U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

OFFICE OF NUCLEAR REACTOR REGULATION

SECTION 3.7.1 SEISMIC INPUT

REVIEW RESPONSIBILITIES

Primary - Structural Engineering Branch (SEB)

Secondary - Site Analysis Branch (SAB)

I. AREAS OF REVIEW

The following areas relating to the seismic input are reviewed:

1. Design Response Spectra

The seismic input, as defined by the design response spectra corresponding to the specified ground acceleration for a site is reviewed. A response spectrum is a plot of the maximum response of a family of single-degree-of-freedom damped oscillators with different frequency characteristics when the base of the oscillator is subjected to vibratory motion indicated by an appropriate time motion record. The response spectra are usually displayed on tripartite log-log graph paper. When obtained from a recorded earthquake record, the response spectrum tends to be irregular, with a number of peaks and valleys. A design response spectrum is a relatively smooth plot, obtained from a number of individual response spectra derived from records of past earthquakes. For high frequencies, spectral acceleration approaches the bound set by the maximum ground acceleration. For intermediate frequencies, spectral velocity is amplified relative to the ground velocity. For low frequencies, spectral displacement is amplified relative to the ground displacement.

Design response spectra for the operating basis earthquake (OBE) and safe shutdown earthquake (SSE) (Ref. 1) are reviewed. The design response spectra in the free field applied at the finished grade or at the various foundation levels of Category I structures are reviewed. Where applicable, the basis for any response spectra that differ from those of Regulatory Guide 1.60 (Ref. 2) is reviewed.

Site Analysis Branch (SAB) is responsible for reviewing the proposed values of the SSE and OBE ground acceleration appropriate for the site (see Standard Review Plan 2.5.2).

2. Design Time History

For the time history analyses, a comparison of the response spectra obtained in the free field at the finished grade level and at the foundation level (obtained from an appropriate time history at the base of the soil-structure interaction system) with the design response spectra is reviewed for each of the damping values to be used in the design of structures, systems, and components. Alternatively if the design response spectra for the OBE and SSE are applied at the foundation levels of Category I structures in the free field, a comparison of the free field response spectra at the foundation level derived from an actual or synthetic time history, applied at the base of the soil-structure interaction system, with the design response spectra is reviewed for each of the damping values to be used in the analysis.

The current practice in the design of nuclear power plants is to use the response spectrum technique for seismic design of buildings and structures. In this technique, the input for the dynamic analysis of the model of major building structural elements is usually given in terms of a design spectrum appropriate for the seismic characteristics of the plant site. The analysis of interior equipment or component may also be based on the design response spectrum. However, such analysis requires an integrated model of the building and interior equipment which may not be practical for the many components which must be considered. In addition, care is required in modeling to assure accuracy of results where orders of magnitude differences exist in stiffness and mass characteristics between the building and component elements of the model.

For the analysis of interior equipment, where the equipment analysis is decoupled from the building, a compatible time history is needed for computation of the time-history response of each floor. The design floor spectra for equipment are obtained from this time history information.

In addition to the comparison of the response spectra derived from the time-history with the design response spectra, the period intervals at which the spectra values are calculated are also reviewed.

3. <u>Critical Damping Values</u>

The specific percentage of critical damping values used for Category I structures, systems, components, and soil are reviewed for both the OBE and the SSE. Critical damping is the amount of damping that would completely eliminate vibration. Although the use of critical damping is of little practical importance in itself, it assumes great significance as a measure of the damping capacity of a structure. Damping is conveniently expressed in the form of some percentage of critical damping.

Vibrating structures have energy losses which 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. A knowledge of appropriate values to represent this characteristic is essential for obtaining realistic results in 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, plastic hinges, concrete cracking, gaps, and other effects which 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.

Only the overall damping used for Category I structures, systems, components, and soil are reviewed. Where applicable, the basis for any damping values that differ from those given in Regulatory Guide 1.61 (Ref. 3) is reviewed.

4. Supporting Media for Category I Structures

   The description of the supporting media for each Category I structure is reviewed, including foundation embedment depth, depth of soil over bedrock, soil layering characteristics, width of the structural foundation, total structural height, and soil properties to permit evaluation of the applicability of finite element or lumped spring approaches for soil-structure interaction analysis.

   SAB is responsible for evaluating the physical properties of foundation soil and rock (see Standard Review Plans 2.5.1 and 2.5.4).

II. ACCEPTANCE CRITERIA

The acceptance criteria for the areas of review described in Section I are as follows:

1. Design Response Spectra

   Design response spectra for the OBE and SSE are considered to be acceptable if the associated amplification factors are in accordance with Regulatory Guide 1.60, "Design Response Spectra for Nuclear Power Plants," for all damping values.

   As noted in Regulatory Guide 1.60, there are site circumstances where the design response spectra are more appropriately developed to suit the particular site characteristics. Design response spectra based upon site-dependent analysis must be derived considering in situ variable soil properties, a representative number of site earthquake records, vertical amplification, possible slanted soil layers, and the influence of any predominant soil layers. The finite element approach or equivalent should be used to consider variable soil properties and nonlinear stress-strain relations in the soil media. The procedures used to obtain site-dependent design response spectra are reviewed on a case-by-case basis.

   It should be noted that to be acceptable the design response spectra should be specified for three mutually orthogonal directions; two horizontal and one vertical. Since the two horizontal spectra have an equal probability of occurrence in any horizontal direction, current practice is to assume that the maximum accelerations in the two horizontal directions are equal, while the maximum vertical acceleration is 2/3 of the maximum horizontal acceleration.

2. Design Time History

In developing the design time history to be used at the base of the soil-structure interaction system, the following represents an acceptable procedure:

a. The design response spectra are defined for the free field and applied at the proposed finished grade level of the site.

b. Using an appropriate analysis method, with appropriate soil properties, obtain a time history at the base of the idealized soil profile.* One acceptable method for deconvolution analysis of the design response spectra at finished grade is a combined application of the SHAKE and LUSH computer codes (Refs. 4, 5). Use of other equivalent computer codes and analysis techniques is also acceptable. When the time history obtained from these methods is applied at the base of the idealized soil profile and the soil-structure interaction system, the resulting free field vibratory ground motion at finished grade level should give response spectra that envelop the design response spectra. This time history should appropriately account for variation in the soil properties at the site. In addition, when the time history obtained is applied at the base of the idealized soil profile, using appropriate soil properties, the vibratory motion calculated at the elevation of Category I structural foundations should, in general, give response spectra at all frequencies (.2 cps to 50 cps), not less than 60% of the design response spectra. The same limitation applies to the response spectra obtained at the foundation level in the free field for the soil-structure interaction system. Response spectral values in the idealized soil profile at the foundation level and those at the foundation level of the interaction system that are less than 60% of the corresponding design response spectral values may be acceptable provided they can be justified. The justification will be reviewed on a case-by-case basis.

c. The time history developed in item 2.b. above should be used at the base of the soil-structure interaction system, with appropriate soil properties, for subsequent soil-structure interaction analysis. The analysis method used should account for the strain dependency of soil modulus and damping. The peaks in the floor response spectra obtained from such a time history need be broadened by only ± 10% of the frequencies corresponding to the peaks.

d. An alternate and acceptable procedure is to apply the design response spectra at the foundation level of Category I structures in the free field. In this case, the design time history for use in the seismic analysis is acceptable if the response spectra in the free field at the foundation level obtained from the time history envelop the design response spectra for all damping values actually used in the analyses. The peaks in the floor response spectra obtained from such a time history should be broadened by a minimum of ± 15% of the frequencies corresponding to the peaks.

*Note: The idealized soil profile is the soil-structure interaction system without the structure.

The frequency intervals at which the spectra values are calculated from the design time history are to be small enough such that any reduction in these intervals does not result in more than 10% change in the computed spectra. Table 3.7.1-1 provides an acceptable set of frequencies .t which the response spectra should be calculated. Another acceptable method is to choose a set of frequencies such that each frequency is within 10% of the previous one.

The acceptance criterion for meeting the spectra-enveloping requirement is that no more than five points of the spectra obtained from the time history should fall below, and no more than 10% below, the design response spectra.

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

Frequency Range (hertz)	Increment (hertz)
0.2 - 3.0	.10
3.0 - 3.6	.15
3.6 - 5.0	.20
5.0 - 8.0	.25
8.0 - 15.0	.50
15.0 - 18.0	1.0
18.0 - 22.0	2.0
22.0 - 34.0	3.0

3. Critical Damping Values
The specific percentage of critical damping values used in the analyses of Category I structures, systems, and components are considered to be acceptable if they are in accordance with Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants." Damping values in this guide are based upon the current (1973) state of the art. Higher damping values may be used in a dynamic seismic analysis if documented test data are provided to support them. These values would be reviewed and accepted by the staff on a case-by-case basis. The damping value for soil must be based upon actual measured values or other pertinent laboratory data considering variation in soil properties and strains within the soil.

4. Supporting Media for 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, width of the structural foundation, total structural height, and soil properties such as shear wave velocity, shear modulus, and density as a function of depth.

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III. REVIEW PROCEDURES

For each area of review, the following review procedure is followed. The reviewer will select and emphasize material from the procedures given below as may be appropriate for a particular case.

1. Design Response Spectra

Design response spectra for the OBE and SSE for all damping values are checked to assure that the spectra are in accordance with the acceptance criteria as given in Section II. Any differences between the regulatory guide spectra and the proposed response spectra which have not been adequately justified are identified and the applicant is informed of the need for additional technical justification.

Design response spectra based upon site-dependent analyses are reviewed to assure that the procedure used to develop these spectra considers in situ variable soil properties, a representative number of site earthquake records, vertical amplification, possible slanted soil layers, nonlinear stress-strain relations, and the influence of possibly predominant soil layers.

2. Design Time History

Methods of defining the design time history are reviewed to ascertain that the acceptance criteria of Section II.2 are met.

3. Critical Damping Values

The specific percentage of critical damping values for the OBE and SSE used in the analyses of Category I structures, systems, and components are checked to assure that the damping values are in accordance with the acceptance criteria as given in Section II.3. Any differences in damping values which have not been adequately justified are identified and the applicant is informed of the need for additional technical justification.

4. Supporting Media for Category I Structures

The description of the supporting media is reviewed to verify that sufficient information, as specified in the acceptance criteria of Section II.4 is included. Any deficiency in the required information is identified and a request for additional information is transmitted to the applicant.

IV. EVALUATION FINDINGS

The reviewer verifies that sufficient information has been provided and that his evaluation supports conclusions of the following type, to be included in the staff's safety evaluation report:

"The seismic design response spectra (OBE and SSE) applied in the design of seismic Category I structures, systems, and components comply with the recommendations of Regulatory Guide 1.60, 'Design Response Spectra for Nuclear Power Plants.' The specific percentage of critical damping values used in the seismic analysis of Category I structures, systems, and components are in conformance with Regulatory Guide 1.61, 'Damping Values for Seismic Analysis of Nuclear Power Plants.' The synthetic time history used for seismic design of Category I plant structures, systems, and components is adjusted in amplitude and frequency content to obtain reponse spectra that envelop the design response spectra specified for the site. Conformance with the recommendations of Regulatory Guides 1.60 and 1.61 assures that the seismic inputs to Category I structures, systems, and components are adequately defined so as to form a conservative basis for the design of such structures, systems, and components to withstand seismic loadings."

Alternatively, if a site-dependent analysis is used to develop the shape of the design response spectra, the language of the evaluation findings should be similar to the following:

"The site-dependent analysis has used a finite element approach to develop the seismic design response spectra from site-related information, including site time histories. This approach, used in lieu of the response spectra specified in Regulatory Guide 1.60, is acceptable since the free field response spectra at finished grade level (or at the structural foundation level) include consideration of appropriate amplification factors based upon an acceptable set of site earthquake records, and the analysis has taken into account actual soil properties at the site and includes consideration of appropriate damping values corresponding to the calculated soil stress levels. The specific percentage of critical damping values used in the seismic analysis of Category I structures, systems, and components are in conformance with Regulatory Guide 1.61, 'Damping Values for Seismic Analysis of Nuclear Power Plants.'

"The use of the site-dependent analysis and the damping values of Regulatory Guide 1.61 assures that the seismic inputs to Category I structures, systems, and components are adequately defined so as to form a conservative basis for the design of such structures, systems, and components to withstand seismic loadings."

V. REFERENCES

1. 10 CFR Part 100, Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants."

2. Regulatory Guide No. 1.60, "Design Response Spectra for Nuclear Power Plants."

3. Regulatory Guide No. 1.61, "Damping Values for Seismic Analysis for Nuclear Power Plants."

4. Per B. Schnabel, J. Lysmer, and H. B. Seed, "SHAKE - A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites," EERC 72-12, Earthquake Engineering Research Center, University of California, Berkeley (1972).

5. J. Lysmer, T. Udaka, H. B. Seed, and R. Hwang, "LUSH - A Computer Program for Complex Response Analysis of Soil-Stucture Systems," Draft Report, Earthquake Engineering Research Center, University of California, Berkeley (1974).

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