Proposed - For Interim Use and Comment

U.S. NUCLEAR REGULATORY COMMISSION

DESIGN-SPECIFIC REVIEW STANDARD FOR mPOWER™ iPWR DESIGN

3.7.1 SEISMIC DESIGN PARAMETERS

REVIEW RESPONSIBILITIES

Primary - Organization responsible for seismic and structural analysis reviews

Secondary - Organization responsible for review of seismic ground motion development

I. AREAS OF REVIEW

The specific areas of review are as follows:

1. Design Ground Motion. For the seismic design of nuclear power plants, it is customary to specify the design earthquake ground motions that are exerted on the plant structures and used in soil-structure interaction analyses. The design earthquake ground motion, also known as the seismic input motion or control motion, is based on the seismicity and geologic conditions at the site and expressed in such a manner that it can be applied to the dynamic analysis of structures, systems, and components (SSCs).

   Two levels of design earthquake ground motions are considered: 1) operating basis earthquake (OBE) and 2) safe shutdown earthquake (SSE). The three spatial components of the design ground motions (two horizontal and one vertical) are reviewed. The design ground motions for the OBE and SSE should be consistent with the description of the free-field ground motions at the site provided in NUREG-0800 Standard Review Plan (SRP) Section 2.5.2, which includes the variation in and distribution of ground motions in the free field, sources and directions of the motion, propagation and transmission of seismic waves, and other site response characteristics including the variation of this seismic motion over the depth of the facility. The seismic free-field ground motions can be developed based on Regulatory Guides 1.60 or 1.208, and are reviewed under SRP Section 2.5.2. These regulatory guides provide procedures that are acceptable to the staff for defining the ground motion response spectra (GMRS) in the free-field for use in developing the OBE and SSE design ground motion needed for the design of nuclear power plant SSCs.

   A. Design Response Spectra. For a standard plant design, the design response spectra can be developed based on smooth-shaped broadband spectra consistent with the site conditions postulated for the standard design. For a non-standard plant (e.g., combined license (COL) application referencing only an early site permit (ESP), or a COL application not referencing a design certification (DC) and ESP), the design response spectra are typically developed from the site-specific GMRS.

      The GMRS reviewed under SRP Section 2.5.2 are site-specific horizontal and vertical ground spectra determined as free-field motions at the ground surface or as free-field outcrop motions defined at the uppermost in-situ competent material using performance-based procedures in accordance with Regulatory Guide 1.208. The performance-based site-specific GMRS transferred to the foundation level in the free-field is referred to as the foundation input response spectra (FIRS). Therefore, the FIRS meet the same performance requisite as the GMRS. Both the GMRS and the FIRS are defined as free-field outcrop spectra (not including any soil layers above that elevation). The FIRS is the starting point for conducting a soil-structure interaction (SSI) analysis and making a one-to-one comparison of the seismic design capacity of the standard design and the site-specific seismic demand for a site. The FIRS for the vertical direction is obtained with the vertical to horizontal (V/H) ratios appropriate for the site. GMRS are those derived from the global understanding of the site soil layers above the rock condition as determined from the site exploration activities, and therefore, are unique to a particular site.

Competent material is generally considered to be in-situ material having a minimum shear wave velocity of 1,000 feet/second (fps). If non-competent material is present, any excavation and/or backfilling should not alter the development or location of the GMRS; however, the development of the FIRS uses the site profiles including the effect of backfill. The remaining soft soil or backfill material needs to be considered in the soil-structure-interaction (SSI) or other analyses. Further information on the development of the GMRS and FIRS is provided in DC/COL-ISG-01 and DC/COL-ISG-17.

In addition to the FIRS, additional performance-based response spectra (PBRS) need to be developed at one or more intermediate depths between the foundation and ground surface that are probabilistically determined using procedures that are consistent with the development of the FIRS. The PBRS are performance-based free-field outcrop response spectra generated using the soil column corresponding to the building for which the performance-based FIRS are also generated. The properties of the soil column are used to generate 60 or more randomized sets of properties similar to those used in the probabilistic seismic hazard analysis (PSHA) process as described in SRP 2.5.2. The resulting spectra described above are the PBRS for the horizontal direction and may be established at various elevations in the free field (e.g., the PBRS developed at the ground surface is referred to as the PBSRS as described in DC/COL-ISG-017). The PBRS for the vertical direction can be obtained with the appropriate V/H ratios used to develop the FIRS. In addition, the methodology for developing V/H ratios for deep soil site conditions is reviewed on a case-by-case basis. The PBRS are used to verify and ensure that the soil columns to be used in a deterministic SSI analysis produce response spectra at the surface and other locations in the free field, which envelope the corresponding PBRS. Additional guidance to demonstrate the adequacy of the soil columns is provided in Design Specific Review Standard (DSRS) Section 3.7.2 II.4. The PBRS are associated with subsurface conditions localized to a specific building.

In addition, 10 CFR Part 50, Appendix S is applicable to applications for a design certification (DC) or combined license (COL) pursuant to 10 CFR Part 52 or a construction permit (CP) or operating license (OL) pursuant to 10 CFR Part 50 submitted on or after January 10, 1997. Applications subject to this appendix must:

- Demonstrate that the SSE ground motion in the horizontal direction in the free-field at the foundation level of the structures (FIRS) must be an appropriate response spectrum with a peak ground acceleration of at least 0.1g.

- Design SSCs to the OBE and SSE loadings. However, if the OBE is set at one-third or less of the SSE, the requirements associated with OBE can be satisfied without the applicant performing an explicit response or design analysis. If the OBE is set at a value greater than one-third of the SSE, an analysis and design must be performed for the OBE to demonstrate that the applicable stress, strain, and deformation limits of the SSCs are satisfied.

The magnitude of the OBE in the application is reviewed to determine whether a seismic analysis is required for this earthquake level. Throughout this DSRS section, whenever the OBE is discussed, it is understood that it may not apply to the particular licensing application being reviewed depending on the magnitude of the OBE as defined above.

For structures with either surface or shallow embedded foundations, the seismic input motions to the SSI analyses can typically be placed at the free ground surface or at the foundation level using the guidance in this DSRS Section 3.7.1, as supplemented by DC/COL- ISG-017. However, the input motions defined at locations other than the foundation level may not be appropriate for deeply embedded structures such as those encountered in iPWRs. In these situations, the seismic input should only be specified at the foundation level as FIRS.

For the site-specific deterministic SSI analysis, based on the procedure described in DSRS Section 3.7.2, the PBRS are used to ensure the adequacy of the soil columns used. For sites that have relatively uniform variation of shear wave velocity with depth, it is anticipated that the PBRS developed at the surface and at a central depth between the surface and foundation level of the deeply embedded facility should be adequate for verifying the adequacy of the soil columns. For sites that have unusual velocity characteristics with depth such as those containing significant inversions in the layer profiles, one or more additional depths are selected at which PBRS are developed that maximize the effects of the variation in input motion on facility response. The process for selecting the number and locations of these intermediate depths is reviewed on a case-by-case basis.

The proposed design response spectra at the foundation at both the OBE and SSE levels, are reviewed. The design response spectra, in general, are relatively smooth plots not exhibiting random peaks and valleys. The use of smooth spectra is preferred in the design and is needed for generic site seismic hazard evaluation, as in the design of a standard plant. The use of unsmoothed design response spectra to develop the input ground motions (design time histories) will be reviewed on a case-by-case basis.

A review is also made of the approach used to demonstrate that the horizontal component of the SSE ground motion in the free-field at the foundation level of seismic Category I structures is an appropriate response spectrum with a peak ground acceleration of at least 0.1 g, as required by Appendix S to 10 CFR Part 50.

B. Design Time Histories. Acceleration time histories for computing the response of seismic Category I SSCs are reviewed. The extent to which these time histories are compatible with the design response spectra is reviewed.

When an appropriate recorded or specified time history is not available as input ground motion for seismic system analysis, the three spatial components of artificial time histories may be generated from the design response spectra for the purpose of carrying out a time history analysis of the SSCs. In demonstrating the statistical independence of the three components of ground motion, the correlation coefficients between the time histories are reviewed. The response spectra obtained from such artificial time histories of ground motion should generally envelop the design response spectra for all damping values to be used. The procedures used to generate response spectra from the artificial time histories and the comparisons of these response spectra with the design response spectra are reviewed.

In addition to the comparison of the response spectra derived from the ground motion time histories with the design response spectra, the frequency intervals at which the spectral values are calculated are also reviewed.

When time history analyses are performed, either of the following options may be considered. In either case, the time histories may be real or artificial.

Option 1: Single Set of Time Histories. The justification for the use of the single set of time histories is reviewed. The approach used to demonstrate that the response spectra generated from the time histories envelop the design response spectra are reviewed. Depending on the approach used, the application of the requirements to match a target power spectral density (PSD) function compatible with the design response spectra may also need to be reviewed.

Option 2: Multiple Sets of Time Histories. In lieu of the use of a single time history, multiple artificial or real ground motion time histories may be used for the seismic analyses and design of the SSCs. The parameters describing the time histories and the number of time histories are reviewed. The approach used to demonstrate the adequacy of the set of multiple time histories, in terms of the enveloping requirements and having sufficient power over the frequency range of interest, is reviewed.

In some instances, a nonlinear analysis of the SSCs may be appropriate (e.g., the evaluation of existing structures). Multiple time history analyses incorporating real earthquake time histories are appropriate when such analyses are proposed. The adequacy of time histories used for the nonlinear analyses is reviewed.

2. Percentage of Critical Damping Values. The percentage of critical damping values used for the seismic analysis of Category I SSCs is reviewed for both the OBE and the SSE. Critical damping is the amount of damping that would completely eliminate free vibration and is an important measure of the damping capacity of a structure.

Vibrating SSCs have energy losses that depend on numerous factors, such as material characteristics, stress levels, and geometric configuration. This dissipation of energy, or damping effect, occurs because a part of the excitation input is transformed into heat, sound waves, and other energy forms. The response of a system to dynamic loads is a function of the amount and type of damping existing in the system. Knowledge of appropriate values to represent this characteristic is essential for obtaining realistic results in any dynamic analysis.

In practical seismic analysis, which usually employs linear methods of analysis, damping is also used to account for many nonlinear effects such as changes in boundary conditions, joint slippage, concrete cracking, gaps, and other effects that tend to alter response amplitude. In real structures, it is often impossible to separate "true" material damping from system damping, which is the measure of the energy dissipation, from the nonlinear effects. Overall structural damping used in design is normally determined by observing experimentally the total response of the structure.

Damping values assigned to members of seismic Category I SSCs, including material damping and system damping, are reviewed. When applicable, the basis for any damping values that differ from those given in Regulatory Guide (RG) 1.61 is reviewed.

3. Supporting Media for Seismic Category I Structures. The description of the supporting media for each seismic Category I structure is reviewed, including foundation embedment depth, depth of soil over bedrock, soil layering characteristics, highest groundwater elevation, dimensions of the structural foundation, total structural height, topographical conditions of the sites, and soil properties (including strain-dependent properties) and their assumed variability to permit evaluation of the applicability of continuum, finite-element or lumped-spring approaches for soil-structure interaction analysis.

4. Review Considerations for DC and COL Applications. For a DC application, the postulated seismic design response spectra are reviewed. The input or control location for the postulated seismic design response spectra is also reviewed. The postulated seismic design response spectra will become the certified seismic design response spectra (CSDRS) when the design is certified by the Commission under 10 CFR Part 52. For a COL application referencing a certified design, the demonstration that the CSDRS envelops the site-specific FIRS is reviewed.

5. Inspections, Tests, Analyses, and Acceptance Criteria (ITAAC). For design certification (DC) and combined license (COL) reviews, the staff reviews the applicant's proposed ITAAC associated with the SSCs (if any are identified related to this DSRS section) in accordance with SRP Section 14.3, "Inspections, Tests, Analyses, and Acceptance Criteria." The staff recognizes that the review of ITAAC cannot be completed until after the rest of this portion of the application has been reviewed against acceptance criteria contained in this DSRS section. Furthermore, the staff reviews the ITAAC to ensure that all SSCs in this area of review are identified and addressed as appropriate in accordance with SRP Section 14.3.

6. COL Action Items and Certification Requirements and Restrictions. For a DC application, the review will also address COL action items and requirements and restrictions (e.g., interface requirements and site parameters).

For a COL application referencing a DC or ESP, a COL applicant must address COL action items (referred to as COL license information in certain DCs) included in the referenced DC or ESP. Additionally, a COL applicant must address requirements and restrictions (e.g., interface requirements, site parameters, and permit conditions) included in the referenced DC or ESP.

COL action items related to seismic design parameters include soil layering assumptions used in the certified design, range of soil parameters considered, and shear wave velocity values.

Review Interfaces

Other SRP and DSRS sections interface with this section as follows:

1. Review of geological and seismological information to establish the free-field ground motion over the complete depth of the embedded facility is performed under SRP Sections 2.5.1 through 2.5.3.

2. The geotechnical parameters and methods employed in the analysis of free-field soil media and the soil properties are reviewed under SRP section 2.5.4.

3. The seismic system analysis, which utilizes the design earthquake ground motion developed in this DSRS section, is reviewed under DSRS Section 3.7.2.

4. The seismic subsystem analysis for some components (e.g., buried piping, tunnels, and atmospheric tanks), which utilize the design earthquake ground motion developed in this DSRS section, is reviewed under DSRS Section 3.7.3.

5. For DC applications and COL applications referencing a DC rule or DC application, review of the site parameters in the Design Control Document (DCD) Tier 1 and Chapter 2 of the DCD Tier 2[1] submitted by the applicant is performed under SRP Section 2.0, "Site Characteristics/Site Parameters."

6. Review of the Probabilistic Risk Assessment is performed under SRP Section 19.0 in conjunction with DC/COL-ISG-020, "Interim Staff Guidance on Implementation of a Probabilistic Risk Assessment-Based Seismic Margin Analysis for New Reactors," for potential risk significance of SSCs and the risk-based susceptibility of risk significant SSCs to failure due to seismic hazards.

The results of the reviews for the OBE and the SSE site-specific free-field ground motion, soil properties, etc., are used as an integral part of the seismic analysis review of Category I SSCs.

II. ACCEPTANCE CRITERIA

Requirements

Acceptance criteria are based on meeting the relevant requirements of the following Commission regulations:

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[1]Additional supporting information of prior DC rules may be found in DCD Tier 2 Section 14.3.

1. 10 CFR Part 50, Appendix A, General Design Criterion (GDC) 2 - The design basis shall reflect appropriate consideration of the most severe earthquakes that have been historically reported for the site and surrounding area with sufficient margin for the limited accuracy, quantity, and period of time in which historical data have been accumulated.

2. 10 CFR Part 50, Appendix S is applicable to applications for a design certification or combined license to 10 CFR Part 52 or a construction permit or operating license pursuant to 10 CFR Part 50 on or after January 10, 1997. Appendix S requires that for SSE ground motions, SSCs will remain functional and within applicable stress, strain, and deformation limits. The required safety functions of SSCs must be assured during and after the vibratory ground motion through design, testing, or qualification methods. The evaluation must take into account soil-structure interaction effects and the expected duration of the vibratory motion. If the OBE is set at one-third or less of the SSE, an explicit analysis or design is not required. If the OBE is set at a value greater than one-third of the SSE, an analysis and design must be performed to demonstrate that the applicable stress, strain, and deformation limits are satisfied. Appendix S also requires that the horizontal component of the SSE ground motion in the free-field at the foundation level of the structures must be an appropriate response spectrum with a peak ground acceleration of at least. 0.1g.

3. 10 CFR 52.47(a)(1) requires a DC applicant provide site parameters postulated for the design and an analysis and evaluation of the design in terms of those site parameters.

4. 10 CFR 52.47(b)(1), which requires that a DC application contain the proposed inspections, tests, analyses, and acceptance criteria (ITAAC) that are necessary and sufficient to provide reasonable assurance that, if the inspections, tests, and analyses are performed and the acceptance criteria met, a facility that incorporates the design certification has been constructed and will be operated in conformity with the design certification, the provisions of the Atomic Energy Act, and the Commission's rules and regulations.

5. 10 CFR 52.79(b)(1) for a COL referencing an ESP as it relates to information sufficient to demonstrate that the design of the facility falls within the site characteristics and design parameters specified in the ESP.

6. 10 CFR 52.79(d)(1) for a combined license referencing a DC as it relates to information sufficient to demonstrate that the characteristics of the site fall within the site parameters specified in the design certification.

7. 10 CFR 52.80(a), which requires that a COL application contain the proposed inspections, tests, and analyses, including those applicable to emergency planning, that the licensee shall perform, and the acceptance criteria that are necessary and sufficient to provide reasonable assurance that, if the inspections, tests, and analyses are performed and the acceptance criteria met, the facility has been constructed and will operate in conformity with the combined license, the provisions of the Atomic Energy Act, and the Commission's regulations..

DSRS Acceptance Criteria

Specific DSRS acceptance criteria acceptable to meet the relevant requirements of the NRC's regulations identified above are as follows for review described in this DSRS section. The DSRS is not a substitute for the NRC's regulations, and compliance with it is not required. Identifying the differences between this DSRS section and the design features, analytical techniques, and procedural measures proposed for the facility, and discussing how the proposed alternative provides an acceptable method of complying with the regulations that underlie the DSRS acceptance criteria, is sufficient to meet the intent of 10 CFR 52.47(a)(9), "Contents of applications; technical information."

The paragraphs below provide specific emphasis on acceptance criteria for development of free-field ground motion input applicable to deeply embedded facilities.

1. Design Ground Motion

   A. Design Response Spectra. The site-specific FIRS and PBRS reviewed under this DSRS section are determined as free-field outcrop motions at the foundation level. FIRS and associated deterministic soil profiles developed using the PBRS to meet the performance goal will establish the design basis for the site-specific SSI analysis; this design basis is developed using the guidance reviewed under SRP Section 2.5.2. For sites with soil layers near the surface that will be completely excavated (defined as excavations to distances sufficiently far from the structures to be considered infinitely far from the facility over the frequency range of interest) and replaced with compacted backfill, the FIRS and PBRS are determined using the site profiles including the replacement backfill. The competent material is generally considered to be in-situ material having a minimum shear wave velocity of 1,000 fps. Any remaining soft soil or backfill material needs to be considered in the SSI or other analyses.

      According to Appendix S to 10 CFR Part 50, the minimum peak ground acceleration (pga) for the horizontal component of the SSE at the foundation level in the free-field should be 0.1g or higher. The response spectrum associated with this minimum pga should be a smooth broadband response spectrum (e.g., RG 1.60, or other appropriate shaped spectra, if justified) and is defined as outcrop response spectra at the free-field foundation level. This response spectrum anchored to 0.1g will be referred in this DSRS section as the minimum required response spectrum.

      i. Non-standard Plant Design. For a non-standard plant design (e.g., COL application referencing only an ESP, or a COL application not referencing a DC and ESP), the design response spectra are developed from the site-specific GMRS or from a broadband shaped spectra similar to RG 1.60 which also envelops the site-specific GMRS. Foundation level response spectra (FIRS) consistent with the design response spectra are determined for each seismic Category I structure. These foundation level spectra are compared to the minimum required spectrum to ensure they meet the 0.1g pga requirement in accordance with Appendix S to 10 CFR Part 50. If the foundation level spectra do not bound the minimum required response spectrum, then the design response spectra can be adjusted/modified in order to bound the minimum required spectrum. If the design response spectra are not modified, then the use of the two separate sets of spectra in the analysis and design of SSCs need to be reviewed for adequacy.

ii. Certified Standard Plant Design (CD). For a design certification (DC) application, the postulated seismic design response spectra need to bound the minimum required response spectrum anchored at 0.1g (as specified in Appendix S to 10 CFR Part 50). These design response spectra are referred to as the CSDRS when the design is certified by the Commission under 10 CFR Part 52.

For a DC, a similar approach described above (under subsection II.1.A.i) is used to ensure that the CSDRS envelop the minimum required spectrum at the foundation level. Foundation level response spectra consistent with the CSDRS are determined for each seismic Category I structure. These foundation level spectra are compared to the minimum required spectrum to ensure that they meet the 0.1g pga requirement in accordance with Appendix S to 10 CFR Part 50. If the foundation level spectra do not bound the minimum required spectrum, then the CSDRS can be adjusted/modified in order to bound the minimum required spectrum. If the CSDRS are not modified, then the use of the two separate sets of spectra in the analysis and design of SSCs needs to be reviewed for adequacy.

For evaluation of soil liquefaction and soil/rock stability of slopes that may affect plant safety, the use of the site-specific GMRS rather than the CSDRS is reviewed on a case-by-case basis in accordance with SRP Section 2.5.4.

The free-field design response spectra (also referred to as the CSDRS for a DC) are usually developed for the 5-percent damping value. In the seismic analysis and design, the applicant needs to define the free-field design response spectra corresponding to all damping values to be used. For the case of RG 1.60 response spectra, Tables 1 and 2 of RG 1.60 provide amplification factors at four frequencies for calculating response spectra corresponding to different damping values. For the case of the free-field design response spectra that are different from RG 1.60 response spectra, Appendix C to this DSRS section provides procedures to calculate response spectra for different damping values other than 5 percent.

To be acceptable, the seismic design response spectra should be specified for three mutually orthogonal directions - two horizontal and one vertical. Current practice is to assume that the design response spectra (including maximum ground accelerations) in the two horizontal directions are the same.

B. Design Time Histories. The SSE and OBE design ground motion time histories can be either real time histories or artificial time histories. To be acceptable, the design ground motion time histories should consist of three mutually orthogonal directions - two horizontal and one vertical. For both horizontal and vertical input motions, either a single time history or multiple time histories can be used. When time histories are used, each of the three ground motion time histories must be shown to be statistically independent from the others. Each pair of time histories are considered to be statistically independent if the absolute value of their correlation coefficient does not exceed 0.16. Simply shifting the starting time of a given time history cannot be used to establish a different time history. When the seed time histories are selected from real earthquake records, the response spectra corresponding to the seed record should be similar in shape to the target spectra across the frequency range of interest to the analysis (e.g., Houston, et al., 2010) and phasing characteristics of the real earthquake records should be preserved. If the target spectra include multiple characteristic events, a single recorded earthquake time history may not able to capture the response characteristics of the target spectra. To this end, the use of multiple time histories may be appropriate in which individual time histories are developed from real earthquake records fairly representing the characteristic events embodied in the target spectra. Alternatively, an artificial time history may be developed using random generation routines or through the use of multiple time history techniques. If a random time history generator technique is used to develop the seed time histories, then acceptability of the seed will be reviewed on a case-by-case basis. For generated time histories, it should be demonstrated that acceleration, velocity, and displacement are compatible and do not result in displacement's baseline drift.

For linear structural analyses, the total duration of the artificial ground motion time histories should be long enough such that adequate representation of the Fourier components at low frequency is included in the time history. The corresponding stationary phase strong-motion duration should be consistent with the longest duration of strong motion from the earthquakes defined in SRP Section 2.5.2 at low and high frequency and as presented in NUREG/CR-6728. The strong motion duration is defined as the time required for the Arias Intensity to rise from 5% to 75%. The uniformity of the growth of this Arias Intensity should be reviewed. The minimum acceptable strong motion duration should be six seconds. In addition to the duration, the ratios V/A and AD/V^2 (A, V, D are peak ground acceleration, ground velocity, and ground displacement, respectively) should be consistent with characteristic values for the magnitude and distance of the appropriate controlling events defining the uniform hazard response spectra. These parameters should be consistent with the values determined for the low and high frequency events described in Appendix D of RG 1.208.

For nonlinear structural analysis problems, multiple sets of ground motion time histories should be used to represent the design ground motion. Each set of ground motion time histories shall be selected from real recorded ground motions appropriate for the characteristic low and high frequency events. The amplitude of these ground motions may be scaled but the phasing of Fourier components must be maintained. The adequacy of this set of ground motions, including-duration estimates, is reviewed on a case-by-case basis.

<u>Option 1: Single Set of Time Histories</u>. To be considered acceptable, the response spectra generated from the artificial time history to be used as input ground motion in the free-field should satisfy the enveloping requirements for either Approach 1 or Approach 2 below:

i. Approach 1. For Approach 1, the spectrum from the artificial ground motion time history must envelop the free-field design response spectra for all damping values used in the seismic response analysis. When spectral values (e.g., spectral accelerations) are calculated from the artificial time history, the frequency intervals at which spectral values are determined are to be sufficiently small. Table 3.7.1-1 (below) provides an acceptable set of frequencies at which the response spectra may be calculated.

Table 3.7.1-1
Suggested Frequency Intervals for Calculation of Response Spectra

Frequency Range (hertz)	Increment (hertz)
0.2 - 3.0	0.10
3.0 - 3.6	0.15
3.6 - 5.0	0.20
5.0 - 8.0	0.25
8.0 - 15.0	0.50
15.0 - 18.0	1.0
18.0 - 22.0	2.0
22.0 - highest frequency of interest	3.0

Each calculated spectrum of the artificial time history is considered to envelop the design response spectrum when no more than five points fall below, and no more than 10 percent below, the design response spectrum.

Studies indicate that numerically generated artificial ground acceleration histories produce PSD functions having a quite different appearance from one individual function to another, even when all these time histories are generated so as to closely envelop the same design response spectra. For example, the use of the available techniques of generating acceleration time histories that satisfy enveloping RG 1.60 spectra usually results in PSD functions that fluctuate significantly and randomly as a function of frequency. It is also recognized that the more closely one tries to envelop the specified design response spectra, the more significantly and randomly do the spectral density functions tend to fluctuate and these fluctuations may lead to unconservative results for the response of SSCs. Therefore, when a single artificial ground motion time history is used in the design of seismic Category I SSCs, it should satisfy requirements for both enveloping design response spectra as well as adequately matching a target PSD function compatible with the design response spectra. Therefore, in addition to the response spectra enveloping requirement, the use of a single time history should also be justified by demonstrating sufficient energy at the frequencies of interest through the generation of PSD function, which envelops the target PSD function throughout the frequency range of significance.

When RG 1.60 response spectra are used as design response spectra, the requirements for a compatible target PSD are contained in Appendix A to this DSRS section. Target PSD functions other than those given in Appendix A can be used if justified. For design response spectra other than RG 1.60 response spectra, a compatible target PSD should be generated. For generation of target PSD in such cases, the guidelines and procedures provided in Appendix B to this DSRS section can be used. Procedures used to generate the target PSD will be reviewed on a case-by-case basis. The PSD requirements are included as secondary and minimum requirements to prevent potential deficiency of power over the frequency range of interest. It should be noted that the ground motion is still primarily defined by the design response spectrum. The use of PSD criteria alone can yield time histories that may not envelop the design response spectrum.

ii. Approach 2. For Approach 2, the artificial ground motion time histories that are generated to match or envelop the design response spectra shall comply with Steps (a) through (d) below. The general objective is to generate a modified recorded or artificial accelerogram which achieves approximately mean based fit to the target response spectrum; that is, the average ratio of the spectral acceleration calculated from the accelerogram to the target, where the ratio is calculated frequency by frequency, is only slightly greater than "1." The aim is to achieve an accelerogram that does not have significant gaps in the Fourier amplitude spectrum, but which is not biased high with respect to the target.

(a) The time history shall have a sufficiently small time increment and sufficiently long duration. Records shall have a Nyquist frequency of at least 50 Hz, (e.g., a time increment of at most 0.010 seconds) and a total duration of at least 20 seconds. If frequencies higher than 50 Hz are of interest, the time increment of the record must be suitably reduced to provide a Nyquist frequency (N_f =1/(2Δt), where Δt = time increment) above the maximum frequency of interest. The total duration of the record can be increased by zero packing to satisfy these frequency criteria.

(b) Spectral acceleration at 5% damping shall be computed at a minimum of 100 points per frequency decade, uniformly spaced over the log frequency scale from 0.1 Hz to 50 Hz or the Nyquist frequency. The comparison of the response spectrum obtained from the artificial ground motion time history with the target response spectrum shall be made at each frequency computed in the frequency range of interest.

(c) The computed 5% damped response spectrum of the acceleration time history shall not fall more than 10% below the target response spectrum at any one frequency. To prevent response spectra in large frequency windows from falling below the target response spectrum, the response spectra within a frequency window of no larger than ±10% centered on the frequency shall be allowed to fall below the target response spectrum. This corresponds to response spectra at no more than 9 adjacent frequency points defined in (b) above from falling below the target response spectrum.

(d) The computed 5% damped response spectrum of the acceleration time history shall not exceed the target response spectrum at any frequency by more than 30% (a factor of 1.3) in the frequency range of interest. In addition, the power spectrum density of the accelerogram needs to be computed and shown to not have significant gaps in energy at any frequency over this frequency range.

If the artificial ground motion time history, defined in Approach 2 above, is intended to be compatible to a site-specific GMRS, it shall have characteristics consistent with characteristic values for the magnitude and distance of the appropriate controlling events defined for the corresponding uniform hazard response spectrum (UHRS).

<u>Option 2: Multiple Sets of Time Histories</u>. As discussed in Section I.1.B and Section II.1.B of this DSRS section, the use of multiple real or artificial time histories for analyses and design of SSCs is acceptable. For linear structural analyses, a minimum of four times histories should be used. For nonlinear structural analyses, the number of time histories must be greater than four and the technical basis for the appropriate number of time histories are reviewed on a case-by-case basis. This review also includes the adequacy of the characteristics of the multiple time histories.

The response spectra calculated for each individual time history need not envelop the design response spectra. However, the multiple time histories are acceptable if the average calculated response spectra generated from these time histories envelop the design response spectra. An acceptable method to demonstrate the adequacy of a set of multiple time histories, in terms of enveloping requirements and having sufficient power over the frequency range of interest, is to follow the procedures described for Approach 2 presented in subsection II.1.B.ii of this DSRS. When implementing Approach 2, the criteria in paragraphs (a) and (b) of this approach need to be satisfied for each of the time histories. The criteria in paragraphs (c) and (d) of this approach can be satisfied by utilizing the results for the average of the suite of multiple time histories.

When calculating the response of structures (e.g., accelerations, member forces, and displacements) from linear analyses, the average value of the responses from the multiple time histories may be used. When calculating the response of structures from nonlinear analyses (e.g., seismic evaluation of as-built structures), the average value of the responses from the multiple time histories may be used if at least seven nonlinear time history analyses are performed. Otherwise, the maximum value (i.e., envelope) of the individual responses from the multiple time histories should be used.

In addition, if the extent of the nonlinear response is found to be significant or if the nonlinear response due to one or several time histories is found to be substantially different from the other results, then additional time histories should be considered. If there is a particular ground motion or time history analysis that dominates the response values, it should not be replaced with another motion or analysis to reduce the responses. Also, if a ratcheting effect is noted (e.g., increasing deformation with subsequent cycling of earthquake motion), then the system characteristics should be reviewed to ensure that they have been conservatively considered or the design should be revised to eliminate this behavior.

2. Percentage of Critical Damping Values. The specific percentage of critical damping values used in the analyses of Category I SSCs is considered to be acceptable if they are in accordance with RG 1.61. Damping values different from those listed in RG 1.61 (e.g., higher damping values) may be used in a dynamic seismic analysis if test data are provided to support them. These damping values will be reviewed and accepted by the staff on a case-by-case basis.

   In addition, a demonstration of the correlation between stress levels and damping values will be required and reviewed for compliance with the applicable regulatory position in RG 1.61. If other methods for correlation of damping values with stress level are used, they will need to be reviewed and accepted on a case-by-case basis.

   The material soil damping for foundation soils should be based upon validated values or other pertinent laboratory data, considering variation in soil properties and strains within the soil, and should include an evaluation of dissipation from pore pressure effects as well as material damping for saturated site conditions. The maximum soil damping value acceptable to the staff is 15 percent.

3. Supporting Media for Seismic Category I Structures. To be acceptable, the description of supporting media for each Category I structure must include foundation embedment depth, depth of soil over bedrock, soil layering characteristics, design groundwater elevation, dimensions of the structural foundation, total structural height, and soil properties such as shear wave velocity, shear modulus, material damping, including strain-dependent effect, as well as Poisson's ratios, and density as a function of depth. If the minimum shear wave velocity of the supporting foundation material is less than 1,000 fps, additional studies need to be performed which consider the average shear wave velocity, and its degree of variability addressing potential impact of soft soil on soil-structure interaction, potential settlements and design of foundation elements.

4. Review Considerations for DC and COL Applications

   A. COL Application Referencing an ESP and DC

      i. Site-specific FIRS and PBRS are reviewed separately under this DSRS section for adequacy. For COL application referencing an ESP and DC, the FIRS and PBRS are included in the COL application. This review should include determination of the PBRS at the surface and intermediate depth(s) and associated deterministically defined soil columns needed for determining the adequacy of the check on performance goal. The FIRS with the consistent soil columns together form the design basis that is used for the seismic analysis of the facilities.

ii. Confirm that the criterion for the minimum required response spectrum (in accordance with subsection II.1.A.ii) has been satisfied.

iii. Confirm that COL action items contained in the DC have been met. This includes seismic design parameters such as soil layering assumptions used in the certified design, range of soil parameters, shear wave velocity values, and minimum soil bearing capacity. Technical justification for all deviations from the range of values used in the standard plant design must be provided for review.

iv. Confirm that the ESP conditions have been met or review the COL applicant's approach to address any deviations.

v. The performance-based response spectra (PBRS) are generated using the soil profiles for which the performance-based FIRS are generated. The properties of the individual realizations of the soil column consist of at least 60 or more randomized sets of soil profiles similar to those used in the probabilistic seismic hazard analysis (PSHA) process and reviewed under SRP Section 2.5.2 and as described in DC/COL-ISG-017. From this set of randomized columns, three individual soil columns are generated with individual layer properties (shear wave velocity and iterated hysteretic damping) selected at the best estimate (BE), lower bound at minus one-sigma (LB), and upper bound at plus one-sigma (UB) values. For SSI analyses, the LB and UB profiles may need to be modified to ensure that they satisfy the requirements of COV in velocity properties as described in DSRS Section 3.7.2. These individual soil columns are to be used in deterministic site response and SSI analyses described in DSRS Section 3.7.2. Free-field response spectra are then generated at the ground surface and intermediate depth(s) from the FIRS input at the foundation level for each of these three deterministic soil profiles. The envelope of these three spectra (BE, LB, and UB) should equal or exceed the corresponding performance-based PBRS at the ground surface and intermediate depth(s). If the envelope spectra do not exceed the PBRS, additional soil profiles can be developed for which SSI analyses are to be performed or, alternatively, the three soil profiles can be suitably scaled to ensure that the envelope responses exceed the performance-based criteria.

vi. When the site-specific FIRS and the CSDRS are calculated at the same elevation, confirm that the CSDRS envelop the FIRS as indicated in DC/COL-ISG-017 provided that the site-specific soil profile is captured within the range of profiles considered in the development of the CSDRS. For this case the standard design is acceptable for that site, assuming no other issue is identified during the review process. If the CSDRS do not envelop the site-specific FIRS, then proceed to step viii.

vii. When the site-specific FIRS and the CSDRS are determined at different elevations, the CSDRS-consistent spectra need to be calculated at the foundations of each seismic Category I structure. For each seismic Category I structure foundation, if the CSDRS-consistent spectra at the foundation level envelop the site-specific FIRS at the foundation level, the standard design is acceptable for that site, provided that the potential effects of the variation in ground motion over the depth of the facilities are defined and incorporated into the analysis and assuming no other issue is identified during the review process. If not, then proceed to step viii.

viii. Perform an analysis of the seismic response of the facilities using the site-specific FIRS as input and an advanced seismic analytical technique (e.g., method that considers the effects of ground motion variation with depth and, if necessary, incoherent ground motion). When such analytical methods are utilized, the detailed technical justification shall be reviewed on a case-by-case basis. Further discussion on consideration of the effects of incoherent ground motion is provided in subsection II.4.C (under the heading Input Ground Motion, Specific Guidelines for SSI Analysis) in DSRS Section 3.7.2. The in-structure responses in terms of floor response spectra, building member forces, and deformations at key locations in the structure shall be obtained using seismic analysis methods provided in DSRS Section 3.7.2 II. The key locations for calculating the in-structure responses, proposed by the licensee, need to be evaluated to ensure that they are sufficient to represent the various locations throughout the building. Locations should include responses at peripheral locations to detect rocking and torsion, and should include responses to check overturning, torsional, and sliding stability of the structures. The dynamic models and analysis techniques need to be sufficiently refined to be able to capture the response of the structures throughout the frequency range of interest, including the high frequency responses, typically expected in the central and eastern United States (CEUS) regions. The SSI analysis shall also consider the site-specific soil variability (i.e., best estimate, lower bound estimate, and upper bound estimate of site properties) as described in item v above. Compare these responses at the key locations in the structure to the standard design in-structure responses. If the computed responses from the CSDRS envelop the corresponding in-structure responses from the individual deterministic soil columns, the standard design is acceptable, assuming no other issue is identified during the review process. If the responses are not enveloped, additional analyses are required to demonstrate the acceptability of the design or the design might need to be modified. If further analyses are utilized, then the analyses must consider the potentially higher responses at all locations, not only those at the key locations described above.

B. <u>COL Application Referencing a DC</u>. Follow the same steps described above under A, a COL Application Referencing an ESP and DC, except that step iv does not apply to this case.

C. COL Application Referencing an ESP.

i. Site-specific FIRS and PBRS are reviewed separately under this DSRS section for adequacy. For COL application referencing an ESP, the FIRS and PBRS are included in the COL application. This review should include determination of the PBRS at the surface and intermediate depth(s) and associated deterministically defined soil columns needed for determining the adequacy of the check on performance goal. The FIRS with the consistent soil columns together form the design basis that is used for the seismic analysis of the facilities.

ii. Confirm that the ESP conditions have been met or review the COL applicant's approach to address any deviations.

iii. Follow the acceptance criteria described in subsection II.1.A (excluding subsection II.1.A.ii) of this DSRS Section to develop the seismic design response spectra. The seismic SSI analysis would then follow the conventional approach for SSI analyses, considering the entire seismic environment over the depth of the facility.

D. COL Application not Referencing an ESP and DC.

i. Site-specific FIRS and PBRS are reviewed separately under this DSRS section for adequacy. This review should include determination of the PBRS at the surface and intermediate depth(s) and associated deterministically defined soil columns needed for determining the adequacy of the check on performance goal. The FIRS with the consistent soil columns together form the design basis that is used for the seismic analysis of the facilities.

ii. Follow the acceptance criteria described in subsection II.1.A (excluding subsection II.1.A.ii), of this DSRS Section to develop the seismic design response spectra. The seismic SSI analysis would then follow the conventional approach for SSI analyses, considering the entire seismic environment over the depth of the facility.

Technical Rationale:

The technical rationale for application of these requirements to reviewing this DSRS section is discussed in the following paragraphs:

1. GDC 2 requires, in the relevant parts, that SSCs important to safety be designed to withstand the effects of natural phenomena such as earthquakes without loss of capability to perform their intended safety functions. GDC 2 further requires that the design bases reflect appropriate consideration for the most severe natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated in the past.

   DSRS 3.7.1 describes acceptance criteria for developing seismic design parameters to assure that they are appropriate and contain sufficient margin such that seismic analyses (reviewed under other DSRS sections) accurately and/or conservatively represent the behavior of SSCs during postulated seismic events. Criteria is provided for developing the seismic design ground motion, percentage of critical damping, supporting media, and the technical interface requirements for ESP, DC, and/or COL applications, as well as site acceptability determination. Reference is made to Regulatory Guides 1.60 and 1.208, which provide procedures that are acceptable to the staff for defining seismic ground motion response spectra for input into the seismic design analysis of nuclear power plants SSCs. In addition, RG 1.61 is referenced for guidance of acceptable damping values to be used in performing dynamic analyses of SSCs.

Meeting these requirements provides assurance that seismic Category I SSCs will be adequately designed to withstand the effects of earthquakes, and thus, will be able to perform their intended safety function.

2. 10 CFR Part 50, Appendix S is applicable to applications for a design certification or combined license to 10 CFR Part 52 or a construction permit or operating license pursuant to 10 CFR Part 50 on or after January 10, 1997. For SSE ground motions, 10 CFR Part 50, Appendix S requires that SSCs will remain functional and within applicable stress, strain, and deformation limits. The required safety functions of SSCs must be assured during and after the vibratory ground motion through design, testing, or qualification methods. The evaluation must take into account SSI effects and the expected duration of the vibratory motion. If the OBE is set at one-third or less of the SSE, an explicit analysis or design is not required. If the OBE is set at a value greater than one-third of the SSE, an analysis and design must be performed to demonstrate that the applicable stress, strain, and deformation limits are satisfied. Appendix S also requires that the horizontal component of the SSE ground motion in the free-field at the foundation level of the structures must be an appropriate response spectrum with a peak ground acceleration of at least 0.1g.

   DSRS Section 3.7.1 describes acceptance criteria for developing the required earthquake loadings consisting of the SSE and OBE (if applicable) and other seismic design parameters needed to perform an SSI analysis. This DSRS section indicates that an explicit analysis for the OBE, in addition to the SSE, should be performed unless the magnitude of the OBE is set at one-third or less of the SSE. Criteria for the required characteristics of the earthquake motion are presented which include the duration of the seismic ground motion. DSRS 3.7.1 also specifies that the horizontal free-field SSE ground motion at the foundation level shall be represented by an appropriate response spectrum, such as that defined in Regulatory Guide 1.60, with a minimum peak ground acceleration of 0.1g. The criteria presented in this DSRS section provide the earthquake loadings and seismic design parameters so that the SSI analysis can determine the response of the SSCs in terms of stresses, strains, and deformations. In addition, the use of these criteria allows the SSI analysis to calculate the floor response spectra for use in qualification of equipment.

   Meeting these requirements provides assurance that appropriate methods will be used to determine the required OBE and SSE loadings and the response of SSCs, which will ensure that they will remain functional within applicable acceptance limits.

III. REVIEW PROCEDURES

These review procedures are based on the identified DSRS acceptance criteria. For deviations from these acceptance criteria, the staff should review the applicant's evaluation of how the proposed alternatives provide an acceptable method of complying with the relevant NRC requirements identified in Subsection II.

1. In accordance with 10 CFR 52.47(a)(8),(21), and (22), and 10 CFR 52.79(a)(17) and (20), for new reactor license applications submitted under Part 52, the applicant is required to (1) address the proposed technical resolution of unresolved safety issues and medium- and high-priority generic safety issues which are identified in the version of NUREG-0933 current on the date up to 6 months before the docket date of the application and which are technically relevant to the design; (2) demonstrate how the operating experience insights have been incorporated into the plant design; and, (3) provide information necessary to demonstrate compliance with any technically relevant portions of the Three Mile Island requirements set forth in 10 CFR 50.34(f), except paragraphs (f)(1)(xii), (f)(2)(ix), and (f)(3)(v). These cross-cutting review areas should be addressed by the reviewer for each technical subsection and relevant conclusions documented in the corresponding safety evaluation report (SER) section.

2. Design Ground Motion

   A. Design Response Spectra. For the non-standard plant design (i.e., COL application that does not reference a DC), the design response spectra for the OBE and SSE, for all applicable damping values, are checked to ensure that the response spectra over the depth of the facilities are in accordance with the acceptance criteria as given in subsection II.1.A.i. For the DC, the CSDRS for the OBE and SSE for applicable damping values are checked to ensure that the CSDRS are in accordance with the acceptance criteria as given in subsection II.1.A.ii. Any deviations from the acceptance criteria applicable to the development of the design response spectra or CSDRS that have not been adequately justified are identified, and the applicant is informed of the need for additional technical justification.

   B. Design Time History. Methods of defining the design ground motion time histories are reviewed to confirm that the acceptance criteria of subsection II.1.B of this DSRS section are met.

3. Percentage of Critical Damping Values. The specific percentage of critical damping values for the OBE and SSE used in the analyses of Category I SSCs are checked to ensure that the damping values are in accordance with the acceptance criteria as given in subsection II.2 of this DSRS section. Any differences in damping values that have not been adequately justified are identified, and the applicant is informed of the need for additional technical justification.

4. Supporting Media for Seismic Category I Structures. The description of the supporting media is reviewed to verify that sufficient information, as specified in the acceptance criteria of subsection II.3 of this DSRS section, is included.

5. Review Considerations for DC and COL Applications. The information provided by the applicant to address the review considerations in the DSRS acceptance criteria of

subsection II.4 of this DSRS section is reviewed. The review should conclude that the CSDRS envelop the site-specific FIRS for a COL application that references a DC. In addition, the review should conclude that the applicant addressed the identified COL action items. If compliance with these acceptance criteria is not achieved, then the technical basis for alternative methods needs to be provided by the applicant for review and approval.

For review of a DC application, the reviewer should follow the above procedures to verify that the design, including requirements and restrictions (e.g., interface requirements and site parameters), set forth in the final safety analysis report (FSAR) meets the acceptance criteria. DCs have referred to the FSAR as the design control document (DCD). The reviewer should also consider the appropriateness of identified COL action items. The reviewer may identify additional COL action items; however, to ensure these COL action items are addressed during a COL application, they should be added to the DC FSAR.

For review of a COL application, the scope of the review is dependent on whether the COL applicant references a DC, an early site permit (ESP) or other NRC approvals (e.g., manufacturing license, site suitability report or topical report).

For review of both DC and COL applications, SRP Section 14.3 should be followed for the review of ITAAC. The review of ITAAC cannot be completed until after the completion of this section.

IV. EVALUATION FINDINGS

The reviewer verifies that the applicant has provided sufficient information and that the review and calculations (if applicable) support conclusions of the following type to be included in the staff's safety evaluation report. The reviewer also states the bases for those conclusions.

The staff concludes that the seismic design parameters used in the design of plant SSCs are acceptable and meet the applicable requirements of 10 CFR 50, Appendix A, General Design Criterion (GDC) 2, and 10 CFR Part 50, Appendix S. This conclusion is based on the following.

The applicant has met the relevant requirements of GDC 2 and 10 CFR Part 50, Appendix S by appropriate consideration for the most severe earthquake recorded for the site with an appropriate margin and considerations for two levels of earthquakes - the safe shutdown earthquake (SSE) and operating basis earthquake (OBE). The applicant has met these requirements by the use of the methods and procedures indicated below. The seismic design response spectra (OBE and SSE) applied in the design of seismic Category I SSCs meet or exceed the free-field response spectra provided in SRP Section 2.5.2. For the plant subject to Appendix S of 10 CFR Part 50, the horizontal component of the SSE ground motion in the free-field at the foundation level of the structures is based on an appropriate response spectrum with a peak ground acceleration of at least 0.1g. The appropriate response spectrum associated with this minimum pga should be a smooth broadband response spectrum (e.g., RG 1.60, or other appropriate shaped spectra, if justified). The percentage of critical damping values used in the seismic analysis of Category I SSCs is in conformance with RG 1.61, "Damping Values for Seismic Design of Nuclear Power Plants." The artificial time history used for seismic design of Category I plant SSCs is adjusted in amplitude and frequency content to obtain response spectra that envelop the design response spectra specified for the site and also exhibits sufficient energy in the frequency range of interest. Conformance with the recommendations of Section 2.5.2 and RG 1.61 ensures that the seismic inputs to the analysis of Category I SSCs are adequately defined so as to form a conservative basis for the design of such SSCs to withstand seismic loadings.

The CSDRS used in the certified design of seismic Category I SSCs meet the requirements of 10 CFR 100.23 and Appendix S to 10 CFR Part 50 by either: (1) demonstrating that the CSDRS meet or exceed the site-specific GMRS reviewed and approved in the SRP Section 2.5.2 and meet or exceed the minimum required response spectrum specified in 10 CFR Part 50, Appendix S, or (2) by showing that the design resulting from application of the CSDRS is still adequate to resist design demands resulting from the analysis conducted using the site-specific GMRS.

The design response spectra used in a non-standard plant for design of seismic Category I SSCs meet the requirements of 10 CFR 100.23 and Appendix S to 10 CFR Part 50, since they meet or exceed the site-specific GMRS reviewed and approved in the SRP Section 2.5.2 and meet or exceed the minimum required response spectrum specified in Appendix S to 10 CFR Part 50. The design response spectra used in these seismic analyses include definition of the appropriate spectra at the foundation (FIRS). In addition, the definition of performance-based response spectra (PBRS) is included to ensure that the deterministic soil profiles used for SSI analyses meet the performance goal. The FIRS together with the deterministic soil profiles form the design basis for the seismic analysis of the facilities.

For DC and COL reviews, the findings will also summarize the staff's evaluation of requirements and restrictions (e.g., interface requirements and site parameters) and COL action items relevant to this DSRS section.

In addition, to the extent that the review is not discussed in other SER sections, the findings will summarize the staff's evaluation of the ITAAC, including design acceptance criteria, as applicable.

V. IMPLEMENTATION

The staff will use this DSRS section in performing safety evaluations of mPower™-specific design certification (DC), combined license (COL), or early site permit (ESP) applications submitted by applicants pursuant to 10 CFR Part 52. The staff will use the method described herein to evaluate conformance with Commission regulations.

Because of the numerous design differences between the mPower™ and large light-water nuclear reactor power plants, and in accordance with the direction given by the Commission in SRM- COMGBJ-10-0004/COMGEA-10-0001, "Use of Risk Insights to Enhance the Safety Focus of Small Modular Reactor Reviews," dated August 31, 2010 (ML102510405), to develop risk-informed licensing review plans for each of the small modular reactor (SMR) reviews including the associated pre-application activities, the staff has developed the content of this DSRS section as an alternative method for mPower™-specific DC, COL, or ESP applications submitted pursuant to 10 CFR Part 52 to comply with 10 CFR 52.47(a)(9), "Contents of applications; technical information."

This regulation states, in part, that the application must contain "an evaluation of the standard plant design against the Standard Review Plan (SRP) revision in effect 6 months before the docket date of the application." The content of this DSRS section has been accepted as an alternative method for complying with 10 CFR 52.47(a)(9) as long as the mPower™ DCD FSAR does not deviate significantly from the design assumptions made by the NRC staff while preparing this DSRS section. The application must identify and describe all differences between the standard plant design and this DSRS section, and discuss how the proposed alternative provides an acceptable method of complying with the regulations that underlie the DSRS acceptance criteria. If the design assumptions in the DC application deviate significantly from the DSRS, the staff will use the SRP as specified in 10 CFR 52.47 (a)(9). Alternatively, the staff may supplement the DSRS section by adding appropriate criteria in order to address new design assumptions. The same approach may be used to meet the requirements of 10 CFR 52.17 (a)(1)(xii) and 10 CFR 52.79 (a)(41), for ESP and COL applications, respectively.

VI. REFERENCES

1. 10 CFR Part 50, “Domestic Licensing of Production and Utilization Facilities."

2. 10 CFR Part 50, Appendix A, General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena."

3. 10 CFR Part 50, Appendix S, “Earthquake Engineering Criteria for Nuclear Power Plants.”

4. 10 CFR Part 52, “Early Site Permits; Standard Design Certifications; and Combined Licenses for Nuclear Power Plants."

5. 10 CFR Part 100, Subpart A, "Evaluation Factors for Stationary Power Reactor Site Applications Before January 10, 1997 and for Test Reactors.”

6. 10 CFR Part 100, Subpart B, "Evaluation Factors for Stationary Power Reactor Site Applications on or After January 10, 1997.”

7. 10 CFR Part 100, Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants.”

8. RG 1.61, "Damping Values for Seismic Design of Nuclear Power Plants,”

9. NUREG/CR-6728, “Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard- and Risk-consistent Ground Motion Spectra Guidelines.”

10. RG 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants."

11. RG 1.70, “Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants.”

12. RG 1.206, “Combined License Applications for Nuclear Power Plants (LWR Edition).”

13. RG 1.208, “A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion.”

14. Houston, T. W., Mertz, G. E., Costantino, M. C., Costantino, and C. J., “Investigation of the Impact of Seed Record Selection on Structural Response.” Proceedings of the 2010 ASME PVP Conference, Division K, Paper 25919, Bellevue Washington, July 18-22, 2010.

15. DC/COL-ISG-01, "Interim Staff Guidance on Seismic Issues Associated with High Frequency Ground Motion in Design Certification and Combined License Applications," June 12, 2009.

16. DC/COL-ISG-017, "Interim Staff Guidance on Ensuring Hazard-Consistent Seismic Input for Site Response and Soil Structure Interaction Analyses," April 15, 2010.

17. DC/COL-ISG-020, "Interim Staff Guidance on Seismic Margin Analysis for New Reactors Based on Probabilistic Risk Assessment," March 15, 2010.

APPENDIX A TO DSRS SECTION 3.7.1

SPECIFICATION FOR MINIMUM POWER SPECTRAL DENSITY (PSD) REQUIREMENT

For a Regulatory Guide (RG) 1.60 horizontal response spectrum anchored to 1.0 g, the following minimum PSD requirement should be satisfied. For other peak accelerations, this PSD requirement should be scaled by the square of the peak acceleration.

The one-sided PSD is related to the Fourier amplitude $\left|F(f)\right|$ of the time history by the equation

$$S_o(f) = \frac{2\left|F(f)\right|^2}{2\pi T_D} \quad \text{.........(1)}$$

where T_D is the strong motion duration over which $F(f)$ is evaluated. This duration T_D represents the duration of near maximum and nearly stationary power of an acceleration time history record. Additional guidance on estimation of T_D for artificial time history or actual earthquake time history is provided in Appendix B of NUREG/CR-5347.

The average one-sided PSD defined by Equation (1) should exceed 80 percent of the target PSD as defined by Equation (2) from 0.3 Hz to 24 Hz.

Less than 2.5 Hz

$S_o(f)$ = 0.419 m ^{2}/sec ^{3} (f / 2.5 Hz) $^{0.2}$

2.5 Hz to 9.0 Hz

$S_o(f)$ = 0.419 m ^{2}/sec ^{3} (2.5 Hz / f) $^{1.8}$ ....(2)

9.0 Hz to 16.0 Hz

$S_o(f)$ = 418 cm ^{2}/sec ^{3} (9.0 Hz / f) ^{3}

Greater than 16 Hz

$S_o(f)$ = 74.2 cm ^{2}/sec ^{3} (16.0 Hz / f) ^{8}

At any frequency f, the average PSD is computed over a frequency band width of ±20 percent, centered on the frequency f (e.g., 4 Hz to 6 Hz band width for f = 5 Hz).

The power above 24 Hz for the target PSD is so low as to be inconsequential so that checks above 24 Hz are unnecessary. (However, note that the response spectrum calculations are required beyond 24 Hz as governed by RG 1.60 definitions.) Similarly, power below 0.3 Hz has no influence on stiff nuclear plant facilities, so that checks below 0.3 Hz are unnecessary. This minimum check is set at 80 percent of the target PSD so as to be sufficiently high to prevent a deficiency of power over any broad frequency band, but sufficiently low that this requirement introduces no additional conservatism over that already embodied in the Regulatory Guide 1.60 response spectrum.

A time history meeting this minimum PSD requirement will produce a response spectrum that lies below the RG 1.60 response spectrum at all frequencies. To produce a response spectrum that accurately fits the 2 percent damped, 1.0 g, Regulatory Guide 1.60 response spectrum at all frequencies above 0.25 Hz, the PSD defined by Equation (2) can be used with the resulting time history being clipped at ±1.0 g (see NUREG/CR-3509).

To produce a response spectrum that conservatively envelops the 1.0 g, RG 1.60 response spectrum at 2 percent damping and greater, a PSD set at 130 percent of the PSD defined by Equation (2) can be used with the resulting time history being clipped at ±1.0 g.

REFERENCES

1. RG 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants."

2. NUREG/CR-3509, "Power Spectral Density Functions Compatible with NRC Regulatory Guide 1.60 Response Spectra," June 1988.

3. NUREG/CR-5347, "Recommendations for Resolution of Public Comments on USI A-40, Seismic Design Criteria," June 1989.

APPENDIX B TO DSRS SECTION 3.7.1

SPECIFICATION FOR MINIMUM POWER SPECTRAL DENSITY (PSD) REQUIREMENT FOR HORIZONTAL SPECTRUM BASED ON NUREG/CR-6728

For a horizontal response spectrum anchored to 1.0g that is based on spectrum consistent with the Magnitude and Distance bin shapes in NUREG/CR-6728, the following minimum PSD requirement should be satisfied. When the response spectrum is derived from an envelope of spectra from multiple Magnitude and Distance bins, the envelope of the PSD should be used. For other peak accelerations, this PSD requirement should be scaled by the square of the peak acceleration.

The power spectral density for an acceleration time history can be computed as either a two-sided function of positive and negative frequencies or a one-sided function of only positive frequencies. Since only positive frequencies are realizable, the one-sided PSD is used to define the target criterion. The one sided PSD is related to the Fourier amplitude $|F(f)|$ of the time history by the equation

$$S_o(f) = \frac{2|F(f)|^2}{2\pi T_D} \qquad \text{.......................................(1)}$$

where T_D is the strong motion duration over which $F(f)$ is evaluated. This duration T_D represents the duration of near maximum and nearly stationary power of an acceleration time history record. Additional guidance on estimation of T_D for artificial time history or actual earthquake time history is provided in Appendix B of NUREG/CR-5347.

The average one-sided PSD defined by Equation (1) should exceed 80 percent of the appropriate Magnitude and Distance bin target PSD as shown in Tables 1 through 4.

At any frequency f, the average PSD is computed over a frequency band width of ±20 percent, centered on the frequency f (e.g., 4 Hz to 6 Hz band width for f = 5 Hz).

The power above 25 Hz for the PSD targets for Western US Sites and Central and Eastern US Soil Sites is so low as to be inconsequential so that checks above 25 Hz are unnecessary. For Central and Eastern US Rock Sites checks above 50 Hz are unnecessary. (However, note that the response spectrum calculations are required beyond 25 Hz and 50 Hz, as appropriate.) Similarly, power below 0.3 Hz has no influence on stiff nuclear plant facilities, so that checks below 0.3 Hz are unnecessary. This minimum check is set at 80 percent of the target PSD so as to be sufficiently high to prevent a deficiency of power over any broad frequency band, but sufficiently low that this requirement introduces no additional conservatism over that already embodied in the specified target response spectrum.

A time history meeting this minimum PSD requirement will produce a response spectrum that lies below the target response spectrum at all frequencies. To produce a response spectrum that accurately fits the 2 percent damped, 1.0 g, target response spectrum at all frequencies above 0.25 Hz, the PSD specified in Tables 1 through 4 can be used with the resulting time history being clipped at ±1.0 g (see NUREG/CR-3509).

To produce a response spectrum that conservatively envelops the 1.0 g target response spectrum at 2 percent damping and greater, a PSD set at 130 percent of the PSD specified in Tables 1 through 4 can be used with the resulting time history being clipped at ±1.0 g.

Table 1 – Central and Eastern US Rock Sites

CEUS Rock Sites

frequency	Magnitude 5 - 6		Magnitude 6 - 7				Magnitude 7+			
(hz)	0-50 km	50-100 km	0-10 km	10-50 km	50-100 km	100-200 km	0-10 km	10-50 km	50-100 km	100-200 km
	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3
0.3	0.73	0.05	7.72	1.76	0.88		7.72	1.76	0.88	
0.4	0.95	0.07	10.39	3.61	1.69	4.76	10.39	3.61	1.69	4.76
0.5	1.19	0.09	15.55	6.95	3.08	9.52	15.55	6.95	3.08	9.52
0.6	1.55	0.12	21.44	9.16	4.93	14.45	21.44	9.16	4.93	14.45
0.7	1.96	0.18	24.60	10.49	6.92	18.08	24.60	10.49	6.92	18.08
0.8	2.43	0.27	26.74	11.18	7.90	20.16	26.74	11.18	7.90	20.16
0.9	2.87	0.40	31.62	12.71	10.46	22.86	31.62	12.71	10.46	22.86
1	3.22	0.54	41.36	12.55	12.87	22.99	41.36	12.55	12.87	22.99
1.5	5.44	1.08	71.33	15.85	40.17		71.33	15.85	40.17	
2	9.25	1.52	70.54	14.83	49.20	50.39	70.54	14.83	49.20	50.39
3	15.94	2.58	66.75	14.67	49.94	56.52	66.75	14.67	49.94	56.52
4	14.83	5.00	46.65	13.27	46.45	52.65	46.65	13.27	46.45	52.65
5	21.66	6.24	45.32	14.97	48.43	53.32	45.32	14.97	48.43	53.32
6	22.69	6.39	46.17	18.30	47.74	50.54	46.17	18.30	47.74	50.54
7	18.27	6.23	36.84	17.56	40.28	41.35	36.84	17.56	40.28	41.35
8	13.31	5.96	28.58	16.15	30.83	33.07	28.58	16.15	30.83	33.07
9	11.30	5.65	24.82	14.48	23.39	26.97	24.82	14.48	23.39	26.97
10	9.81	5.57	22.43	12.97	19.87	23.07	22.43	12.97	19.87	23.07
15	7.03	4.32	19.68	11.14	11.78		19.68	11.14	11.78	
20	7.11	2.98	14.26	9.35	10.93	12.09	14.26	9.35	10.93	12.09
30	5.49	0.79	6.91	7.21	9.40	7.69	6.91	7.21	9.40	7.69
40	4.22	0.31	4.26	5.29	8.37	5.80	4.26	5.29	8.37	5.80
50	2.13	0.09	1.63	2.67	4.51	2.95	1.63	2.67	4.51	2.95

Table 2 – Central and Eastern US Soil Sites

CEUS Soil Sites

frequency	Magnitude 5 - 6		Magnitude 6 - 7				Magnitude 7+			
(hz)	0-50 km	50-100 km	0-10 km	10-50 km	50-100 km	100-200 km	0-10 km	10-50 km	50-100 km	100-200 km
	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3
0.3	0.93	0.58	61.77	2.09	2.78	2.75	56.19	14.47	5.49	12.00
0.4	1.29	0.71	106.32	3.90	5.63	6.31	79.09	20.75	12.57	18.25
0.5	1.78	1.12	127.23	4.91	9.00	10.84	84.37	27.33	19.14	24.19
0.6	2.09	1.74	120.50	7.04	10.89	12.46	86.42	37.29	27.60	30.45
0.7	2.31	2.13	132.92	8.59	14.55	18.23	84.71	44.64	34.79	37.66
0.8	2.88	2.71	169.93	10.73	19.93	25.57	86.21	44.59	40.16	47.55
0.9	4.01	3.32	193.21	14.99	25.63	34.70	90.44	44.83	43.32	57.16
1	5.95	4.56	204.17	19.09	34.81	46.07	90.27	47.70	45.25	68.00
1.5	20.86	14.59	203.55	35.88			78.32	52.17	44.29	59.19
2	23.59	22.00	162.15	47.94	85.87	108.79	56.02	37.64	25.27	35.82
3	25.08	56.53	117.61	46.88	56.88	105.51	33.69	23.82	12.49	26.25
4	27.66	47.10	102.48	47.22	41.11	75.32	22.54	15.11	8.10	21.31
5	29.33	36.96	66.93	42.94	39.94	60.52	13.54	8.98	5.55	17.68
6	28.49	27.09	40.66	31.72		45.35	8.63	5.24	3.84	13.56
7	24.49	24.25	29.94	21.71	17.40	29.31	5.97	3.72	2.92	9.14
8	22.60	20.83	21.40	17.20	13.20	23.45	3.98	2.83	2.31	7.00
9	19.33	17.75	15.03	13.34	11.01	19.48	2.67	2.20	1.85	5.65
10	16.42	7.21	10.62	10.43	9.05	14.42	1.87	1.70	1.55	4.68
15	5.06	17.73	3.12	2.93			0.48	0.57	0.65	1.93
20	1.97	3.13	1.36	1.25	2.24	4.21	0.17	0.26	0.35	0.99
30	0.45	0.78	0.40	0.31	0.86	1.27	0.04	0.08	0.12	0.33

Table 3 – Western US Rock Sites

WUS Rock Sites

frequency	Magnitude 5 - 6		Magnitude 6 - 7				Magnitude 7+			
(hz)	0-50 km	50-100 km	0-10 km	10-50 km	50-100 km	100-200 km	0-10 km	10-50 km	50-100 km	100-200 km
	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3
0.3	3.37	0.29	15.35	6.78	1.24	11.56	37.52	5.03	3.81	5.03
0.4	2.39	0.32	17.02	8.26	1.81	16.06	36.12	4.67	4.80	5.89
0.5	2.60	0.36	24.17	9.36	2.28	25.21	36.13	7.20	4.59	8.38
0.6	3.15	0.37	38.04	12.16	2.95	31.68	49.07	9.45	4.76	9.13
0.7	3.74	0.50	53.21	16.38	3.84	34.97	58.95	10.11	5.38	10.04
0.8	4.50	0.74	61.32	19.02	4.83	40.05	69.52	10.14	5.55	10.31
0.9	5.62	1.11	70.66	21.94	6.95	48.09	76.13	11.36	6.53	10.30
1	7.26	1.50	78.87	24.28	9.09	51.37	77.60	11.83	7.78	10.18
1.5	10.63	3.12	140.98	33.32	16.94	65.26	80.42	15.86	8.96	7.74
2	15.94	3.52	130.39	33.48	19.06	66.07	58.68	19.18	8.56	4.88
3	29.62	5.17	114.91	31.93	18.88	78.35	44.57	19.79	7.48	2.96
4	28.47	6.14	62.76	21.37	13.95	54.77	25.39	14.29	7.18	1.57
5	25.37	6.58	40.23	17.21	10.47	36.24	13.73	10.29	4.86	0.83
6	18.46	4.98	30.67	14.39	7.06	21.55	9.35	7.62	3.13	0.43
7	11.67	3.58	20.30	10.28	4.88	12.91	7.10	5.25	1.91	0.25
8	6.64	2.44	13.85	7.13	2.78	7.26	5.11	3.52	1.34	0.13
9	4.70	1.79	9.76	4.47	1.71	4.42	3.47	2.46	0.95	0.08
10	3.39	1.33	6.96	2.95	1.08	2.83	2.43	1.68	0.67	0.04
15	0.84	0.33	2.07	0.62	0.13	0.38	0.67	0.38	0.12	0.01
20	0.27	0.11	0.75	0.19	0.04	0.10	0.23	0.12	0.04	
30	0.06	0.01	0.01	0.02		0.01	0.01			

Table 4 – Western US Soil Sites

WUS Soil Sites

frequency	Magnitude 5 - 6		Magnitude 6 - 7				Magnitude 7+			
(hz)	0-50 km	50-100 km	0-10 km	10-50 km	50-100 km	100-200 km	0-10 km	10-50 km	50-100 km	100-200 km
	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3	in^2/sec^3
0.3	1.55	0.69	79.89	3.88	2.79	3.14	78.12	12.61	3.95	5.66
0.4	1.49	1.01	121.51	4.84	5.98	5.54	102.28	13.06	8.27	7.84
0.5	2.04	1.30	130.32	5.18	7.81	9.63	106.71	17.29	12.46	8.73
0.6	2.86	1.74	122.18	7.17	8.20	11.92	100.43	22.30	16.48	10.50
0.7	3.51	2.10	120.71	9.31	12.41	15.01	96.05	23.96	17.97	12.50
0.8	3.95	2.63	142.04	10.45	15.68	17.96	99.68	26.45	18.10	15.01
0.9	4.26	2.99	154.20	11.08	18.68	20.80	101.28	29.09	17.96	16.93
1	5.20	3.46	154.18	12.57	23.58	23.37	93.75	31.80	18.56	16.59
1.5	14.58	8.77	143.07	18.24	34.20	41.92	77.18	30.27	13.58	10.17
2	17.38	13.72	114.85	28.01	35.60	38.55	61.94	23.17	8.43	6.24
3	21.31	24.93	90.64	26.27	20.40	21.86	31.72	14.57	3.50	3.05
4	18.52	15.59	67.28	24.88	10.71	11.65	19.57	7.78	1.55	1.97
5	16.67	8.64	41.92	18.48	6.97	6.46	10.80	4.21	0.76	1.24
6	14.31	5.82	25.16	12.13	4.12	3.65	6.51	2.49	0.42	0.68
7	10.70	3.97	17.94	6.96	2.29	1.90	4.38	1.55	0.25	0.36
8	8.64	2.94	11.85	4.77	1.35	1.05	2.73	1.01	0.15	0.20
9	5.80	2.09	7.86	3.23	0.84	0.61	1.85	0.74	0.09	0.12
10	4.34	1.46	5.21	2.41	0.50	0.41	1.24	0.53	0.06	0.08
15	0.85	0.16	1.20	0.42	0.08	0.07	0.32	0.11	0.01	0.01
20	0.23	0.04	0.42	0.12	0.03	0.02	0.12	0.03		0.01
25					0.01		0.05			

As an example, the target PSD for a Western US rock site, Magnitude 6 - 7, 10 to 50 km, is extracted from Table 3 and shown in Figure 1. The PSD for the time history developed to match the design spectrum shall exceed 80% of this target for frequencies between 0.3 Hz and 25 Hz.

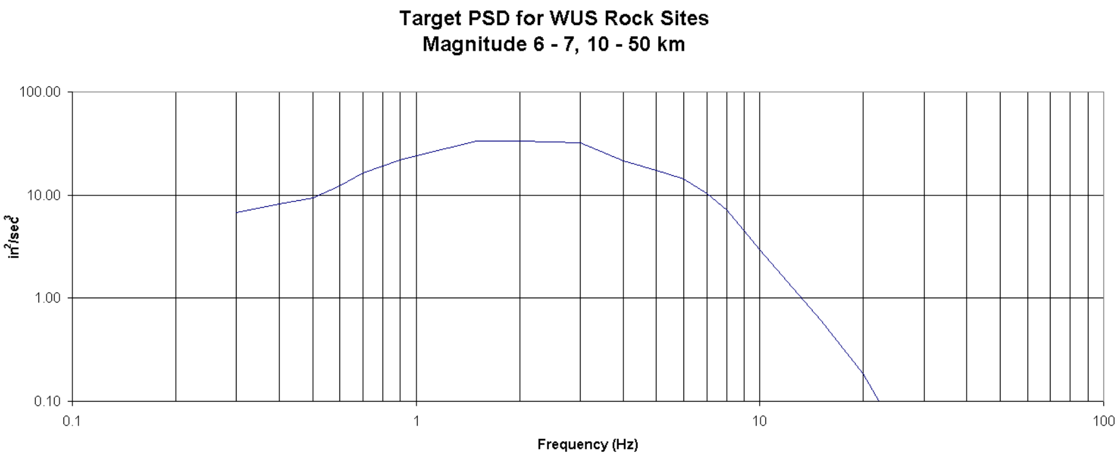

Figure 1

REFERENCES

1. NUREG/CR-6728, “Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard- and Risk-consistent Ground Motion Spectra Guidelines.”

2. NUREG/CR-5347,"Recommendations for Resolution of Public Comments on USI A-40, Seismic Design Criteria," June 1989.

3. NUREG/CR-3509, "Power Spectral Density Functions Compatible with NRC Regulatory Guide 1.60 Response Spectra," June 1988.

APPENDIX C TO DSRS SECTION 3.7.1

SCALE FACTORS FOR RESPONSE SPECTRA DAMPING RATIOS RELATIVE TO THE 5% DAMPED RESPONSE SPECTRA

The purpose of this appendix is to present the ratios of response spectra at a given damping value to the 5% damped response spectrum. A number of previous recommendations have been made over the years but these have generally been limited by the restricted data set of recordings used to develop the recommendations. This study performed the evaluation using all the records currently available in the data set presented with NUREG/CR-6728. These are three component data sets (two horizontal and one vertical) of both empirical (recorded) and modified time history records. For this evaluation, spectra have been computed for each of these three records individually and then the average horizontal spectrum computed by (lognormally) averaging the two horizontal spectral accelerations for each damping value considered frequency by frequency. From these sets of three, individual bin averages have been computed for damping ratios of 2%, 3%, 5%, 7% and 10%. Spectral ratios were then computed relative to the 5% damped spectra. The spectral ratios were then smoothed using a 9-point running average smoothing algorithm. The results of this process are presented and compared in the following.

The NUREG/6728 record set is binned by both magnitude and distance as well as for both rock and soil site categories. The magnitude bins are defined as magnitude 5 to 6 (M55), magnitude 6 to 7 (M65) and magnitudes greater than 7 (M75). Distance bins are typically defined as from 00 to 10 kms (000010), 10 to 50 kms (010050), 50 to 100 kms (050100) and 100 to 200 kms (100200). In addition to magnitude, distance and site binning, the record sets associated with NUREG/CR-6728 are also categorized into Western US (WUS) and Central and Eastern US (CEUS) record sets. The WUS data set is composed of empirical recorded motions while the CEUS data set is primarily composed of modified WUS recordings attempting to account for differences in source and site parameters WUS to CEUS.

Average spectral ratios were computed for each of these bin categories. Tables 1 through 4 present averages for CEUS-Rock, CEUS-Soil, WUS-Rock and WUS-Soil site categories. It should be noted that the data tables of spectral ratio generally refer to horizontal spectra only. It was found that the spectral ratios for vertical motions in the data sets were essentially the same as those of the corresponding horizontal ratios.

In Table 1, the spectral ratios for the gross bin averages for EUS Rock sites are listed for spectral ratios of 2% to 10% damping. Similarly, Tables 2 through 4 provide the spectral ratios for the gross bin averages for the CEUS-Soil, WUS-Rock, and WUS-Soil categories, of 2% to 10% damping.

REFERENCES

1. NUREG/CR-6728, “Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard- and Risk-consistent Ground Motion Spectra Guidelines.”

EUS ROCK SITES
AVERAGE HORIZONTAL AND VERTICAL SPECTRAL RATIOS

FREQUENCY (HZ)	EUS-ROCK H AVG 2% DAMPING	EUS-ROCK V AVG 2% DAMPING	EUS-ROCK H AVG 3% DAMPING	EUS-ROCK V AVG 3% DAMPING	EUS-ROCK H AVG 7% DAMPING	EUS-ROCK V AVG 7% DAMPING	EUS-ROCK H AVG 10% DAMPING	EUS-ROCK V AVG 10% DAMPING
0.500	1.1588	1.1600	1.0835	1.0843	0.9620	0.9614	0.9500	0.9484
0.600	1.2038	1.2038	1.1113	1.1113	0.9381	0.9381	0.8927	0.8927
0.700	1.2299	1.2299	1.1263	1.1263	0.9263	0.9263	0.8651	0.8651
0.800	1.2487	1.2487	1.1369	1.1369	0.9190	0.9190	0.8480	0.8480
0.900	1.2631	1.2631	1.1445	1.1445	0.9137	0.9137	0.8359	0.8359
1.000	1.2749	1.2749	1.1503	1.1503	0.9096	0.9096	0.8266	0.8266
1.100	1.2836	1.2836	1.1546	1.1546	0.9062	0.9062	0.8193	0.8193
1.200	1.2889	1.2889	1.1571	1.1571	0.9045	0.9045	0.8147	0.8147
1.300	1.2914	1.2914	1.1587	1.1587	0.9038	0.9038	0.8121	0.8121
1.400	1.2941	1.2941	1.1603	1.1603	0.9027	0.9027	0.8096	0.8096
1.500	1.2991	1.2991	1.1623	1.1623	0.9022	0.9022	0.8084	0.8084
1.600	1.3060	1.3060	1.1657	1.1657	0.9008	0.9008	0.8059	0.8059
1.700	1.3099	1.3099	1.1675	1.1675	0.9000	0.9000	0.8041	0.8041
1.800	1.3145	1.3145	1.1699	1.1699	0.8986	0.8986	0.8017	0.8017
1.900	1.3173	1.3173	1.1720	1.1720	0.8973	0.8973	0.7993	0.7993
2.000	1.3215	1.3215	1.1745	1.1745	0.8964	0.8964	0.7980	0.7980
2.100	1.3287	1.3287	1.1785	1.1785	0.8943	0.8943	0.7947	0.7947
2.200	1.3355	1.3355	1.1816	1.1816	0.8923	0.8923	0.7912	0.7912
2.300	1.3388	1.3388	1.1828	1.1828	0.8916	0.8916	0.7902	0.7902
2.400	1.3400	1.3400	1.1831	1.1831	0.8919	0.8919	0.7908	0.7908
2.500	1.3391	1.3391	1.1825	1.1825	0.8920	0.8920	0.7909	0.7909
2.600	1.3392	1.3392	1.1829	1.1829	0.8914	0.8914	0.7902	0.7902
2.700	1.3392	1.3392	1.1827	1.1827	0.8916	0.8916	0.7902	0.7902
2.800	1.3386	1.3386	1.1820	1.1820	0.8919	0.8919	0.7908	0.7908
2.900	1.3354	1.3354	1.1796	1.1796	0.8931	0.8931	0.7925	0.7925
3.000	1.3330	1.3330	1.1781	1.1781	0.8944	0.8944	0.7945	0.7945
3.150	1.3330	1.3330	1.1777	1.1777	0.8951	0.8951	0.7959	0.7959
3.300	1.3341	1.3341	1.1779	1.1779	0.8953	0.8953	0.7964	0.7964
3.450	1.3309	1.3309	1.1764	1.1764	0.8954	0.8954	0.7965	0.7965
3.600	1.3279	1.3279	1.1748	1.1748	0.8962	0.8962	0.7980	0.7980
3.800	1.3238	1.3238	1.1721	1.1721	0.8979	0.8979	0.8004	0.8004
4.000	1.3238	1.3238	1.1719	1.1719	0.8985	0.8985	0.8014	0.8014
4.200	1.3238	1.3238	1.1717	1.1717	0.8989	0.8989	0.8016	0.8016
4.400	1.3308	1.3308	1.1752	1.1752	0.8973	0.8973	0.7989	0.7989
4.600	1.3357	1.3357	1.1773	1.1773	0.8960	0.8960	0.7964	0.7964
4.800	1.3387	1.3387	1.1791	1.1791	0.8948	0.8948	0.7938	0.7938
5.000	1.3427	1.3427	1.1813	1.1813	0.8938	0.8938	0.7915	0.7915
5.250	1.3512	1.3512	1.1853	1.1853	0.8925	0.8925	0.7889	0.7889
5.500	1.3596	1.3596	1.1892	1.1892	0.8906	0.8906	0.7852	0.7852
5.750	1.3726	1.3726	1.1961	1.1961	0.8874	0.8874	0.7804	0.7804
6.000	1.3800	1.3800	1.2002	1.2002	0.8847	0.8847	0.7764	0.7764
6.250	1.3856	1.3856	1.2024	1.2024	0.8839	0.8839	0.7751	0.7751
6.500	1.3838	1.3838	1.2010	1.2010	0.8844	0.8844	0.7760	0.7760

Table 1: CEUS-Rock Sites Spectral Ratios

EUS ROCK SITES
AVERAGE HORIZONTAL AND VERTICAL SPECTRAL RATIOS

6.750	1.3815	1.3815	1.1995	1.1995	0.8849	0.8849	0.7775	0.7775
7.000	1.3776	1.3776	1.1973	1.1973	0.8862	0.8862	0.7800	0.7800
7.250	1.3723	1.3723	1.1945	1.1945	0.8878	0.8878	0.7835	0.7835
7.500	1.3662	1.3662	1.1917	1.1917	0.8892	0.8892	0.7867	0.7867
7.750	1.3605	1.3605	1.1887	1.1887	0.8907	0.8907	0.7895	0.7895
8.000	1.3574	1.3574	1.1863	1.1863	0.8921	0.8921	0.7921	0.7921
8.500	1.3566	1.3566	1.1857	1.1857	0.8931	0.8931	0.7940	0.7940
9.000	1.3600	1.3600	1.1877	1.1877	0.8928	0.8928	0.7942	0.7942
9.500	1.3625	1.3625	1.1892	1.1892	0.8932	0.8932	0.7953	0.7953
10.000	1.3653	1.3653	1.1906	1.1906	0.8942	0.8942	0.7972	0.7972
10.500	1.3668	1.3668	1.1911	1.1911	0.8951	0.8951	0.7993	0.7993
11.000	1.3690	1.3690	1.1920	1.1920	0.8951	0.8951	0.7994	0.7994
11.500	1.3735	1.3735	1.1941	1.1941	0.8947	0.8947	0.7989	0.7989
12.000	1.3761	1.3761	1.1953	1.1953	0.8945	0.8945	0.7988	0.7988
12.500	1.3758	1.3758	1.1952	1.1952	0.8948	0.8948	0.7994	0.7994
13.000	1.3758	1.3758	1.1946	1.1946	0.8958	0.8958	0.8011	0.8011
13.500	1.3722	1.3722	1.1924	1.1924	0.8966	0.8966	0.8029	0.8029
14.000	1.3682	1.3682	1.1900	1.1900	0.8977	0.8977	0.8049	0.8049
14.500	1.3622	1.3622	1.1868	1.1868	0.8982	0.8982	0.8058	0.8058
15.000	1.3614	1.3614	1.1866	1.1866	0.8978	0.8978	0.8053	0.8053
16.000	1.3583	1.3583	1.1845	1.1845	0.8992	0.8992	0.8079	0.8079
17.000	1.3536	1.3536	1.1819	1.1819	0.9003	0.9003	0.8098	0.8098
18.000	1.3501	1.3501	1.1801	1.1801	0.9018	0.9018	0.8127	0.8127
20.000	1.3490	1.3490	1.1796	1.1796	0.9022	0.9022	0.8135	0.8135
22.000	1.3456	1.3456	1.1781	1.1781	0.9025	0.9025	0.8142	0.8142
25.000	1.3413	1.3413	1.1759	1.1759	0.9040	0.9040	0.8168	0.8168
28.000	1.3402	1.3402	1.1755	1.1755	0.9039	0.9039	0.8166	0.8166
31.000	1.3412	1.3412	1.1764	1.1764	0.9037	0.9037	0.8165	0.8165
34.000	1.3386	1.3386	1.1745	1.1745	0.9054	0.9054	0.8196	0.8196
40.000	1.3344	1.3344	1.1723	1.1723	0.9066	0.9066	0.8219	0.8219
45.000	1.3240	1.3240	1.1671	1.1671	0.9095	0.9095	0.8274	0.8274
50.000	1.3089	1.3089	1.1592	1.1592	0.9134	0.9134	0.8350	0.8350
55.000	1.2851	1.2851	1.1465	1.1465	0.9201	0.9201	0.8473	0.8473
60.000	1.2566	1.2566	1.1316	1.1316	0.9279	0.9279	0.8621	0.8621
65.000	1.2289	1.2289	1.1171	1.1171	0.9359	0.9359	0.8771	0.8771
70.000	1.1980	1.1980	1.1009	1.1009	0.9449	0.9449	0.8944	0.8944
75.000	1.1670	1.1670	1.0847	1.0847	0.9540	0.9540	0.9119	0.9119
80.000	1.1361	1.1361	1.0691	1.0691	0.9621	0.9621	0.9274	0.9274

Table 1: CEUS-Rock Sites Spectral Ratios (continued)

EUS SOIL SITES
AVERAGE HORIZONTAL AND VERTICAL SPECTRAL RATIOS

FREQUENCY (HZ)	EUS-SOIL H AVG 2% DAMPING	EUS-SOIL V AVG 2% DAMPING	EUS-SOIL H AVG 3% DAMPING	EUS-SOIL V AVG 3% DAMPING	EUS-SOIL H AVG 7% DAMPING	EUS-SOIL V AVG 7% DAMPING	EUS-SOIL H AVG 10% DAMPING	EUS-SOIL V AVG 10% DAMPING
0.500	1.1731	1.1739	1.0915	1.0921	0.9592	0.9580	0.9475	0.9445
0.600	1.2188	1.2188	1.1193	1.1193	0.9362	0.9362	0.8921	0.8921
0.700	1.2448	1.2448	1.1341	1.1341	0.9240	0.9240	0.8632	0.8632
0.800	1.2644	1.2644	1.1445	1.1445	0.9161	0.9161	0.8442	0.8442
0.900	1.2827	1.2827	1.1540	1.1540	0.9095	0.9095	0.8286	0.8286
1.000	1.2987	1.2987	1.1624	1.1624	0.9044	0.9044	0.8179	0.8179
1.100	1.3152	1.3152	1.1704	1.1704	0.9002	0.9002	0.8093	0.8093
1.200	1.3259	1.3259	1.1763	1.1763	0.8963	0.8963	0.8013	0.8013
1.300	1.3321	1.3321	1.1793	1.1793	0.8942	0.8942	0.7962	0.7962
1.400	1.3393	1.3393	1.1833	1.1833	0.8916	0.8916	0.7901	0.7901
1.500	1.3457	1.3457	1.1867	1.1867	0.8886	0.8886	0.7841	0.7841
1.600	1.3528	1.3528	1.1904	1.1904	0.8865	0.8865	0.7802	0.7802
1.700	1.3586	1.3586	1.1941	1.1941	0.8846	0.8846	0.7768	0.7768
1.800	1.3607	1.3607	1.1953	1.1953	0.8838	0.8838	0.7757	0.7757
1.900	1.3606	1.3606	1.1950	1.1950	0.8837	0.8837	0.7746	0.7746
2.000	1.3592	1.3592	1.1942	1.1942	0.8841	0.8841	0.7751	0.7751
2.100	1.3624	1.3624	1.1955	1.1955	0.8840	0.8840	0.7756	0.7756
2.200	1.3628	1.3628	1.1959	1.1959	0.8844	0.8844	0.7767	0.7767
2.300	1.3626	1.3626	1.1948	1.1948	0.8857	0.8857	0.7793	0.7793
2.400	1.3622	1.3622	1.1939	1.1939	0.8871	0.8871	0.7822	0.7822
2.500	1.3590	1.3590	1.1924	1.1924	0.8881	0.8881	0.7840	0.7840
2.600	1.3592	1.3592	1.1919	1.1919	0.8883	0.8883	0.7844	0.7844
2.700	1.3609	1.3609	1.1925	1.1925	0.8888	0.8888	0.7852	0.7852
2.800	1.3606	1.3606	1.1923	1.1923	0.8888	0.8888	0.7856	0.7856
2.900	1.3602	1.3602	1.1919	1.1919	0.8888	0.8888	0.7850	0.7850
3.000	1.3612	1.3612	1.1923	1.1923	0.8883	0.8883	0.7832	0.7832
3.150	1.3674	1.3674	1.1952	1.1952	0.8867	0.8867	0.7800	0.7800
3.300	1.3719	1.3719	1.1978	1.1978	0.8852	0.8852	0.7769	0.7769
3.450	1.3776	1.3776	1.2007	1.2007	0.8837	0.8837	0.7740	0.7740
3.600	1.3843	1.3843	1.2037	1.2037	0.8824	0.8824	0.7720	0.7720
3.800	1.3887	1.3887	1.2059	1.2059	0.8813	0.8813	0.7696	0.7696
4.000	1.3939	1.3939	1.2083	1.2083	0.8799	0.8799	0.7664	0.7664
4.200	1.4010	1.4010	1.2123	1.2123	0.8777	0.8777	0.7627	0.7627
4.400	1.4074	1.4074	1.2158	1.2158	0.8761	0.8761	0.7602	0.7602
4.600	1.4104	1.4104	1.2173	1.2173	0.8753	0.8753	0.7593	0.7593
4.800	1.4115	1.4115	1.2182	1.2182	0.8756	0.8756	0.7601	0.7601
5.000	1.4130	1.4130	1.2187	1.2187	0.8761	0.8761	0.7608	0.7608
5.250	1.4139	1.4139	1.2190	1.2190	0.8763	0.8763	0.7614	0.7614
5.500	1.4097	1.4097	1.2170	1.2170	0.8770	0.8770	0.7626	0.7626
5.750	1.4036	1.4036	1.2134	1.2134	0.8785	0.8785	0.7654	0.7654
6.000	1.3974	1.3974	1.2104	1.2104	0.8801	0.8801	0.7690	0.7690
6.250	1.3910	1.3910	1.2060	1.2060	0.8829	0.8829	0.7739	0.7739
6.500	1.3854	1.3854	1.2022	1.2022	0.8857	0.8857	0.7787	0.7787

Table 2: CEUS-Soil Sites Spectral Ratios

EUS SOIL SITES
AVERAGE HORIZONTAL AND VERTICAL SPECTRAL RATIOS

6.750	1.3803	1.3803	1.1990	1.1990	0.8877	0.8877	0.7825	0.7825
7.000	1.3755	1.3755	1.1955	1.1955	0.8894	0.8894	0.7863	0.7863
7.250	1.3715	1.3715	1.1929	1.1929	0.8912	0.8912	0.7900	0.7900
7.500	1.3679	1.3679	1.1906	1.1906	0.8921	0.8921	0.7920	0.7920
7.750	1.3687	1.3687	1.1906	1.1906	0.8925	0.8925	0.7928	0.7928
8.000	1.3732	1.3732	1.1925	1.1925	0.8916	0.8916	0.7917	0.7917
8.500	1.3771	1.3771	1.1940	1.1940	0.8902	0.8902	0.7893	0.7893
9.000	1.3817	1.3817	1.1961	1.1961	0.8893	0.8893	0.7878	0.7878
9.500	1.3838	1.3838	1.1971	1.1971	0.8892	0.8892	0.7877	0.7877
10.000	1.3836	1.3836	1.1966	1.1966	0.8898	0.8898	0.7885	0.7885
10.500	1.3840	1.3840	1.1969	1.1969	0.8903	0.8903	0.7890	0.7890
11.000	1.3832	1.3832	1.1961	1.1961	0.8902	0.8902	0.7893	0.7893
11.500	1.3842	1.3842	1.1961	1.1961	0.8907	0.8907	0.7905	0.7905
12.000	1.3839	1.3839	1.1958	1.1958	0.8922	0.8922	0.7933	0.7933
12.500	1.3782	1.3782	1.1929	1.1929	0.8942	0.8942	0.7976	0.7976
13.000	1.3730	1.3730	1.1902	1.1902	0.8970	0.8970	0.8030	0.8030
13.500	1.3653	1.3653	1.1866	1.1866	0.8993	0.8993	0.8075	0.8075
14.000	1.3594	1.3594	1.1838	1.1838	0.9001	0.9001	0.8100	0.8100
14.500	1.3555	1.3555	1.1821	1.1821	0.9014	0.9014	0.8129	0.8129
15.000	1.3474	1.3474	1.1780	1.1780	0.9040	0.9040	0.8179	0.8179
16.000	1.3375	1.3375	1.1731	1.1731	0.9071	0.9071	0.8235	0.8235
17.000	1.3244	1.3244	1.1671	1.1671	0.9107	0.9107	0.8303	0.8303
18.000	1.3094	1.3094	1.1591	1.1591	0.9147	0.9147	0.8380	0.8380
20.000	1.2971	1.2971	1.1527	1.1527	0.9191	0.9191	0.8463	0.8463
22.000	1.2802	1.2802	1.1435	1.1435	0.9239	0.9239	0.8550	0.8550
25.000	1.2633	1.2633	1.1347	1.1347	0.9287	0.9287	0.8644	0.8644
28.000	1.2437	1.2437	1.1244	1.1244	0.9346	0.9346	0.8755	0.8755
31.000	1.2269	1.2269	1.1151	1.1151	0.9403	0.9403	0.8869	0.8869
34.000	1.2071	1.2071	1.1045	1.1045	0.9456	0.9456	0.8970	0.8970
40.000	1.1882	1.1882	1.0947	1.0947	0.9508	0.9508	0.9070	0.9070
45.000	1.1687	1.1687	1.0841	1.0841	0.9566	0.9566	0.9175	0.9175
50.000	1.1513	1.1513	1.0752	1.0752	0.9614	0.9614	0.9269	0.9269
55.000	1.1347	1.1347	1.0663	1.0663	0.9661	0.9661	0.9357	0.9357
60.000	1.1187	1.1187	1.0585	1.0585	0.9703	0.9703	0.9439	0.9439
65.000	1.1054	1.1054	1.0515	1.0515	0.9743	0.9743	0.9510	0.9510
70.000	1.0946	1.0946	1.0459	1.0459	0.9772	0.9772	0.9565	0.9565
75.000	1.0816	1.0816	1.0398	1.0398	0.9795	0.9795	0.9608	0.9608
80.000	1.0737	1.0737	1.0360	1.0360	0.9817	0.9817	0.9651	0.9651

Table 2: CEUS-Soil Sites Spectral Ratios (continued)

WUS ROCK SITES
AVERAGE HORIZONTAL AND VERTICAL SPECTRAL RATIOS

FREQUENCY (HZ)	WUS-ROCK H AVG 2% DAMPING	WUS-ROCK V AVG 2% DAMPING	WUS-ROCK H AVG 3% DAMPING	WUS-ROCK V AVG 3% DAMPING	WUS-ROCK H AVG 7% DAMPING	WUS-ROCK V AVG 7% DAMPING	WUS-ROCK H AVG 10% DAMPING	WUS-ROCK V AVG 10% DAMPING
0.500	1.1698	1.1690	1.0897	1.0888	0.9569	0.9577	0.9365	0.9387
0.600	1.2102	1.2102	1.1144	1.1144	0.9355	0.9355	0.8855	0.8855
0.700	1.2372	1.2372	1.1300	1.1300	0.9237	0.9237	0.8577	0.8577
0.800	1.2579	1.2579	1.1417	1.1417	0.9155	0.9155	0.8398	0.8398
0.900	1.2724	1.2724	1.1495	1.1495	0.9097	0.9097	0.8275	0.8275
1.000	1.2835	1.2835	1.1556	1.1556	0.9061	0.9061	0.8192	0.8192
1.100	1.2904	1.2904	1.1593	1.1593	0.9030	0.9030	0.8125	0.8125
1.200	1.2956	1.2956	1.1616	1.1616	0.9017	0.9017	0.8087	0.8087
1.300	1.2984	1.2984	1.1632	1.1632	0.9000	0.9000	0.8050	0.8050
1.400	1.3013	1.3013	1.1650	1.1650	0.8988	0.8988	0.8024	0.8024
1.500	1.3056	1.3056	1.1670	1.1670	0.8981	0.8981	0.8011	0.8011
1.600	1.3084	1.3084	1.1683	1.1683	0.8976	0.8976	0.7996	0.7996
1.700	1.3097	1.3097	1.1692	1.1692	0.8974	0.8974	0.7988	0.7988
1.800	1.3148	1.3148	1.1720	1.1720	0.8970	0.8970	0.7979	0.7979
1.900	1.3152	1.3152	1.1722	1.1722	0.8970	0.8970	0.7974	0.7974
2.000	1.3183	1.3183	1.1738	1.1738	0.8974	0.8974	0.7979	0.7979
2.100	1.3221	1.3221	1.1761	1.1761	0.8959	0.8959	0.7959	0.7959
2.200	1.3265	1.3265	1.1783	1.1783	0.8949	0.8949	0.7943	0.7943
2.300	1.3286	1.3286	1.1791	1.1791	0.8952	0.8952	0.7943	0.7943
2.400	1.3300	1.3300	1.1792	1.1792	0.8953	0.8953	0.7942	0.7942
2.500	1.3330	1.3330	1.1799	1.1799	0.8948	0.8948	0.7933	0.7933
2.600	1.3342	1.3342	1.1801	1.1801	0.8943	0.8943	0.7920	0.7920
2.700	1.3329	1.3329	1.1791	1.1791	0.8934	0.8934	0.7904	0.7904
2.800	1.3348	1.3348	1.1797	1.1797	0.8926	0.8926	0.7892	0.7892
2.900	1.3335	1.3335	1.1790	1.1790	0.8922	0.8922	0.7889	0.7889
3.000	1.3335	1.3335	1.1789	1.1789	0.8923	0.8923	0.7892	0.7892
3.150	1.3342	1.3342	1.1789	1.1789	0.8931	0.8931	0.7905	0.7905
3.300	1.3352	1.3352	1.1789	1.1789	0.8933	0.8933	0.7913	0.7913
3.450	1.3335	1.3335	1.1784	1.1784	0.8936	0.8936	0.7920	0.7920
3.600	1.3323	1.3323	1.1780	1.1780	0.8943	0.8943	0.7935	0.7935
3.800	1.3314	1.3314	1.1774	1.1774	0.8951	0.8951	0.7952	0.7952
4.000	1.3347	1.3347	1.1787	1.1787	0.8953	0.8953	0.7956	0.7956
4.200	1.3368	1.3368	1.1802	1.1802	0.8948	0.8948	0.7953	0.7953
4.400	1.3429	1.3429	1.1834	1.1834	0.8943	0.8943	0.7943	0.7943
4.600	1.3463	1.3463	1.1844	1.1844	0.8941	0.8941	0.7937	0.7937
4.800	1.3472	1.3472	1.1842	1.1842	0.8934	0.8934	0.7922	0.7922
5.000	1.3487	1.3487	1.1850	1.1850	0.8929	0.8929	0.7914	0.7914
5.250	1.3525	1.3525	1.1863	1.1863	0.8926	0.8926	0.7908	0.7908
5.500	1.3543	1.3543	1.1870	1.1870	0.8925	0.8925	0.7902	0.7902
5.750	1.3586	1.3586	1.1887	1.1887	0.8915	0.8915	0.7887	0.7887
6.000	1.3574	1.3574	1.1882	1.1882	0.8916	0.8916	0.7891	0.7891
6.250	1.3572	1.3572	1.1874	1.1874	0.8922	0.8922	0.7900	0.7900
6.500	1.3554	1.3554	1.1861	1.1861	0.8923	0.8923	0.7906	0.7906

Table 3: WUS-Rock Sites Spectral Ratios

WUS ROCK SITES
AVERAGE HORIZONTAL AND VERTICAL SPECTRAL RATIOS

6.750	1.3546	1.3546	1.1856	1.1856	0.8922	0.8922	0.7907	0.7907
7.000	1.3539	1.3539	1.1862	1.1862	0.8923	0.8923	0.7913	0.7913
7.250	1.3517	1.3517	1.1848	1.1848	0.8933	0.8933	0.7933	0.7933
7.500	1.3471	1.3471	1.1824	1.1824	0.8946	0.8946	0.7960	0.7960
7.750	1.3442	1.3442	1.1810	1.1810	0.8953	0.8953	0.7982	0.7982
8.000	1.3413	1.3413	1.1796	1.1796	0.8962	0.8962	0.8001	0.8001
8.500	1.3382	1.3382	1.1778	1.1778	0.8973	0.8973	0.8026	0.8026
9.000	1.3375	1.3375	1.1772	1.1772	0.8981	0.8981	0.8048	0.8048
9.500	1.3330	1.3330	1.1743	1.1743	0.8998	0.8998	0.8080	0.8080
10.000	1.3305	1.3305	1.1730	1.1730	0.9018	0.9018	0.8123	0.8123
10.500	1.3268	1.3268	1.1701	1.1701	0.9043	0.9043	0.8175	0.8175
11.000	1.3225	1.3225	1.1679	1.1679	0.9060	0.9060	0.8211	0.8211
11.500	1.3188	1.3188	1.1658	1.1658	0.9073	0.9073	0.8242	0.8242
12.000	1.3120	1.3120	1.1619	1.1619	0.9095	0.9095	0.8284	0.8284
12.500	1.3040	1.3040	1.1577	1.1577	0.9123	0.9123	0.8340	0.8340
13.000	1.2980	1.2980	1.1541	1.1541	0.9154	0.9154	0.8398	0.8398
13.500	1.2889	1.2889	1.1491	1.1491	0.9189	0.9189	0.8464	0.8464
14.000	1.2802	1.2802	1.1445	1.1445	0.9223	0.9223	0.8529	0.8529
14.500	1.2675	1.2675	1.1371	1.1371	0.9259	0.9259	0.8596	0.8596
15.000	1.2549	1.2549	1.1306	1.1306	0.9293	0.9293	0.8659	0.8659
16.000	1.2398	1.2398	1.1222	1.1222	0.9337	0.9337	0.8742	0.8742
17.000	1.2214	1.2214	1.1124	1.1124	0.9391	0.9391	0.8843	0.8843
18.000	1.2024	1.2024	1.1026	1.1026	0.9451	0.9451	0.8954	0.8954
20.000	1.1817	1.1817	1.0917	1.0917	0.9510	0.9510	0.9065	0.9065
22.000	1.1587	1.1587	1.0798	1.0798	0.9570	0.9570	0.9174	0.9174
25.000	1.1346	1.1346	1.0676	1.0676	0.9630	0.9630	0.9288	0.9288
28.000	1.1119	1.1119	1.0560	1.0560	0.9689	0.9689	0.9402	0.9402
31.000	1.0891	1.0891	1.0450	1.0450	0.9749	0.9749	0.9516	0.9516
34.000	1.0690	1.0690	1.0347	1.0347	0.9807	0.9807	0.9628	0.9628
40.000	1.0528	1.0528	1.0266	1.0266	0.9852	0.9852	0.9714	0.9714
45.000	1.0409	1.0409	1.0207	1.0207	0.9885	0.9885	0.9780	0.9780
50.000	1.0305	1.0305	1.0155	1.0155	0.9911	0.9911	0.9831	0.9831
55.000	1.0218	1.0218	1.0110	1.0110	0.9937	0.9937	0.9881	0.9881
60.000	1.0152	1.0152	1.0078	1.0078	0.9956	0.9956	0.9919	0.9919
65.000	1.0110	1.0110	1.0057	1.0057	0.9969	0.9969	0.9942	0.9942
70.000	1.0085	1.0085	1.0043	1.0043	0.9977	0.9977	0.9956	0.9956
75.000	1.0078	1.0078	1.0039	1.0039	0.9980	0.9980	0.9961	0.9961
80.000	1.0067	1.0067	1.0033	1.0033	0.9982	0.9982	0.9966	0.9966

Table 3: WUS-Rock Sites Spectral Ratios (continued)

WUS SOIL SITES
AVERAGE HORIZONTAL AND VERTICAL SPECTRAL RATIOS

FREQUENCY (HZ)	EUS-SOIL H AVG 2% DAMPING	EUS-SOIL V AVG 2% DAMPING	EUS-SOIL H AVG 3% DAMPING	EUS-SOIL V AVG 3% DAMPING	EUS-SOIL H AVG 7% DAMPING	EUS-SOIL V AVG 7% DAMPING	EUS-SOIL H AVG 10% DAMPING	EUS-SOL V AVG 10% DAMPING
0.500	1.2041	1.2042	1.1110	1.1108	0.9415	0.9423	0.9029	0.9044
0.600	1.2444	1.2444	1.1353	1.1353	0.9218	0.9218	0.8557	0.8557
0.700	1.2681	1.2681	1.1487	1.1487	0.9116	0.9116	0.8311	0.8311
0.800	1.2870	1.2870	1.1583	1.1583	0.9053	0.9053	0.8165	0.8165
0.900	1.2979	1.2979	1.1643	1.1643	0.9014	0.9014	0.8069	0.8069
1.000	1.3093	1.3093	1.1698	1.1698	0.8984	0.8984	0.8013	0.8013
1.100	1.3176	1.3176	1.1741	1.1741	0.8963	0.8963	0.7977	0.7977
1.200	1.3233	1.3233	1.1773	1.1773	0.8943	0.8943	0.7942	0.7942
1.300	1.3264	1.3264	1.1787	1.1787	0.8938	0.8938	0.7935	0.7935
1.400	1.3278	1.3278	1.1796	1.1796	0.8934	0.8934	0.7928	0.7928
1.500	1.3300	1.3300	1.1809	1.1809	0.8924	0.8924	0.7911	0.7911
1.600	1.3361	1.3361	1.1835	1.1835	0.8913	0.8913	0.7895	0.7895
1.700	1.3370	1.3370	1.1847	1.1847	0.8905	0.8905	0.7883	0.7883
1.800	1.3406	1.3406	1.1862	1.1862	0.8896	0.8896	0.7870	0.7870
1.900	1.3385	1.3385	1.1850	1.1850	0.8896	0.8896	0.7865	0.7865
2.000	1.3381	1.3381	1.1843	1.1843	0.8898	0.8898	0.7864	0.7864
2.100	1.3417	1.3417	1.1859	1.1859	0.8894	0.8894	0.7855	0.7855
2.200	1.3439	1.3439	1.1870	1.1870	0.8887	0.8887	0.7846	0.7846
2.300	1.3491	1.3491	1.1891	1.1891	0.8883	0.8883	0.7846	0.7846
2.400	1.3541	1.3541	1.1906	1.1906	0.8883	0.8883	0.7849	0.7849
2.500	1.3521	1.3521	1.1898	1.1898	0.8882	0.8882	0.7850	0.7850
2.600	1.3534	1.3534	1.1902	1.1902	0.8878	0.8878	0.7840	0.7840
2.700	1.3558	1.3558	1.1911	1.1911	0.8878	0.8878	0.7843	0.7843
2.800	1.3578	1.3578	1.1919	1.1919	0.8878	0.8878	0.7842	0.7842
2.900	1.3578	1.3578	1.1914	1.1914	0.8879	0.8879	0.7844	0.7844
3.000	1.3552	1.3552	1.1897	1.1897	0.8886	0.8886	0.7851	0.7851
3.150	1.3567	1.3567	1.1898	1.1898	0.8890	0.8890	0.7855	0.7855
3.300	1.3542	1.3542	1.1884	1.1884	0.8894	0.8894	0.7856	0.7856
3.450	1.3500	1.3500	1.1864	1.1864	0.8904	0.8904	0.7870	0.7870
3.600	1.3501	1.3501	1.1857	1.1857	0.8919	0.8919	0.7896	0.7896
3.800	1.3515	1.3515	1.1858	1.1858	0.8928	0.8928	0.7915	0.7915
4.000	1.3505	1.3505	1.1851	1.1851	0.8933	0.8933	0.7923	0.7923
4.200	1.3538	1.3538	1.1865	1.1865	0.8934	0.8934	0.7930	0.7930
4.400	1.3578	1.3578	1.1887	1.1887	0.8934	0.8934	0.7935	0.7935
4.600	1.3616	1.3616	1.1903	1.1903	0.8930	0.8930	0.7937	0.7937
4.800	1.3618	1.3618	1.1908	1.1908	0.8929	0.8929	0.7943	0.7943
5.000	1.3631	1.3631	1.1913	1.1913	0.8930	0.8930	0.7943	0.7943
5.250	1.3678	1.3678	1.1936	1.1936	0.8917	0.8917	0.7926	0.7926
5.500	1.3689	1.3689	1.1950	1.1950	0.8906	0.8906	0.7912	0.7912
5.750	1.3674	1.3674	1.1944	1.1944	0.8906	0.8906	0.7909	0.7909
6.000	1.3687	1.3687	1.1949	1.1949	0.8905	0.8905	0.7910	0.7910
6.250	1.3660	1.3660	1.1934	1.1934	0.8906	0.8906	0.7912	0.7912
6.500	1.3645	1.3645	1.1922	1.1922	0.8912	0.8912	0.7919	0.7919
6.750	1.3621	1.3621	1.1909	1.1909	0.8918	0.8918	0.7928	0.7928
7.000	1.3620	1.3620	1.1906	1.1906	0.8920	0.8920	0.7932	0.7932
7.250	1.3625	1.3625	1.1907	1.1907	0.8923	0.8923	0.7942	0.7942

Table 4: WUS-Soil Sites Spectral Ratios

WUS SOIL SITES
AVERAGE HORIZONTAL AND VERTICAL SPECTRAL RATIOS

7.500	1.3601	1.3601	1.1892	1.1892	0.8931	0.8931	0.7957	0.7957
7.750	1.3586	1.3586	1.1876	1.1876	0.8941	0.8941	0.7969	0.7969
8.000	1.3581	1.3581	1.1869	1.1869	0.8948	0.8948	0.7985	0.7985
8.500	1.3521	1.3521	1.1840	1.1840	0.8960	0.8960	0.8003	0.8003
9.000	1.3473	1.3473	1.1814	1.1814	0.8981	0.8981	0.8037	0.8037
9.500	1.3407	1.3407	1.1774	1.1774	0.8999	0.8999	0.8072	0.8072
10.000	1.3353	1.3353	1.1740	1.1740	0.9018	0.9018	0.8108	0.8108
10.500	1.3292	1.3292	1.1702	1.1702	0.9041	0.9041	0.8150	0.8150
11.000	1.3237	1.3237	1.1672	1.1672	0.9061	0.9061	0.8190	0.8190
11.500	1.3183	1.3183	1.1645	1.1645	0.9079	0.9079	0.8228	0.8228
12.000	1.3122	1.3122	1.1611	1.1611	0.9102	0.9102	0.8275	0.8275
12.500	1.3042	1.3042	1.1569	1.1569	0.9130	0.9130	0.8331	0.8331
13.000	1.2979	1.2979	1.1533	1.1533	0.9154	0.9154	0.8382	0.8382
13.500	1.2897	1.2897	1.1491	1.1491	0.9176	0.9176	0.8429	0.8429
14.000	1.2796	1.2796	1.1444	1.1444	0.9201	0.9201	0.8482	0.8482
14.500	1.2681	1.2681	1.1387	1.1387	0.9237	0.9237	0.8552	0.8552
15.000	1.2535	1.2535	1.1311	1.1311	0.9283	0.9283	0.8636	0.8636
16.000	1.2357	1.2357	1.1216	1.1216	0.9337	0.9337	0.8734	0.8734
17.000	1.2152	1.2152	1.1108	1.1108	0.9398	0.9398	0.8847	0.8847
18.000	1.1934	1.1934	1.0993	1.0993	0.9464	0.9464	0.8973	0.8973
20.000	1.1721	1.1721	1.0880	1.0880	0.9527	0.9527	0.9094	0.9094
22.000	1.1488	1.1488	1.0757	1.0757	0.9593	0.9593	0.9219	0.9219
25.000	1.1259	1.1259	1.0637	1.0637	0.9660	0.9660	0.9345	0.9345
28.000	1.1035	1.1035	1.0521	1.0521	0.9726	0.9726	0.9468	0.9468
31.000	1.0819	1.0819	1.0411	1.0411	0.9783	0.9783	0.9579	0.9579
34.000	1.0636	1.0636	1.0318	1.0318	0.9833	0.9833	0.9674	0.9674
40.000	1.0477	1.0477	1.0237	1.0237	0.9875	0.9875	0.9758	0.9758
45.000	1.0354	1.0354	1.0175	1.0175	0.9909	0.9909	0.9824	0.9824
50.000	1.0258	1.0258	1.0127	1.0127	0.9932	0.9932	0.9869	0.9869
55.000	1.0170	1.0170	1.0083	1.0083	0.9953	0.9953	0.9909	0.9909
60.000	1.0116	1.0116	1.0058	1.0058	0.9969	0.9969	0.9940	0.9940
65.000	1.0088	1.0088	1.0043	1.0043	0.9978	0.9978	0.9958	0.9958
70.000	1.0071	1.0071	1.0035	1.0035	0.9983	0.9983	0.9967	0.9967
75.000	1.0065	1.0065	1.0032	1.0032	0.9984	0.9984	0.9969	0.9969
80.000	1.0057	1.0057	1.0028	1.0028	0.9986	0.9986	0.9973	0.9973

Table 4: WUS-Soil Sites Spectral Ratios (continued)