twice the hazard probabilities for these sites combined with the appropriate constant scale factors. Hence, for sites near tectonic plate boundaries, target performance goals may be adequately achieved with hazard probabilities and seismic scale factors of $1x10^{-3}$ and 1.0 for PC 3 and $2x10^{-4}$ and 1.25 for PC 4.

C.3 Seismic Design/Evaluation Input

The seismic performance goals presented in Tables C-1 and C-2 are achieved by defining the seismic hazard in terms of a site-specified design response spectrum (called herein, the Design/Evaluation Basis Earthquake, [DBE]). Either a site-specific design response spectrum specifically developed for the site, or a generic design response spectrum that is appropriate or conservative for the site may be used as the site-specified design response spectrum. Probabilistic seismic hazard estimates are used to establish the DBE. These hazard curves define the amplitude of the ground motion as a function of the annual probability of exceedance P_H of the specified seismic hazard.

An annual exceedance probability for the DBE, P_H is specified from which the maximum ground acceleration (or velocity) may be determined from probabilistic seismic hazard curves. Evaluating maximum ground acceleration from a specified annual probability of exceedance is illustrated in Figure C-3. Earthquake input excitation to be used for design and evaluation by these provisions is defined by a median amplification smoothed and broadened design/evaluation response spectrum shape such as that shown in Figure C-3 anchored to this maximum ground acceleration. Note that the three spectra presented in Figure C-3 are identical; the top spectrum has spectral acceleration plotted against natural frequency on a log scale, the middle spectrum is on what is termed a tripartite plot where spectral velocities and displacements as well as accelerations are shown, and the bottom spectrum has spectral acceleration plotted against natural period on a linear scale.

It should be understood that the spectra shown in Figure C-3 represent inertial effects. They do not include relative or differential support motions of structures, equipment, or distribution systems supported at two or more points typically referred to as seismic anchor motion (SAM). While SAM is not usually applicable to building design, it might have a significant effect on seismic adequacy of equipment or distribution systems.

Seismic design/evaluation criteria based on target probabilistic performance goals requires that Design/Evaluation Basis Earthquake (DBE) motions be based on probabilistic seismic hazard assessments. In accordance with DOE Order 420.1 and the associated Guide (Ref. C-27 and C-67), it is not required that a site-specific probabilistic seismic hazard assessment be conducted if the site includes only PC-1 and PC-2 SSCs. If such an assessment has not been performed, it is acceptable to determine seismic loads (as summarized in Section C.3.2.2) from those determined in accordance with the IBC (Ref. C-28). Design/evaluation earthquake ground motion determined from a recent site-specific probabilistic seismic hazard assessment is considered to be preferable to the IBC 2000 but cannot be lower than limitations in the IBC 2000.

For design or evaluation of SSCs in Performance Category 3 and higher, a modern site-specific seismic hazard assessment shall be performed to provide the basis for DBE ground motion levels and response spectra (See DOE-STD-1023). DOE Order 420.1 and the associated NPH Guide (Refs. C-27 and C-67), require that the need for updating the site seismic hazard assessment be reviewed at least every 10 years.

Minimum values of the DBE are provided in Section 2.3 to assure a minimum level of seismic design at all DOE sites. Such a minimum level of seismic design is believed to be necessary due to the considerable uncertainty about future earthquake potential in the lower seismicity regions of the United States where most DOE sites are located.

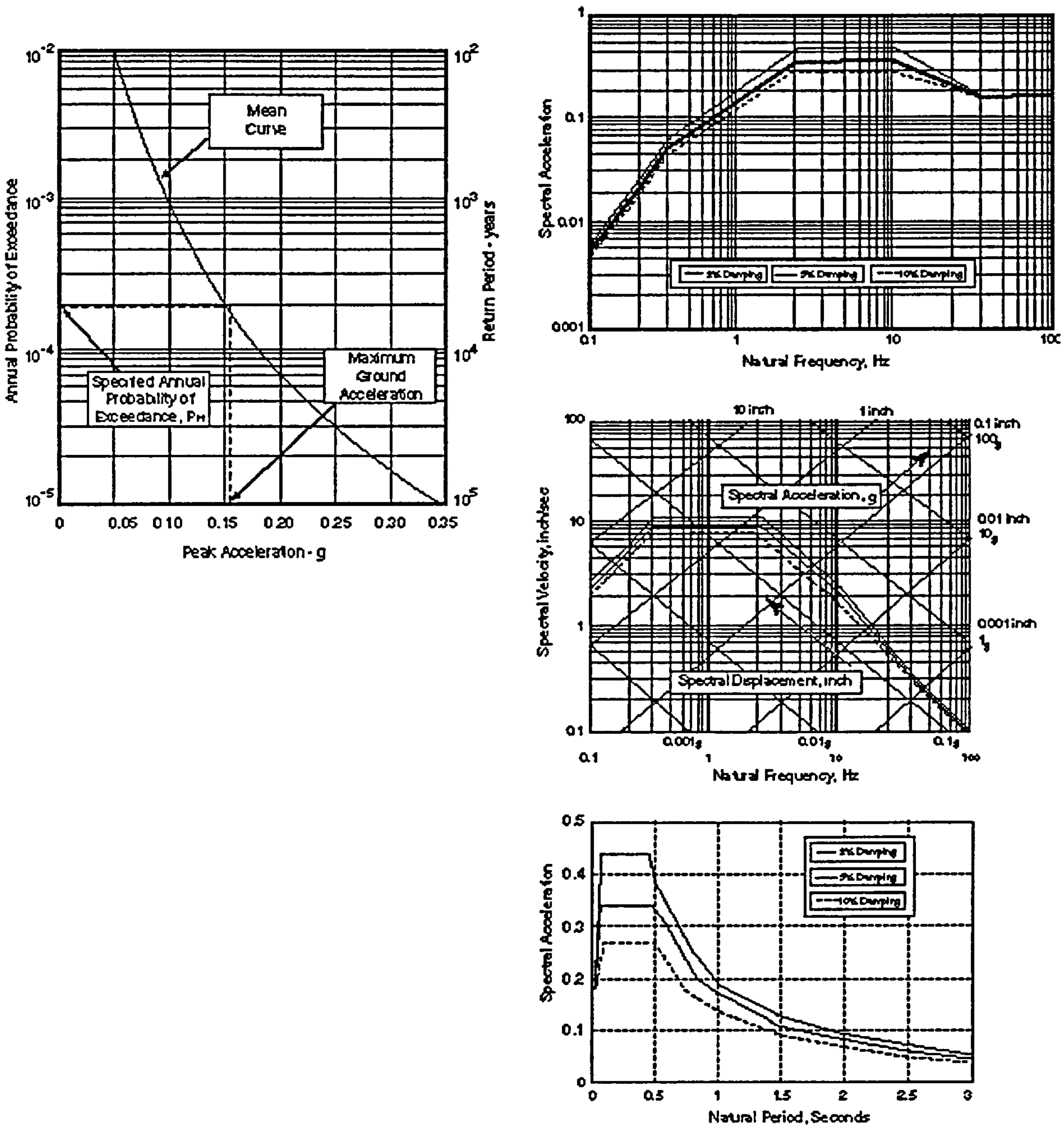

Figure C-3 Earthquake Input Excitation is Defined by Maximum Ground Acceleration Anchoring Site-Specific Response Spectra

C.3.1 Earthquake Hazard Annual Exceedance Probabilities

Historically, non-Federal Government General Use and Essential or Low Hazard facilities located in California, Nevada, and Washington have been designed for the seismic hazard defined in the Uniform Building Code. Other regions of the U.S. have used the UBC seismic hazard definition, other building code requirements, or have ignored seismic design. Past UBC seismic provisions (1985 and earlier) are based upon the largest earthquake intensity that has occurred in a given region during about the past 200 years. These provisions do not consider the probability of occurrence of such an earthquake and thus do not make any explicit use of a probabilistic seismic hazard analysis. However, within the last 20 years there have been developments in building codes in which the seismic hazard provisions are based upon a consistent annual probability of exceedance for all regions of the U.S. In 1978, ATC-3 provided probabilistic-based seismic hazard provisions (Ref. C-1). From the ATC-3 provisions, changes to the UBC (Ref. C-2) and the development of the National Earthquake Hazards Reduction Program (NEHRP, Ref. C-3) have resulted. A probabilistic-based seismic zone map was incorporated into the UBC beginning with the 1988 edition. Canada and the U.S. Department of Defense have adopted this approach (Refs. C-4 and C-5). The suggested annual frequency of exceedance for the design seismic hazard level differs somewhat between proposed codes, but all lie in the range of 10^{-2} to 10^{-3}. For instance, UBC (Ref. C-2), ATC-3 (Ref. C-1), and NEHRP (Ref. C-3) have suggested that the design seismic hazard level should have about a 10 percent frequency of exceedance level in 50 years which corresponds to an annual exceedance frequency of about $2x10^{-3}$. The Canadian building code used $1x10^{-2}$ as the annual exceedance level for their design seismic hazard definition. The Department of Defense (DOD) tri-services seismic design provisions for essential buildings (Ref. C-5) suggests a dual level for the design seismic hazard. Facilities should remain essentially elastic for seismic hazard with about a 50 percent frequency of exceedance in 50 years or about a $1x10^{-2}$ annual exceedance frequency, and they should not fail for a seismic hazard which has about a 10 percent frequency of exceedance in 100 years or about $1x10^{-3}$ annual exceedance frequency. Recently the IBC 2000 has adopted use of USGS maps for 2% exceedence probability in 50 years based on NEHRP 1997 provisions. These are being incorporated in this standard for PC-1 and PC-2 facilities.

On the other hand, nuclear power plants are designed so that safety systems do not fail if subjected to a safe shutdown earthquake (SSE). The SSE generally represents the expected ground motion at the site either from the largest historic earthquake within the tectonic province within which the site is located or from an assessment of the maximum earthquake potential of the appropriate tectonic structure or capable fault closest to the site. The key point is that this is a deterministic definition of the design SSE. Recent probabilistic hazard studies (e.g., Ref. C-6) have indicated that for nuclear plants in the eastern U.S., the design SSE level generally corresponds to an estimated annual frequency of exceedance of between $0.1x10^{-4}$ and $10x10^{-4}$ as is illustrated in Figure C- 4. The probability level of SSE design spectra (between 5 and 10 hz) at the 69 eastern U.S. nuclear power plants considered by Ref. C-6 fall within the above stated range. Figure C-4 also demonstrates that for 2/3 of these plants the SSE spectra corresponds to probabilities between about $0.4x10^{-4}$ and $2.5x10^{-4}$. Hence, the specified hazard probability level of $1x10^{-4}$ in this standard is consistent with SSE levels. (See also U.S. NRC Regulatory Guide 1.165)

These seismic hazard definitions specified in this standard are appropriate as long as the seismic design or evaluation of the SSCs for these earthquake levels is conservatively performed. The level of conservatism of the evaluation for these hazards should increase as one goes from PC-1 to PC-4 SSCs. The conservatism associated with Performance Categories 1 and 2 should be consistent with that contained in the IBC (Ref. C-28), or NEHRP (Ref. C-68) for normal or essential facilities, respectively. The level of conservatism in the seismic evaluation for Performance Category 4 SSCs should approach that used for nuclear power plants when the seismic hazard is designated as shown above. In general for majority of DOE sites, the criteria contained herein follow the philosophy of a gradual increase in the conservatism of the evaluation procedures and acceptance criteria as one goes from Performance Category 1 to Performance Category 4.

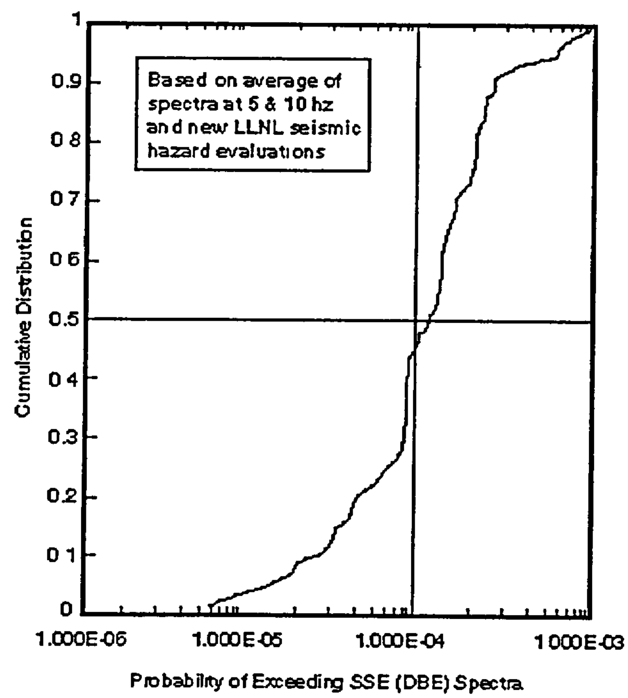

Figure C-4 Probability of Exceeding SSE Response Spectra

C.3.2 Earthquake Ground Motion Response Spectra

Design/evaluation Basis Earthquake (DBE) response spectra generally have the shape shown in Figure C-3. The DBE spectrum shape is similar to that for an actual earthquake except that peaks and valleys that occur with actual earthquake spectra are smoothed out. Also, design/evaluation spectra typically include motions from several potential earthquakes such that they are broader in frequency content than spectra computed for actual earthquake ground