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ABSTRACT

It is the policy of the Department of Energy (DOE) to design, construct, and operate DOE facilities so that workers, the general public, and the environment are protected from the impacts of natural phenomena hazards (NPH). Furthermore, DOE has established explicit goals of acceptable risk for NPH performance. As a result, natural phenomena hazard (earthquake, extreme wind, and flood) design and evaluation criteria for DOE facilities have been developed based on target probabilistic performance goals. These criteria include selection of design/evaluation NPH input from probabilistic hazard curves combined with commonly practiced deterministic response evaluation methods and acceptance criteria with controlled levels of conservatism. For earthquake considerations, conservatism is intentionally introduced in specification of material strengths and capacities, in the allowance of limited inelastic behavior, and by a seismic scale factor. Criteria have been developed following a graded approach for several performance goals ranging from that appropriate for normal-use facilities to that appropriate for facilities involving hazardous or critical operations. Performance goals are comprised of qualitative expressions of acceptable behavior and of target quantitative probabilities that acceptable limits of behavior are maintained. The criteria are simple procedures but have a rigorous basis. This paper addresses DOE seismic design and evaluation criteria.

INTRODUCTION

Seismic design and evaluation criteria for DOE facilities have been developed which are based on target performance goals. The use of DOE seismic criteria as well as criteria for other natural phenomena hazards is typically closely tied with the preparation of safety analysis reports as governed by Ref. 17. Meeting performance goals is desirable because they are needed for compliance with risk-based DOE safety policy and they are a rational approach for assigning the level of conservatism for design or evaluation. Seismic criteria are provided for performance categories each of which has a different target goal following a graded approach in which the conservatism and rigor employed is consistent with the hazard, mission, and cost of the facilities considered. Performance categories cover the range from normal or conventional facilities to critical or hazardous facilities. These seismic design and evaluation criteria are intended to apply equally to the design of new facilities and to the evaluation of existing facilities. In addition, the criteria are intended to cover design and evaluation of buildings, equipment,

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piping, and other structures. These criteria are prescriptive procedures that establish earthquake loadings from probabilistic seismic hazard curves; specify acceptable methods for evaluating response to these loadings; provide acceptance criteria to judge whether computed seismic response is acceptable; and to provide detailing requirements. The criteria include controlled intentional levels of conservatism based on the target probabilistic performance goals as illustrated in Figure 1. These criteria are given in DOE-STD-1020-94, a standard for DOE facilities (Ref. 1) and are an update of previous DOE criteria, UCRL-15910 as given in Ref. 2.

PERFORMANCE GOALS AND CATEGORIES

DOE requirements for earthquake mitigation are established within a graded approach in order to provide the appropriate level of seismic protection for:

1. Occupant and public health and safety
2. The environment
3. Production and research objectives
4. Potential property losses.

A graded approach is one in which seismic design, evaluation, and construction requirements have varying conservatism and rigor. By these criteria, the graded approach is implemented by defining five performance categories each with a performance goal. Performance Category 0 covers items which have negligible safety, mission, or cost significance such that no seismic criteria are needed. Criteria range from those provided by model building codes (Ref. 3) for Performance Category (PC) 1 to those approaching nuclear power plant criteria (Ref. 4) for PC 4.

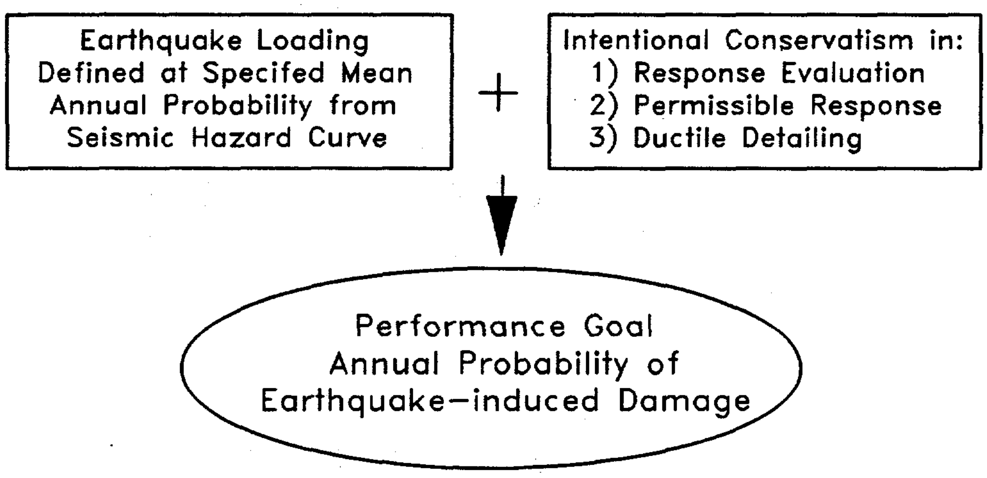

FIGURE 1 PERFORMANCE GOAL ACHIEVEMENT

Target performance goals include both quantitative probability values and qualitative descriptions of acceptable performance. The quantitative performance goals are defined in terms of a permissible mean 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. Values of P_F for Performance Categories 1, 2, 3, and 4 are about 10^{-3}, about

$5x10^{-4}$, about 10^{-4}, and about 10^{-5}, respectively. The qualitative descriptions of expected performance following design/evaluation levels of earthquake ground motions are shown in Table 1. These descriptions of acceptable performance are specifically tailored to the needs in many DOE facilities.

TABLE 1 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.

MEETING PERFORMANCE GOALS BY SEISMIC CRITERIA

The details of meeting performance goals by DOE seismic criteria are described in Ref. 5. The basic principles are described below. Performance goals are expressed in terms of desired behavior and the probability of exceeding structure, system, or component damage levels to the extent that the desired behavior goal may not be achieved. The means of meeting performance goals may be illustrated by examining the probabilistic seismic hazard curve shown in Figure 2. Probabilistic seismic hazard curves display the likelihood of future earthquake ground motion as they relate probability of exceedance to ground motion levels (such as peak ground acceleration as shown in Figure 2). For example, the mean annual probability of ground motion level a_{PH} being exceeded is P_H. Probabilistic seismic hazard curves also display the required capacity needed to achieve various probabilities of seismic-induced damage. For example, if the performance goal probability is P_F, the structure, system, or component under consideration must have the capacity to withstand ground motion level, a_{PF} without damage to the extent that the desired performance cannot be achieved.

If the seismic loading is established at mean annual probability of exceedance P_H and the performance goal probability is P_F, there must be conservatism in the seismic design process such that there is increased capacity from the seismic load level to the required capacity level and such that there is reduced risk from the hazard probability level to the performance goal probability level. Hence, the basic approach of DOE seismic criteria to achieve performance goal, P_F is: (1) specify the design/evaluation basis earthquake (DBE) seismic load, a_{PH}, on a probabilistic basis at hazard probability, P_H and (2) include sufficient intentional conservatism in the other steps of seismic criteria (i.e., response evaluation methods and acceptance criteria) to provide increased capacity, I_C from DBE level, a_{PH} to required capacity level, a_{PF} or to reduce the risk by R_R from P_H to P_F.

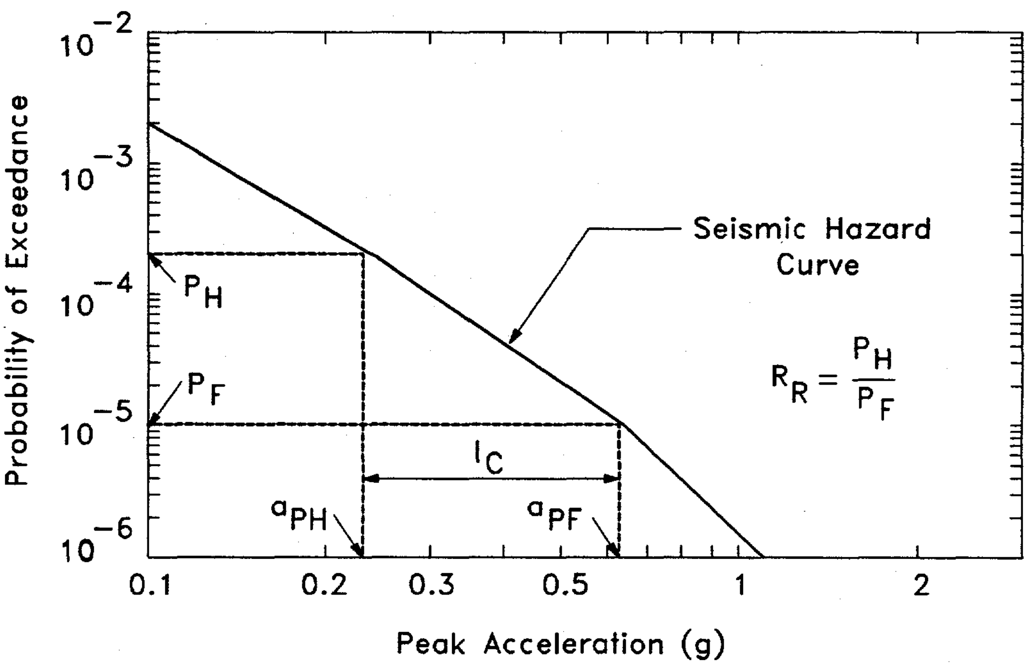

FIGURE 2 REPRESENTATIVE PROBABILISTIC SEISMIC HAZARD CURVE

The risk reduction ratio, R_R establishes the level of conservatism to be employed in the seismic design or evaluation process. For example, if the performance goal and earthquake hazard annual probabilities are the same (R_R = 1), the seismic design or evaluation approach should introduce no conservatism. However, if conservative design or evaluation approaches are employed, the earthquake hazard annual probability of exceedance can be larger (i.e., more frequent) than the performance goal annual probability ($R_R > 1$). Table 2 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 1.

TABLE 2 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	$1x10^{-3}$	$2x10^{-3}$	2
2	$5x10^{-4}$	$1x10^{-3}$	2
3	$1x10^{-4}$	$5x10^{-4}$ $(1x10^{-3})$[1]	5 (10)[1]
4	$1x10^{-5}$	$1x10^{-4}$ $(2x10^{-4})$[1]	10 (20)[1]

1 For sites such as LLNL, SNL-Livermore, SLAC, LBL, and ETEC where seismicity is governed by activity related to tectonic plate boundaries.

It is demonstrated in Ref. 5 that the PC 1 and PC 2 target performance goals, P_F, of $1x10^{-3}$ and $5x10^{-4}$, respectively, are met provided there is about a 10% probability of unacceptable performance when a structure, system, or component (SSC) is subjected to the DBE. Based on experience from past earthquakes, normal building codes such as the Uniform Building Code (Ref. 3) result in less than a 10% probability of unacceptable performance when an SSC is subjected to earthquake ground motion which corresponds to Z for the Uniform Building Code. DOE-STD-1020-94 follows Uniform Building Code provisions for PC 1 and PC 2 and it can be expected that those provisions achieve the required risk reduction of 2.

The Uniform Building Code (UBC) has been followed for PC 1 and PC 2 because it is believed that more engineers are familiar with this code than other model building codes. The Interagency Committee on Seismic Safety in Construction (ICSSC, Ref. 13) has concluded that the following seismic provisions are equivalent for a given DBE:

1) 1991 Uniform Building Code (Ref. 3)

2) 1991 NEHRP Recommended Provisions (Ref. 14)

3) 1992 Supplement to the BOCA National Building Code (Ref. 15)

4) 1992 Amendment to the SBCCI Standard Building Code (Ref. 16)

Meeting target performance goals for PC 3 and PC 4 is discussed below. For PC 3 and PC 4, meeting target performance goals, P_F, of $1x10^{-4}$ and $1x10^{-5}$, respectively, is significantly affected by the slopes of seismic hazard curves from which DBE ground motion is determined and by the uncertainty in those slopes. Seismic hazard curve slope does not have a significant effect on performance for PC 1 and PC 2 because P_F and P_H do not differ greatly (i.e. $R_R = P_H/P_F = 2$).

Over any ten-fold difference in exceedance probabilities, seismic hazard curves may be approximated by a straight line on a log-log plot with a slope of $-k_H$. Slope coefficient, A_R is the increase in ground motion corresponding to a ten-fold reduction in exceedance probability. A_R is related to k_H by:

$$k_H = \frac{1}{\log(A_R)} \tag{1}$$

Reference 5 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 must reflect the effect of seismic hazard curve slope (i.e., A_R or k_H) 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 mean annual probability, P_H, it is shown in Ref. 5 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:

$$R_R = (C_{50}/\mathrm{DBE})^{k_H} e^{-\frac{1}{2}(k_H \beta)^2} \tag{2}$$

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

Reference 5 demonstrates 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. Using this relationship, Equation 2 may be rewritten as:

$$R_R = (1.5\mathrm{SF})^{k_H} e^{\left[1.282 k_H \beta - \frac{1}{2}(k_H \beta)^2\right]} \tag{3}$$

Equation 3 demonstrates the risk reduction ratio achieved by DOE seismic criteria as a function of hazard curve slope, uncertainty, β, and seismic scale factor, SF. Note from Table 2 that for Performance Category 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 Performance Category 3, the hazard probability is 5×10^{-4} and the performance goal is 1×10^{-4} such that the target risk reduction ratio, R_R is 5. The actual risk reduction ratios from Equation 3 versus slope coefficient A_R

are plotted in Figures 3 and 4 for Performance Categories 3 and 4, respectively. In these figures, SF of 1.0 is used for PC 3 and SF of 1.25 is used for PC 4 and the range of β from 0.3 to 0.6 has been considered. For the hazard curves considered by DOE-STD-1024-92 (Ref. 6), 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. 7) give 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.

Figure 3 demonstrates that for SF = 1.0, 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 $2x10^{-4}$ to $5x10^{-5}$. 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 5 for PC 3 and sites not near tectonic plate boundaries. Figure 4 demonstrates 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.

For sites near tectonic plate boundaries for which AR is in the range of about 1.5 to 2.25, such as LLNL, SNL-Livermore, SLAC, LBL, and ETEC. Figures 3 and 4 demonstrate that larger risk reduction ratios are achieved than the target levels of 5 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.

The risk reduction ratio (or target performance goal) achieved may be improved by using a variable formulation of SF which is a function of A_R. By such an approach, risk reduction factors achieved are within about 10 percent of the target values of 5 and 10, respectively. As a result, target performance goals would be met within about the same 10 percent deviation level. A variable formulation of SF is available as an option by DOE criteria.

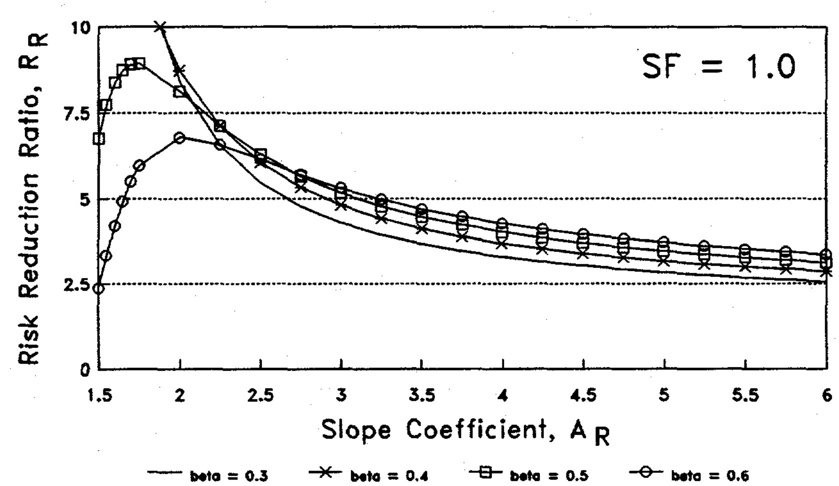

FIGURE 3 VALUE OF R_R VS A_R FOR SF = 1.0 (PC 3)

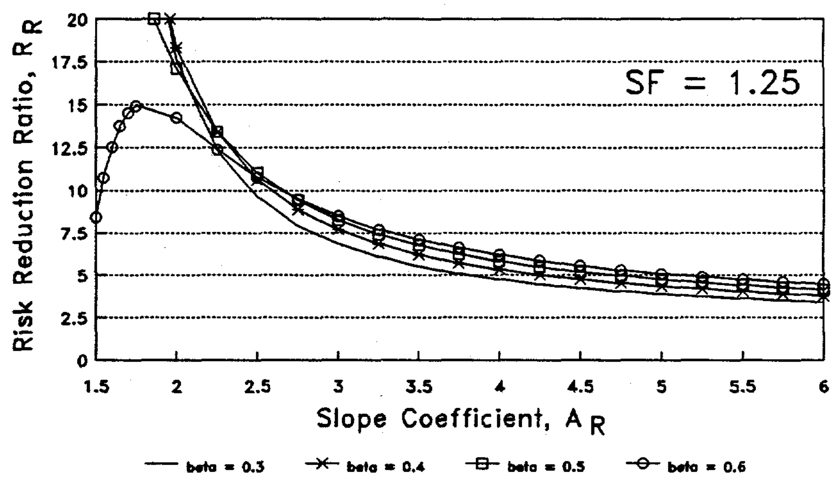

FIGURE 4 VALUE OF R_R VS A_R FOR SF = 1.25 (PC 4)

DOE SEISMIC CRITERIA

These seismic design and evaluation criteria are summarized in Table 3. Criteria for all performance categories include the following elements:

1) Establish the DBE from probabilistic seismic hazard assessments.
2) Evaluate response by industry accepted methods.
3) Utilize acceptance criteria which compares scaled inelastic demand to code specified capacities.
4) Employ seismic detailing practice and peer review to avoid abrupt, premature, or brittle failures.

Acceptance criteria by DOE seismic design and evaluation provisions may be expressed simply as:

Scaled Inelastic Seismic Demand (plus concurrent non-seismic demand)	≤	Code Capacity Levels at Minimum Specified Material Properties	(4a)

For PC 1 and PC 2 structures, systems, and components, the acceptance criteria are given by:

$$LF\left(D_{NS} + \frac{I D_S}{R_w} \right) \leq C_C \tag{4b}$$

where the scaled inelastic seismic demand is the elastically calculated seismic response, D_S to the Design/Evaluation Basis Earthquake (DBE) multiplied by a code specified load factor, LF and code specified importance factor, I, and divided by the code specified coefficient, R_w. D_{NS} is concurrent non-seismic demand. C_C is the code capacity at minimum specified material strengths. For PC 1 and PC 2, the elastic response is computed by means of either equivalent static analysis or dynamic analysis following the Uniform Building Code (Ref. 3).

For PC 3 and PC 4 structures, systems, and components, the acceptance criteria are given by:

$$D_{NS} + SF \frac{D_S}{F_\mu} \le C_C \qquad (4c)$$

where the scaled inelastic seismic demand is the elastically calculated seismic response, D_S to the Design/Evaluation Basis Earthquake (DBE) multiplied by a scale factor, SF, and divided by an inelastic energy absorption factor, F_μ. For PC 3 and PC 4, the elastic response is computed generally by means of dynamic analysis following ASCE 4 (Ref. 8).

TABLE 3 SUMMARY OF EARTHQUAKE EVALUATION PROVISIONS

	Performance Category			
	1	2	3	4
Hazard Exceedance Probability, P_H	2×10^{-3}	1×10^{-3}	5×10^{-4} 1×10^{-3} [1]	1×10^{-4} 2×10^{-4} [1]
Risk Reduction Ratio, R_R	2	2	5 10 [1]	10 20 [1]
Response Spectra	Median amplification (no conservative bias)			
Damping	5%		Post yield levels	
Acceptable Analysis Approaches	Static or dynamic force method normal-ized to code level base shear		Dynamic analysis	
Importance Factor	I=1.0	I=1.25	Not used	
Load Factors or Scale Factors	Code specified load factors appropriate for structural material		SF = 1.0	SF = 1.25
Inelastic Energy Absorption Ratios	Accounted for by R_w in UBC base shear equation		F_μ value by which elastic seismic response is reduced to account for permissible inelastic behavior	
Material Strength	Minimum specified or 95% exceedance in-situ values			
Structural Capacity	Code ultimate or allowable level		Code ultimate or limit-state level	
Peer Review & QA Program	Required within a graded approach			

1 For sites such as LLNL, SNL-Livermore, SLAC, LBL, and ETEC where seismicity is governed by activity related to tectonic plate boundaries.

As mentioned above, these seismic criteria are based on meeting target performance goals. For PC 1 and PC 2, the specification of the DBE combined with intentional conservatism introduced in parameters, LF, R_w, and C_C are sufficient to meet the goals. For PC 3 and PC 4, the specification of the DBE combined with intentional conservatism introduced in parameters, SF, F_μ, and C_C are sufficient to meet the goals.

Establish DBE Loads - Evaluation of the DBE is accomplished by utilizing ground motion at the hazard probability level, P_H (Equation 5).

$$DBE \geq \alpha_{PH} \tag{5}$$

where α_{PH} is the mean ground motion parameter at the seismic hazard probability, P_H. By these criteria, it is necessary to develop site-specific probabilistic seismic hazard curves to establish earthquake loading.

Ideally, it is desirable for the DBE response spectrum to be defined by the mean uniform hazard response spectrum associated with the seismic hazard annual frequency of exceedance specified in Table 2 over the entire frequency range of interest (generally 0.5 to 40 Hz). Alternatively, it is permissible to utilize a DBE response spectrum defined by a deterministic smooth and broad frequency content median response spectrum shape scaled so as to be anchored to appropriate ground motion parameters such as mean DBE peak ground acceleration (PGA), peak ground velocity (PGV), or average spectral values established using Equation 5 as specified in DOE-STD-1023 (Ref. 12). Preferably, the median deterministic DBE response spectrum shape should be site-specific and consistent with the expected earthquake magnitudes, and distances, and the site soil profile and embedment depths. When a site-specific response spectrum shape is unavailable, then a median standardized spectral shape such as the spectral shape defined in NUREG/CR-0098 (Ref. 9) may be used if such a shape is either reasonably consistent with or conservative for the site conditions.

The use of median response spectrum amplification anchored to mean DBE PGA or PGV is an approximate method for achieving mean ground motion input over the entire range of frequencies. The use of conservative response spectrum amplification, such as 84% nonexceedance level, is not recommended because the level of conservatism is then not equal over the entire frequency range.

Response Evaluation Methods - For Performance Category 1 and 2 SSCs, these seismic design and evaluation criteria employ the UBC provisions with the exception that site-specific information may be used to define the earthquake input excitation used to establish seismic loadings. Maximum ground acceleration from probabilistic seismic hazard curves and site-specific ground response spectra are used in the appropriate terms of the UBC equation for base shear. Use of site-specific earthquake ground motion data, if they are available, is considered to be preferable to the general seismic zonation maps from the UBC.

UBC provisions for buildings require a static or dynamic analysis approach in which loadings are scaled to the base shear equation value. In the base shear equation, inelastic energy absorption capacity of structures is accounted for by the parameter, R_w. Elastically computed seismic response is reduced by R_w values ranging from 4 to 12 as a means of accounting for inelastic energy absorption capability in the UBC provisions and by these criteria for Performance Category 1 and 2. This reduced seismic response is combined with non-seismic concurrent loads and then compared to code allowable response limits (or code ultimate limits and code specified load factors) as indicated by Equation 4b.

For Performance Category 1 and 2 systems and components, design or evaluation may be based on the UBC provisions. By the UBC provisions, systems and components must be designed to withstand the total lateral seismic force, F_p, as given by:

$$F_p = ZIC_pW_p \tag{6}$$

where Z is the peak ground acceleration, I is an importance factor ranging from 1 to 1.5, W_p is the weight of the system or component, and C_p is a coefficient depending on the characteristics of the system or component. The lateral force determined using Eq. 6 should be distributed in proportion to the mass distribution of the element or component and applied in the horizontal direction that results in the most critical loadings for design/evaluation of the component and its anchorage.

For Performance Category 3 and 4 SSCs, these seismic design and evaluation criteria specify that seismic evaluation be accomplished by dynamic analysis. The recommended approach is to perform an elastic response spectrum dynamic analysis to evaluate elastic seismic demand on SSCs. However, inelastic energy absorption capability is recognized by permitting limited inelastic behavior. By these provisions for Performance Category 3 and 4, inelastic energy absorption capacity of structures is accounted for by the parameter, F_μ. Elastically computed seismic response is reduced by F_μ values ranging from 1 to 3 as a means of accounting for inelastic energy absorption capability for more hazardous facilities. F_μ values are much lower than R_w resulting in larger values of the risk reduction ratio, R_R. The same F_μ values are specified for all Performance Categories of 3 and higher. In order to achieve different risk reduction ratios, R_R appropriate for the different performance categories, the reduced seismic response is multiplied be a seismic scale factor, SF. The resulting factored seismic response is combined with non-seismic concurrent loads and then compared to code ultimate response limits as indicated by Equation 4c.

For Performance Category 3 and 4 systems and components, seismic design or evaluation shall be based on dynamic analysis, or testing. Evaluation of existing systems and components may be based on past earthquake or testing experience data. In any case, the input to systems and components supported within a building is determined from in-structure response spectra at the component attachment point in the building. In addition to evaluating seismic capacity of Performance Category 3 and 4 systems and components, it is also important to evaluate potential seismic interaction with lower category SSCs. Seismic interaction includes lower category items collapsing, overturning, sliding, or displacing sufficiently to impact the higher category system or component. Another form of seismic interaction occurs where distribution lines such as piping, tubing, conduit, or cables connected to an item have insufficient flexibility to accommodate relative movement between the item and adjacent structures or equipment to which the distribution line is anchored.

Performance Category 1 or 2 SSCs may be seismically evaluated using the simplified approaches specified in the UBC seismic provisions since these provisions achieve an R_R ratio of about two or greater. However, for Performance Category 3 or 4, the seismic evaluation must be performed by a dynamic analysis approach. A dynamic analysis approach requires that:

1) the input to the SSC model be defined by either a design response spectrum, or a time history input motion.
2) the important natural frequencies of the SSC be estimated, or the peak of the design response spectrum be used as input.
3) the resulting seismic induced inertial forces be appropriately distributed with the SSC and a load path evaluation be performed.

The words "dynamic analysis approach" are not meant to imply that complex dynamic models must be used in the evaluation. Often equivalent static analysis models are sufficient so long as the above listed three factors are incorporated. This dynamic analysis approach should comply with the seismic response analysis provisions of ASCE 4 (Ref. 8).

Acceptance Criteria - For Performance Categories 1 and 2, acceptance criteria from the Uniform Building Code and UBC referenced material standards are followed. Seismic design and evaluation criteria for Performance Categories 3 and 4 have intentional conservatism introduced which achieve the target performance goals by:

1) establishing material strength properties at the 95% exceedance strength associated with the time during the service life at which such strengths are minimum;

2) basing capacities upon code-specified minimum ultimate or limit-state capacity levels with the appropriate capacity reduction factor (e.g., concrete - ACI-318 or ACI-349 ultimate strength approach, structural steel - AISC-LRFD limit-state strength approach or AISC plastic design approach, ASME components - ASME Service Level D);

3) permitting limited inelastic behavior by specifying inelastic energy absorption factors, F_μ by which elastic response may exceed capacity (F_μ values are provided or may be estimated as the value associated with a permissible level of inelastic distortion specified at about the 5% failure probability level);

4) using a seismic scale factor, SF, of 1.0 for Performance Category 3 and 1.25 for Performance Category 4; and

5) requiring equipment qualified by test to be tested at the required input spectrum scaled by a factor of 1.4SF.

6) requiring equipment verified by experience data to utilize experience based response spectra scaled by factors as given in Ref. 10.

Ductile Detailing - For all performance categories, the design detailing provisions from the UBC, which provide ductility, toughness, and redundancy, are required such that SSCs can fully realize potential inelastic energy absorption capability. Guidance on ductile detailing measures for DOE facilities can be found in "Structural Concepts and Details for Seismic Design" (Ref. 11).

SUMMARY AND CONCLUSIONS

The Department of Energy utilizes deterministic seismic design/evaluation criteria developed based on target probabilistic performance goals. Four separate sets of seismic design/evaluation criteria have been presented each with a different performance goal. In all these criteria, earthquake loading is selected from seismic hazard curves on a probabilistic basis but seismic response evaluation methods and acceptable behavior limits are deterministic approaches with which design engineers are familiar. For analytical evaluations, conservatism has been introduced through the use of conservative inelastic demand-capacity ratios combined with ductile detailing requirements, through the use of minimum specified material strengths and conservative code capacity equations, and through the use of a seismic scale factor. For evaluation by testing or by experience data, conservatism has been introduced through the use of an increase scale factor which is applied to the prescribed design/evaluation input motion. These criteria and similar criteria for wind and flood are presented in DOE-STD-1020-94 (Ref. 1).

Criteria given in DOE-STD-1020-94 are intended to apply to both new design and evaluation of existing facilities. In addition, these criteria are intended to be applicable to both buildings and equipment or piping. DOE-STD-1020-94 provides the basic framework for achieving DOE performance goals but further guidance is needed for both existing facilities and for equipment and piping. For existing facilities, guidance is needed for establishing appropriate values for R_w or F_μ which are consistent with the detailing that exists in the existing facility. For equipment and piping, guidance is needed on analytical methods which account for the considerable inelastic energy absorption capacity in many such items.

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