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OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE 1.61

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DAMPING VALUES FOR SEISMIC DESIGN OF NUCLEAR POWER PLANTS

A. INTRODUCTION

This regulatory guide is being revised to update the guidance for applicants and licensees regarding the acceptable damping values that the U.S. Nuclear Regulatory Commission (NRC) staff used in the seismic response analysis of Seismic Category I[1] nuclear power plant structures, systems, and components (SSCs) in accordance with Title 10, Part 50, of the *Code of Federal Regulations* (10 CFR Part 50), "Domestic Licensing of Production and Utilization Facilities" [Ref. 1].

Specifically, General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50 requires that SSCs important to safety be designed to withstand the effects of natural phenomena such as earthquakes without losing the ability to perform their safety functions. Such SSCs must also be designed to accommodate the effects of and be compatible with the environmental conditions associated with normal operation and postulated accidents. Appendix S, "Earthquake Engineering Criteria for Nuclear Power Plants," to 10 CFR Part 50 specifies the requirements for the implementation of General Design Criterion 2 with respect to earthquakes.[2]

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1 Structures, systems, and components of a nuclear power plant that are designated as Seismic Category I are designed to withstand the effects of the safe shutdown earthquake (SSE) and remain functional, see Regulatory Guide 1.29, "Seismic Design Classification."

2 Appendix S to 10 CFR Part 50 applies to applicants for a design certification or combined license pursuant to 10 CFR Part 52, "Early Site Permits; Standard Design Certifications; and Combined Licenses for Nuclear Power Plants," or a construction permit or operating license pursuant to 10 CFR Part 50 after January 10, 1997. However, for either an operating license applicant or holder whose construction permit was issued before January 10, 1997, the earthquake engineering criteria in Section VI of Appendix A to 10 CFR Part 100 continue to apply.

This regulatory guide specifies the damping values that the NRC staff considers acceptable for complying with the agency's regulations and guidance for seismic analysis. The specified damping values are intended for elastic modal dynamic seismic analysis where energy dissipation is accounted for by viscous damping (i.e., the damping force is proportional to the velocity).

This regulatory guide contains information collections that are covered by the requirements of 10 CFR Part 50, which the Office of Management and Budget (OMB) approved under OMB control number 3150-0011. The NRC may neither conduct nor sponsor, and a person is not required to respond to, an information collection request or requirement unless the requesting document displays a currently valid OMB control number.

B. DISCUSSION

Background

Damping is a measure of the energy dissipation of a material or structural system as it responds to dynamic excitation. It is a term used to assist in mathematically modeling and solving dynamic equations of motion for a vibratory system in which energy is dissipated. When performing an elastic dynamic seismic analysis, one can account for the energy dissipated by specifying the amount of viscous damping (i.e., damping force proportional to the velocity) in the analytical model.

Current NRC guidance on damping values to be used in the elastic design of nuclear power plants is presented in this regulatory guide, which was first issued in October 1973 [Ref. 2]. Like the original version of this guide, this revision specifies equivalent viscous modal damping values as a percentage of critical damping for Seismic Category I SSCs. However, the staff based the original damping values on limited data, expert opinion, and other information available in 1973. Since that time, the NRC and industry have been involved in various studies, research work, and testing to predict and estimate damping values of SSCs. In view of the available data, the damping values provided in the original version of Regulatory Guide 1.61 may not reflect realistic damping values for SSCs. Also, it is recognized that additional guidance is needed to address issues, such as correlation between damping and structures stress level, and damping values for materials not included in the original version of Regulatory Guide 1.61 (e.g., electrical distribution systems and reinforced masonry structures).

Over the past three decades, the nuclear industry has proposed damping values and discussed these values during various meetings and reviews of licensing issues. Nuclear industry groups and licensees have suggested that the NRC ought to accept more realistic damping values for seismic design and analysis of SSCs, in place of the damping values provided in the original Regulatory Guide 1.61.

Structural Damping

In 1993, the NRC completed an investigation of the adequacy of original Regulatory Guide 1.61 structure damping values and other recommendations, and reported the results in NUREG/CR-6011 [Ref. 3]. Data were analyzed to identify the parameters that significantly influenced structure damping. Based on that study, the NRC determined that the original Regulatory Guide 1.61 damping values for structure design were adequate but required one significant revision. Specifically, Regulatory Guide 1.61 should distinguish between "friction-bolted" and "bearing-bolted" connections for steel structures. Friction-bolted connections are also referred to as "slip-critical" connections. In these connections, the bolt preload is high enough to ensure that friction is not overcome, and the bolt does not experience shear loading. Regulatory Position 1 in Section C of this revised guide provides the updated structural damping values.

Piping Damping

In 1986, the American Society of Mechanical Engineers (ASME) established Code Case N-411, "Alternative Damping Values for Response Spectra Analysis of Class 1, 2, and 3 Piping," in Section III, Division 1, of the ASME Boiler and Pressure Vessel Code [Ref. 4]. The NRC staff used Code Case N-411, with certain limitations specified in Regulatory Guide 1.84 [Ref. 5], to review operating reactor issues until Code Case N-411 expired in 2000. The staff also approved the use of alternate damping values for the General Electric Advanced Boiling Water Reactor Design in 1994 [Ref. 6], Combustion Engineering System 80+ Design in 1992 [Ref. 7], and Westinghouse AP600 Design in 1998 [Ref. 8]. Regulatory Position 2 in Section C of this revised guide provides the piping damping values that resulted from the staff's experience with ASME Code Case N–411 and application reviews of new reactor designs.

Electrical Distribution System Damping

Regulatory Guide 1.61 did not originally provide damping values for cable tray or conduit systems. Historically, the nuclear power industry used the damping values for bolted steel structures for seismic design of cable tray and conduit systems. In the late 1980s, however, the NRC staff reviewed the results of the cable tray test at the Comanche Peak Steam Electrical Station [Ref. 9]. Regulatory Position 3 in Section C of this revised guide provides the damping values that resulted from the staff's review of data from the Comanche Peak test [Ref. 10] and two safety evaluation reports [Refs. 9, 11].

Heating Ventilation and Air Conditioning Duct Damping

The damping values for heating ventilation and air conditioning (HVAC) systems are consistent with the guidance provided for bolted steel structures. Because no tests of welded duct construction have been identified, the damping values are the same as for welded steel structures, and Regulatory Position 4 in Section C of this revised guide provides these same damping values. In addition, the NRC provides related information on HVAC duct damping in NUREG/CR-6919, "Recommendations for Revision of Seismic Damping Values in Regulatory Guide 1.61" [Ref. 12].

Mechanical and Electrical Component Damping

NUREG/CR-6919 [Ref. 12] considers guidance in American Society of Civil Engineers (ASCE) Standard 43-05, "Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities" [Ref. 13], and Non-Mandatory Appendix N, "Dynamic Analysis Methods," to Section III, Division 1, of the ASME Boiler & Pressure Vessels Code [Ref. 14]. In addition, NUREG/CR-6919 [Ref. 12] provides recommendations and commentary on damping values for (1) containment structures, containment internal structures, and other Seismic Category I structures; (2) piping; (3) electrical distribution systems (i.e., cable tray or conduit systems); (4) HVAC; and (5) mechanical and electrical components. Regulatory Position 5 in Section C of this revised guide provides the damping values that resulted from the staff's review of this industry guidance.

C. REGULATORY POSITION

The following regulatory positions provide acceptable damping values to be used in the elastic dynamic seismic analysis and design of SSCs, where energy dissipation is approximated by viscous damping unless otherwise specified. Damping values higher than those provided may be used if documented test data support the higher values. Damping values associated with soil-structure interaction analysis are not within the scope of this regulatory guide.

1. Structural Damping

1.1 Acceptable Structural Damping Values for Containment Structures, Containment Internal Structures, and Other Seismic Category I Structures

1.1.1 *Safe-Shutdown Earthquake (SSE)*

Table 1 provides acceptable damping values for the SSE analysis.

Table 1. SSE Damping Values

Structural Material	Damping (% of Critical Damping)
Reinforced Concrete	7%
Reinforced Masonry	7%
Prestressed Concrete	5%
Welded Steel or Bolted Steel with Friction Connections	4%
Bolted Steel with Bearing Connections	7%
Note: For steel structures with a combination of different connection types, use the lowest specified damping value, or as an alternative, use a "weighted average" damping value based on the number of each type present in the structure.	

1.1.2 *Operating-Basis Earthquake (OBE)*

If the design-basis OBE ground acceleration is selected to be less than or equal to one-third of the design-basis SSE ground acceleration, then a separate OBE analysis is not required. However, if the design-basis OBE ground acceleration is selected to be greater than one-third of the design-basis SSE ground acceleration, then a separate OBE analysis should be conducted. Table 2 provides acceptable damping values for the OBE analysis.

Table 2. OBE Damping Values

Structural Material	Damping (% of Critical Damping)
Reinforced Concrete	4%
Reinforced Masonry	4%
Prestressed Concrete	3%
Welded Steel or Bolted Steel with Friction Connections	3%
Bolted Steel with Bearing Connections	5%

1.2 Special Consideration for In-Structure Response Spectra Generation

The SSE damping values specified in Table 1 for linear dynamic analysis of structures have been selected based on the expectation that the structural response attributed to load combinations that include SSE will be close to applicable code stress limits, as defined in Section 3.8 of NUREG-0800 [Ref. 15].

However, there may be cases where the predicted structural response to load combinations that include SSE is significantly below the applicable code stress limits. Because equivalent viscous damping ratios have been shown to be dependent on the structural response level, it is necessary to consider that the SSE damping values specified in Table 1 may be inconsistent with the predicted structural response level.

For structural evaluation, this is not a concern, because the stresses resulting from the use of damping-compatible structural response will still be less than the applicable code stress limits, as defined in Section 3.8 of NUREG-0800 [Ref. 15].

However, for in-structure response spectra generation, it is necessary to use the damping-compatible structural response. Consequently, the following additional guidance is provided for analyses used to determine in-structure response spectra:

(1) Use the OBE damping values specified in Table 2, which are acceptable to the staff without further review.

(2) Submit a plant-specific technical basis for use of damping values higher than the OBE damping values specified in Table 2, but not greater than the SSE damping values specified in Table 1 (e.g., see NUREG/CR-6919, Section 3.2.3), subject to staff review on a case-by-case basis.

In general, for certified standard plant designs where the design-basis in-structure response spectra represent the envelope of the in-structure responses obtained from multiple analyses conducted to consider a range of expected site soil conditions, it is not necessary for combined license applicants to address this issue. However, if plant-specific seismic analyses are conducted for Category I structures and/or structures not included as part of the standard plant design, then the applicant is expected to address this issue accordingly.

2. Piping Damping

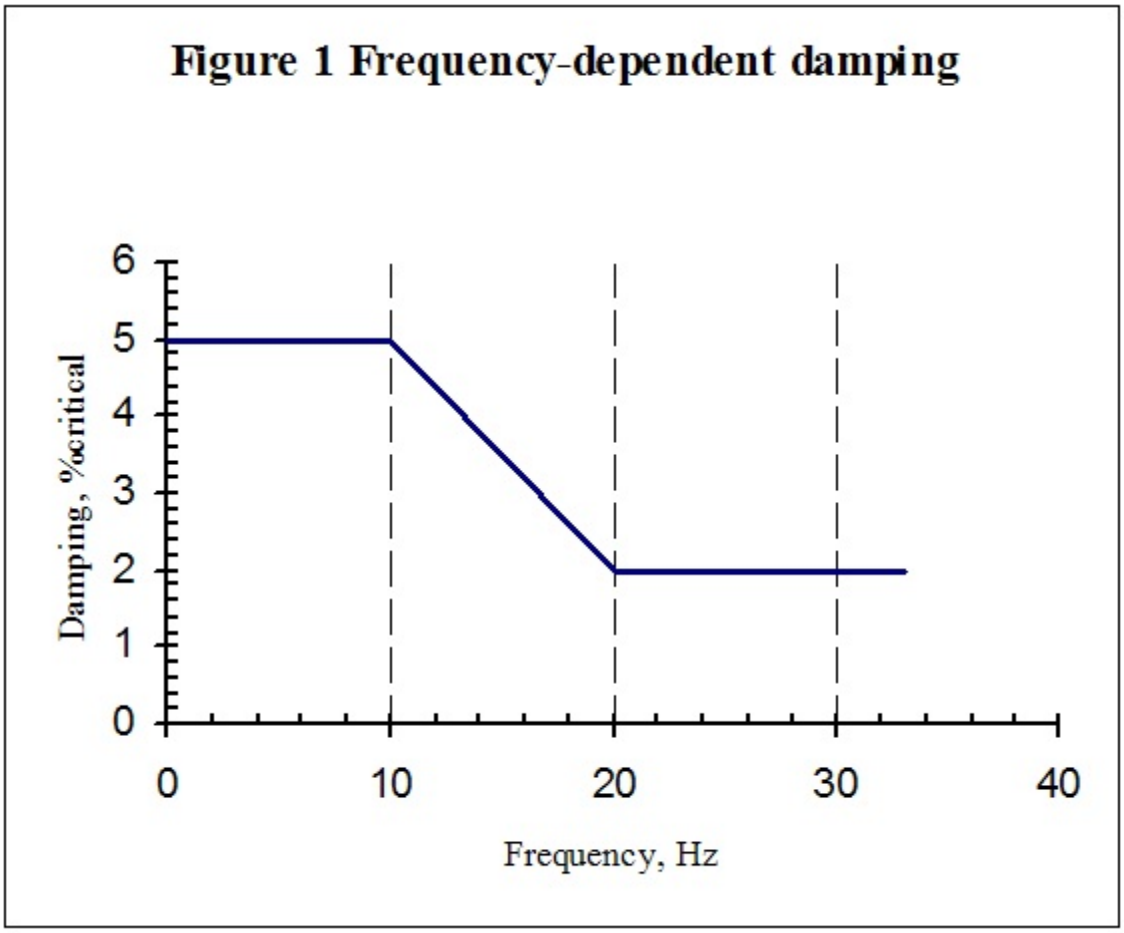
Table 3 presents the constant damping values specified for SSE and OBE (where required) analyses of piping systems. These values are applicable to time-history, response spectra, and equivalent static analysis procedures for structural qualification.

Table 3. Damping Values for Piping Systems

Category	Damping Value	
	SSE	OBE > SSE/3
Piping Systems	4%	3%

As an alternative for response spectrum analyses using an envelope of the SSE or OBE response spectra at all support points (uniform support motion), frequency-dependent damping values shown in Figure 1 may be used, subject to the following restrictions:

- Frequency-dependent damping should be used completely and consistently, if at all. (Damping values specified in Regulatory Guide 1.61 are to be used for equipment other than piping.)
- Use of the specified damping values is limited only to response spectral analyses. Acceptance of the use of the specified damping values with other types of dynamic analyses (e.g., time-history analyses or independent support motion method) requires further justification.
- When used for reconciliation or support optimization of existing designs, the effects of increased motion on existing clearances and online mounted equipment should be checked.
- Frequency-dependent damping is not appropriate for analyzing the dynamic response of piping systems using supports designed to dissipate energy by yielding.
- Frequency-dependent damping is not applicable to piping in which stress corrosion cracking has occurred, unless a case-specific evaluation is provided and reviewed and found acceptable by the NRC staff.



3. Electrical Distribution System Damping

Table 4 presents the constant damping values specified for SSE and OBE (where required) analyses of cable tray and conduit systems. These values are applicable to response spectra and equivalent static analysis procedures for structural qualification. The damping values specified in Table 4 are applicable to all types of supports, including welded supports. The use of higher damping values for cable trays with flexible support systems (e.g., rod-hung trapeze systems, strut-hung trapeze systems, and strut-type cantilever and braced cantilever support systems) is permissible, subject to obtaining NRC review for acceptance on a case-by-case basis.

The analysis methodology should consider the flexibility of supports in determining the system response to seismic excitation.

Table 4. Damping Values for Electrical Distribution Systems

Category	Damping Value	
	SSE	OBE > SSE/3
Cable Tray System[4]		
Maximum Cable Loading[1]	10%	7%
Empty[2]	7%	5%
Sprayed-on Fire Retardant or other cable-restraining mechanism[3]	7%	5%
Conduit Systems[4]		
Maximum Cable fill[1]	7%	5%
Empty[2]	5%	3%

Notes:
1. Maximum cable loadings, in accordance with the plant design specification, are to be utilized in conjunction with these damping values.
2. Spare cable tray and conduit, initially empty, may be analyzed with zero cable load and these damping values. (Note: Re-analysis is expected when put into service.)
3. Restraint of the free relative movement of the cables inside a tray reduces the system damping.
4. When cable loadings of less-than maximum are specified for design calculations, the applicant or licensee is expected to justify the selected damping values and obtain NRC review for acceptance on a case-by-case basis.

4. Heating, Ventilation, and Air Conditioning Duct Damping

Table 5 presents the constant damping values specified for SSE and OBE (when required) analyses of HVAC duct systems. These values are applicable to response spectra and equivalent static analysis procedures for structural qualification.

The analysis methodology must consider the flexibility of supports in determining system response to seismic excitation.

Table 5. Damping Values for HVAC Duct Systems

Type of Duct Construction	Damping Value	
	SSE	OBE > SSE/3
Pocket Lock	10%	7%
Companion Angle	7%	5%
Welded	4%	3%

5. Mechanical and Electrical Component Damping

Table 6 presents the damping values for mechanical and electrical components, which are applicable to passive subcomponents that can be seismically qualified by analysis. Active subcomponents do not readily lend themselves to seismic qualification by analysis, and require qualification by test, as described in Section 3.10 of NUREG-0800 [Ref. 15].

Table 6. Damping Values for Mechanical and Electrical Components

Component Type	Damping Value	
	SSE	OBE > SSE/3
Motor, Fan, and Compressor Housings (protection, structural support)	3%	2%
Pressure Vessels, Heat Exchangers, and Pump and Valve Bodies (pressure boundary)	3%	2%
Welded Instrument Racks (structural support)	3%	2%
Electrical Cabinets, Panels, and Motor Control Centers (MCCs) (protection, structural support)	3%	2%
Metal Atmospheric Storage Tanks (containment, protection) — Impulsive Mode — Sloshing Mode	 3% 0.5%	 2% 0.5%

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC staff's plans for using this regulatory guide. No backfitting is intended or approved in connection with the issuance of this guide.

Except in those cases in which an applicant or licensee proposes or has previously established an acceptable alternative method for complying with specified portions of the NRC's regulations, the NRC staff will use the methods described in this guide to evaluate (1) submittals in connection with applications for construction permits, standard plant design certifications, operating licenses, early site permits, and combined licenses; and (2) submittals from operating reactor licensees who voluntarily propose to initiate system modifications if there is a clear nexus between the proposed modifications and the subject for which guidance is provided herein.

REGULATORY ANALYSIS / BACKFIT ANALYSIS

The regulatory analysis and backfit analysis for this regulatory guide are available in Draft Regulatory Guide DG-1157, "Damping Values for Seismic Design of Nuclear Power Plants" (Ref. 16). The NRC issued DG-1157 in October 2006 to solicit public comment on the draft of this Revision 1 of Regulatory Guide 1.61.

REFERENCES

1. *U.S. Code of Federal Regulations*, Title 10, Part 50, "Domestic Licensing of Production and Utilization Facilities," U.S. Nuclear Regulatory Commission, Washington, DC.[3]

2. Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants," U.S. Atomic Energy Commission, Washington, DC, October 1973.[4]

3. NUREG/CR-6011, "Review of Structure Damping Values for Elastic Seismic Analysis of Nuclear Power Plants," U.S. Nuclear Regulatory Commission, Washington, DC, March 1993.[5]

4. "ASME Boiler and Pressure Vessel Code, Code Case N-411-1, Alternative Damping Values for Response Spectra Analysis of Class 1, 2 and 3 Piping," Section III, Division 1, American Society of Mechanical Engineers, New York, New York, February 20, 1986.[6]

5. Regulatory Guide 1.84, "Design, Fabrication, and Materials Code Case Acceptability — ASME Section III," U.S. Nuclear Regulatory Commission, Washington, DC.[3]

6. NUREG-1503, "Final Safety Evaluation Report Related to the Certification of the Advanced Boiling-Water Reactor," U.S. Nuclear Regulatory Commission, Washington, DC, July 1994.[4]

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[3] All NRC regulations listed herein are available electronically through the Electronic Reading Room on the NRC's public Web site, at http://www.nrc.gov/reading-rm/doc-collections/cfr/part050. Copies are also available for inspection or copying for a fee from the NRC's Public Document Room at 11555 Rockville Pike, Rockville, MD; the PDR's mailing address is USNRC PDR, Washington, DC 20555; telephone (301) 415-4737 or (800) 397-4209; fax (301) 415-3548; email PDR@nrc.gov.

[4] All regulatory guides listed herein were published by the U.S. Nuclear Regulatory Commission or its predecessor, the U.S. Atomic Energy Commission. Most are available electronically through the Electronic Reading Room on the NRC's public Web site, at http://www.nrc.gov/reading-rm/doc-collections/reg-guides/. Single copies of regulatory guides may also be obtained free of charge by writing the Reproduction and Distribution Services Section, ADM, USNRC, Washington, DC 20555-0001, by fax to (301) 415-2289, or by email to DISTRIBUTION@nrc.gov. Active guides may also be purchased from the National Technical Information Service (NTIS). Details may be obtained by contacting NTIS at 5285 Port Royal Road, Springfield, Virginia 22161, online at http://www.ntis.gov, by telephone at (800) 553-NTIS (6847) or (703) 605-6000, or by fax to (703) 605-6900. Copies are also available for inspection or copying for a fee from the NRC's Public Document Room (PDR), which is located at 11555 Rockville Pike, Rockville, Maryland; the PDR's mailing address is USNRC PDR, Washington, DC 20555-0001. The PDR can also be reached by telephone at (301) 415-4737 or (800) 397-4209, by fax at (301) 415-3548, and by email to PDR@nrc.gov.

[5] All NUREG-series reports listed herein were published by the U.S. Nuclear Regulatory Commission. Copies are available for inspection or copying for a fee from the NRC's Public Document Room at 11555 Rockville Pike, Rockville, MD; the PDR's mailing address is USNRC PDR, Washington, DC 20555; telephone (301) 415-4737 or (800) 397-4209; fax (301) 415-3548; email PDR@nrc.gov. Copies are also available at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328, telephone (202) 512-1800; or from the National Technical Information Service (NTIS) at 5285 Port Royal Road, Springfield, Virginia 22161, online at http://www.ntis.gov, by telephone at (800) 553-NTIS (6847) or (703) 605-6000, or by fax to (703) 605-6900. NUREG-0800 and NUREG/CR-6919 are also available electronically through the Electronic Reading Room on the NRC's public Web site, at http://www.nrc.gov/ reading-rm/doc-collections/nuregs/.

[6] Copies may be obtained from the American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5990. Phone (212)591-8500; fax (212)591-8501; www.asme.org.

7. NUREG-1462, "Draft Safety Evaluation Report related to the Design Certification of the System 80+ Design," U.S. Nuclear Regulatory Commission, Washington, DC, September 1992.[4]

8. NUREG-1512, "Final Safety Evaluation Report related to Certification of the AP600 Standard Design," U.S. Nuclear Regulatory Commission, Washington, DC, September 1998.[4]

9. NUREG-0797, "Safety Evaluation Report Related to the Operation of Comanche Peak Steam Electric Station, Units 1 and 2," Supplement No. 16, U.S. Nuclear Regulatory Commission, Washington, DC, July 1988.[4]

10. Ware, A.G., and C.B. Slaughterbeck, "A Survey of Cable Tray and Conduit Damping Research," Idaho National Engineering Laboratory, Report No. EGG-EA-7346, Rev. 1, prepared for the U.S. Nuclear Regulatory Commission, Washington, DC, August 1986.[7]

11. NUREG-0847, "Safety Evaluation Report for Watts Bar Nuclear Plant, Units 1 and 2," Supplement No. 8, U.S. Nuclear Regulatory Commission, Washington, DC, January 1992.[4]

12. NUREG/CR-6919, "Recommendations for Revision of Seismic Damping Values for the Seismic Damping Values in Regulatory Guide 1.61," U.S. Nuclear Regulatory Commission, Washington, DC, November 2006.[4]

13. American Society of Civil Engineers, ASCE Standard 43-05, "Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities," Reston, VA, 2005.[8]

14. American Society of Mechanical Engineers, "Boiler and Pressure Vessel Code," Section III, Division 1, Non-Mandatory Appendix N, "Dynamic Analysis Methods," New York, New York, 2004.[5]

15. NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," U.S. Nuclear Regulatory Commission, Washington, DC.[4]

16. Draft Regulatory Guide DG-1157, "Damping Values for Seismic Design of Nuclear Power Plants," U.S. Nuclear Regulatory Commission, Washington, DC.[9]

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[7] Copies are available for inspection or copying for a fee from the NRC's Public Document Room at 11555 Rockville Pike, Rockville, MD; the PDR's mailing address is USNRC PDR, Washington, DC 20555 (telephone: 301-415-4737 or 800-397-4209; fax: 301-415-3548; email: PDR@nrc.gov).

[8] Copies may be purchased from the American Society for Civil Engineers (ASCE), 1801 Alexander Bell Drive, Reston, VA 20190 [phone: (800) 548-ASCE (2723)]. Purchase information is available through the ASCE Web site at http://www.pubs.asce.org.

[9] Draft Regulatory Guide DG-1157 is available electronically under Accession #ML062680189 in the NRC's Agencywide Documents Access and Management System (ADAMS) at http://www.nrc.gov/reading-rm/adams.html. Copies are also available for inspection or copying for a fee from the NRC's Public Document Room (PDR), which is located at 11555 Rockville Pike, Rockville Maryland; the PDR's mailing address is USNRC PDR, Washington, DC 20555-0001. The PDR can also be reached by telephone at (301) 415-4737 or (800) 397-4209 by fax at (301) 415-3548, and by email to PDR@nrc.gov.