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DOE-STD-1020-94
April 1994
Change Notice #1
January 1996

DOE STANDARD

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

NUCLEAR REGULATORY COMMISSION
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Foreword

Change notice #1 has been included in this standard to provide information to help meet the requirements in DOE Order 420.1 and its associated implementation guides, accounting for the cancellation of DOE Order 6430.1A, correcting errors in the prevoius standard, and updating this standard to the most current references.

This DOE standard is approved for use by all departments and contractors of the Department of Energy (DOE). This Standard will still apply when DOE Order 420.1 is converted to a rule. In addition, this Standard will still apply when other referenced Orders such as 5480.23, the SAR Order, 5480.22, the TSR Order, etc. are converted to rules.

There is an established hierarchy in the set of documents that specify NPH requirements. In this hierarchy, DOE Order 420.1 is the highest authority. The next set of controlling documents are the associated implementation guides followed by the set of NPH standards. In the event of conflicts in the information provided by these documents, the information provided in the document of higher authority should be utilized (e.g., the definitions provided in the implementation guides should be utilized even though corresponding definitions are provided in the NPH standards).

The Department of Energy (DOE) has issued an Order 420.1 which establishes policy for its facilities in the event of natural phenomena hazards (NPH) along with associated NPH mitigation requirements. This DOE Standard gives design and evaluation criteria for NPH effects as guidance for implementing the NPH mitigation requirements of DOE Order 420.1 and the associated implementation Guides. These are intended to be consistent design and evaluation criteria for protection against natural phenomena hazards at DOE sites throughout the United States. The goal of these criteria is to assure that DOE facilities can withstand the effects of natural phenomena such as earthquakes, extreme winds, tornadoes, and flooding. These criteria apply to the design of new facilities and the evaluation of existing facilities. They may also be used for modification and upgrading of existing facilities as appropriate. It is recognized that it is likely not cost-effective to upgrade existing facilities which do not meet these criteria by a small margin. Hence, flexibility in the criteria for existing facilities is provided by permitting limited relief from the criteria for new design. The intended audience is primarily the civil/structural or mechanical engineers familiar with building code methods who are conducting the design or evaluation of DOE facilities.

The design and evaluation criteria presented herein control the level of conservatism introduced in the design/evaluation process such that earthquake, wind, and flood hazards are treated on a consistent basis. These criteria also employ a graded approach to ensure that the level of conservatism and rigor in design/evaluation is appropriate for facility characteristics such as importance, hazards to people on and off site, and threat to the environment. For each natural phenomena hazard covered, these criteria consist of the following:

1. Performance Categories and target performance goals as specified in the DOE Order 420.1 NPH Implementation Guide, and DOE-STD-1021.

2. Specified probability levels from which natural phenomena hazard loading on structures, equipment, and systems is developed.

3. Design and evaluation procedures to evaluate response to NPH loads and criteria to assess whether or not computed response is permissible.

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Chapter 1
Introduction

1.1 Overview of DOE Natural Phenomena Hazards Order, Standards, and Guidance

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 on DOE facilities. DOE Order 420.1, "Facility Safety" (Ref. 1-1) and the associated Implementation Guides, "Implementation Guide for the Mitigation of Natural Phenomena Hazards for DOE Nuclear Facilities and Non-nuclear Facilities" (Ref. 1-2), "Implementation Guide for Nonreactor Nuclear Safety Design Criteria and Explosives Safety Criteria" (Ref. 1-3), and "Implementation Guide for use with DOE Orders 420 and 470 Fire Safety Program" (Ref. 1-4) identify the responsibilities and requirements to execute this policy in a consistent manner throughout DOE which includes: (1) providing safe work places; (2) protecting against property loss and damage; (3) maintaining operation of essential facilities; and (4) protecting against exposure to hazardous materials during and after occurrences of natural phenomena hazards. There is an established hierarchy in the set of documents that specify NPH requirements. In this hierarchy, DOE Order 420.1 is the highest authority. The next set of controlling documents are the associated Implementation Guides followed by the set of NPH standards. The NPH requirements have been developed to provide the necessary information that assess the NPH safety basis for DOE facilities, which is documented in Safety Analysis Reports (SARs), if available. DOE 5480.23 (Ref. 1-5) and the guidance provided in the associated Standard, DOE-STD-3009-94 (Ref. 1-6) prescribed the use of a graded approach for the effort expended in safety analysis and the level of detail presented in associated documentation. DOE NPH mitigation requirements are also consistent with the National Earthquake Hazards Reduction Program and Executive Orders 12699 (Ref. 1-7) and 12941 (Ref. 1-8).

The overall approach for NPH mitigation shall be consistent with the graded approach embodied in the SAR. The application of NPH design requirements to structures, systems, and components (SSCs) shall be based on the life-safety or the safety classifications for the SSCs as established by safety analysis. The application of the most rigorous design requirements should be limited to those SSCs classified by safety analysis as Safety-Class or Safety-Significant consistent with DOE-STD-3009-94. Although DOE-STD-3009-94 is specifically

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applicable to non-reactor nuclear facilities, it is DOE's intention to apply DOE-STD-3009-94 definitions for "Safety-Class" and "Safety-Significant" to all nuclear reactor and other hazardous facilities, and this broader approach is applied here. Mission importance and economic considerations should also be used to categorize SSCs which require NPH design. Once the SSCs have been classified, DOE Order 420.1 and the associated Implementation Guides specifies the NPH requirements to ensure that the SSCs are adequately designed to resist NPH. The NPH requirements utilize a graded approach in order to provide a reasonable level of NPH protection for the wide variety of DOE facilities. A graded approach is one in which various levels of NPH design, evaluation and construction requirements of varying conservatism and rigor are established ranging from common practice for conventional facilities to practices used for more hazardous critical facilities.

Five DOE Standards have been developed to provide specific acceptance criteria for various aspects of NPH to meet the requirements of DOE Order 420.1 and the associated Implementation Guides. These requirements should be used in conjunction with the NPH Implementation Guide and other pertinent documents which provide more detailed methods on specific NPH design and evaluation subjects such as DOE guidance documents, consensus national standards, model building codes, and industry accepted codes and specifications. Figure 1-1 presents a conceptual NPH design framework which identifies how the DOE NPH standards are used to assess NPH design requirements.

The following national consensus codes and standards have been referred to in this standard:

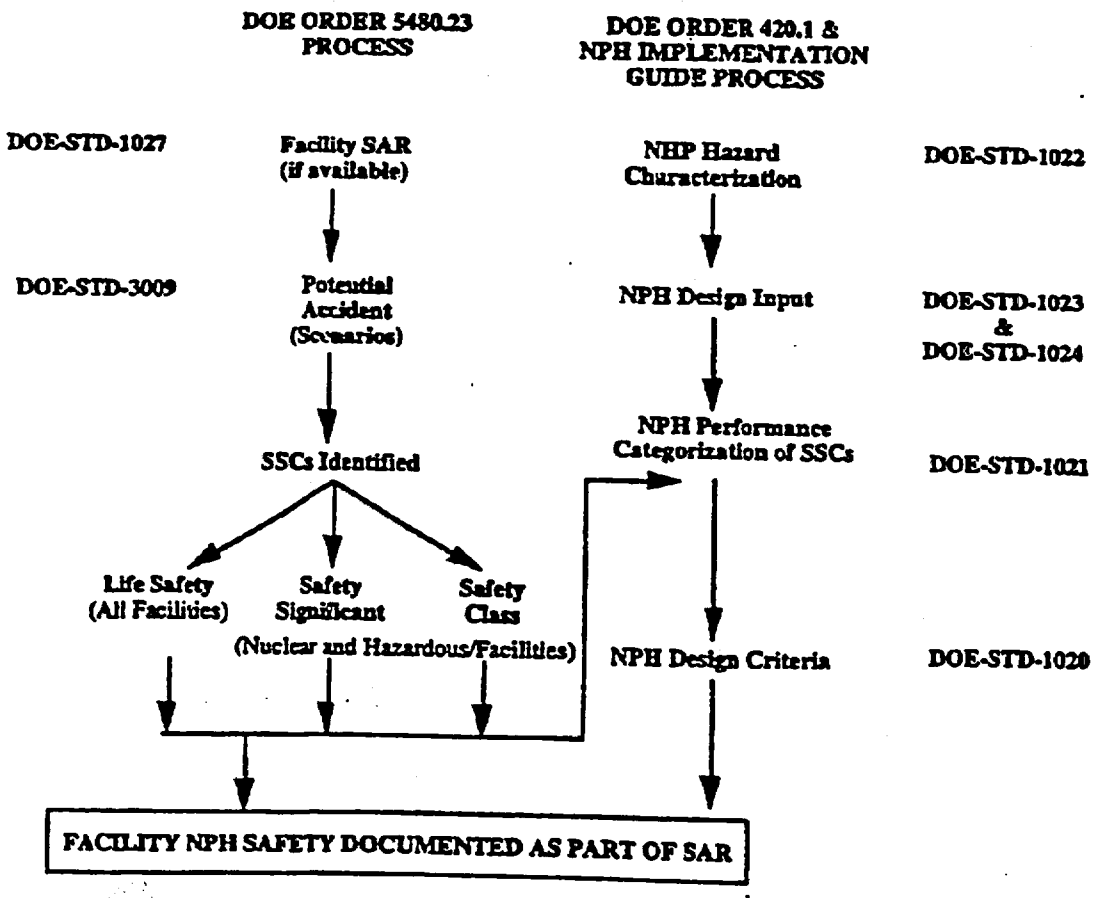
ACI 318	—	Building Code Requirements for Reinforced Concrete
ACI 349	—	Code Requirements for Nuclear Safety-Related Concrete Structures
AISC N690	—	Nuclear Facilities - Steel Safety Related Structures for Design, Fabrication, and Erection
AISC (LRFD)	—	Manual of Steel Construction, Load & Resistance Factor Design
AISC (ASD)	—	Manual of Steel Construction, Allowable Stress Design
ASCE 4	—	Seismic Analysis of Safety-Related Nuclear Structures
ASCE 7	—	Minimum Design Loads for Buildings and Other Structures
ASME	—	Boiler and Pressure Vessel Code
ATC-14	—	Evaluating the Seismic Resistance of Existing Buildings
ATC-22	—	A Handbook for Seismic Evaluation of Existing Buildings
IEEE 344	—	IEEE Recommended Practice for Seismic Qualification of Class IE Equipment for Nuclear Power Generating Stations
UBC	—	Uniform Building Code

NBC	—	National Building Code
SBC	—	Standard Building Code
FEMA 222A	—	NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings
ICSSC RP3	—	Guidelines for Identification and Mitigation of Seismically Hazardous of Existing Federal Buildings
ICSSC RP4	—	Standards of Seismic Safety for Existing Federally Owned or Leased Buildings
ICSSC RP5	—	ICSSC Guidance on Implementing Executive Order 12941 on Seismic Safety of Existing Federally Owned or Leased Buildings

Figure 1-1

Natural Phenomena Design Input

Conceptual Framework



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The NPH Implementation Guide of DOE Order 420.1 has established Performance Categories and target probabilistic performance goals for each category. Performance goals are expressed as the mean annual probability of exceedance of acceptable behavior limits of structures and equipment due to the effects of natural phenomena. Five Performance Categories (PC) have been established in the NPH Implementation Guide of DOE Order 420.1. Performance Categories and performance goals range from those for conventional buildings to those for facilities with hazardous materials for operations. The selection of NPH Performance Categories for SSCs is dependent on several factors including the overall risk of facility operation and the assigned function to the SSC. An SSC's safety classification is based on its function in accident prevention or mitigation as determined by safety analysis. The safety classification should be applied to specific SSCs on a case-by-case basis and need not apply to an entire facility. Experience to date has demonstrated that only a few nuclear facilities are likely to contain Safety-Class SSCs. This indicates that most SSCs in nuclear facilities should be assigned to NPH Performance Category 3 and lower. DOE is revisiting the approach used to assign NPH Performance Categories, and is likely to develop a direct link between NPH Performance Categories and accident dose (radiological or toxicological) criteria. Once this is completed, DOE-STD-1021 will be revised as necessary. The use of NPH Performance Category 4 should be reserved for those facilities whose accident dose potential is similar to that of commercial nuclear reactors.

1.2 Overview of the NPH Design and Evaluation Criteria

This natural phenomena hazard standard (DOE-STD-1020), developed from UCRL-15910 (Ref. 1-9), provides criteria for design of new structures, systems, and components (SSCs) and for evaluation, modification, or upgrade of existing SSCs so that Department of Energy (DOE) facilities safely withstand the effects of natural phenomena hazards (NPHs) such as earthquakes, extreme winds, and flooding. DOE-STD-1020 provides consistent criteria for all DOE sites across the United States. These criteria are provided as the means of implementing DOE Order 420.1 and the associated Implementation Guides, and Executive Orders 12699 and 12941 for earthquakes.

The design and evaluation criteria presented in this document provide relatively straightforward procedures to evaluate, modify, or upgrade existing facilities or to design new facilities for the effects of NPHs. The intent is to control the level of conservatism in the

design/evaluation process such that: (1) the hazards are treated consistently; and (2) the level of conservatism is appropriate for structure, system, and component (SSC) characteristics related to safety, environmental protection, importance, and cost. The requirements for each hazard are presented in subsequent chapters. Terminology, guidelines, and commentary material are included in appendices which follow the requirement chapters.

Prior to applying these criteria, SSCs will have been placed in one of five Performance Categories ranging from PC-0 to PC-4. No special considerations for NPH are needed for PC-0; therefore, no guidance is provided. Different criteria are provided for the remaining four Performance Categories, each with a specified performance goal. Design and evaluation criteria aimed at target probabilistic performance goals require probabilistic natural phenomena hazard assessments. NPH loads are developed from such assessments by specifying natural phenomena hazard mean annual probabilities of exceedance. Performance goals may then be achieved by using the resulting loads combined with deterministic design and evaluation procedures that provide a consistent and appropriate level of conservatism. Design/Evaluation procedures conform closely to industry practices using national consensus codes and standards so that the procedures will be easily understood by most engineers. Structures, systems, and components comprising a DOE facility are to be assigned to a Performance Category utilizing the approach described in the DOE performance categorization standard (Ref. 1-10). These design and evaluation criteria (DOE-STD-1020) are the specific provisions to be followed such that the performance goal associated with the Performance Category of the SSC under consideration is achieved. For each category, the criteria include the following steps:

1. NPH loads are determined at specified NPH probabilities as per DOE-STD-1023 (Ref. 1-11).
2. Design and evaluation procedures are used to evaluate SSC response to NPH loads.
3. Criteria are used to assess whether or not computed response in combination with other design loads is permissible.
4. Design detailing provisions are implemented so that the expected performance during a potential NPH occurrence will be achieved.
5. Quality assurance and peer review are applied using a graded approach.

For each Performance Category, target performance goals are provided in the NPH Implementation Guide of DOE Order 420.1 in terms of mean annual probability of exceedance of acceptable behavior limits. In item 1, the annual probability of exceedance of an NPH parameter such as ground acceleration, wind speed, or water elevation is specified. The level

of conservatism in Items 2, 3, 4, and 5 above is controlled such that sufficient risk reduction from the specified NPH probability is achieved so that the target performance goal probability is met. DOE-STD-1020 provides an integrated approach combining definition of loading due to natural phenomena hazards, response evaluation methods, acceptance criteria, and design detailing requirements.

Performance goals and NPH levels are expressed in probabilistic terms; design and evaluation procedures are presented deterministically. Design/evaluation procedures specified in this document conform closely to common standard practices so that most engineers will readily understand them. The intended audience for these criteria is the civil/structural or mechanical engineer conducting the design or evaluation of facilities. These NPH design and evaluation criteria do not preclude the use of probabilistic or alternative design or evaluation approaches if these approaches meet the specified performance goals.

1.3 Evaluation of Existing Facilities

Evaluations of existing SSCs must follow or, at least, be measured against the NPH criteria provided in this document. For SSCs not meeting these criteria and which cannot be easily remedied, budgets and schedule for required strengthening must be established on a prioritized basis. A back-fit analysis should be conducted. Prioritization criteria for evaluation and upgrade of existing DOE facilities are currently being developed. Priorities should be established on the basis of Performance Category, cost of strengthening, and margin between as-is SSC capacity and the capacity required by the criteria. For SSCs which are close to meeting criteria, it is probably not cost effective to strengthen the SSC in order to obtain a small reduction in risk. As a result, some relief in the criteria is allowed for evaluation of existing SSCs. It is permissible to perform such evaluations using natural phenomena hazard exceedance probability of twice the value specified for new design. For example, if the natural phenomena hazard annual probability of exceedance for the SSC under consideration was 10^{-4}, it would be acceptable to reconsider the SSC at hazard annual probability of exceedance of 2×10^{-4}. This would have the effect of slightly reducing the seismic, wind, and flood loads in the SSC evaluation by about 10% to 20%. This amount of relief is within the tolerance of meeting the target performance goals and is only a minor adjustment of the corresponding NPH design and evaluation criteria. In addition, it is consistent with the intent of the Federal Program (Ref. 1-8) being developed by the Interagency Committee on Seismic Safety in Construction. The Implementation Guide provides guidance for facilities with a remaining service life of less than 5 years.

1.4 Quality Assurance and Peer Review

All DOE structures, systems, and components must be designed or evaluated utilizing a formal quality assurance plan as required by 10 CFR 830.120 (Ref. 1-12). The QA and peer review should be conducted within the framework of a graded approach with increasing level of rigor employed from Performance Category 1 to 4. Specific details about a formal quality assurance plan for NPH design and evaluation should be similar to the seismic plan described in the Commentary, Appendix C. The major features of a thorough quality assurance plan for design or evaluation for natural phenomena hazards are described below.

In general, it is good practice for a formal quality assurance plan to include the following requirements. On the design drawings or evaluation calculations, the engineer must describe the NPH design basis including (1) description of the system resisting NPH effects and (2) definition of the NPH loading used for the design or evaluation. Design or evaluation calculations should be checked for numerical accuracy and for theory and assumptions. For new construction, the engineer should specify a program to test materials and inspect construction. In addition, the engineer should review all testing and inspection reports and visit the site periodically to observe compliance with plans and specifications.

For Performance Categories 2, 3, and 4, NPH design or evaluation must include independent peer review. The peer review is to be performed by independent, qualified personnel. The peer reviewer must not have been involved in the original design or evaluation. If the peer reviewer is from the same company/organization as the designer/evaluator, he must not be part of the same program where he could be influenced by cost and schedule consideration. Individuals performing peer reviews must be degreed civil/mechanical engineers with 5 or more years of experience in NPH evaluation.

For more information concerning the implementation of a formal engineering quality assurance program and peer review, Chapter 19 of Reference 1-9 should be consulted. This reference should also be consulted for information on a construction quality assurance program consistent with the implementation of the engineering quality assurance program.

1.5 References

1-1. U. S. Department of Energy, Facility Safety, DOE Order 420.1, Washington, DC, October 13, 1995.

1-2. U. S. Department of Energy, Implementation Guide for the Mitigation of Natural Phenomena Hazards for DOE Nuclear Facilities and Non-Nuclear Facilities (draft for interim use), Washington, DC, November 13, 1995.

1-3. U. S. Department of Energy, Implementation Guide for Nonreactor Nuclear Safety Design Criteria and Explosives Safety Criteria (draft for interim use), Washington, DC, November 13, 1995.

1-4. U. S. Department of Energy, Implementation Guide for use with DOE Orders 420.1 and 440.1 Fire Safety Program, Washington, DC, November 13, 1995.

1-5. U. S. Department of Energy, Nuclear Safety Analysis Reports, DOE Order 5480.23, Washington, DC, April 30, 1992.

1-6. U. S. Department of Energy, Preparation Guide For U. S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports, DOE-STD-3009-94, Washington, DC, July 1994.

1-7. Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction, Executive Order 12699, Washington, DC, January 5, 1990.

1-8. Seismic Safety of Existing Federally Owned or Leased Buildings, Executive Order 12941, Washington, DC, December 1, 1994.

1-9. Kennedy, R.P., S.A. Short, J.R. McDonald, M.W. McCann, R.C. Murray, J.R. Hill, Design and Evaluation Guidelines for Department of Energy Facilities Subjected to Natural Phenomena Hazards, UCRL-15910, Lawrence Livermore National Laboratory, Livermore, CA, June 1990. (Superceded)

1-10. U.S. Department of Energy, Performance Categorization Criteria for Structures, Systems, and Components at DOE Facilities Subjected to Natural Phenomena Hazards, DOE-STD-1021-93, Washington, DC, July 1993.

1-11. U. S. Department of Energy, Natural Phenomena Hazards Assessment Criteria, DOE-STD-1023-95, Washington, DC, September 1995.

1-12. U. S. Department of Energy, Quality Assurance Requirements, U.S. Government Printing Office, Washington, DC, 10 CFR 830.120.

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1-14. U. S. Department of Energy, Guidelines for Use of Probabilistic Seismic Hazard Curves at Department of Energy Sites, DOE-STD-1024-92, Department of Energy Seismic Working Group, December 1992.

1-15. U. S. Department of Energy, Natural Phenomena Hazards Site Characterization Criteria, DOE-STD-1022-94, Washington, DC, March 1994.

Chapter 2
Earthquake Design and Evaluation Criteria

2.1 Introduction

This chapter describes requirements for the design or evaluation of all classes of structures, systems, and components (SSCs) comprising DOE facilities for earthquake ground shaking. These classes of SSCs include safety class and safety significant SSCs per DOE-STD-3009-94 (ref. 1-6) and life-safety SSCs per Uniformed Building Codes. This material deals with how to establish Design/Evaluation Basis Earthquake (DBE) loads on various classes of SSCs; how to evaluate the response of SSCs to these loads; and how to determine whether that response is acceptable. This chapter also covers the importance of design details and quality assurance to earthquake safety. These earthquake design and evaluation provisions are equally applicable to buildings and to items contained within the building, such as equipment and distribution systems. These provisions are intended to cover all classes of SSCs for both new construction and existing facilities. These design and evaluation criteria have been developed such that the target performance goals of the NPH Implementation Guide are achieved. For more explanation see the Commentary (Appendix C) herein and the Basis Document (Ref. 2-1).

2.2 General Approach for Seismic Design and Evaluation

This section presents the approach upon which the specific seismic force and story drift provisions for seismic design and evaluation of structures, systems, and components in each Performance Category (as described in Section 2.3) is based. These provisions include the following steps:

1. Selection of earthquake loading
2. Evaluation of earthquake response
3. Specification of seismic capacity and drift limits, (acceptance criteria)
4. Ductile detailing requirements

It is important to note that the above four elements taken together comprise seismic design and evaluation criteria. Acceptable performance (i.e., achieving performance goals) can only be reached by consistent specification of all design criteria elements as shown in Figure 2-1. In order to achieve the target performance goals, these seismic design and evaluation criteria specify seismic loading in probabilistic terms. The remaining elements of the criteria (see Fig. 2-1) are deterministic design rules which are familiar to design engineers and

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which have a controlled level of conservatism. This level of conservatism combined with the specification of seismic loading, leads to performance goal achievement.

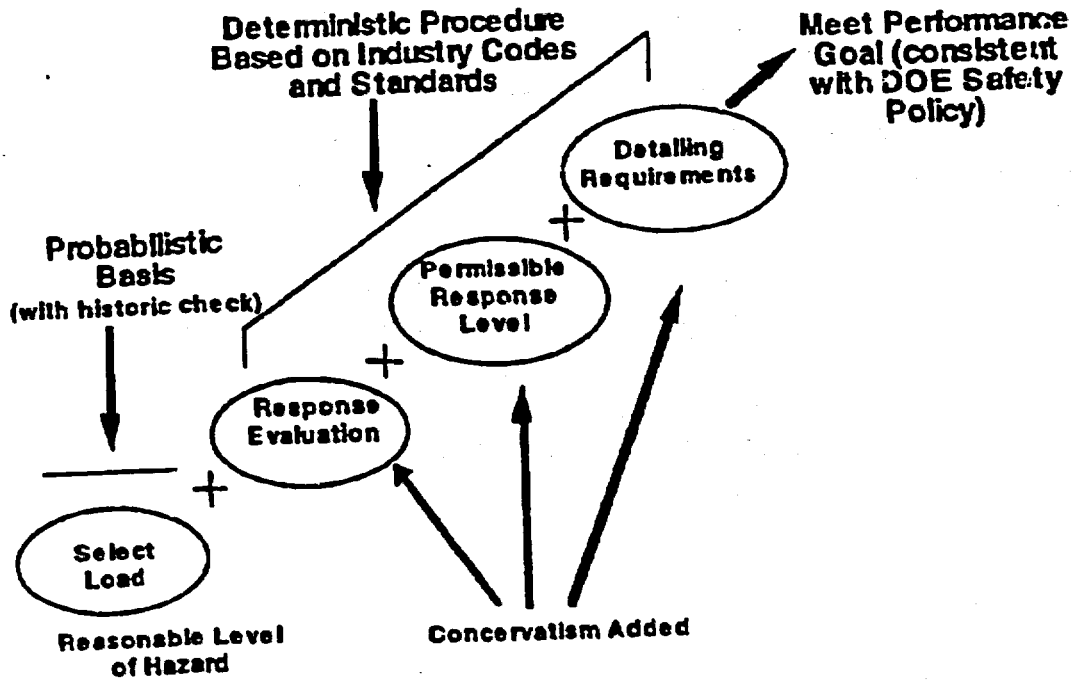


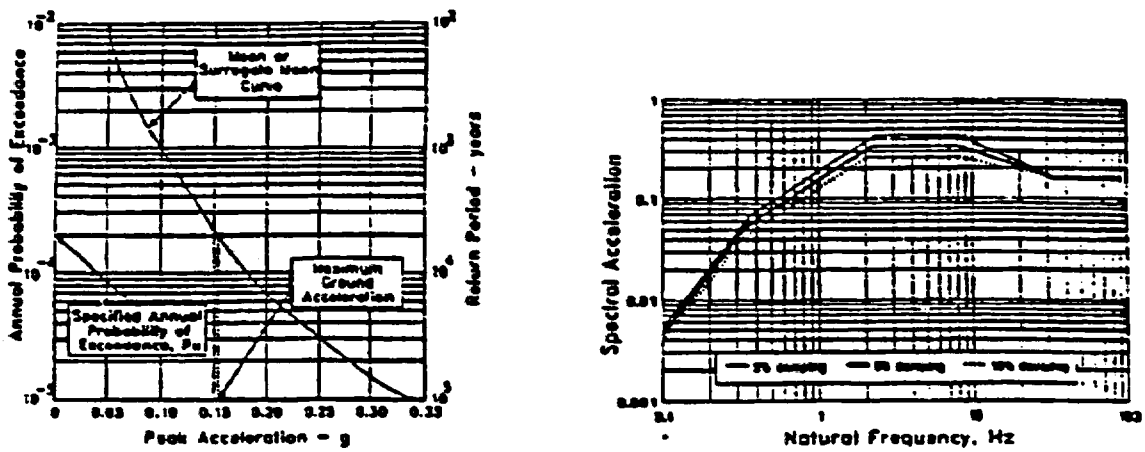
Figure 2-1. DOE-STD-1020 Combines Various Steps to Achieve Performance Goals

Criteria are provided for each of the four Performance Categories 1 to 4 as defined in the NPH Implementation Guide of DOE Order 420.1 and DOE-STD-1021 (Ref. 1-6). The criteria for Performance Categories 1 and 2 are similar to those from model building codes, with the exception that DOE requirements specify a 1000 year return period in the case of PC-2. Criteria for PC-3 are similar to those for Department of Defense Essential Facilities (Ref. C-5) Tri-Services Manual. Criteria for PC-4 approach the provisions for commercial nuclear power plants.

Seismic loading is defined in terms of a site-specified design response spectrum (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. Seismic hazard estimates are used to establish the DBE per DOE-STD-1023 (REF. 2-22).

For each Performance Category, a mean annual exceedance probability for the DBE, P_H is specified from which the maximum ground acceleration (and/or velocity) may be determined from probabilistic seismic hazard curves, see Table 2-1. Evaluating maximum ground acceleration from a specified mean annual probability of exceedance is illustrated in Figure 2-2a. 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 2-2b (from Ref. 2-2) anchored to the maximum ground acceleration and/or velocity. Such spectra are determined in accordance with DOE-STD-1023 (Ref. 2-22).

It should be understood that the spectra shown in Figure 2-2 or in-structure spectra developed from them represent inertial effects. They do not include differential support motions, typically called seismic anchor motion (SAM), of structures, equipment, or distribution systems supported at two or more points. While SAM is not usually applicable to building design, it might have a significant effect on seismic adequacy of equipment or distribution systems.



a) Evaluating Peak Acceleration from Annual Probability of Exceedance with a Seismic Hazard Curve

b) Median Amplification, smoothed and broadened, Design/Evaluation Response Spectra

Figure 2-2. Earthquake Input Excitation Is Defined by Maximum Ground Acceleration Anchoring Site-Specific Response Spectra

Table 2-1 Seismic Performance Categories and Seismic Hazard Exceedance Levels

Performance Category	Mean Seismic Hazard Exceedance Levels, P_H	Return Period
0	No Requirements	
1	$2x10^{-3}$	500yr
2	$1x10^{-3}$	1000yr
3	$5x10^{-4}$ ($1x10^{-3}$)[1]	2000yr (1000yr)[1]
4	$1x10^{-4}$ ($2x10^{-4}$)[1]	10,000yr (5000yr)[1]

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

Performance Category 2 and lower SSCs may be seismically designed or evaluated using the approaches specified in building code seismic provisions. However, for Performance Category 3 or higher, 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 compatible 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. Multi-mode effects must be considered.
3. The resulting seismic induced inertial forces be appropriately distributed and a load path evaluation (see Section C.4.2) for structural adequacy 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 if the above listed three factors are incorporated. However, use of such simplified models for

structures in Performance Category 3 or higher must be justified and approved by DOE. This dynamic analysis approach should comply with the seismic response analysis provisions of ASCE 4 (Ref. 2-3) except where specific exceptions are noted.

The maximum ground acceleration and ground response spectra determined in the manner illustrated in Figure 2-2 are used in the appropriate terms of the UBC equation for base shear. The maximum ground acceleration is also used in the UBC equation for seismic force on equipment and non-structural components. Use of modern site-specific earthquake ground motion data is considered to be preferable to the general seismic zonation maps from the UBC and should be applied according to the guidance provided in DOE-STD-1023 (Ref. 2-22). For structures, UBC provisions 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 2 and lower SSCs. This reduced seismic response is combined with non-seismic concurrent loads and then compared to code allowable response limits (or code ultimate limits combined with code specified load factors). The design detailing provisions from the UBC, which provide ductility, toughness, and redundancy, are also required such that SSCs can fully achieve potential inelastic energy absorption capability. Normally, relative seismic anchor motion (SAM) is not considered explicitly by model building code seismic provisions. However, SAM should be considered for SSCs in PC-2 or higher categories.

The Uniform Building Code (UBC) has been followed for Performance Categories 1 and 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. 2-4) has concluded that the following seismic provisions are equivalent for a given DBE:

1. 1994 Uniform Building Code (Ref. 2-5)
2. 1991 NEHRP Recommended Provisions (Ref. 2-6)
3. 1993 BOCA National Building Code (Ref. 2-7)
4. 1994 SBCCI Standard Building Code (Ref. 2-8)

These other model building codes may be followed provided site-specific ground motion data is incorporated into the development of earthquake loading in a manner similar to that described in this document for the UBC.

For Performance Category 3 and 4 SSCs, these seismic design and evaluation criteria specify that seismic evaluation be accomplished by dynamic analysis. The recommended

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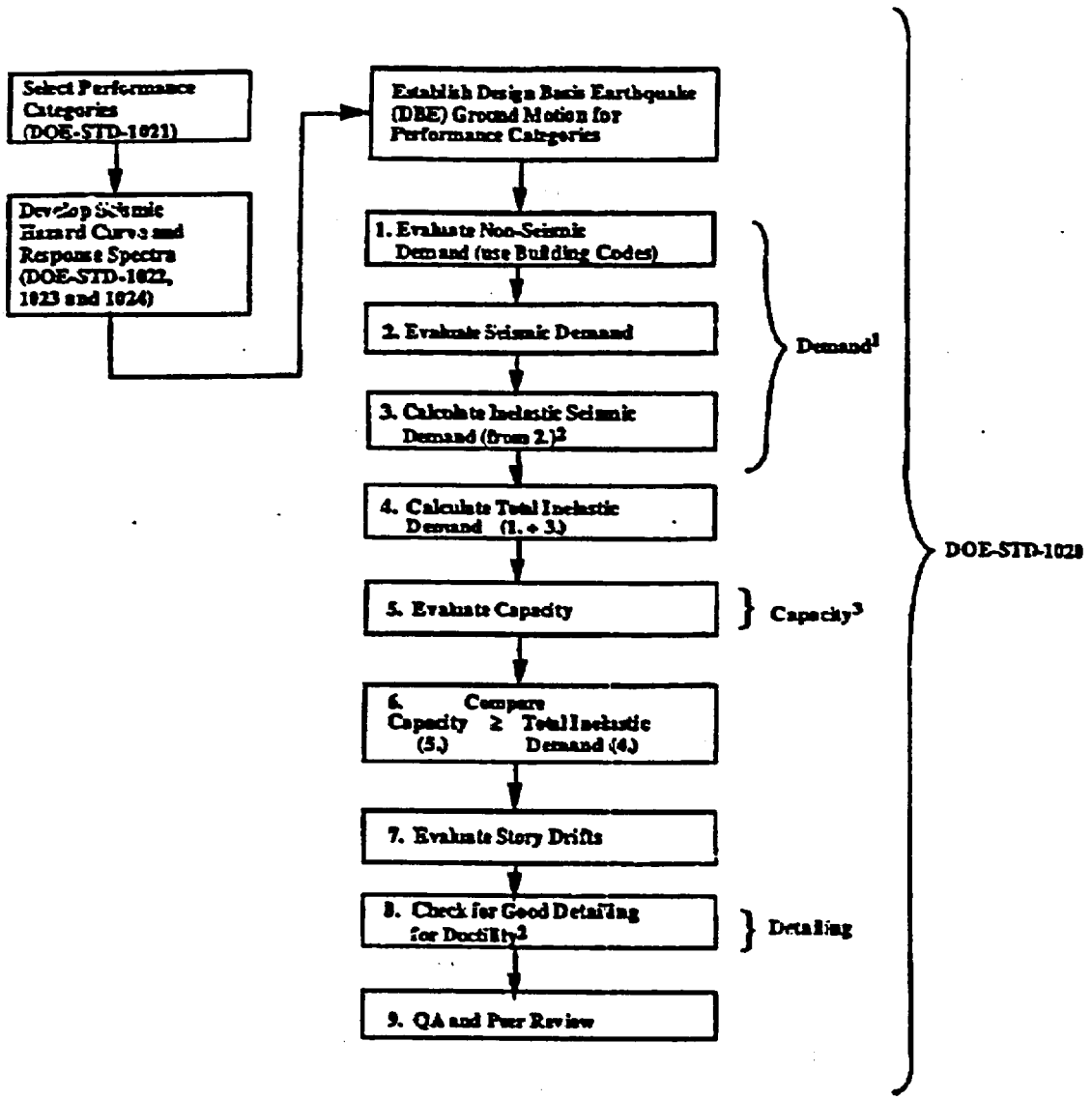
approach is to perform an elastic response spectrum dynamic analysis to evaluate elastic seismic demand on SSCs. Inelastic energy absorption capability is allowed by permitting limited inelastic behavior. By these provisions, inelastic energy absorption capacity of structures is accounted for by the parameter, F_μ. However, strength and ductile detailing for the entire load path should be assured. 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. The same F_μ values are specified for both Performance Categories of 3 and 4. In order to achieve the conservatism appropriate for the different Performance Categories, the reduced seismic forces are multiplied by a scale factor. Scale factors are specified for Performance Category 3 and 4. The resulting factored seismic forces are combined with non-seismic concurrent loads and then compared to code ultimate response limits. The design detailing provisions from the UBC, which provide ductility, toughness, and redundancy, are also required such that SSCs can fully achieve potential inelastic energy absorption capability. Also, explicit consideration of relative seismic anchor motion (SAM) effects is required for Performance Category 3 and higher.

The overall DOE Seismic Design and Evaluation Procedure is shown in Figure 2-3. In addition to the general provisions described in this chapter, the topics discussed in Appendix C should be considered before commencing design or evaluation.

2.3 Seismic Design and Evaluation of Structures, Systems, and Components

- Select Performance Categories of structure, system, or component based on DOE-STD-1021 (Ref. 1-10).
- For sites with Performance Category 3 or 4 structures, systems, and components, obtain or develop a seismic hazard curve and design response spectra in accordance with DOE-STD-1023 (Ref. 2-22) for all performance categories based on site characterization discussed in DOE-STD-1022 (Ref. 1-15). In the interim, Eastern U.S. sites may use DOE-STD-1024. (Ref. 2-23)
- Establish design basis earthquake from P_H, (see Table 2-1) mean seismic hazard curve, and median response spectra.

  For sites with only PC-1 or 2 SSC, and no site-specific seismic hazard curve, obtain seismic coefficients from model building codes.



1. See Section C.4 for further discussion.
2. For evaluation of existing facilities, the strength and detailing of the entire load path must be checked prior to assignment of ductility reduction factors.
3. See Section C.5 for further discussion.

Figure 2-3. DOE Seismic Design and Evaluation Procedure

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can be estimated by multiplying calculated drifts by 3 ($R_W/8$). These drifts limits may be exceeded when it is demonstrated that greater drift can be tolerated by both structural systems and non-structural elements.

- Elements of the facility shall be checked to assure that all detailing requirements of the UBC provisions are met. The basic UBC seismic detailing provisions must be met if Z is 0.11g or less. UBC Seismic Zone No. 2 provisions shall be met when Z is between 0.12 and 0.24g. UBC Seismic Zone Nos. 3 & 4 provisions shall be followed when Z is 0.25g or more.
- A quality assurance program consistent with model building code requirements shall be implemented for SSCs in Performance Categories 1 and 2. In addition, peer review shall be conducted for Performance Category 2 SSCs.

2.3.2 Performance Category 3 and 4 Structures, Systems, and Components

The steps in the procedure for PC-3 and 4 SSCs are as follows:

- Evaluate element forces, D_{NS}, for the non-seismic loads expected to be acting concurrently with an earthquake.
- Calculate the elastic seismic response to the DBE, D_S, using a dynamic analysis approach and appropriate damping values from Table 2-3. Response Level 3 is to be used only for justifying the adequacy of existing SSCs with adequate ductile detailing. Note that for evaluation of systems and components supported by the structure, in-structure response spectra are used. For PC-3 and PC-4 SSCs, the dynamic analysis must consider 3 orthogonal components of earthquake ground motion (two horizontal and one vertical). Responses from the various direction components shall be combined in accordance with ASCE 4. Include, as appropriate, the contribution from seismic anchor motion. To determine response of SSCs which use $F\mu > 1$, note that for fundamental periods lower than the period at which the maximum spectral amplification occurs, the maximum spectral acceleration should be used. For higher modes, the actual spectral accelerations should be used.

- Calculate the inelastic seismic demand element forces, D_{SI}, as

$$D_{SI} = SF \frac{D_S}{F_\mu} \qquad (2\text{-}2)$$

where: F_μ = Inelastic energy absorption factor from Table 2-4 for the appropriate structural system and elements having adequate ductile detailing

SF = Scale factor related to Performance Category
= 1.25 for PC-4
= 1.0 for PC-3

Variable scale factors, based on the slope of site-specific hazard curves, may be used as discussed in Appendix C to result in improved achievement of performance goals. SF is applied for evaluation of structures, systems, and components. At this time, F_μ values are not provided for systems and components. It is recognized that many systems and components exhibit ductile behavior for which F_μ values greater than unity would be appropriate (see Section C.4.4.2). Low F_μ values in Table 2-4 are intentionally specified to avoid brittle failure modes.

- Evaluate the total inelastic-factored demand D_{TI} as the sum of D_{SI} and D_{NS} (the best-estimate of all non-seismic demands expected to occur concurrently with the DBE).

$$D_{TI} = D_{NS} + D_{SI} \qquad (2\text{-}3)$$

- Evaluate capacities of elements, C_C, from code ultimate or yield values

  Reinforced Concrete

    Use UBC Chapter 19

  Steel

    Use UBC Chapter 22 Standards

    — LRFD provisions, or

    — Plastic Design provisions, or

    — Allowable Stress Design provision scaled by 1.4 for shear in members and bolts and 1.7 for all other stresses.

Refer to References 2-9 and 2-10 for related industry standards. Note that strength reduction factors, ϕ, are retained. Minimum specified or 95%

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nonexceedence in-situ values for material strengths should be used to estimate capacities.

- The seismic capacity is adequate when C_C exceeds D_{TI}, i.e.:

$$C_C \geq D_{TI} \qquad (2\text{-}4)$$

- Evaluate story drifts due to lateral forces, including both translation and torsion. It may be assumed that inelastic drifts are adequately approximated by elastic analyses (note that lateral seismic forces are not reduced by F_μ when computing story drifts). Calculated story drifts should not exceed 0.010 times the story height for structures with contribution to distortion from both shear and flexture. For structures in which shear distortion is the primary contributer to drift, such as those with low rise shear walls or concentric braced-frames, the calculated story drift should not exceed 0.004 times the story height. These drift limits may be exceeded when acceptable performance of both the structure and nonstructural elements can be demonstrated at greater drift.

- Check elements to assure that good detailing practice has been followed (e.g., see sect. C.4.4.2). Values of F_μ given in Table 2-4 are upper limit values assuming good design detailing practice and consistency with recent UBC provisions. Existing facilities may not be consistent with recent provisions, and, if not, must be assigned reduced F_μ. Basic UBC seismic detailing provisions shall be followed if the PGA at P_H is 0.11g or less. UBC Seismic Zone No. 2 provisions should be met when the PGA at P_H is between 0.12 and 0.24g. UBC Seismic Zone Nos. 3 & 4 provisions should be followed when the PGA at P_H is 0.25g or more.

- Implement peer review of engineering drawings and calculations (including proper applicaton of F_μ values), increased inspection and testing of new construction or existing facilities.

2.3.3 Damping Values for Performance Category 3 and 4 Structures, Systems, and Components

Damping values to be used in linear elastic analyses are presented in Table 2-3 at three different response levels as a function of D_T/C_C.

D_T is the elastically computed total demand,

$$D_T = D_{NS} + D_S \qquad (2\text{-}5)$$

and C_C is the code specified capacity.

When determining the input to subcomponents mounted on a supporting structure, the damping value to be used in elastic response analyses of the supporting structure shall be based on the response level reached in the majority of the seismic load resisting elements of the supporting structure. This may require a second analysis.

In lieu of a second analysis to determine the actual response of the structure, Response Level 1 damping values may be used for generation of in-structure spectra. Response Level 1 damping values must be used if stability considerations control the design.

When evaluating the structural adequacy of an existing SSC, Response Level 3 damping may be used in elastic response analyses independent of the state of response actually reached, because such damping is expected to be reached prior to structural failure.

When evaluating a new SSC, damping is limited to Response Level 2. For evaluating the structural adequacy of a new SSC, Response Level 2 damping may be used in elastic response analyses independent of the state of response actually reached.

The appropriate response level can be estimated from the following:

Response Level	D_T/C_C
3**	≥1.0
2*	≈0.5 to 1.0
1*	≤ 0.5

* Consideration of these damping levels is required only in the generation of floor or amplified response spectra to be used as input to subcomponents mounted on the supporting structure. For analysis of structures including soil-structure interaction effects (sec C.4.3), D_T/C_C ratios for the best estimate case shall be used to determine response level.

** Only to be used for justifying the adequacy of existing SSCs with adequate ductile detailing. However, functionality of SSCs in PC-3 and PC-4 must be given due consideration.

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Table 2-3 Specified Damping Values

Type of Component	Damping (% of critical)		
	Response Level 1	Response Level 2	Response Level 3
Welded and friction bolted metal structures	2	4	7
Bearing-bolted metal structures	4	7	10
Prestressed concrete structures (without complete loss of prestress)	2	5	7
Reinforced concrete structures	4	7	10
Masonry shear walls	4	7	12
Wood structures with nailed joints	5	10	15
Distribution systems***	3	5	5
Massive, low-stressed components (pumps, motors, etc.)	2	3	–*
Light welded instrument racks	2	3	–*
Electrical cabinets and other equipment	3	4	5**
Liquid containing metal tanks			
Impulsive mode	2	3	4
Sloshing mode	0.5	0.5	0.5

* Should not be stressed to Response Level 3. Use damping for Response Level 2.

** May be used for anchorage and structural failure modes which are accompanied by at least some inelastic response. Response Level 1 damping values should be used for functional failure modes such as relay chatter or relative displacement issues which may occur at a low cabinet stress level.

*** Cable trays more than one half full of loose cables may use 10% of critical damping.

Table 2-4 Inelastic Energy Absorption Factors, F_μ

Structural System (terminology is identical to Ref. 2-5)	F_μ
MOMENT RESISTING FRAME SYSTEMS - Beams	
Steel Special Moment Resisting Frame (SMRF)	3.0
Concrete SMRF	2.75
Concrete Intermediate Moment Frame (IMRF)	1.5
Steel Ordinary Moment Resting Frame	1.5
Concrete Ordinary Moment Resisting Frame	1.25
SHEAR WALLS	
Concrete or Masonry Walls	
In-plane Flexure	1.75
In-plane Shear	1.5
Out-of-plane Flexure	1.75
Out-of plane Shear	1.0
Plywood Walls	1.75
Dual System, Concrete with SMRF	2.5
Dual System, Concrete with Concrete IMRF	2.0
Dual System, Masonry with SMRF	1.5
Dual System, Masonry with Concrete IMRF	1.4
STEEL ECCENTRIC BRACED FRAMES (EBF)	
Beams and Diagonal Braces	2.75
Beams and Diagonal Braces, Dual System with Steel SMRF	3.0
CONCENTRIC BRACED FRAMES	
Steel Beams	2.0
Steel Diagonal Braces	1.75
Concrete Beams	1.75
Concrete Diagonal Braces	1.5
Wood Trusses	1.75
Beams and Diagonal Braces, Dual Systems	
Steel with Steel SMRF	2.75
Concrete with Concrete SMRF	2.0
Concrete with Concrete IMRF	1.4
METAL LIQUID STORAGE TANKS	
Moment and Shear Capacity	1.25
Hoop Capacity	1.5

Note: 1. Values herein assume good seismic detailing practice per Reference 2-5, along with reasonably uniform inelastic behavior. Otherwise, lower values should be used.

2. $F\mu$ for columns for all structural systems is 1.5 for flexure and 1.0 for axial compression and shear. For columns subjected to combined axial compression and bending, interaction formulas shall be used.

3. Connections for steel concentric braced frames should be designed for at least the lesser of:
   The tensile strength of the bracing.
   The force in the brace corresponding to $F\mu$ of unity.
   The maximum force that can be transferred to the brace by the structural system.

4. Connections for steel moment frames and eccentric braced frames and connections for concrete, masonry, and wood structural systems should follow Reference 2-5 provisions utilizing the prescribed seismic loads from these criteria and the strength of the connecting members. In general, connections should develop the strength of the connecting members or be designed for member forces corresponding to $F\mu$ of unity, whichever is less.

5. $F\mu$ for chevron, V. and K bracing is 1.5. K bracing requires special consideration for any building if Z is 0.25g or more.

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1. If an existing SSC is close to meeting the criteria, a slight increase in the annual risk to natural phenomena hazards can be allowed within the tolerance of meeting the target performance goals (See Section 1.3). Note that reduced criteria for seismic evaluation of existing SSCs is supported in Reference 2-16. As a result, some relief in the criteria can be allowed by performing the evaluation using hazard exceedance probability of twice the value recommended in Table 2-1 for the Performance Category of the SSC being considered.
2. The SSC may be strengthened such that its seismic resistance capacity is sufficiently increased to meet these seismic criteria. When upgrading is required it should be designed for the original Performance Goal.
3. The usage of the facility may be changed such that it falls within a less hazardous Performance Category and consequently less stringent seismic requirements.
4. It may be possible to conduct the aspects of the seismic evaluation in a more rigorous manner that removes conservatism such that the SSC may be shown to be adequate. Alternatively, a probabilistic assessment might be undertaken in order to demonstrate that the performance goals can be met.

Requirements of Executive order 12941 (Ref. 1-6), as discussed in the Implementation Guide are to be implemented.

2.4.3 Basic Intention of Dynamic Analysis Based Deterministic Seismic Evaluation and Acceptance Criteria

The basic intention of the deterministic seismic evaluation and acceptance criteria defined in Section 2.3 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:

$$SDBE=(1.5SF)(DBE) \qquad (2\text{-}7)$$

where SF is the appropriate seismic scale factor from Equation 2-2.

The seismic evaluation and acceptance criteria presented in this section has intentional and controlled conservatism such that the target performance goals are achieved. The amount of intentional conservatism has been evaluated in Reference 2-1 such that there should be less than 10% probability of unacceptable performance at input ground motion defined by a scale

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factor of 1.5SF times the DBE. Equation 2-7 is useful for developing alternative evaluation and acceptance criteria which are also based on the target performance goals such as inelastic seismic response analyses. To evaluate items for which specific acceptance criteria are not yet developed, such as overturning or sliding of foundations, or some systems and components; this basic intention must be met. If a nonlinear inelastic response analysis which explicitly incorporates the hysteretic energy dissipation is performed, damping values that are no higher than Response Level 2 should be used to avoid the double counting of this hysteretic energy dissipation which would result from the use of Response Level 3 damping values.

2.5 Summary of Seismic Provisions

Table 2-5 summarizes recommended earthquake design and evaluation provisions for Performance Categories 1 through 4. Specific provisions are described in detail in Section 2.3. The basis for these provisions is described in Reference 2-1.

Table 2-5 Summary of Earthquake Evaluation Provisions

	Performance Category (PC)			
	1	2	3	4
Hazard Exceedance Probability, P_H	$2x10^{-3}$	$1x10^{-3}$	$5x10^{-4}$ ($1x10^{-3}$)[1]	$1x10^{-4}$ ($2x10^{-4}$)[1]
Response Spectra	Median amplification (no conservative bias)			
Damping for Structural Evaluation	5%		Table 2-3	
Acceptable Analysis Approaches for Structures	Static or dynamic force method normalized to code level base shear		Dynamic analysis	
Analysis approaches for systems and components	UBC Force equation for equipment and non-structural elements (or more rigorous approach)		Dynamic analysis using in-structure response spectra (Damping from Table 2-3)	
Importance Factor	I=1.0	I=1.25	Not used	
Load Factors	Code specified load factors appropriate for structural material		Load factors of unity	
Scale Factors	Not Used		SF = 1.0	SF = 1.25
Inelastic Energy Absorption Ratios	Accounted for by R_w from Table 2-2		$F\mu$ from Table 2-4 by which elastic response is reduced to account for permissible inelastic behavior	
Material Strength	Minimum specified or 95% non-exceedance in-situ values			
Structural Capacity	Code ultimate strength or allowable behavior level		Code ultimate strength or limit-state level	
Quality Assurance Program	Required within a graded approach (i.e., with increasing rigor ranging from UBC requirements from PC-1 to nuclear power plant requirements for PC-4)			
Peer Review	Not Required	Required within a graded approach (i.e., with increasing rigor ranging from UBC requirements from PC-2 to nuclear power plant requirements for PC-4)		

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

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Appendix B
Commentary on General NPH Design and Evaluation Criteria

B.1 NPH Design and Evaluation Philosophy

The natural phenomena hazard (NPH) design and evaluation criteria presented in this document (DOE-STD-1020) implement the requirements of DOE Order 420.1, "Facility Safety" (Ref. B-1) and the associated Implementation Guides: "Implementation Guide for the Mitigation of Natural Phenomena Hazards for DOE Nuclear Facilities and Non-nuclear Facilities" (Ref. B-2), "Implementation Guide for Nonreactor Nuclear Safety Design Criteria and Explosives Safety Criteria" (Ref. B-3), and "Implementation Guide for Use with DOE Orders 420.1 and 440.1 Fire Safety Program" (Ref. B-4) which are intended to assure acceptable performance of DOE facilities in the event of earthquake, wind/tornado, and flood hazards. As discussed in Chapter 1, performance is measured by target performance goals expressed as an annual probability of exceedance of acceptable behavior limits (i.e., behavior limits beyond which damage/failure is unacceptable). DOE Order 420.1 and the associated Implementation Guides establish a graded approach for NPH requirements by defining performance categories (numbered 0 through 4) each with a qualitative performance goal for behavior (i.e., maintain structural integrity, maintain ability to function, maintain confinement of hazardous materials) and a qualitative target probabilistic performance goal. DOE-STD-1020 provides four sets of NPH design and evaluation criteria (explicit criteria are not needed for Performance Category 0). These criteria range from those provided by <u>model building codes</u> for Performance Category 1 to those approaching <u>nuclear power plant criteria</u> for Performance Category 4.

DOE-STD-1020 employs the graded approach by following the philosophy of probabilistic performance goal-based design and evaluation criteria for natural phenomena hazards. Target performance goals range from low probability of NPH-induced damage/failure to very high confidence of extremely low probability of NPH-induced damage/failure. In this manner, structures, systems, and components (SSCs) are governed by NPH criteria which are appropriate for the potential impact on safety, mission, and cost of those SSCs. For example, a much higher likelihood of damage would be acceptable for an unoccupied storage building of low value than for a high-occupancy facility or a facility containing hazardous materials. SSCs containing hazardous materials which, in the event of damage, threaten public safety or the environment, and/or which have been determined to require special consideration, should have a very low probability of damage due to natural phenomena hazards (i.e., much lower probability of damage than would exist from the use of model building code design and evaluation procedures). For ordinary SSCs of relatively low

cost, there is typically no need or requirement to add conservatism to the design beyond that of model building codes. For these SSCs, it is also typically not cost-effective to strengthen structures more than required by model building codes that consider extreme loads due to natural phenomena hazards.

Performance goals correspond to probabilities of structure or equipment damage due to natural phenomena hazards; they do not extend to consequences beyond structure or equipment damage. The annual probability of exceedance of SSC damage as a result of natural phenomena hazards (i.e., performance goal) is a combined function of the annual probability of exceedance of the event, factors of safety introduced by the design/evaluation procedures, and other sources of conservatism. These criteria specify hazard annual probabilities of exceedance, response evaluation methods, and permissible behavior criteria for each natural phenomena hazard and for each performance category such that desired performance goals are achieved for either design or evaluation. The ratio of the hazard annual probability of exceedance and the performance goal annual probability of exceedance is called the risk reduction ratio, R_R in DOE-STD-1020. This ratio establishes the level of conservatism to be employed in the design or evaluation process. For example, if the performance goal and hazard annual probabilities are the same ($R_R = 1$), the design or evaluation approach should introduce no conservatism. However, if conservative design or evaluation approaches are employed, the hazard annual probability of exceedance can be larger (i.e., more frequent) than the performance goal annual probability ($R_R > 1$). In the criteria presented herein, the hazard probability and the conservatism in the design/evaluation method are not the same for earthquake, wind, and flood hazards. However, the accumulated effect of each step in the design/evaluation process is to aim at the performance goal probability values which are applicable to each natural phenomena hazard separately.

Design and evaluation criteria are presented in Chapters 2, 3, and 4 for earthquake, wind, and flood hazards, respectively. These criteria are deterministic procedures that establish SSC loadings from probabilistic natural phenomena hazard curves; specify acceptable methods for evaluating SSC response to these loadings; provide acceptance criteria to judge whether computed SSC response is acceptable; and to provide detailing requirements such that behavior is as expected as illustrated in Figure B-1. These criteria are intended to apply equally for design of new facilities and for evaluation of existing facilities. In addition, the criteria are intended to cover buildings, equipment, distribution systems (piping, HVAC, electrical raceways, etc.), and other structures.

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DOE-STD-1020 primarily covers (1) methods of establishing load levels on SSCs from natural phenomena hazards and (2) methods of evaluating the behavior of structures and equipment to these load levels. These items are very important, and they are, typically, emphasized in design and evaluation criteria. However, there are other aspects of facility design that are equally important and that should be considered. These aspects include quality assurance considerations and attention to design details. Quality assurance requires peer review of design drawings and calculations; inspection of construction; and testing of material strengths, weld quality, etc. The peer reviewers should be qualified personnel who were not involved in the original design. Important design details include measures to assure ductile behavior and to provide redundant load paths, as well as proper anchorage of equipment and nonstructural building features. Although quality assurance and design details are not discussed in this report to the same extent as NPH load levels and NPH response evaluation and acceptance criteria, the importance of these parts of the design/evaluation process should not be underestimated. Quality assurance and peer review are briefly addressed in Section 1.4, in addition to discussions in the individual chapters on each natural phenomena hazard. Design detailing for earthquake and wind hazards is covered by separate manuals. Reference B-5 describes earthquake design considerations including detailing for ductility. Reference B-6 gives structural details for wind design.

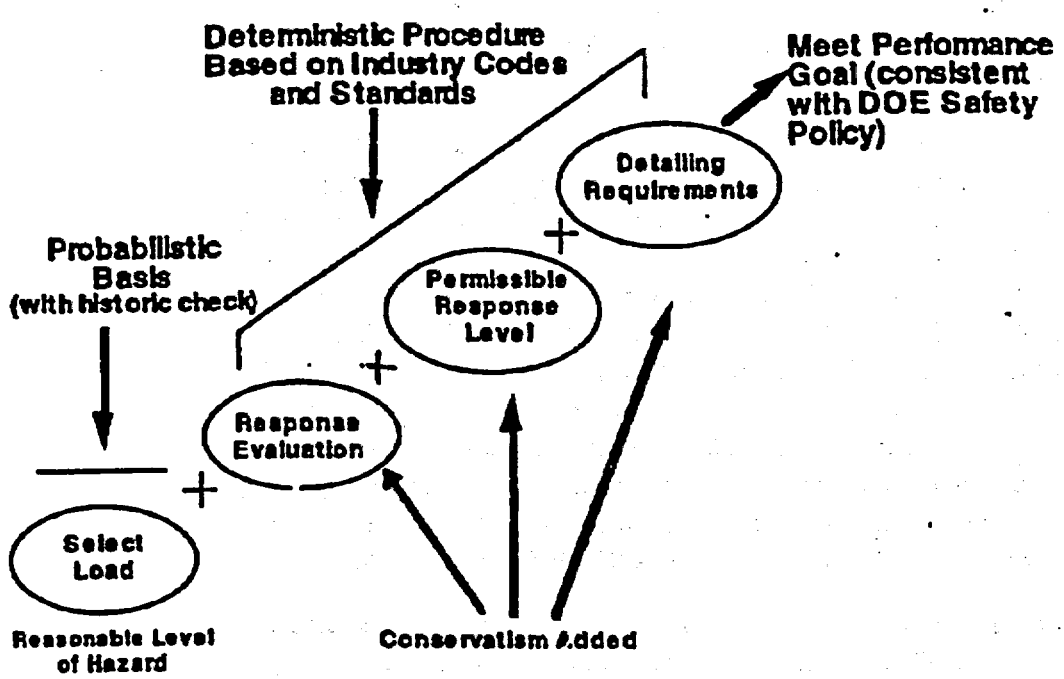

Figure B-1 DOE-STD-1020 Combines Various Methods to Achieve Performance Goals

B.2 Graded Approach, Performance Goals, and Performance Categories

As stated above, DOE Order 420.1 and the associated Implementation Guides establish a graded approach in which NPH requirements are provided for various performance categories each with a specified performance goal. The motivation for the graded approach is that it enables design or evaluation of DOE structures, systems, and components to be performed in a manner consistent with their importance to safety, importance to mission, and cost. There are only a few "reactor" facilities in the DOE complex and many facilities with a wide variety of risk potential, mission, and cost. Also, the graded approach enables cost-benefit studies and establishment of priorities for existing facilities. There are few new designs planned for the DOE complex and the evaluation of existing facilities requires cost benefit considerations and prioritizing upgrading and retrofit efforts. Finally, the graded approach is common practice by model building codes such as the Uniform Building Code (Ref. B-7), Department of Defense earthquake provisions (Ref. B-8), and even by the Nuclear Regulatory Commission which provides graded criteria from power plants to other licensed nuclear facilities.

The motivation for the use of probabilistic performance goals by the NPH Implemenation Guide for DOE Order 420.1 and DOE-STD-1020 is that accomplish the graded approach using a quantified approach consistent with the variety of DOE facilities as well as meeting the risk-based DOE safety policy. Furthermore, the use of probabilistic performance goals enables the development of consistent criteria both for all natural phenomena hazards (i.e., earthquakes, winds, and floods) and for all DOE facilities which are located throughout the United States. The use of performance goal based criteria is becoming common practice as: it is embedded in recent versions of the Uniform Building Code and in the DOD seismic provisions for essential buildings; it has been used for DOE new production reactor NPH criteria; and it has been utilized in recent Nuclear Regulatory Commission applications such as for the advanced light water reactor program and for revisions to commercial reactor geological siting criteria in 10CFR100, Appendix A.

Five performance categories are specified in the Implementation Guide for DOE Order 420.1 for design/evaluation of DOE structures, systems, and components for natural phenomena hazards ranging from 0 through 4. Table B-1 presents both the qualitative and quantitative descriptions of the performance goals for each performance category. Both the qualitative description of acceptable NPH performance and the quantitative probability value for each performance category are equally significant in establishing these NPH

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design and evaluation criteria within a graded approach. SSCs are to be placed in categories in accordance with DOE-STD-1021-93 (Ref. B-9) Additional guidance on performance categorization is available in Reference B-10.

As mentioned previously, the quantitative performance goal probability values are applicable to each natural phenomena hazard (earthquake, wind, and flood) individually. The earthquake and flood design and evaluation criteria presented in this document are aimed at meeting the target performance goals given in Table B-1. The extreme wind and tornado design and evaluation criteria presented in this document are conservative compared to earthquake and flood criteria in that they are aimed at lower probability levels than the target performance goals in Table B-1. It is estimated that for extreme winds, the probabilities of exceeding acceptable behavior limits are less than one order of magnitude smaller than the performance goals in Table B-1. For tornado criteria, the probabilities of exceeding acceptable behavior limits are greater than one but less than two orders of magnitude smaller than the performance goals for Performance Categories 3 and 4. This additional conservatism in wind and tornado criteria for design and evaluation of DOE facilities is consistent with common practice in government and private industry. Furthermore, this additional conservatism can be accommodated in the design and evaluation of SSCs without significantly increasing costs. SSCs in Performance Categories 3 and 4 should be designed for tornadoes at certain sites around the country where tornado occurrences are high. The tornado hazard probability must be set lower than necessary to meet the performance goals in order for tornadoes rather than straight w. ds or hurricanes to control the design criteria.

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

Performance Category	Performance Goal Description	NPH Performance Goal Annual Probability of Exceeding Acceptable Behavior Limits, P_f
0	No Safety, Mission, or Cost Considerations	No requirements
1	Maintain Occupant Safety	$\approx 10^{-3}$ of the onset of SSC[1] damage to the extent that occupants are endangered
2	Occupant Safety, Continued Operation with Minimum Interruption	$\approx 5\times10^{-4}$ of SSC damage to the extent that the component cannot perform its function
3	Occupant Safety, Continued Operation, Hazard Confinement	$\approx 10^{-4}$ of SSC damage to the extent that the component cannot perform its function
4	Occupant Safety, Continued Operation, Confidence of Hazard Confinement	$\approx 10^{-5}$ of SSC damage to the extent that the component cannot perform its function

(1) These performance goals are for each natural phenomena hazard (earthquake, wind, and flood).
(2) SSC refers to structure, distribution system, or component (equipment).

The design and evaluation criteria for SSCs in Performance Categories 0, 1, and 2 are similar to those given in model building codes. Performance Category 0 recognizes that for certain lightweight equipment items, furniture, etc., and for other special circumstances where there is little or no potential impact on safety, mission, or cost, design or evaluation for natural phenomena hazards may not be needed. Assignment of an SSC to Performance Category 0 is intended to be consistent with, and not take exception to, model building code NPH provisions. Performance Category 1 criteria include no extra conservatism against natural phenomena hazards beyond that in model building codes that include earthquake, wind, and flood considerations. Performance Category 2 criteria are intended to maintain the capacity to function and to keep the SSC operational in the event of natural phenomena hazards. Model building codes would treat hospitals, fire and police stations, and other emergency-handling facilities in a similar manner to DOE-STD-1020 Performance Category 2 NPH design and evaluation criteria.

Performance Category 3 and 4 SSCs handle significant amounts of hazardous materials or have significant programmatic impact. Damage to these SSCs could potentially endanger worker and public safety and the environment or interrupt a significant mission. As a result, it is very important for these SSCs to continue to function in the event of natural phenomena hazards, such that the hazardous materials may be controlled and confined. For these categories, there must be a very small likelihood of damage due to natural phenomena hazards. DOE-STD-1020 NPH criteria for Performance Category 3 and higher SSCs are more conservative than requirements found in model building codes and are similar to DOD criteria for high risk buildings and NRC criteria for various applications as illustrated in Table B-2. Table B-2 illustrates how DOE-STD-1020 criteria for the performance categories defined in DOE Order 420.1 and the associated Implementation Guides compare with NPH criteria from other sources.

Table B-2 Comparison of Performance Categories from Various Sources

Source	SSC Categorization			
DOE-STD-1020 - DOE Natural Phenomena Hazard Criteria	1	2	3	4
Uniform Building Code	General Facilities	Essential Facilities	-	-
DOD Tri-Service Manual for Seismic Design of Essential Buildings	-	-	High Risk	-
Nuclear Regulatory Commission	-		Evaluation of NRC Fuel Facilities	Evaluation of Existing Reactors

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The design and evaluation criteria presented in this document for SSCs subjected to natural phenomena hazards have been specified to meet the performance goals presented in Table B-1. The basis for selecting these performance goals and the associated annual probabilities of exceedance are described briefly in the remainder of this section.

For *Performance Category 1 SSCs*, the primary concern is preventing major structural damage or collapse that would endanger personnel. A performance goal annual probability of exceedance of about 10^{-3} of the onset of significant damage is appropriate for this category. This performance is considered to be consistent with model building codes (Refs. B-7, B-11, B-12, and B-13), at least for earthquake and wind considerations. The primary concern of model building codes is preventing major structural failure and maintaining life safety under major or severe earthquakes or winds. Repair or replacement of the SSC or the ability of the SSC to continue to function after the occurrence of the hazard is not considered.

Performance Category 2 SSCs are of greater importance due to mission-dependent considerations. In addition, these SSCs may pose a greater danger to on-site personnel than Performance Category 1 SSCs because of operations or materials involved. The performance goal is to maintain both capacity to function and occupant safety. Performance Category 2 SSCs should allow relatively minor structural damage in the event of natural phenomena hazards. This is damage that results in minimal interruption to operations and that can be easily and readily repaired following the event. A reasonable performance goal is judged to be an annual probability of exceedance of between 10^{-3} and 10^{-4} of structure or equipment damage, with the SSC being able to function with minimal interruption. This performance goal is slightly more severe than that corresponding to the design criteria for essential facilities (e.g., hospitals, fire and police stations, centers for emergency operations) in accordance with model building codes (e.g., Ref. B-7).

Performance Category 3 and higher SSCs pose a potential hazard to public safety and the environment because radioactive or toxic materials are present. Design considerations for these categories are to limit SSC damage so that hazardous materials can be controlled and confined, occupants are protected, and functioning of the SSC is not interrupted. The performance goal for Performance Category 3 and higher SSCs is to limit damage such that DOE safety policy is achieved. For these categories, damage must typically be limited in confinement barriers (e.g., buildings, glove boxes, storage cannisters, vaults), ventilation systems and filtering, and monitoring and control equipment in the event of an occurrence of severe earthquakes, winds, or floods. In addition, SSCs can be placed in Performance Categories 3 or 4 if improved performance is needed due to cost or mission requirements.

For Performance Category 3 SSCs, an appropriate performance goal has been set at an annual probability of exceedance of about 10^{-4} of damage beyond which hazardous material confinement and safety-related functions are impaired. For Performance Category 4 SSCs, a reasonable performance goal is an annual probability of exceedance of about 10^{-5} of damage beyond which hazardous material confinement and safety-related functions are impaired. These performance goals approaches and approximates, respectively, at least for earthquake considerations, the performance goal for seismic-induced core damage associated with design of commercial nuclear power plants (Refs. B-14, B-15, B-16, and B-17). Annual frequencies of seismic core damage from published probabilistic risk assessments (PRA) of recent commercial nuclear plants have been summarized in Reference B-18. This report indicates that mean seismic core damage frequencies ranged from 4×10^{-6}/year to 1×10^{-4}/year based on consideration of 12 plants. For 10 of the 12 plants, the annual seismic core damage frequency was greater than 1×10^{-5}. Hence, the Performance Category 4 performance goals given in the NPH Implementation Guide for DOE Order 420.1 are consistent with Reference B-18 information.

B.3 Evaluation of Existing Facilities

New SSCs can be designed by these criteria, but existing SSCs may not meet these NPH provisions. For example, most facilities built a number of years ago in the eastern United States were designed without consideration of potential earthquake hazard. It is, therefore, likely that some older DOE facilities do not meet the earthquake criteria presented in this document.

For existing SSCs, an assessment must be made for the as-is condition. This assessment includes reviewing drawings and conducting site visits to determine deviations from the drawings and any in-service deterioration. In-place strength of the materials can be used when available. Corrosive action and other aging processes should be considered. Evaluation of existing SSCs is similar to evaluations performed of new designs except that a single as-is configuration is evaluated instead of several configurations in an iterative manner, as required in the design process. Evaluations should be conducted in order of priority, with highest priority given to those areas identified as weak links by preliminary investigations and to areas that are most important to personnel safety and operations with hazardous materials. Prioritization criteria for evaluation and upgrade of existing DOE facilities are currently being developed.

If an existing SSC does not meet the natural phenomena hazard design/evaluation criteria, several options (such as those illustrated by the flow diagram in Figure B-2) need to be considered. Potential options for existing SSCs include:

1. Conduct a more rigorous evaluation of SSC behavior to reduce conservatism which may have been introduced by simple techniques used for initial SSC evaluation. Alternatively, a probabilistic assessment of the SSC might be undertaken in order to demonstrate that the performance goals for the SSC can be met.
2. The SSC may be strengthened to provide resistance to natural phenomena hazard effects that meets the NPH criteria.
3. The usage of the SSC may be changed so that it falls within a lower performance category and consequently, less stringent requirements.

If SSC evaluation uncovers deficiencies or weaknesses that can be easily remedied, these should be upgraded without considering the other options. It is often more cost-effective to implement simple SSC upgrades than to expend effort on further analytical studies. Note that the actions in Table B-2 need not necessarily be accomplished in the order shown.

Evaluations of existing SSCs must follow or, at least, be measured against the NPH criteria provided in this document. For SSCs not meeting these criteria and which cannot be easily remedied, budgets and schedule for required strengthening must be established on a prioritized basis. As mentioned previously, prioritization criteria for evaluation and upgrade of existing DOE facilities are currently being developed. Priorities should be established on the basis of performance category, cost of strengthening, and margin between as-is SSC capacity and the capacity required by the criteria. For SSCs which are close to meeting criteria, it is probably not cost effective to strengthen the SSC in order to obtain a small reduction in risk. As a result, some relief in the criteria is allowed for evaluation of existing SSCs. It is permissible to perform such evaluations using natural phenomena hazard exceedance probability of twice the value specified for new design. For example, if the natural phenomena hazard annual probability of exceedance for the SSC under consideration was 10^{-4}, it would be acceptable to reconsider the SSC at hazard annual probability of exceedance of 2×10^{-4}. This would have the effect of slightly reducing the seismic, wind, and flood loads in the SSC evaluation. This amount of relief is within the tolerance of meeting the target performance goals and is only a minor adjustment of the corresponding NPH design and evaluation criteria.

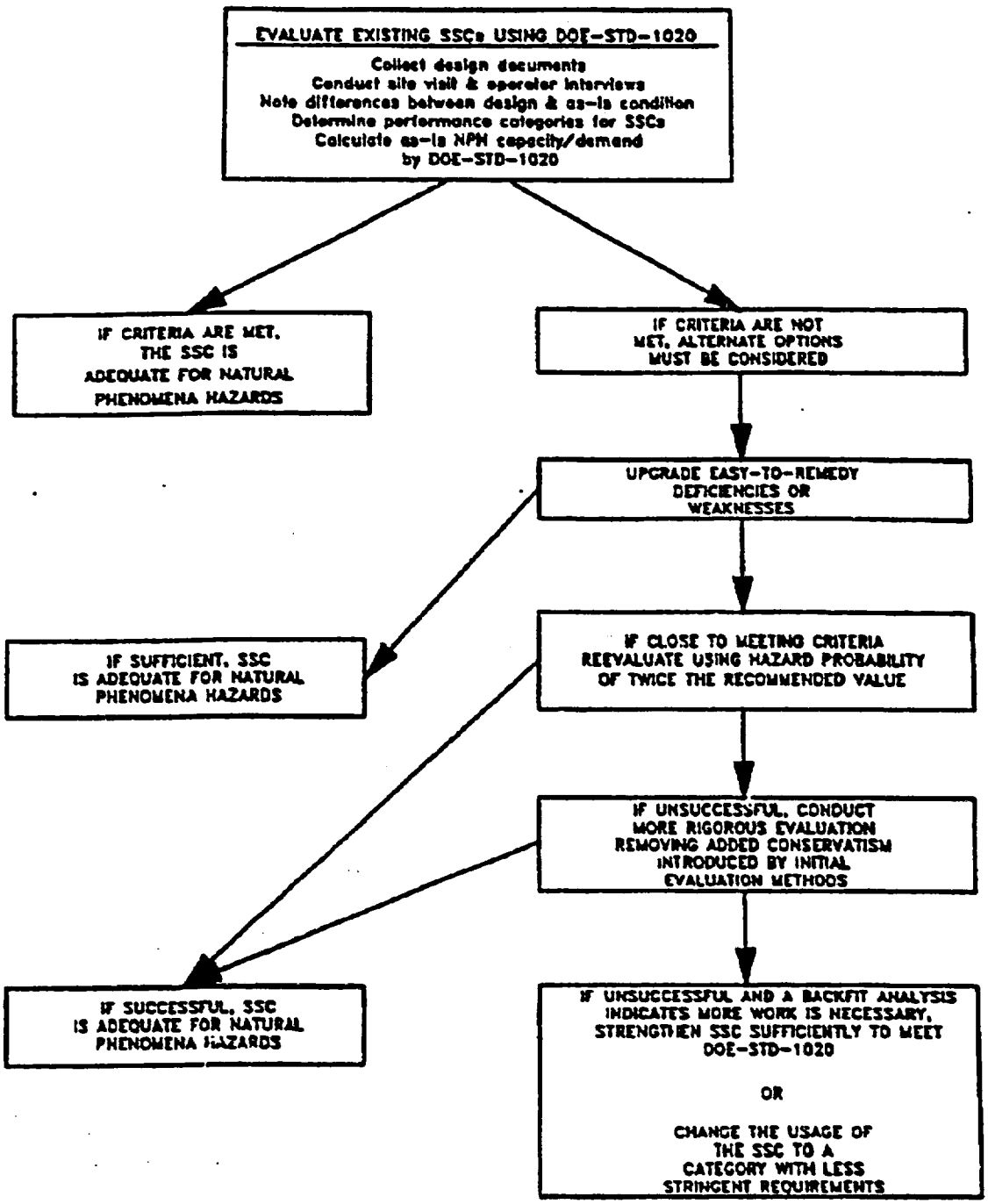

Figure B-2 Evaluation Approach for an Existing SSC

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B.4 References

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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 ·ction C.8. Alternate seismic mitigation measures are discussed in Section C.9.

These seismic criteria use the target performance goals of the NPH Implementation Guide for DOE Order 420.1 (Ref. C-67) to assure safe and reliable performance of DOE facilities during future potential earthquakes. Design of structures, systems, and components to withstand 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 the NPH Implementation Guide for DOE Order 420.1 (Ref. C-67) and 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-STD-1021-93 (Ref. C-26). 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) Seismic 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	$\approx 10^{-3}$ of the onset of SSC[1] damage to the extent that occupants are endangered
2	Occupant Safety, Continued Operation with Minimum Interruption	$\approx 5 \times 10^{-4}$ of SSC damage to the extent that the component cannot perform its function
3	Occupant Safety, Continued Operation, Hazard Confinement	$\approx 10^{-4}$ of SSC damage to the extent that the component cannot perform its function
4	Occupant Safety, Continued Operation, Confidence of Hazard Confinement	$\approx 10^{-5}$ 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.

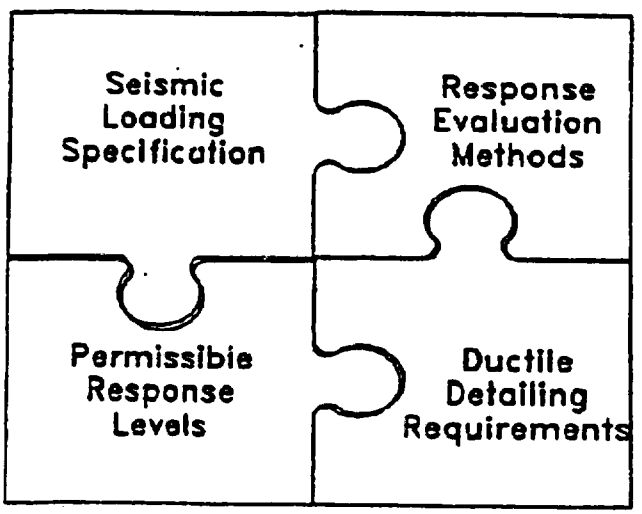


Figure C-1 Consistent Specification of All Seismic Design/Evaluation Criteria Elements

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

C.2.1 Overall Approach for DOE Seismic Criteria

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 Performance Category 1) and for nuclear power plants (similar to DOE Performance Category 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.

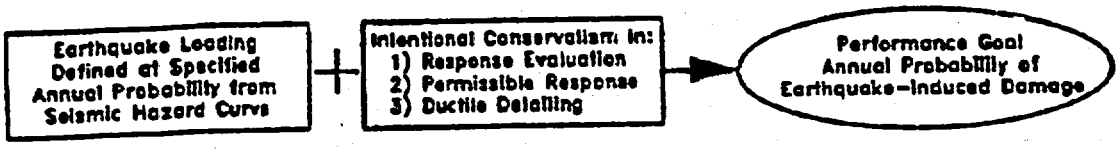


Figure C-2 Performance Goal Achievement

The performance goals for Performance Category 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 Performance Category 3 SSC's are consistent with DOE essential facilities and Pu handling facilities. The perform-

ance 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 this standard, 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:

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

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) gradual reduction in hazard annual exceedance probability
2) 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	1×10^{-3}	2×10^{-3}	2
2	5×10^{-4}	1×10^{-3}	2
3	1×10^{-4}	5×10^{-4} (1×10^{-3})[1]	5 (10)[1]
4	1×10^{-5}	1×10^{-4} (2×10^{-4})[1]	10 (20)[1]

[1] For sites such as LLNL, SNL-Livermore, SLAC, LBL, 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 imple-

mentation document that invokes these criteria. As shown in Table 2-3, 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.
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 and importance factors have been retained for the evaluation of Performance Category 2 and lower SSCs because the UBC approach (which includes these factors) is followed for these categories. Importance 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 Performance Categories 3 and 4. Material strengths and structural capacities specified for Performance Category 3 and higher SSCs correspond to ultimate strength code-type provisions (i.e., ACI 318-89 for reinforced concrete, LRFD, or AISC Chapter N for steel). Material strengths and structural capacities specified for Performance Category 2 and lower 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 introduced if considerations of effective peak ground motion, soil-structure interaction, 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 hazard exceedance probability is lowered and importance factor is 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 1.0 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 of the Implementation Guide for DOE Order 420.1 are the basis of the seismic design and evaluation criteria presented in this standard. It is known that for PC 1 and PC 2, target performance goals, P_F, of 1×10^{-3} and 5×10^{-4}, respec-

tively, are met relatively closely. However, for PC 3 and PC 4, target performance goals, P_F, of $1x10^{-4}$ and $1x10^{-5}$, 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. Seismic hazard curve slope does not have a significant effect on performance for PC 1 and PC 2 because P_F and P_N do not differ greatly (i.e. $R_R = P_N/P_F = 2$).

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

$$H(a) = K a^{-k_H} \tag{C-3}$$

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:

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

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_N, 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:

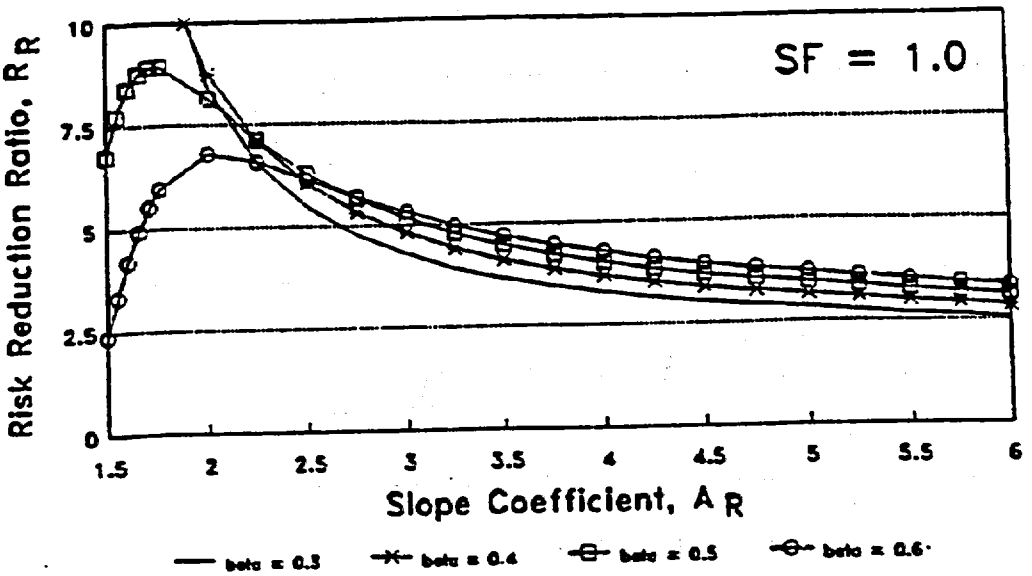
$$R_R = (C_{50}/\mathrm{DBE})^{k_N} e^{-\frac{1}{2}(k_N\beta)^2} \qquad \text{(C-5)}$$

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

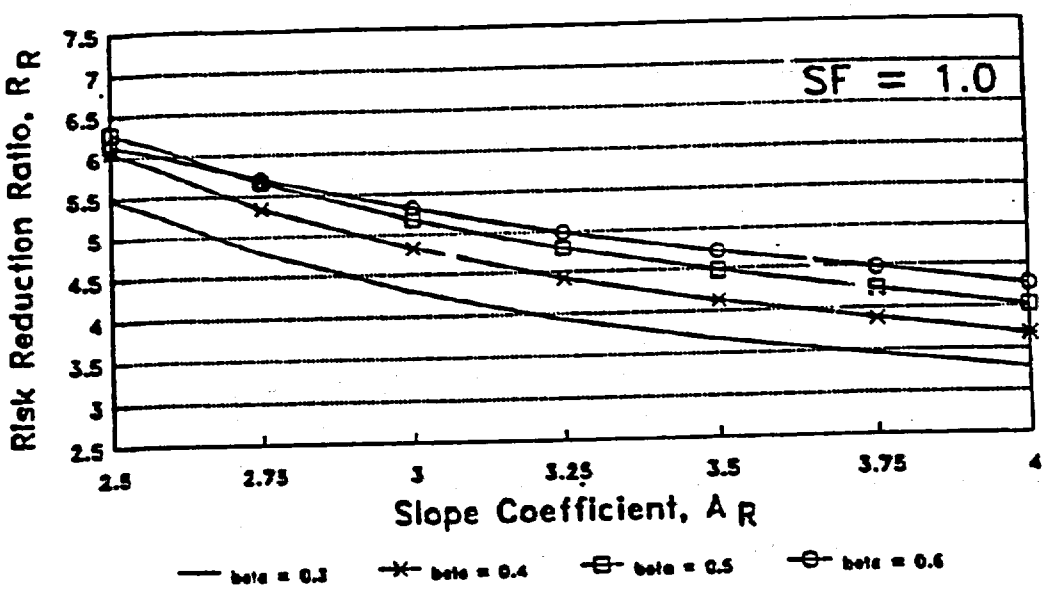
Using the basic criterion of DOE-STD-1020 that target performance goals are achieved when the minimum required 10% probability of failure capacity, C_{10} is equal to 1.5 times the seismic scale factor, SF, times the DBE ground motion, Equation (C-5) may be rewritten as:

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

Equation (C-6) demonstrates the risk reduction ratio achieved by DOE seismic criteria as a function of hazard curve slope, uncertainty, β, and seismic scale factor, SF. Note from Table C-3 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 (C-6) versus slope coefficient A_R are plotted in Figures C-3 and C-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. 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. As a result, Figure C-3 includes a blown-up view for the 2.5 to 4 A_R range and Figure C-4 includes a blown-up view for the 2 to 3 A_R range.

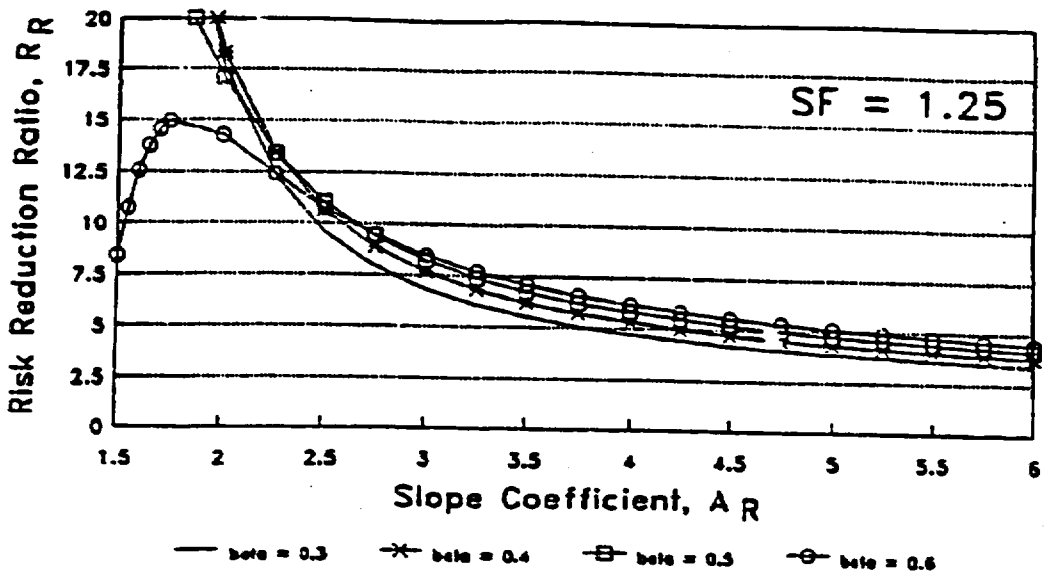


a) A_R from 1.5 to 6

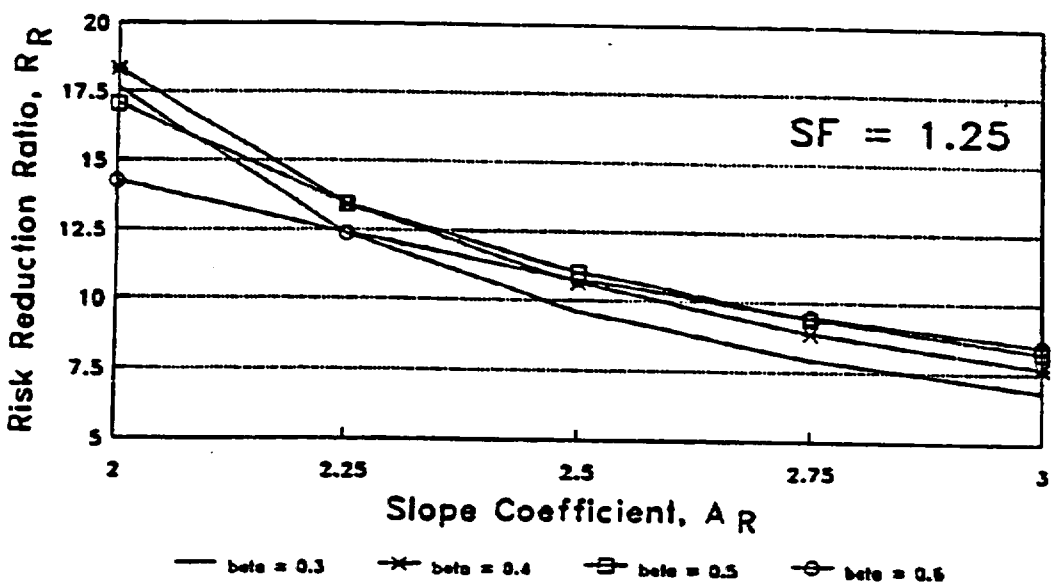


b) A_R from 2.5 to 4

Figure C-3 Value of R_R vs A_R for SF = 1.0 (PC 3)



a) A_R from 1.5 to 6



b) A_R from 2 to 3

Figure C-4 Value of R_R vs A_R for SF = 1.25 (PC 4)

Figure C-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 C-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 $3x10^{-4}$ to $5x10^{-5}$. 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 Figure C-5 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 Figure C-5 combined with Equation C-6 improves the R_R values compared to target values as shown in Figures C-6 and C-7 for PC 3 (R_R = 5) and PC 4 (R_R = 10), respectively. Figures C-6 and C-7 demonstrate that when the variable scale factors from Figure C-5 are used, risk reduction factors achieved are within about 10% of the target values of 5 and 10, respectively. As a result, target performance goals would be met within about the same 10%.

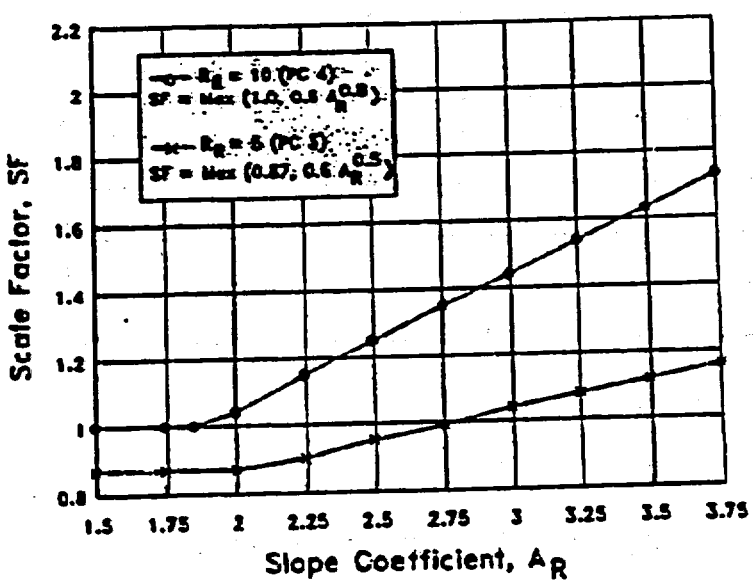


Figure C-5 Variable II Seismic Scale Factor for PC 3 and PC 4

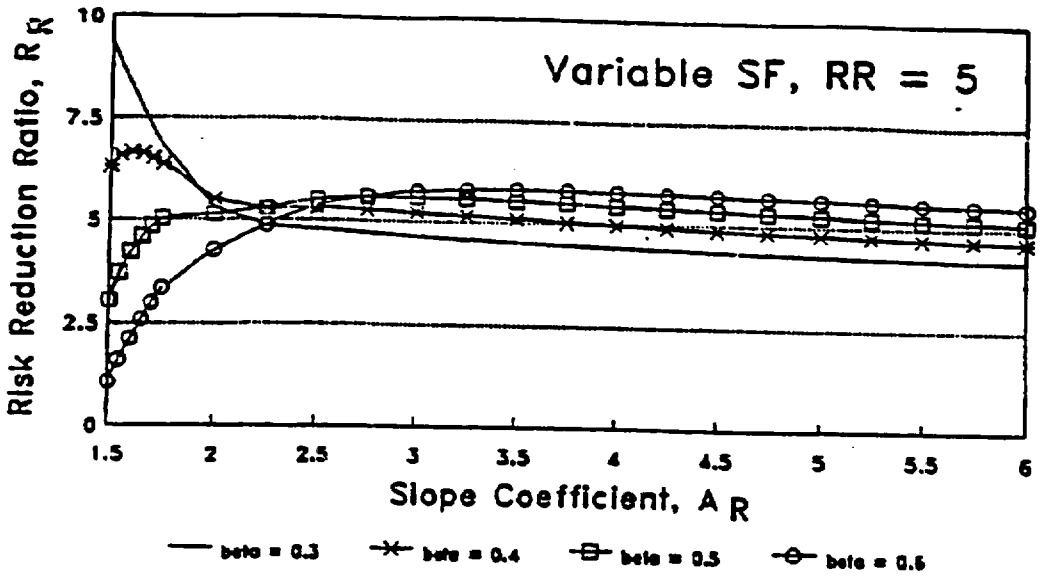


Figure C-6 Value of R_R vs A_R for Variable SF (Fig. C-5 for PC 3)

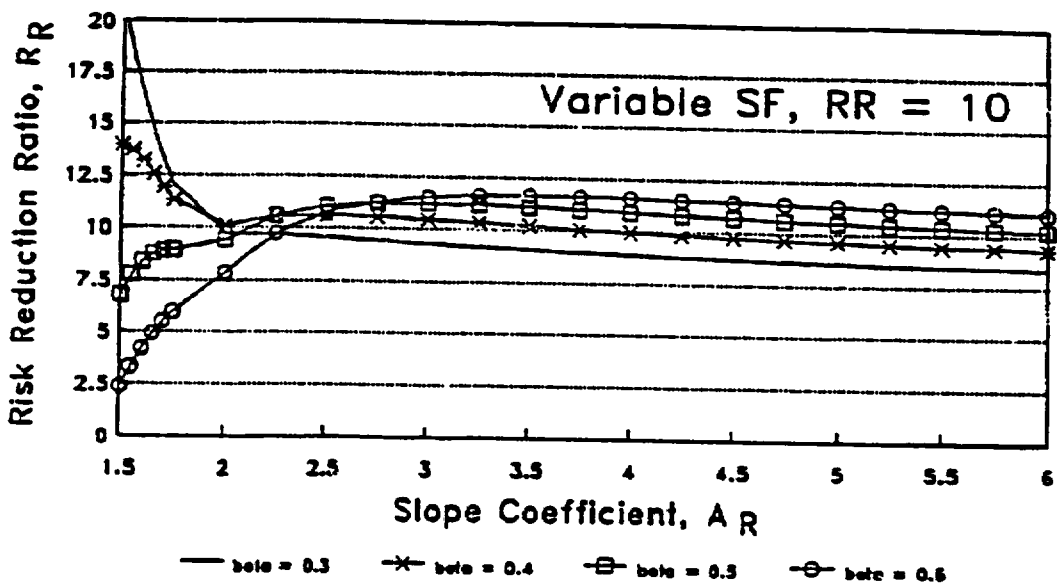


Figure C-7 Value of R_R vs A_R for Variable SF (Fig. C-5 for PC 4)

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 C-3a and C-4a 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 1×10^{-3} and 1.0 for PC 3 and 2×10^{-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.

For each performance category, 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-8. 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-8 anchored to this maximum ground acceleration. Note that the three spectra presented in Figure C-8 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-8 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 NPH Implementation Guide (Refs. C-27 and C-67), it is not required that a site-specific probabilistic seismic hazard assessment be conducted if the site includes only Performance Category 2 and lower 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 the larger of those determined in accordance with the UBC (Ref. C-2) and with UCRL-53582, Rev. 1 (Ref. C-14). Design/evaluation earthquake ground motion determined from a recent site-specific probabilistic seismic hazard assessment is considered to be preferable to the UBC for determining ZC. Therefore, the DBE response spectrum for Performance Category 2 and lower may be developed from a new probabilistic seismic hazard assessment following the guidance given herein for Performance Category 3 and higher. However, when design/evaluation earthquake ground motion is based on recent site-specific geotechnical studies and the resulting seismic loads are less than that determined by the UBC, the differences must be justified and approval of seismic loads must be obtained from DOE.

For design or evaluation of SSCs in Performance Category 3 and higher, it is strongly recommended that a modern site-specific seismic hazard assessment be performed to provide the basis for DBE ground motion levels and response spectra. DOE Order 420.1 and the associated NPH Implementation 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. The DOE seismic working group interim standard, DOE-STD-1024-92 (Ref. C-13), indicates that the approach used for the seismic hazard assessments summarized in UCRL-53582 (Ref. C-14), which are more than 10 years old, are out of date relative to the current state of the art. However, in accordance with DOE-STD-1024-92, it is permissible to establish DBE ground motion levels and response spectra for Performance Categories 3 and 4 based on UCRL-53582 in the interim until a modern site-specific seismic hazard assessment becomes available. DBE ground motion levels for Performance Categories 3 and 4 based on UCRL-53582 are also provided in Section C.3.2.2.

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.

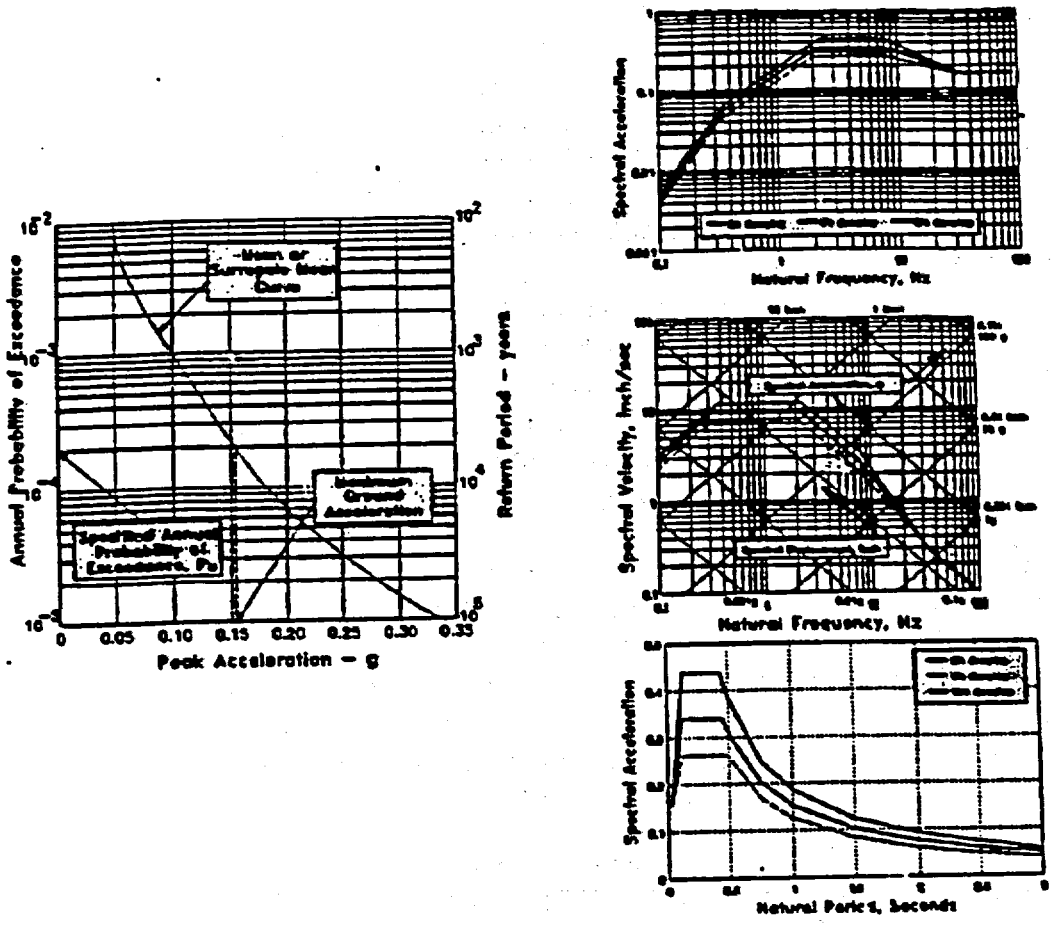


Figure C-8 Earthquake Input Excitation is Defined by Maximum Ground Acceleration Anchoring Site-Specific Response Spectra

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 15 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 2×10^{-3}. The Canadian building code used 1×10^{-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 1×10^{-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 1×10^{-3} annual exceedance frequency.

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 0.1×10^{-4} and 10×10^{-4} as is illustrated in Figure C-9. 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-9 also demonstrates that for 2/3 of these plants the SSE spectra corresponds to probabilities between about 0.4×10^{-4} and 2.5×10^{-4}. Hence, the specified hazard probability level of 1×10^{-4} in this standard is consistent with SSE levels.

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 Performance Category 1 to 4 SSCs. The conservatism associated with Performance Categories 1 and 2 should be consistent with that contained in the UBC (Ref. C-2), ATC-3 (Ref. C-1), or NEHRP (Ref. C-3) 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. The criteria contained herein follow the philosophy of a gradual reduction in the annual exceedance probability of the hazard coupled with a gradual increase in the conservatism of the evaluation procedures and acceptance criteria as one goes from Performance Category 1 to Performance Category 4.

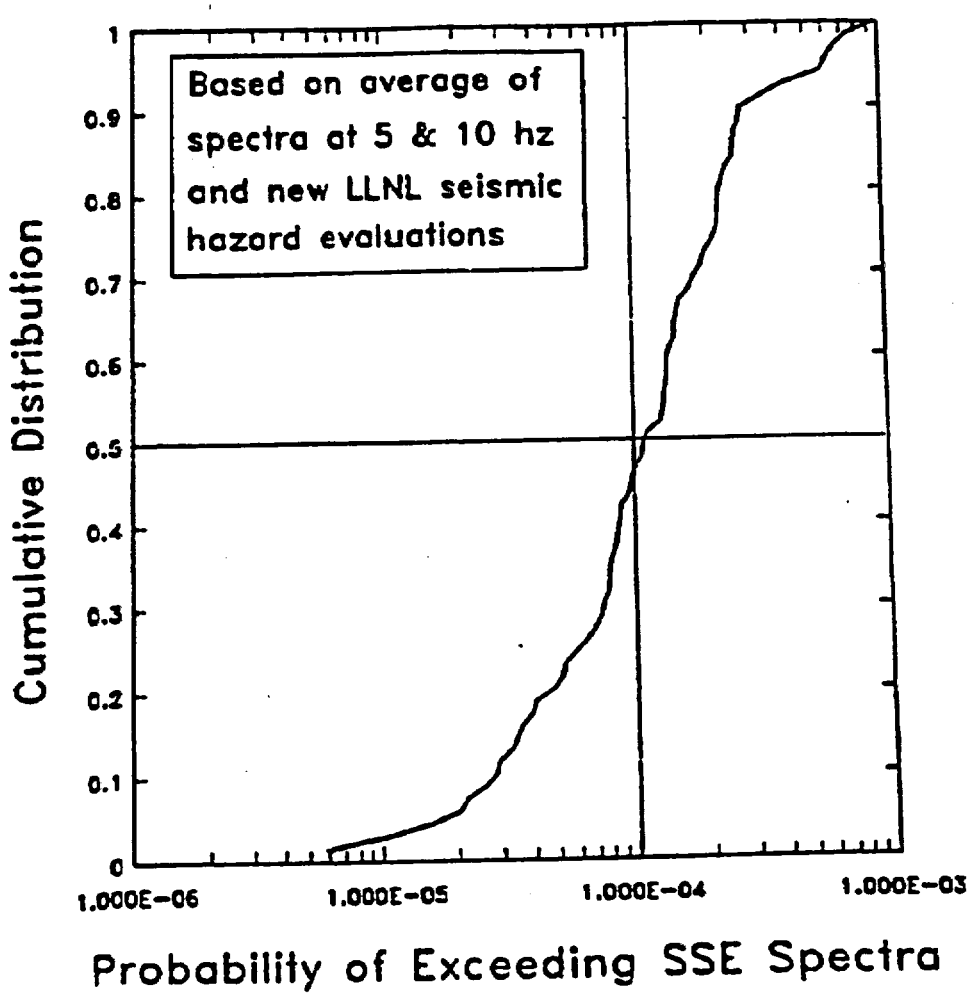


Figure C-9 Probability of Exceeding SSE Response Spectra