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Recommendations for Revision of Seismic Damping Values in Regulatory Guide 1.61

Brookhaven National Laboratory

**U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001**

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ABSTRACT

This report provides recommendations developed by Brookhaven National Laboratory (BNL) for revision of the damping values in U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 1.61, "Damping Values for the Seismic Design of Nuclear Power Plants," Rev. 0, issued October 1973. The recommendations included herein are based on the results of various damping studies, as well as NRC licensing actions related to the resolution of damping issues. Recommendations of the NRC Damping Task Force, and additional work performed by BNL to address staff questions have been incorporated into the final recommendations.

The recommendations in this document considered recently published guidance on damping for seismic analysis included in ASCE Standard 43-05, "Seismic Design Criteria For Structures, Systems, and Components in Nuclear Facilities" and ASME Boiler and Pressure Vessel Code, Section III, Division 1, Non-Mandatory Appendix N, "Dynamic Analysis Methods", 2004 Edition.

FOREWORD

The U.S. Nuclear Regulatory Commission issues Regulatory Guides to provide guidance for licensees on how to meet various regulations for the design, construction, licensing, and operation of nuclear power plants. These Regulatory Guides are developed using the best technical information available at the time. However, as experience is gained in the nuclear industry, and progress is made in the development of new technologies, Regulatory Guides must be updated to incorporate this new information.

Regulatory Guide 1.61, "Damping Values for the Seismic Design of Nuclear Power Plants," provides information on the proper selection of damping values for use in the seismic analysis of nuclear power plants. This Regulatory Guide was first issued in October 1973. Since that time, many advances have been made in the understanding of seismic analysis and its application to nuclear power plants. Various studies have been performed since the original issue of Regulatory Guide 1.61 that provide new insights into the appropriate selection of damping values used in seismic analyses.

The work documented herein provides an overview and evaluation of industry advancements, and how they can best be incorporated into the seismic analyses used in the design of nuclear power plants. This report also provides commentary on damping values for seismic analysis in five areas: 1) containment structures and containment internal structures; 2) piping; 3) electrical distribution systems; 4) heating ventilation and air conditioning systems; and 5) mechanical and electrical components. The findings of this report will be considered by the staff for inclusion in Revision 1 to Regulatory Guide 1.61.

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TABLE OF CONTENTS

LIST OF FIGURES

Page No.

LIST OF TABLES

Page No.

EXECUTIVE SUMMARY

The U.S. Nuclear Regulatory Commission (NRC) issues Regulatory Guides to provide guidance for licensees on how to meet various regulations for the design, construction, licensing, and operation of nuclear power plants. These Regulatory Guides are developed using the best technical information available at the time. However, as experience is gained in the nuclear industry, and progress is made in the development of new technologies, Regulatory Guides must be updated to incorporate this new information.

Regulatory Guide 1.61, "Damping Values for the Seismic Design of Nuclear Power Plants," provides information on the proper selection of damping values for use in the seismic analysis of nuclear power plants. This Regulatory Guide was first issued in October 1973. Since that time, many advances have been made in the understanding of seismic analysis and its application to nuclear power plants. Various studies have been performed since the original issue of Regulatory Guide 1.61, that provide new insights into the appropriate selection of damping values used in seismic analyses.

In November 1995, Brookhaven National Laboratory (BNL) submitted recommendations to the NRC Office of Nuclear Regulatory Research (NRC/RES) for revision of the damping values in Regulatory Guide 1.61. These recommendations were developed under a NRC/RES program entitled, "Application of Damping Research." The technical inputs for this effort were the results of damping studies and NRC licensing actions related to resolution of damping issues, conducted since the release of Regulatory Guide 1.61 in 1973. The scope did not include any new testing or detailed evaluation of raw test data.

The NRC Damping Task Force, which is comprised of NRC staff members from licensing and research, reviewed the submitted recommendations. BNL presented the recommendations to the Task Force at a working session held on November 20, 1995. A meeting report, summarizing the results of the working session, was prepared by BNL and submitted to the NRC Program Manager on January 3, 1996. The meeting report was the final deliverable for the project.

In June 2005, NRC/RES requested that BNL provide technical assistance for a revision to Regulatory Guide 1.61. The staff indicated that the starting point for the revision would be BNL's recommendations submitted in November 1995. NRC/RES Contract Job Control Number (JCN) N6185 was initiated in February 2006, to obtain BNL's technical assistance.

This report is an update to the November 1995 technical report. It incorporates staff recommendations from two (2) recent working sessions of the NRC Damping Task Force, held on December 15, 2005 and March 6, 2006, and additional work performed by BNL to address staff questions. The NRC Damping Task Force has reviewed and concurs with the final recommendations.

The recommendations in this report considered recently published guidance on damping for seismic analysis included in ASCE Standard 43-05, "Seismic Design Criteria For Structures, Systems, and Components in Nuclear Facilities" and ASME Boiler and Pressure Vessel Code, Section III, Division 1, Non-Mandatory Appendix N, "Dynamic Analysis Methods", 2004 Edition.

The recommendations proposed herein do not include any radical changes from the damping values specified in Regulatory Guide 1.61, Rev. 0. The primary improvements are (1) explicit guidance for damping of mechanical and electrical components and for damping of non-piping distribution systems; (2) explicit guidance for structural damping at low response levels; and (3) consideration of experimental data, significant staff licensing actions related to damping, and revisions to codes and standards related to damping, developed since Revision 0 was issued in 1973.

Issuance of Revision 1 to Regulatory Guide 1.61, incorporating the recommendations contained herein, will help to streamline the application and staff review process by minimizing the number of case-by-case assessments required.

ACKNOWLEDGMENTS

The author wishes to acknowledge the support of Herman L. Graves, NRC Program Manager, in facilitating the development of the final recommendations, as BNL's interface with the NRC Damping Task Force.

The author also wishes to acknowledge the critical review and recommendations provided by the NRC Damping Task Force.

Finally, the author wishes to acknowledge the support of Robert J. Lofaro, Brookhaven National Laboratory, for his editorial comments and assistance in preparing this report in NUREG/CR format.

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ABBREVIATIONS

ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
BNL	Brookhaven National Laboratory
DCM	Damping Correction Multiplier
FSAR	Final Safety Analysis Report
HVAC	Heating Ventilation and Air Conditioning
JCN	Job Control Number
MCC	Motor Control Center
NRC	Nuclear Regulatory Commission
OBE	Operating Basis Earthquake
PGA	Peak Ground Acceleration
RES	U.S. NRC, Office of Nuclear Regulatory Research
SER	Safety Evaluation Report
SRP	Standard Review Plan (NUREG-0800)
SSE	Safe Shutdown Earthquake
TVA	Tennessee Valley Authority
ZPA	Zero-Period Spectral Acceleration

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1. INTRODUCTION

1.1 Background

In November 1995, Brookhaven National Laboratory (BNL) submitted recommendations (Ref. 1) to the Nuclear Regulatory Commission, Office of Nuclear Regulatory Research (NRC/RES) for revision of the damping values in Regulatory Guide 1.61, "Damping Values for the Seismic Design of Nuclear Power Plants" (Ref. 2). These recommendations were developed under a NRC/RES program entitled, "Application of Damping Research." The technical inputs for this effort were the results of damping studies and NRC licensing actions related to resolution of damping issues, conducted since the release of Regulatory Guide 1.61 in 1973. The scope did not include any new testing or detailed evaluation of raw test data.

The NRC Damping Task Force, comprised of NRC staff members from licensing and research, reviewed the submitted recommendations. BNL presented the recommendations to the Task Force at a working session held on November 20, 1995. A meeting report, summarizing the results of the working session, was prepared by BNL and submitted to the NRC Program Manager on January 3, 1996. The meeting report was the final deliverable for the project.

In June 2005, NRC/RES requested that BNL provide technical assistance for a revision to Regulatory Guide 1.61. The staff indicated that the starting point for the revision would be BNL's recommendations submitted in November 1995. NRC/RES Contract Job Control Number (JCN) N6185 was initiated in February 2006, to obtain BNL's technical assistance.

This report is an update to the November 1995 technical report. It incorporates staff recommendations from two (2) recent working sessions of the NRC Damping Task Force, held on December 15, 2005 and March 6, 2006, and additional work performed by BNL to address staff questions. The NRC Damping Task Force has reviewed and concurs with the final recommendations.

This update considered recently published guidance on damping for seismic analysis included in American Society of Civil Engineers (ASCE) Standard 43-05, "Seismic Design Criteria For Structures, Systems, and Components in Nuclear Facilities" (Ref. 3), and American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Non-Mandatory Appendix N, "Dynamic Analysis Methods", 2004 Edition (Ref. 4).

1.2 Proposed General Qualifications for Use of Regulatory Guide 1.61 Revision

This report includes proposed damping values for inclusion in Regulatory Guide 1.61 that are intended to be used in the seismic analysis of various nuclear power plant systems and components. The following qualifications apply to the damping values provided herein:

- If there is any deviation from current NRC criteria and guidance for seismic analysis, then the damping values used in the analysis will require specific detailed justification; review and evaluation will be on a case-by-case basis.

- Damping values higher than those specified herein may be used, if supported by specific, applicable test data. This will be subject to review and evaluation on a case-by-case basis.

- Except as noted under specific damping categories, the tabulated damping values are applicable to time-history, response spectrum, and equivalent static seismic analyses.

- When inelastic analysis methods are used, the selected viscous damping values should be limited to the damping values specified herein for the Operating Basis Earthquake (OBE). The use of different damping values will be subject to review and evaluation on a case-by-case basis.

- Special limits on damping values apply to time-history analyses of building structures used for structural design and for generation of in-structure response spectra. These are noted where applicable.

Section 2 of this report presents a proposed revision to the introduction for Regulatory Guide 1.61. Sections 3 through 7 of this report present recommendations for structural damping; piping damping; damping for electrical distribution systems; damping for heating, ventilation, and air conditioning ducting; and damping for mechanical and electrical components, respectively.

2. PROPOSED INTRODUCTION FOR REVISED REGULATORY GUIDE 1.61

To more clearly state the objectives and technical basis for Regulatory Guide 1.61, and how it relates to the NRC's Standard Review Plan (SRP), NUREG-0800, (Ref. 5), it is proposed that the introduction be revised to read as follows:

> ### DAMPING COEFFICIENTS FOR SEISMIC ANALYSIS OF NUCLEAR POWER PLANT STRUCTURES, SYSTEMS, AND COMPONENTS
>
> #### Introduction
>
> The specified damping coefficient values are applicable to design calculations performed in accordance with current NRC criteria and guidance for seismic analysis (i.e., NUREG-0800, latest revision). They are specifically intended for elastic seismic analysis where energy dissipation is approximated by viscous damping (i.e., proportional to velocity). This is the most common analysis methodology applied to design.
>
> For design load combinations which include the Safe Shutdown Earthquake (SSE), structural response which somewhat exceeds the elastic response limit is typically permitted. The specified SSE damping coefficient values, for use with elastic analysis, take into consideration the fact that some energy dissipation occurs due to inelastic structural response. Consequently, the specified SSE damping values are not applicable to analyses that explicitly include inelastic structural behavior.

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3. STRUCTURAL DAMPING

This section discusses structural damping values for use in the analysis of containment structures, containment internal structures, and other seismic category I structures.

3.1 Proposed Structural Damping Values

Proposed structural damping values are discussed in the following subsections for the safe shutdown earthquake (SSE) and the operating basis earthquake (OBE).

3.1.1 Safe Shutdown Earthquake

Table 1 presents the structural damping values proposed for containment structures, containment internal structures, and other seismic category I structures for a SSE:

Table 1 Proposed structural damping values for a safe shutdown earthquake

Structure	Proposed Damping Value
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.

3.1.2 Operating Basis Earthquake

If the design-basis OBE ground acceleration is greater than one-third of the design-basis SSE ground acceleration, then a separate OBE analysis is required. For the OBE analysis, the damping values presented in Table 2 are applicable.

Table 2 Proposed structural damping values for an operating basis earthquake

Structure	Proposed Damping Value
Reinforced Concrete	4%
Reinforced Masonry	4%
Prestressed Concrete	3%
Welded Steel or Bolted Steel with Friction Connections	3%
Bolted Steel with Bearing Connections	5%

3.1.3 Correlation of Structural Response Level with SSE Damping

The SSE equivalent viscous damping ratios specified in Table 1, for linear dynamic analysis of structures, were selected based on the expectation that the structural response due to load combinations that include SSE will be close to applicable code stress limits, as defined in SRP Section 3.8.

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 the possibility that the SSE damping values specified in Table 1 may be inconsistent with the predicted structural response, and that lower damping values may be more appropriate.

Consequently, the following guidelines are provided to assess the appropriateness of using the SSE damping values specified in Table 1 and, if necessary, to perform a re-analysis using reduced damping values:

(1) If the significant stresses due to load combinations that include SSE are at least 80% of the applicable code stress limits, then use of SSE damping levels for the seismic analysis is appropriate and acceptable.

(2) If the significant stresses due to load combinations that include SSE are less than 80% of the applicable code stress limits, then using SSE damping levels may under-predict the structure's response to seismic loads. In this case, structural evaluation and development of in-structure response spectra should be based on a seismic analysis utilizing the OBE damping values specified in Table 2.

(3) As an alternative to (2), the applicant/licensee may submit a plant-specific justification for using damping values higher than the OBE damping values specified in Table 2, but less than the SSE damping values used initially.

3.2 Justification for Proposed Structural Damping

The main reference for the proposed damping values is the structural damping study performed by EQE for NRC/RES (Ref. 6). This proposal represents Brookhaven National Laboratory's (BNL's) interpretation of the EQE study results. Damping values are specified in "whole percents", consistent with the current Regulatory Guide 1.61. The following subsections provide the basis for the proposal.

3.2.1 Safe Shutdown Earthquake

Based on EQE's extensive study of structural damping, the current SSE damping values provided in Regulatory Guide 1.61 should remain essentially unchanged with one (1) major exception. A distinction is made between "friction-bolted" and "bearing-bolted" connections for steel structures. EQE's recommendation, to treat friction-bolted connections as welded connections appears to be well founded, based on the design intent of friction-bolted connections. Use of pre-loaded high-strength bolts, with reduced allowable shear stresses, is intended to preclude slip of the joint. From the perspective of energy dissipation, this type of connection would appear to perform more like a welded connection than a bearing connection. Consequently, EQE's recommendation is incorporated in the proposed SSE damping values.

EQE has concluded that reinforced masonry behaves similarly to reinforced concrete. EQE's recommendation has been incorporated in the proposed SSE damping values.

EQE recommended that SSE damping for "bearing-bolted" connections in steel structures be specified at 6%. This represents a 1% decrease in damping from the current Regulatory Guide 1.61 value for "Bolted Steel Structures". Discussion on this point with EQE at an NRC/RES presentation on September 11, 1992 indicated that this recommendation is based on very limited data. Considering the very modest impact of this change on SSE structural qualification and the absence of conclusive data to support the reduction, the SSE damping for "Bolted Steel with Bearing Connections" is retained at 7%.

3.2.2 Operating Basis Earthquake

The proposed OBE damping values are consistent with EQE's study results for stress levels in the range of one-half yield stress. They reflect a 1% increase over the current Regulatory Guide 1.61 values for prestressed concrete and steel. Reinforced concrete and reinforced masonry are specified at the current Regulatory Guide 1.61 value for reinforced concrete.

For welded and friction-bolted steel structures, EQE concluded that damping is relatively insensitive to stress level, exhibiting 3% damping at low seismic excitation, and up to 4% damping at the SSE level of seismic excitation. In accordance with the decision to specify only "whole percents", 3% was selected.

For bearing-bolted steel structures, EQE concluded that the range of damping values is from 4% at low seismic excitation to 6% at the SSE level of seismic excitation. Based on this, 5% was selected for the proposed OBE damping value.

For prestressed concrete structures, EQE concluded that the range of damping values is from 2% at low seismic excitation to 5% at the SSE level of excitation. Based on this, 3% was selected for the proposed OBE damping value.

3.2.3 Correlation of Structural Response Level with SSE Damping

Damping has been observed to be directly dependent on the response level. The SSE seismic analysis of building structures is typically performed using damping values that are consistent with response levels at or close to the maximum allowable response level for SSE load combinations. In some cases, however, the predicted response may be significantly lower than the maximum allowable response. Consequently, the damping value utilized in the SSE time history analysis may be inconsistent with the predicted response level due to SSE load combinations.

This potential inconsistency is highlighted in Regulatory Position C.3 of the current Regulatory Guide 1.61. The correlation between damping and the response level has been recognized for many years, and is illustrated by the different damping values specified for OBE and SSE in Regulatory Guide 1.61. This dependence is particularly important when generating in-structure response spectra for subsequent response spectrum analysis of systems and components. Use of SSE damping values is not appropriate if the structure response is significantly lower than the maximum allowable response for SSE load combinations. The objective is to achieve a damping-compatible structural response This will yield more realistic estimates of internal forces, moments, displacements, rotations, accelerations, and velocities in the structure.

BNL developed a procedure to provide guidance on this subject. The proposed procedure involves determining the need to make a damping adjustment and, if necessary, either scaling the initial results obtained using SSE damping, or performing additional time-history analysis for SSE, with reduced damping values.

BNL's proposed scaling method is based on standard scaling methods, such as presented in ASCE 4-98 (Ref. 7), for interpolation of spectral acceleration values for intermediate damping values. Based on a numerical study, a damping correction multiplier (DCM), defined as

$$\text{DCM} = [0.8 \text{ x maximum PGA(ZPA) / design PGA(ZPA)}]^{1/3}; \ \text{DCM} \geq 1.0$$

was determined to provide a convenient method for direct scaling of results obtained using SSE damping.

The procedural steps are:

Step 1: Analyze the structure for the combined effect of the design-basis SSE input in 3 directions, using the SSE damping value specified in Table 1.

Step 2: By linearly scaling the initial SSE analysis results obtained in Step 1, determine the maximum peak ground acceleration (PGA) or zero-period spectral acceleration (ZPA) that satisfies the SRP Section 3.8 load combination acceptance criteria, for the type of structure being analyzed.

Step 3: If the design PGA (ZPA) is greater than or equal to 0.8 times the maximum PGA (ZPA), the SSE damping value specified in Table 1 is considered appropriate. Use the initial analysis results obtained in Step 1 for both structural evaluation and generation of in-structure response spectra.

Step 4: If the ratio of the design PGA (ZPA) to the maximum PGA (ZPA) is less than 0.8, the SSE damping value specified in Table 1 may not be appropriate. Implement Step 5.

Step 5: Where site conditions dictate the need for a soil-structure interaction analysis, the soil stiffness typically controls the fundamental horizontal response ("rigid body" rocking/horizontal translation) and the fundamental vertical response ("rigid body" vertical translation) of the structure. While these response modes impart significant acceleration to the structure, the contribution to the elastic response of the structure is independent of the equivalent viscous damping value that is assigned to the structure, because the structure responds essentially as a rigid body in these modes.

The equivalent viscous damping value that is assigned to the structure primarily affects the amplitude of the fundamental structural modal responses in the two (2) horizontal directions. Their frequencies typically fall within the amplified region of the design-basis SSE response spectrum. For higher frequency horizontal modes of the structure, the importance of the assigned damping value diminishes.

The frequency of the fundamental structural modal response in the vertical direction is typically above the frequency region of significant amplification in the design-basis SSE response spectrum. The minor variations in spectral acceleration as a function of damping value have a relatively minor effect on the overall response of the structure to 3-directions of seismic loading.

(A) For fixed-base analyses, excitation of the fundamental horizontal modes of the structure are the major contributors to the total response of the structure. Using the appropriate level of structural damping is important, because it has a significant effect on the structure's response due to excitation of these fundamental horizontal modes. In lieu of performing re-analysis using a reduced damping value, an acceptable approach is to apply a damping correction multiplier (DCM) to the dynamic analysis results obtained in Step 1. DCM is defined as follows:

DCM = [0.8 x maximum PGA(ZPA) / design PGA(ZPA)]$^{1/3}$

As a lower bound, DCM = 1.0 when the design PGA(ZPA) $\geq$ 0.8 x maximum PGA(ZPA).

(i) As an example, if the design PGA(ZPA) = 0.4 x maximum PGA(ZPA), then DCM = $(0.8/0.4)^{1/3}$ = 1.26. Use of the DCM produces results consistent with re-analysis using the OBE damping value.

(ii) As a second example, if the design PGA(ZPA) = 0.6 x maximum PGA(ZPA), then DCM = $(0.8/0.6)^{1/3}$ = 1.10. Use of the DCM produces results consistent with re-analysis using a damping value midway between the SSE and OBE damping values.

(iii) As a third example, if the design PGA(ZPA) = 0.2 x maximum PGA(ZPA), then DCM = $(0.8/0.2)^{1/3}$ = 1.59. Use of the DCM produces results consistent with re-analysis using a damping value equal to ½ x OBE damping value.

The scaled dynamic results are then used for both the structural evaluation and the generation of in-structure response spectra.

(B) When soil-structure interaction is included in the analysis of structural response, it is conservative but acceptable to scale the dynamic analysis results obtained in Step 1 in accordance with (A) above.

(C) An acceptable approach for both fixed-base analyses and soil-structure interaction analyses is to perform one or a number of re-analyses using reduced structural damping values, and provide a technical justification for the structural damping value selected for the design-basis analysis used for both the structural evaluation and the generation of in-structure response spectra.

After review of BNL's proposal, the NRC Damping Task Force concluded that a simpler approach would be more appropriate for inclusion in the Regulatory Guide 1.61 revision. This simpler approach is delineated in 3.1.3 above. It is consistent with the approach recommended in ASCE Standard 43-05 (Ref. 3), when use of SSE damping values cannot be justified. However, the damping adjustment is applied for both structural evaluation and generation of in-structure response spectra.

4. PIPING DAMPING

This section discusses damping values for use in the analysis of piping systems.

4.1 Proposed Piping Damping Values

Table 3 presents the constant damping values specified for SSE and OBE (where required) analyses of piping systems. They are applicable to time-history, response spectrum, and equivalent static analysis procedures for piping 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 response spectra at all support points (uniform support motion), frequency-dependent damping, as shown in Figure 1, may be used, subject to the following restrictions:

- Frequency-dependent damping should be used completely and consistently, if used at all. (For equipment other than piping, the damping values specified in Regulatory Guide 1.61, “Damping Values for Seismic Design of Nuclear Power Plants,” are to be used).
- The damping values specified may be used only in those analyses in which current seismic spectra and procedures have been employed. Such use is to be limited only to response spectral analyses. The acceptance of the use with other types of dynamic analyses (e.g., time-history analyses or independent support motion method) is pending further justification.
- When used for reconciliation work or for support optimization of existing designs, the effects of increased motion on existing clearances and on-line 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 made and is reviewed by the NRC staff.

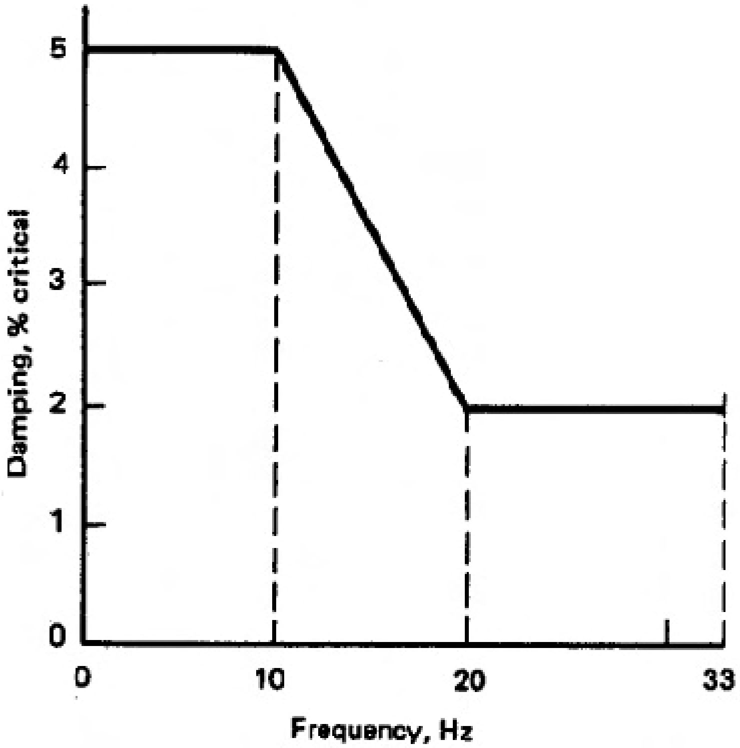

Figure 1 Frequency-dependent damping

4.2 Justification for Proposed Piping Damping

The subject of piping damping for seismic analysis of nuclear power plant systems received considerable attention over the twenty years following the original issuance of Regulatory Guide 1.61 in 1973. Reference 8 provides a detailed summary through 1990. The basic issues can be summarized as follows:

- Regulatory Guide 1.61 piping damping is conservative.
- Utilization of these conservative values has not improved overall plant safety; to the contrary, pipe stresses due to repeated operational loads are generally increased by conservative seismic support requirements.
- Specification of equivalent viscous damping values for piping system analysis is based as much on philosophy and "gut feel" as it is on hard data.
- Industry proposals, including PVRC Damping, have their detractors on both the conservative side and liberal side.

- While equivalent viscous damping (function of velocity) is mathematically convenient for analysis, it is not representative of the actual energy dissipation mechanisms occurring during seismic excitation of a piping system; this is especially true at high excitation levels, where the primary energy dissipater is inelastic material behavior.

- There is very significant data scatter when piping test results are used to back-calculate the equivalent viscous damping; however, this is not surprising, considering that no comprehensive test program has ever been conducted for the sole purpose of defining damping levels and the primary drivers.

Based on discussion with several NRC personnel and an NRC consultant involved in damping studies, there would appear to be significant support on the regulatory side for constant 4% SSE damping, with no restrictions on its application. Two previous studies (Refs. 11 and 12) would support that this is appropriate if a single value of damping is to be specified.

The role of the OBE in system design is specifically being reduced for new reactors; i.e., there are no specific OBE design requirements if OBE ≤ SSE/3. However, since the plant designer has the option to exceed the above criterion, guidance for an OBE analysis must still be provided in the Regulatory Guide revision. If analysis of loading combinations that include OBE are required, the allowable stresses are typically limited to the yield strength of the pipe material. Consequently, the equivalent viscous damping for use in conjunction with elastic analysis must be specified at a lower value. A constant damping value of 3% is recommended for load combinations that include OBE, with no restrictions on its application.

Based on assessment of several evaluations performed on the existing pipe testing data base (Refs. 8, 13, 14,and 15), there does not appear to be a compelling technical justification to vary piping damping as a function of pipe diameter. There appears to be a relatively weak correlation between damping and pipe diameter. A stronger case can be made for "fundamental" mode vs. higher modes. However, potential analytical complications arising from identification and interpretation of the "fundamental" mode render this a relatively poor parameter for varying the damping.

For simplicity, constant damping values of 3% OBE and 4% SSE are recommended for seismic analysis of piping systems. These would be applicable to time-history, response spectrum, and equivalent static analyses, and would be free of other restrictions.

The NRC previously accepted ASME Code Case N411-1 damping (Ref. 9), with qualifications in accordance with Regulatory Guide 1.84 (Ref. 10). At the time the qualifications were initially specified, the NRC had intended to conduct studies aimed at evaluating the validity of these qualifications, and as appropriate, remove some of the restrictions on N411 damping. However, the required studies were not conducted.

ASME has annulled Code Case N411-1, because Non-Mandatory Appendix N to Section III currently recommends 5% damping at all frequencies, for both OBE and SSE (Ref. 4). The staff had previously accepted 5% SSE damping for AP1000, for uniform support motion, response spectrum analysis of piping systems (Ref. 16). The staff invoked restrictions on its use, consistent with the qualifications formerly in Regulatory Guide 1.84 for Code Case N411-1.

The staff continues to accept former Code Case N411-1 damping subject to the restrictions identified in Regulatory Guide 1.84. The staff considers acceptance of 5% damping for AP1000 to be a case-specific determination.

5. ELECTRICAL DISTRIBUTION SYSTEMS DAMPING

This section discusses damping values for use in the analysis of electrical distribution systems.

5.1 Proposed Cable Tray/Conduit Damping Values

The constant damping values presented in Table 4 are specified for SSE and OBE (when required) analyses of cable tray and conduit systems. They are applicable to response spectrum and equivalent static analysis procedures for structural qualification.

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

Table 4 Damping values for electrical cable tray and conduit systems

Category	Configuration	Damping Value	
		SSE	OBE > SSE/3
Cable Tray Systems [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 Fill [1]	7%	5%
	Empty [2]	5%	3%

Notes:

1. Maximum cable loadings, in accordance with the plant design specification, must 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 required 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 less than maximums are specified for design calculations, the selected damping values must be justified and will be reviewed for acceptance on a case-by-case basis.

The damping values specified above are applicable to all types of supports, including welded supports. 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, but will be subject to staff review on a case-by-case basis.

5.2 Justification for Proposed Cable Tray/Conduit Damping

The justifications for the proposed damping values for cable trays and conduits are discussed in the following subsections.

5.2.1 Cable Trays

Regulatory Guide 1.61, released in 1973, does not provide damping values for cable tray systems. Historically, the nuclear power industry has used the values for bolted steel structures (4% OBE, 7% SSE) for seismic design of cable tray systems.

In early nuclear plant designs, seismic loads were not considered for cable tray systems. Traditional design methods from fossil power plants were carried over to nuclear power plants. In the late 1970's and early 1980's, the need to evaluate these early installations for seismic adequacy led to two major cable tray test programs. The first by BECHTEL/ANCO and the second by URS/BLUME for the Systematic Evaluation Program Owners Group. As part of these programs, the damping characteristics of typical cable tray systems were evaluated. These results are summarized in Reference 17.

In the late 1980's the NRC questioned the seismic adequacy of the cable tray systems at Comanche Peak. This led to another cable tray test program, conducted by ANCO for TU Electric. Key objectives of this program were to justify the use of bolted steel structures damping for cable tray systems with welded steel supports, and also to verify that response spectrum analysis using these damping values produced conservative predictions of seismic response (Refs. 18 and 19).

The results of these three test programs have been reviewed as a basis for the current proposal. In addition, the recommendation for seismic margins studies (Ref. 20) has been reviewed.

The current proposal attempts to address the following considerations:

- Applicable to response spectrum and equivalent static analysis procedures
- Simple to apply in seismic design calculations
- Sufficient conservatism to account for the scatter in experimentally derived damping values
- Straightforward, to facilitate NRC safety evaluations

Based on the test results cited above, a number of parameters have been identified which affect cable tray system damping. The most significant ones are:

- Excitation level

- Quantity of cables in the tray
- Presence of sprayed-on fire retardant, which "bundles" the cables
- Support stiffness

The first three parameters are specifically addressed in the current proposal. The fourth parameter, support stiffness, is not considered in the specification of damping values. However, the proposal requires that the cable tray analysis methodology include consideration of support flexibility effects in the prediction of dynamic response.

The existing data on damping versus support configuration is not sufficiently comprehensive nor consistent to apply in a straightforward manner. Therefore, the proposed damping values were selected to cover all types of cable tray supports. This approach also eliminates potential confusion and inconsistencies in the analysis of mixed support systems.

The cable tray tests summarized in Reference 17 included rod-hung trapeze systems, strut-hung trapeze systems, and strut-type cantilever and braced cantilever support systems. Welded supports were not covered. Based on the test results, cable tray damping values as high as 20-25% were recommended for heavily loaded cable trays at high excitation levels. Reduced damping values were recommended for unloaded or lightly loaded trays (5-7%) and for trays with sprayed-on fire retardant (5-10%).

The tests conducted for Comanche Peak on cable tray systems with welded supports provided valuable input for this proposal (Refs. 18 and 19). Damping values were derived from the dynamic response of six (6) test configurations; most were tested for a range of cable fill level and two (2) excitation levels. There is considerable scatter in the data. However, the data are sufficient to support the proposed damping values for both fully loaded and empty cable trays, at the OBE and SSE excitation levels, for welded support systems.

The proposed damping values for fully-loaded trays (7% OBE, 10% SSE) are conservative for bolted supports, when compared to the results reported in Reference 17. However, the difference in floor spectral accelerations between 10% damping and 20% damping is typically small. Specifying a single set of damping values for all types of supports is judged to be a higher priority. In addition, the option to specify and justify higher damping values is always available to the licensee.

Reference 20 also includes guidance to industry on the subject of cable tray damping. For use in seismic margin evaluations, 15% damping is recommended. Taking into consideration that the system response level in a seismic margin assessment can significantly exceed the response level permitted by design criteria, there is reasonable consistency between this proposal and the recommendation of Reference 20.

The proposed damping values for empty cable trays provide a lower bound to the available test data, based on References 18 and 19. The intent is to provide some regulatory guidance for cases where design calculations assume less than the maximum design cable fill. Note 4 to Table 4 would allow case-by-case justification of damping for intermediate cable fill levels.

It is desirable from a regulatory perspective that the maximum design cable fill be used in all design calculations, regardless of the actual cable fill level. This proposal is intended to promote this course of action by future licensees.

5.2.2 Conduits

Similar to the situation discussed above for cable trays, Regulatory Guide 1.61 does not currently provide damping values specifically for conduit systems. Values specified in Final Safety Analysis Reports (FSARs) and accepted in NRC Safety Evaluation Reports (SERs) have typically been taken from Regulatory Guide 1.61 values for bolted steel structures, welded steel structures, or piping. The values initially specified were perceived to be representative of expected conduit system damping. Because of the advantages of higher damping values for design calculations, the licensees usually tried to justify the use of bolted steel structure damping (4% OBE, 7% SSE). This, in turn, led to regulatory concerns when the conduit system support details did not clearly fit the description of bolted steel structures. A lengthy process of justification and review usually ensued, oftentimes involving the generation and/or interpretation of test data.

At this point in time, there is sufficient test data and regulatory precedence to explicitly define conduit system damping in a revision to Regulatory Guide 1.61. This proposal is based on review of available test data (Refs. 17, 21, 22, and 23) and the history of two safety evaluations (Refs. 24 and 25). The proposed damping values have been selected to satisfy the same four (4) considerations discussed previously for cable trays.

The parameters which are generally accepted as influencing the damping of a conduit system are

- Cables inside the conduit
- Threaded couplings between conduit sections
- Support details
- Excitation level

Conduit systems exhibit lower damping than heavily loaded cable trays in tests of "comparable" configurations (Ref. 21). Trends identified from the test data are

- The damping effect of the cables inside conduits is much less than the damping effect of loose cables in cable trays.
- Conduit damping increases with increased cable fill up to typical design fill levels (which are dictated by electrical criteria rather than structural criteria).
- Overfilling of conduits tends to reduce the measured damping.

- The available test results of damping versus cable fill are not comprehensive and exhibit considerable scatter.

- There is a definite trend toward higher damping as the excitation level is increased.

- Based on test results for empty conduit on rigid supports, the threaded couplings would appear to contribute to system damping.

- Conduit system damping is affected by support and clamp details; however, no clear-cut quantitative trends suitable for regulatory guidance can be readily extracted from the available test data.

The following can be determined from the available test data and regulatory precedence:

- Bolted steel structure damping (4% OBE, 7% SSE) has been approved by the NRC for welded conduit supports at Watts Bar (Ref. 24).

- TVA test data that justified these values were based on "rigidly" mounted test configurations; i.e., the conduit was clamped directly to the test fixture (Ref. 22).

- The data reduction performed by TVA, to satisfy NRC requirements, would also support 5% damping at OBE response levels (Ref. 24).

- 7% damping has been approved by the NRC for Train C conduits supported by one-hole "C" (or "finger") clamps at Comanche Peak (Ref. 25); TU Electric’s technical justification is documented in Reference 23.

- The test results presented in Reference 21 provide the basis for BECHTEL’s recommendation of 7% damping for conduit systems, as reported in Reference 17.

The proposed damping values for conduits with maximum design fill are below most of the available pertinent test data, regardless of support and clamp details. They do not represent a lower bound to all data. However, considering that use of these damping values will be in conjunction with all other NRC requirements and guidance for seismic analysis, the proposed damping values provide an appropriate level of conservatism.

The proposed damping values for empty conduit essentially provide a lower bound to the available test data for conduit with and without cables. The intent is to provide some regulatory guidance for cases where design calculations assume less than the maximum design cable fill. Note 4 to Table 4 would allow case-by-case justification of damping for intermediate cable fill levels.

It is desirable from a regulatory perspective that the maximum design cable fill be used in all design calculations, regardless of the actual cable fill level. This proposal is intended to promote this course of action by future licensees.

6. HEATING VENTILATION AND AIR CONDITIONING (HVAC) DUCT DAMPING

This section discusses damping values for use in the analysis of heating, ventilation, and air conditioning (HVAC) ducting systems.

6.1 Proposed HVAC Duct Damping Values

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

The analysis methodology must consider the flexibility of supports in the determination of 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%

6.2 Justification for Proposed HVAC Duct Damping

The proposed damping values are consistent with the recommendation made for steel structures with the exception that higher damping has been determined experimentally by TVA for "pocket lock" duct construction (see Refs. 26 and 27). The TVA test results for "companion angle" duct construction support the proposed damping values. No tests of welded duct construction have been identified; therefore, the technical basis is the same as for welded steel structures.

For "pocket lock" duct construction, Reference 27 recommends 10% damping for use with Regulatory Guide 1.60 type ground spectra. Damping data were obtained from five (5) tests at a low level of input (0.05 g s) and a stiff support configuration. The mean value obtained was 9.7%, with a standard deviation of 0.9%. Based on this limited test data, 7% OBE and 10% SSE damping are proposed as reasonably conservative values for design calculations.

For "companion angle" duct construction, Reference 27 provides damping estimates at five levels of input (0.05 g s, 0.10 g s, 0.15 g s, 0.20 g s, 0.25 g s), with a stiff support configuration. Based on this data, Reference 27 recommends 6% OBE and 7% SSE damping for use with Regulatory Guide 1.60 type ground spectra.

At the time Reference 27 was prepared, the OBE was specified as SSE/2. With recent changes in the role of the OBE in seismic qualification, it is possible that an OBE as low as SSE/3 may be used in analysis. To provide some conservatism, 5% OBE damping is recommended in this current proposal. This makes the damping values consistent with the proposed bolted steel structure damping.

7. MECHANICAL AND ELECTRICAL COMPONENT DAMPING

This section discusses damping values for use in the analysis of mechanical and electrical components.

7.1 Proposed Component Damping Values

In the seismic qualification of mechanical and electrical components, it is important to distinguish between active sub-components (functionality requirements) and passive sub-components (containment, protection, structural support, pressure boundary requirements).

Active sub-components do not readily lend themselves to seismic qualification by analysis, and require seismic qualification by test. Seismic qualification by test is addressed in SRP Section 3.10.

The damping values specified herein for mechanical and electrical components pertain only to passive sub-components that are amenable to seismic qualification by analysis. Table 6 presents the damping values for mechanical and electrical components.

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, Pump and Valve Bodies (pressure boundary)	3%	2%
Welded Instrument Racks (structural support)	3%	2%
Electrical Cabinets, Panels, Motor Control Centers (protection, structural support)	3%	2%
Metal Atmospheric Storage Tanks (containment, protection) - Impulsive Mode	3%	2%
Metal Atmospheric Storage Tanks (containment, protection) - Sloshing Mode	0.5%	0.5%

7.2 Justification for Proposed Component Damping

The proposed damping values for mechanical and electrical components are based on review of References 2, 3, 4, 16, and 28. For mechanical and electrical components, the limited information provided in References 2 and 4, and the more extensive information provided in References 3 and 28 are reasonably consistent. In Reference 16, the staff accepted the damping values specified in Reference 28 for AP1000. The NRC Damping Task Force has also informally reviewed the damping values in Reference 3, and has found them to be acceptable, with minor exceptions.

7.2.1 Motor, Fan, and Compressor Housings

Reference 3 addresses these sub-components under the category "massive, low-stressed mechanical components", which includes pumps, motors, fans, compressors, etc. The Response Level 1 (2%) and Level 2 (3%) damping values in Reference 3 are proposed for OBE and SSE damping, respectively.

7.2.2 Pressure Vessels, Heat Exchangers, Pump and Valve Bodies

Reference 16 accepted 4% SSE damping for AP1000 welded equipment. Because of their similarity to piping (i.e., highly stressed by operating pressure loads), and for compatibility with damping specified for attached piping, BNL initially proposed 4% SSE damping and 3% OBE damping for this category.

However, Reference 3 includes pumps under the category "massive, low-stressed mechanical components", discussed in 7.2.1 above.

The NRC Damping Task Force recommended that 2% OBE damping and 3% SSE damping be specified for this category, unless there is test data to support the higher values that BNL recommended. Of particular concern to the staff are vertical RHR heat exchangers and vertical pumps with motors (e.g., Deep-Well pumps). In the absence of definitive test data, Table 6 incorporates the staff's recommendations.

7.2.3 Welded Instrument Racks

Both References 3 and 28 address welded instrument racks. The proposed damping values are consistent with each other. Reference 16 accepted the Reference 28 value for SSE (3%). The Response Level 1 (2%) and Level 2 (3%) damping values in Reference 3 are proposed for OBE and SSE damping, respectively.

7.2.4 Electrical Cabinets, Panels, and Motor Control Centers (MCCs)

Both References 3 and 28 address enclosures for electrical devices. Reference 16 accepted 5% SSE damping specified in Reference 28 for "cabinets and panels for electrical equipment." In Reference 3, Response Level 1 damping of 3% and Response Level 2 damping of 4% are specified for "electrical cabinets and other equipment." On this basis, BNL initially proposed 3% OBE damping and 4% SSE damping for this category.

The NRC Damping Task Force recommended that 2% OBE damping and 3% SSE damping be specified for this category, unless there is test data to support the higher values that BNL recommended. Of particular concern to the staff are sensitive electrical equipment with welded support. In the absence of definitive test data, Table 6 incorporates the staff's recommendations.

7.2.5 Metal Atmospheric Storage Tanks

Reference 3 addresses "liquid containing metal tanks", and specifies recommended damping values for both the impulsive mode and the sloshing mode. Response Level 1 (2%) and Level 2 (3%) damping values are specified for the impulsive mode; 0.5% damping is specified for the sloshing mode at all response levels. This is consistent with previous staff guidance for seismic analysis of metal atmospheric storage tanks. The Reference 3 damping values are proposed.

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8. CONCLUSIONS AND RECOMMENDATIONS

The damping values proposed in Sections 3 through 7 of this report are based on the recommendations submitted by BNL in 1995 (Ref. 1), additional work conducted by BNL under the current project, and the recommendations of the NRC Damping Task Force. The recommendations proposed herein do not include any radical changes from the damping values specified in Regulatory Guide 1.61, Rev. 0. The primary improvements are (1) explicit guidance for damping of components and non-piping distribution systems; (2) explicit guidance for structural damping at low response levels; and (3) consideration of experimental data, significant staff licensing actions related to damping, and revisions to codes and standards related to damping, developed since Revision 0 was issued in 1973.

Issuance of Revision 1 to Regulatory Guide 1.61, incorporating the recommendations contained herein, will help to streamline the application and staff review process by minimizing the number of case-by-case assessments required.

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