



U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

3.7.2 SEISMIC SYSTEM ANALYSIS

REVIEW RESPONSIBILITIES

Primary - Organization responsible for reviews of seismic/geotechnical issues

Secondary - None

I. AREAS OF REVIEW

The specific areas of review are as follows:

1. Seismic Analysis Methods. For all seismic Category I structures, systems, and components (SSCs), the applicable seismic analysis methods (response spectrum analysis method, time history analysis method or equivalent static load analysis method) are reviewed. The manner in which the dynamic system analysis is performed, including the modeling of foundation torsion and overall building rocking and translation, is reviewed. The modeling of soil-structure interaction (SSI) effects is reviewed. The method chosen for the determination of significant modes and an adequate number of discrete mass degrees of freedom is reviewed. The manner in which consideration is given in the seismic analysis to maximum relative displacements between supports is reviewed. In addition, other significant effects that are accounted for in the seismic analysis such as hydrodynamic effects and nonlinear analysis methods and responses are reviewed. For each area of review, the staff selects representative locations and seismic response quantities of interest. If tests or empirical methods are used in lieu of analysis for any seismic Category I structure, the testing procedure, load levels, and acceptance basis are also reviewed. The SRP criteria generally deal with linear elastic analysis, coupled with allowable stresses near elastic limits of the structures. However, for certain special cases (e.g., evaluation of as-built structures), the staff has accepted the consideration of limited inelastic/nonlinear behavior when appropriate. The staff conducts a detailed review of all inelastic/nonlinear analyses.

Revision 3 - March 2007

USNRC STANDARD REVIEW PLAN

This Standard Review Plan, NUREG-0800, has been prepared to establish criteria that the U.S. Nuclear Regulatory Commission staff responsible for the review of applications to construct and operate nuclear power plants intends to use in evaluating whether an applicant/licensee meets the NRC's regulations. The Standard Review Plan is not a substitute for the NRC's regulations, and compliance with it is not required. However, an applicant is required to identify differences between the design features, analytical techniques, and procedural measures proposed for its facility and the SRP acceptance criteria and evaluate how the proposed alternatives to the SRP acceptance criteria provide an acceptable method of complying with the NRC regulations.

The standard review plan sections are numbered in accordance with corresponding sections in Regulatory Guide 1.70, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants (LWR Edition)". Not all sections of Regulatory Guide 1.70 have a corresponding review plan section. The SRP sections applicable to a combined license application for a new light-water reactor (LWR) are based on Regulatory Guide 1.206, "Combined License Applications for Nuclear Power Plants (LWR Edition)."

These documents are made available to the public as part of the NRC's policy to inform the nuclear industry and the general public of regulatory procedures and policies. Individual sections of NUREG-0800 will be revised periodically, as appropriate, to accommodate comments and to reflect new information and experience. Comments may be submitted electronically by email to NRR_SRP@nrc.gov.

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2. Natural Frequencies and Responses. The staff reviews the significant natural frequencies and responses (accelerations, displacements, and member forces) for all seismic Category I structures. In addition, the in-structure seismic response spectra at the support locations for seismic Category I subsystems are reviewed.
3. Procedures Used for Analytical Modeling. The criteria and procedures used in modeling for the seismic system analyses (including structural material properties, modeling of member stiffness, modeling of mass [structural masses, live loads, floor loads, and equipment loads], modeling of damping, modeling of hydrodynamic effects, etc.) are reviewed. The criteria and bases for determining whether a structure is analyzed as part of a structural system analysis or independently as a subsystem are also reviewed. In addition, the method used to address floor and wall flexibility in the structural modeling is reviewed.
4. Soil-Structure Interaction. The earthquake ground motion response spectra (GMRS) are defined in the "free-field," i.e., without the presence of structures, at the ground surface. For sites with soil layers near the surface that will be completely excavated to expose competent material, the GMRS are specified on an outcrop or a hypothetical outcrop that will exist after excavation. Motions at this hypothetical outcrop should be developed as a free surface motion, not as an in-column motion. Competent material is defined as in-situ material having a minimum shear wave velocity of 1,000 feet/second (fps). Because of the deformability of the supporting media (rock or soil), the resulting motions at the foundation mat will differ from the corresponding free-field motions. This difference between the foundation mat motion and the free-field motion is known as the SSI effect.

As applicable, the modeling methods (including technical bases) used in the seismic system analysis to account for SSI are reviewed. The factors to be considered in accepting a particular modeling method include: (1) the extent of embedment, (2) the layering of the soil/rock strata, and (3) the boundary of soil-structure model. All SSI analyses must recognize the uncertainties prevalent throughout the phenomenon, including:

- A. The random nature of the soil and rock configuration and material characteristics.
- B. Uncertainty in soil constitutive modeling (soil stiffness, damping, etc.).
- C. Nonlinear soil behavior.
- D. Coupling between the structures and soil.
- E. Lack of uniformity in the soil profile, which is usually assumed to be uniformly layered in all horizontal directions.
- F. Effects of the flexibility of soil/rock.
- G. Effects of the flexibility of basemat.
- H. The effect of pore water on structural responses, including the effects of variability of ground-water level with time.
- I. Effects of partial separation or loss of contact between the structure (embedded portion of the structure and foundation mat) and the soil during the earthquake.

The procedures by which strain-dependent soil properties (damping, shear modulus, pore pressure development), layering, and variation of soil properties are incorporated in the analysis are reviewed. Assumptions for modeling the soil-structure system and computer program validation documents are also reviewed.

If applicable, the criteria for determining the location of the bottom boundary and side boundary of the soil-structure system model are reviewed. The procedures used in the SSI analysis to account for effects of adjacent structures, if any, on structural response are reviewed.

To perform a seismic analysis for an SSI system, it may be necessary to have well-defined excitation or forcing functions applied at the model boundaries to simulate the design earthquake ground motion. It is therefore required in such cases to generate an excitation system acting at the boundaries such that the response motion of the soil media at the plant site in the free field is identical to the design earthquake ground motion. The procedures and theories for regeneration of such an excitation system are reviewed.

Any other modeling methods used for SSI analysis are also reviewed, as is any basis for not using an SSI analysis.

5. Development of In-Structure Response Spectra. The procedures and methods for developing in-structure response spectra (e.g., floor response spectra) are reviewed. There are several methods for generating in-structure response spectra. One method makes use of time history analysis by considering single or multiple (real or artificial) ground motion time histories which have response spectra that satisfy the enveloping criteria for the design ground response spectra and the target power spectral density (PSD) function. A second method, which does not require time history analysis, is generally referred to as direct generation of in-structure response spectra. The basis and justification for the use of either of the above methods are reviewed.
6. Three Components of Earthquake Motion. The staff reviews the procedures by which the three components of earthquake motion (time history or response spectra) are considered in determining the seismic response of all seismic Category I SSCs. If three artificial ground motion time histories (two horizontal and one vertical) are applied in a single time history analysis, the statistical independence among the three components is also reviewed.
7. Combination of Modal Responses. When a modal time history analysis method or a response spectrum analysis method is used to calculate the seismic response of SSCs, the contribution to the total response due to the effects of high frequency modes (i.e., modes with natural frequencies greater than the frequency at which the spectral acceleration converges to approximately the zero period frequency, ZPA) is reviewed, to ensure that the total response closely simulates the behavior of the SSC during a seismic event. For the case of the Regulatory Guide (RG) 1.60 response spectrum, ZPA is about 33 Hz. When a response spectrum method is used, the procedure for combining modal responses, including modes with closely spaced frequencies, is reviewed.
8. Interaction of Non-Category I Structures with Category I SSCs. The design criteria to account for the seismic motion of non-Category I structures (or portions thereof) in the seismic design of Category I structures (or portions thereof) are reviewed. The seismic design of structures whose continued function is not required but whose failure could adversely impact the safety function of a Category I SSC, or result in incapacitating injury to control room occupants, is reviewed. Any special design features employed to protect Category I SSCs from the structural failure of non-Category I structures, due to seismic effects, are reviewed.
9. Effects of Parameter Variations on Floor Responses. The procedures that are used to consider the effects of the expected variations of structural properties, critical damping values, soil properties, and SSI on the floor response spectra and response time histories are reviewed.

10. Use of Equivalent Vertical Static Factors. Where applicable, justification for the use of equivalent vertical static load factors in calculating the vertical response loads for designing seismic Category I SSCs, in lieu of the use of a vertical seismic system dynamic analysis, is reviewed.
11. Methods Used to Account for Torsional Effects. The method employed to consider torsional effects in the seismic analysis of Category I structures is reviewed. The review includes evaluation of the conservatism of any approximate methods to account for torsional effects in the seismic analysis and design of seismic Category I structures. The consideration of accidental torsion for calculating structural responses is also reviewed.
12. Comparison of Responses. Where applicable, the comparison of seismic responses for major Category I structures using modal response spectrum and time history approaches is reviewed.
13. Analysis Procedure for Damping. The procedure employed to account for different critical damping values in different elements of the system structural model is reviewed.
14. Determination of Seismic Overturning Moments and Sliding Forces for Seismic Category I Structures. The description of the method and procedure used to determine design seismic overturning moments and sliding forces for all seismic Category I structures is reviewed.
15. Inspection, Test, Analysis, 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 SRP 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 SRP 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.
16. 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, a COL applicant must address COL action items (referred to as COL license information in certain DCs) included in the referenced DC. Additionally, a COL applicant must address requirements and restrictions (e.g., interface requirements and site parameters) included in the referenced DC.

As part of the review activities, the staff conducts on-site audits. The purpose of these audits is to review technical information and detailed calculations not submitted as part of the license or certification application, and to review additional information needed to resolve open technical issues. See Appendix A of this SRP section for general guidelines on conducting audits.

Review Interfaces:

Other SRP sections interface with this section as follows:

1. Review of geological and seismological information to establish the free-field earthquake ground motion 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 and on-site soil media and soil properties are reviewed under SRP Section 2.5.4.

3. The design earthquake ground motion (response spectra and time histories) is reviewed under SRP Section 3.7.1.
4. Seismic subsystem analysis is reviewed under SRP Section 3.7.3. This includes, but is not limited to, seismic Category I substructures, such as platforms, frame support structures, yard structures; buried piping, tunnels, and conduits; concrete dams; and atmospheric storage tanks.
5. The design of seismic Category I structures for all applicable load combinations is reviewed under SRP Sections 3.8.1 through 3.8.5.

The specific acceptance criteria and review procedures are contained in the referenced SRP sections.

The review of the design earthquake ground motion (SSE; OBE, if applicable), the generic-site or site-specific soil properties, and the SSI analyses is an integral part of the overall review process for seismic Category I structures.

II. ACCEPTANCE CRITERIA

Requirements

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

1. 10 CFR Part 50, 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 100, Subpart A, which is applicable to power reactor site applications before January 10, 1997, refers to Appendix A of this part for seismic criteria. 10 CFR Part 100, Appendix A indicates that the SSE and the OBE shall be considered in the design of safety-related SSCs. 10 CFR Part 100, Appendix A further states that the design used to ensure that the required safety functions are maintained during and after the vibratory ground motion associated with the SSE shall involve the use of either a suitable dynamic analysis or a suitable qualification test to demonstrate that SSCs can withstand the seismic and other concurrent loads, except where it can be demonstrated that the use of an equivalent static load method provides adequate conservatism.

10 CFR Part 100, Subpart B which is applicable to power reactor site applications on or after January 10, 1997, refers to 10 CFR 100.23 of this part for seismic criteria. Section 100.23 describes the criteria and nature of investigations required to obtain the geologic and seismic data necessary to determine the suitability of the proposed site and the plant design bases. 10 CFR 100.23 also indicates that applications to engineering design are contained in 10 CFR part 50, Appendix S.
3. 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, 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 response or design analysis 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.

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 plant that incorporates the design certification is built and will operate in accordance with the design certification, the provisions of the Atomic Energy Act, and the NRC's regulations;.
5. 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 NRC's regulations.

SRP Acceptance Criteria

Specific SRP acceptance criteria acceptable to meet the relevant requirements of the NRC's regulations identified above are as follows for the review described in this SRP section. The SRP is not a substitute for the NRC's regulations, and compliance with it is not required. However, an applicant is required to identify differences between the design features, analytical techniques, and procedural measures proposed for its facility and the SRP acceptance criteria and evaluate how the proposed alternatives to the SRP acceptance criteria provide acceptable methods of compliance with the NRC regulations.

1. Seismic Analysis Methods. The seismic analysis of all seismic Category I SSCs should use either a suitable dynamic analysis method or an equivalent static load analysis method, if justified. The SRP acceptance criteria primarily address linear elastic analysis coupled with allowable stresses near elastic limits of the structures. However, for certain special cases (e.g., evaluation of as-built structures), reliance on limited inelastic/nonlinear behavior when appropriate is acceptable to the staff. Analysis methods incorporating inelastic/nonlinear considerations and the analysis results are reviewed on a case-by-case basis.
 - A. Dynamic Analysis Method. When calculating seismic responses of Category 1 structures, dynamic analysis (response spectrum analysis method or time history analysis method) should be performed. To be acceptable, dynamic analyses should consider the following:
 - i. Use of appropriate methods of analysis (time history analysis method [time domain solution and frequency domain solution]; response spectrum analysis method), accounting for the effects of SSI, if applicable. In general, the response spectrum analysis method is not suitable for SSI analysis.
 - ii. Seismic analysis should be performed for three orthogonal (two horizontal and one vertical) components of earthquake ground motion.
 - iii. Consideration of the torsional, rocking, and translational responses of the structures and their foundations (including footings, basemats and buried walls).
 - iv. Use of an adequate number of discrete mass degrees of freedom in dynamic modeling.

The adequacy of the number of discrete mass degrees of freedom can be confirmed by (1) preliminary modal analysis, and (2) correlation between static analysis results using the dynamic model and static analysis results using a distributed mass representation.

- (1) It is important to ensure that, for each excitation direction (2 horizontal and vertical), all modes with frequencies less than the ZPA (or PGA) frequency of the corresponding spectrum are adequately represented in the dynamic solution. Preliminary modal analysis should be performed to establish that a sufficient number of discrete mass degrees of freedom have been included in the dynamic model to (a) predict a sufficient number of modes, and (2) produce mode shapes that are reasonably smooth. If a mode shape exhibits rapid change in modal displacement between adjacent mass degrees of freedom, additional mass degrees of freedom should be added until reasonably smooth mode shapes are obtained for all modes to be included in the dynamic analysis.
- (2) After completion of (1), simple 1g static analyses of the dynamic model should be performed for each of the three (3) excitation directions, and compared to the corresponding results obtained from static analyses that utilize a distributed mass representation. Lack of correlation, particularly in the vicinity of and at support locations, is indicative of an insufficient number of discrete mass degrees of freedom.

- v. When using either the response spectrum method or the modal superposition time history method, responses associated with high frequency modes (i.e., $f \geq$ ZPA [or PGA] frequency) should be included in the total dynamic solution using the guidance and methods described in Regulatory Guide 1.92, Revision 2, Regulatory Positions C.1.4 and C.1.5.
- vi. Consideration of maximum relative displacements between adjacent supports of seismic Category I SSCs.
- vii. Inclusion of significant effects such as piping interactions, externally applied structural restraints, hydrodynamic (both mass and stiffness effects) loads, and nonlinear responses.

B. Equivalent Static Load Method. An equivalent static load method is acceptable if:

- i. Justification is provided that the system can be realistically represented by a simple model and the method produces conservative results in terms of responses. Typical examples or published results for similar structures may be submitted in support of the use of the simplified method.
- ii. The simplified static analysis method accounts for the relative motion between all points of support.
- iii. To obtain an equivalent static load for an SSC that can be represented by a simple model, a factor of 1.5 is applied to the peak spectral acceleration of the applicable ground or floor response spectrum. A factor less than 1.5 may be used, if adequate justification is provided.

2. Natural Frequencies and Responses. To be acceptable, the following information should be provided:
- A. A summary of modal masses, effective masses, natural frequencies, mode shapes, modal and total responses for the Category I structures, including the containment structure, or a summary of the total responses if the method of direct integration is used.
 - B. The calculated time histories (two horizontal and one vertical), or other parameters of motion, or response spectra (two horizontal and one vertical) used in design, at the major plant equipment elevations and points of support.
 - C. For the multiple time history analysis option, procedures used to account for uncertainties (by variation of parameters) and to develop design responses, including justification for the statistical relationship between input design time histories and output responses. (For example, if the average response spectra generated from the multiple design time histories are used to envelop the design response spectra, then the average responses generated from the multiple analyses are used in design.)
3. Procedures Used for Analytical Modeling. A nuclear power plant facility consists of very complex structural systems. To be acceptable, the stiffness, mass, and damping characteristics of the structural systems should be adequately incorporated into the analytical models. Specifically, the following items should be considered in analytical modeling:
- A. Designation of Systems Versus Subsystems. Category I structures that are considered in conjunction with the foundation and its supporting media are defined as "seismic systems." Other Category I SSCs that are not designated as "seismic systems" should be considered as "seismic subsystems."
 - B. Decoupling Criteria for Subsystems. It can be shown, in general, that frequencies of systems and subsystems have a negligible effect on the error due to decoupling. It can be shown that the mass ratio, R_m , and the frequency ratio, R_f , govern the results where R_m and R_f are defined as:

$$R_m = \frac{\text{Total mass of the supported subsystem}}{\text{Total mass of the supporting system}}$$

$$R_f = \frac{\text{Fundamental frequency of the supported subsystem}}{\text{Dominant frequency of the support motion}}$$

The following criteria are acceptable:

- i. If $R_m < 0.01$, decoupling can be done for any R_f .
- ii. If $0.01 \leq R_m \leq 0.1$, decoupling can be done if $0.8 \geq R_f \geq 1.25$.
- iii. If $R_m > 0.1$, a subsystem model should be included in the primary system model.

If the subsystem is rigid compared to the supporting system, and also is rigidly connected to the supporting system, it is sufficient to include only the mass of the subsystem at the support point in the primary system model. On the other hand, in case of a subsystem supported by very flexible connections, e.g., pipe supported by hangers, the subsystem need not be included in the primary model. In most cases, the equipment and components, which come under the definition of subsystems, are analyzed (or tested) as a decoupled system from the primary

structure and the seismic input for the former is obtained by the analysis of the latter. One important exception to this procedure is the reactor coolant system, which is considered a subsystem but is usually analyzed using a coupled model of the reactor coolant system and primary structure.

- C. Modeling of Structures. Two types of structural models are widely used by the nuclear industry: lumped-mass stick model and finite element model. Either of these two types of modeling techniques is acceptable if the following guidelines are met:

i. Lumped-Mass Stick Model

For a lumped-mass model, the eccentricities between the centroid (the neutral axis for axial and bending deformation), the center of rigidity (the neutral axis for shear and torsional deformation), and the center of mass of structures should be included in the seismic model.

For selecting an adequate number of discrete mass degrees of freedom in the dynamic modeling to determine the response of all seismic Category I and applicable non-seismic I structures, the acceptance criteria given in Subsection II.1.a.iv of this SRP section are acceptable.

ii. Finite Element Model

The type of finite element used for modeling a structural system should depend on the structural details, the purpose of the analysis, and the theoretical formulation upon which the element is based. The mathematical discretization of the structure should consider the effect of element size, shape, and aspect ratio on solution accuracy. The element mesh size should be selected on the basis that further refinement has only a negligible effect on the solution results.

- iii. In developing either a lumped-mass stick model or a finite element model for dynamic response, it is necessary to consider that local regions of the structure, such as individual floor slabs or walls, may have fundamental vibration modes that can be excited by the dynamic seismic loading. These local vibration modes should be adequately represented in the dynamic response model, in order to ensure that the in-structure response spectra include the additional amplification. Also, the additional seismic loading on the overall structure and on the local region is needed for detailed structural design.

In general, three-dimensional models should be used for seismic analyses. However, simpler models can be used if justification can be provided that the coupling effects of those degrees of freedom that are omitted from the three-dimensional models are not significant.

- D. Representation of Floor Loads, Live Loads, and Major Equipment in Dynamic Model. In addition to the structural mass, mass equivalent to a floor load of 50 pounds per square foot should be included, to represent miscellaneous dead weights such as minor equipment, piping, and raceways. Also, mass equivalent to 25 percent of the floor design live load and 75 percent of the roof design snow load, as applicable, should be included. The mass of major equipment should be distributed over a representative floor area or included as concentrated lumped masses at the equipment locations.

- E. Special Consideration for Dynamic Modeling of Structures. It has been common practice that the dynamic model used to predict the seismic response of a structure is not as detailed as the structural model used for the detailed design

analysis of all applicable load combinations. Therefore, a methodology is needed to transfer the seismic response loads determined from the dynamic model to the structural model used for the detailed design analysis of all applicable load combinations. This is reviewed for technical adequacy on a case-by-case basis.

4. Soil-Structure Interaction A complete SSI analysis should properly account for all effects due to kinematic and inertial interaction for surface or embedded structures. Any analysis method based on either a direct approach or a substructure approach can be used provided the following conditions are met:
 - A. The structure, foundation, and soil are properly modeled to ensure that the results of analyses properly capture spatial variation of ground motion, three dimensional effects of radiation damping and soil layering, as well as nonlinear effects from site response analyses.
 - B. The design earthquake ground motions used as input to the SSI analyses should be consistent with the design response spectra as defined in SRP Section 3.7.1.

It is noted that there is enough confidence in the current methods used to perform the SSI analysis to capture the basic phenomenon and provide adequate design information; however, the confidence in the ability to implement these methodologies is uncertain. Therefore, in order to ensure proper implementation, the following considerations should be addressed in performing SSI analysis :

- A. Perform sensitivity studies to identify important parameters (e.g., potential separation and sliding of soil from sidewalls, non-symmetry of embedment, location of boundaries) and to assist in judging the adequacy of the final results. These sensitivity studies can be performed by the use of well-founded and properly substantiated simple models to give better insight;
- B. Through the use of some appropriate benchmark problems, the user should demonstrate its capability to properly implement any SSI methodologies; and
- C. Perform enough parametric studies with the proper variation of parameters (e.g., soil properties) to address the uncertainties (as applicable to the given site) discussed in subsection I.4 of this SRP section.

For sites where SSI effects are considered insignificant and fixed base analyses of structures are performed, bases and justification for not performing SSI analyses are reviewed on a case-by-case basis. If the SSI analysis is not required, the input motion at the base of the structures will be the design motion reviewed in SRP Section 3.7.1.

The acceptance criteria for the constituent parts of the entire SSI system are summarized as follows:

- A. Modeling of Structure. The acceptance criteria given under subsection II.3 of this SRP section are applicable.
- B. Modeling of Supporting Soil. The effect of embedment of structure, ground-water effects, and the layering effect of soil should be accounted for. For the half-space modeling of the soil media, the lumped parameter (soil spring) method and the compliance function methods are acceptable provided that frequency variations and layering effects are incorporated. For the method of modeling soil media with finite boundaries, all boundaries should be properly simulated and the use of types of boundaries should be justified and reviewed on a case-by-case basis. Finite element and finite difference methods are acceptable methods for discretization of a continuum. The properties used in the SSI analysis should be those that are consistent with soil strains developed in free-field site response analyses.

For structures founded on materials having a shear wave velocity of 8,000 feet per second or higher, under the entire surface of the foundation, a fixed base assumption is acceptable.

- C. Input Ground Motion. The acceptance criteria for generating the input ground motion to be used in the SSI analysis are summarized in the following:
- i. If the design earthquake ground motion is defined from generic response spectral shapes (e.g, Reg. Guide 1.60 or NUREG-0098), the location of the ground motion should be consistent with the properties of the soil profile. For profiles consisting of competent soil or rock, with relatively uniform variation of properties with depth, the ground motion should be located at the soil surface at the top of the finished grade. For profiles consisting of one or more soft and/or thin soil layers overlaying competent material, the ground motion should be located at an outcrop (real or hypothetical) at the top of the competent material in the vicinity of the site.
 - ii. If the design earthquake ground motion is defined from site-specific evaluations of uniform hazard spectra, the location of the ground motion should be at the ground surface in the free-field. In developing the ground motion at the surface, the potential effects of soft soil layers need to be considered. For sites with soil layers near the surface that will be completely excavated to expose competent material, the ground motion response spectra are specified on an outcrop or a hypothetical outcrop that will exist after excavation. Motions at this hypothetical outcrop should be developed as a free surface motion, not as an in-column motion. Competent material is defined as in-situ material having a minimum shear wave velocity of 1,000 feet/second (fps).
 - iii. When the guidance for SSI analysis presented above is not completely implemented, the spectral amplitude of the acceleration response spectra (horizontal component of motion) in the free field at the foundation depth shall be not less than 60 per cent of the corresponding design response spectra at the finished grade in the free field. When variation in soil properties are considered (as required by the "Specific Guidelines for SSI Analysis" below), the 60 percent limitation may be satisfied using an envelope of the three spectra corresponding to the three soil properties.

If the accompanying rotational components of the input motion are ignored, no reduction is permitted in the horizontal component at the foundation level.

Specific Guidelines for SSI Analysis

The following specific guidelines are provided here to facilitate the review and draw the attention of reviewers to some important aspects of the SSI analysis. These guidelines are not necessarily requirements for the acceptance of any methodologies or an SSI analysis.

- The behavior of soil, though recognized to be nonlinear, can often be approximated by linear techniques. Truly nonlinear analysis is not required unless the comparison of results from large-scale tests or actual earthquakes and analytical results indicate deficiencies that cannot be accounted for in any other manner. The nonlinear soil behavior may be accounted for by the following:

- Using equivalent linear soil material properties typically determined from an iterative linear analysis of the free-field soil deposit. This accounts for the primary nonlinearity, or
- Performing an iterative linear analysis of the coupled soil-structure system. This accounts for the primary and secondary nonlinearities.

In the event the nonlinear analysis is chosen, the results of the nonlinear analysis should be judged on the basis of the linear or equivalent linear analysis (NUREG/CP-0054).

- Superposition of horizontal and vertical response as determined from separate analyses is acceptable (assuming nonlinear effects are not important) considering the simple material models now available.
- The strain-dependent soil properties (e.g., shear modulus, damping) estimated from analysis of the seismic motion in the free field shall be consistent with the geotechnical information reviewed in SRP Section 2.5.4.
- For cases using standard plant designs, where the site specific spectra fall below the standard plant design spectra, the SSI evaluations are addressed in the standard plant design.
- Enough SSI analyses should be performed so as to account for the effects of the potential variability in the properties of the soils and rock at the site. At least three soil/rock profiles should be considered in these analyses, namely, a best estimate (BE) profile, a lower bound (LB) and an upper bound (UB) profile in the evaluation of SSI effects. The properties of each layer of the site profile are typically defined in terms of its low-strain shear modulus and strain-dependent modulus degradation and strain-dependent hysteretic damping properties. These may be determined from dynamic laboratory testing of the site materials, information obtained from the published literature, or both. The set of properties appropriate for a given soil is reviewed for its adequacy.

For a particular site, the iterated shear modulus and damping values are typically determined from the results of a number of free-field site response analyses, which are intended to account for the effects of the site-specific design ground motions as well as the site nonlinear properties. If only a single site response calculation is performed, with the low strain property of each material layer selected at its BE value, the resulting iterated property is then determined. The upper and lower bound values of soil/rock shear modulus (G) can then be defined in terms of their best estimate values as:

$$G_{LB} = G_{BE} / (1+COV)$$

$$G_{UB} = G_{BE} \times (1+COV)$$

where COV is the coefficient of variation considered appropriate for the site materials. The corresponding damping properties should be defined at the compatible strains associated with the shear moduli.

If many site response calculations are performed (30 to 60 site response calculations) using Monte Carlo techniques to develop site properties, these calculations are typically used to determine the BE, LB and UB iterated site properties. The BE properties are determined from the mean of the resulting properties and the UB and LB values selected from the +/- one sigma values. A sufficient number of site response calculations need to be performed, to ensure that a stable value of sigma for each material of the profile is obtained.

For well-investigated sites (see RGs 1.132 and 1.138), the COV should be no less than 0.5. For sites that are not well investigated, the COV for shear modulus shall be at least 1.0. These COV requirements apply to the “single site response calculation”, as well as the “many site response calculations” described above. In no case should the lower bound shear modulus be less than that value consistent with standard foundation analysis that yields foundation settlement under static loads exceeding design allowables. The upper bound shear modulus should not be less than the best estimate shear modulus defined at low strain and as determined from the geophysical testing program. In no case should the material soil damping as expressed by the hysteretic damping ratio exceed 15 percent (NUREG/CR-1161).

For the case of analyses using generic broad-banded ground motion spectra, the best estimate shear modulus and damping of each material of the site profile can be defined in terms of its low strain values. The upper and low bound shear moduli can then be defined at twice and one-half the best estimate values, with damping maintained at its low strain value. Alternate approaches can be reviewed on a case-by-case basis.

- For dipping soil and rock strata, it is necessary to account for the coupling between the horizontal and vertical degrees of freedom in the stiffness and free-field seismic motion definitions. Also, there may be sites where the reactor building or a seismic Category I structure may have an embedded foundation close to an embankment or a natural slope that preclude the assumption of uniform foundation condition. For such sites, modeling and analysis techniques are reviewed on a case-by-case basis.
- Finite Boundary Modeling or Direct Solution Technique

The direct solution method is characterized as follows:

- Each analysis of the soil and structures is performed in one step.
- Finite element or finite difference discrete methods of analysis are used to spatially discretize the soil-structure system.
- Definition of the motion along the boundaries of the model (bottom and sides) is either known, assumed, or computed as a precondition of the analysis.

Dynamic analysis can be performed using either frequency-domain (limited to linear analysis) or time-integration methods. The mesh size should be adequate for representing the static stress distribution under the foundation and transmitting the frequency content of interest.

The following limitations should be observed for deep soil sites:

- The model depth, generally, should be at least twice the base dimension below the foundation level, which should be verified by parametric studies.
- The fundamental frequency of the soil (or backfill) stratum should be well below the structural frequencies of interest.
- All structural modes of significance should be included.

- Half Space or Substructure Solution Technique

The half space or substructure approach generally comprises the following steps:

- (1) Determine the motion of the massless foundation, including both translational and rotational components.
- (2) Determine the foundation stiffness in terms of frequency-dependent impedance functions.
- (3) Perform SSI analysis.

The procedures, modeling assumptions and analytical bases adopted for performing the half space or substructure analysis, including use of frequency-independent soil spring parameters, and the spring and damping coefficients, will be reviewed on a case-by-case basis.

- There are advanced analytical methods that are being considered by the nuclear industry (e.g., the effects of incoherent ground motion) to reduce the potential effects of high frequency ground motion input. These might be used when a site acceptability determination is performed as discussed in subsection II.4 of SRP Section 3.7.1. If incoherency is used to reduce the high frequency response, the potential effects of increasing other responses (e.g., overturning and torsional responses) shall be considered. When approved for use by the NRC, via issuance of interim staff guidance, it should be noted that the effects of incoherent ground motion may be considered either at the Design Certification stage, or at the site-specific application stage, but not both.

If any advanced analytical methods are utilized, the technical basis and analysis results are subject to detailed review on a case-by-case basis.

5. Development of In-Structure Response Spectra. RG 1.122 describes methods generally acceptable to the staff for developing the two horizontal and the vertical in-structure response spectra (e.g., floor response spectra) from the time history motions resulting from the dynamic analysis of the supporting structure. The topics addressed are

- A SRSS Combination of the three in-structure response spectra in a given direction (e.g., x direction), developed from the output time histories from separate analyses of the three directions (x, y, z) of input motion. SRSS combination is not applicable, if the three directions of the input motion are applied simultaneously in a single analysis.
- B. Frequency increments for calculation of spectral accelerations.
- C. Spectrum smoothing and broadening to account for uncertainty.

The guidance in RG 1.122 is augmented as follows:

- (1) SRSS combination applies to all cases where the three directions of input motion are analyzed separately. There is no longer a distinction made between symmetric and unsymmetric structures.
- (2) The 3 Hz frequency increment in the last row of RG 1.122, Table 1, applies up to the highest frequency of interest. This typically will be the PGA frequency of the design ground response spectrum, which in some cases may significantly exceed 33 Hz.

- (3a) When a single set of three artificial time histories is used as the input motion to the supporting structure, the in-structure response spectra are smoothed and broadened in accordance with the provisions of RG 1.122, to account for uncertainty.
- (3b) When multiple sets of three time histories, derived from actual earthquake records, are used as the input motion to the supporting structure, the multiple sets of in-structure response spectra already account for some of the uncertainty. Therefore, the provisions of RG 1.122, to account for uncertainty, do not strictly apply.

The use of multiple sets of time histories to generate in-structure response spectra is reviewed and accepted on a case-by-case basis. Particularly, the basis for procedures used to account for uncertainties (by variation of parameters) are evaluated.

The same acceptance criteria apply to the in-structure response spectra as apply to the design ground response spectrum, reviewed in subsection II.1.B of SRP Section 3.7.1. As an example, if the average of the multiple response spectra generated from the multiple design time histories is used to envelop the design ground response spectrum, then the average of the multiple in-structure response spectra generated from the multiple analyses (each of which used one of the multiple design time histories) are used in design.

An evaluation of the statistical correlation between the input ground response spectrum and the output in-structure response spectra should also be provided.

The methods used for direct generation of in-structure response spectra are reviewed and accepted on a case-by-case basis.

- 6. Three Components of Earthquake Motion. RG 1.92, describes acceptable methods for combining the responses due to three components of earthquake motion, for both the response spectrum method and the time history method. Use of alternate methods are evaluated on a case-by-case basis for acceptability.

When the three components of earthquake motion are applied simultaneously, using a set of three artificial time histories, the statistical independence of the time histories should be demonstrated. See subsection II.1.B of SRP 3.7.1 for the acceptance criteria to demonstrate statistical independence.

- 7. Combination of Modal Responses. RG 1.92, describes acceptable methods for combination of modal responses, including consideration of closely-spaced modes and high-frequency modes, when the response spectrum method of analysis is used to determine the dynamic response of damped linear systems. Use of alternate methods are evaluated on a case-by-case basis for acceptability.

When the modal superposition time history method of analysis is used, modal responses are combined algebraically, at each output time step. In accordance with RG 1.92, only modes with natural frequencies less than or equal to the ZPA frequency of the input spectrum are included in the modal superposition time history analysis. The contribution of the higher frequency modes to the total response is calculated by the missing mass approach. Since this contribution is in-phase with the input time history, it is treated as one additional modal response, that is scaled by the input time history normalized to the ZPA, and combined algebraically with the modal superposition time history solution at each output time step.

8. Interaction of Non-Category I Structures with Category I SSCs. All non-Category I structures should be assessed to determine whether their failure under SSE conditions could impair the integrity of seismic Category I SSCs, or result in incapacitating injury to control room occupants. Each non-Category I structure should meet at least one of the following criteria:
 - A. The collapse of the non-Category I structure will not cause the non-Category I structure to strike a Category I SSC.
 - B. The collapse of the non-Category I structure will not impair the integrity of seismic Category I SSCs, nor result in incapacitating injury to control room occupants.
 - C. The non-Category I structure will be analyzed and designed to prevent its failure under SSE conditions, such that the margin of safety is equivalent to that of Category I structures.

The disposition of each non-Category I structure should be formally documented.

For criterion (b), it is necessary to provide the technical basis for the determination that collapse of the non-Category I structure is acceptable. This should include a description of any additional loads imposed on the Category I SSCs and the method used to conclude that these loads are not damaging. Also, any protective shields installed to prevent direct impact on Category I SSCs should be described.

9. Effects of Parameter Variations on Floor Response Spectra. Consideration should be given in the analysis to the effects on floor response spectra (e.g., peak width) of expected variations of structural properties, damping values, soil properties, and SSI. The acceptance criteria for the consideration of the effects of parameter variations are provided in subsection II.5 of this SRP section. In addition, for concrete structures, the effect of potential concrete cracking on the structural stiffness should be specifically addressed.
10. Use of Equivalent Vertical Static Factors. The use of equivalent static load factors to calculate vertical response loads for the seismic design of Category I SSCs, in lieu of the use of a vertical seismic system dynamic analysis, is acceptable only if it can be demonstrated that the SSC is rigid in the vertical direction, or the acceptance criteria in subsection 3.7.2.II.1.b of this SRP section are satisfied. The criterion for rigidity is that the lowest frequency in the vertical direction is higher than the ZPA frequency of the input ground or in-structure spectrum.
11. Methods Used to Account for Torsional Effects. An acceptable method to account for torsional effects in the seismic analysis of Category I structures is to perform a dynamic analysis that incorporates the torsional degrees of freedom. An acceptable alternative, if properly justified, is the use of static factors to account for torsional accelerations in the seismic design of Category I structures.

To account for accidental torsion, an additional eccentricity of ± 5 percent of the maximum building dimension shall be assumed for both horizontal directions. The magnitude and location of the two eccentricities is determined separately for each floor elevation.

12. Comparison of Responses. If both the time history analysis method and the response spectrum analysis method are used to analyze an SSC, the peak responses obtained from these two methods should be compared, to demonstrate approximate equivalency between the two methods.
13. Analysis Procedure for Damping. Either the composite modal damping approach or the modal synthesis technique can be used to account for element-associated damping.

Use of composite modal damping for computing the response of systems with nonclassical modes may lead to unconservative results (Miller, et al., 1985). Therefore, the composite modal damping approach is acceptable provided the composite modal damping is limited to 20 percent. One of the other methods mentioned below is generally applicable if the composite modal damping exceeds 20 percent.

- A. Time domain analysis using complex modes/frequencies,
- B. Frequency domain analysis, or
- C. Direct integration of uncoupled equation of motion.

For the composite modal damping approach, two techniques of determining an equivalent modal damping matrix or composite damping matrix are commonly used. They are based on the use of the mass or stiffness as a weighting function in generating the composite modal damping. The formulations lead to:

$$\bar{\beta}_j = \{\phi\}^T [\bar{M}] \{\phi\} \quad (1)$$

$$\beta_j = \frac{\{\phi\}^T [\bar{K}] \{\phi\}}{K^*} \quad (2)$$

where

$$K^* = \{\phi\}^T [K] \{\phi\},$$

[K] = assembled stiffness matrix,

$\bar{\beta}_j$ = equivalent modal damping ratio of the j^{th} mode,

$[\bar{K}], [\bar{M}]$ = the modified stiffness or mass matrix constructed from element matrices formed by the product of the damping ratio for the element and its stiffness or mass matrix, and

$\{\phi\}$ = j^{th} normalized modal vector.

For models that take SSI into account by the lumped soil spring approach, the method defined by equation (2) is acceptable. For fixed base models, either equation (1) or (2) may be used. Other techniques based on modal synthesis have been developed and are particularly useful when more detailed data on the damping characteristics of structural subsystems are available. The modal synthesis analysis procedure consists of (1) extraction of sufficient modes from the structure model, (2) extraction of sufficient modes from the finite element soil model, and (3) performance of a coupled analysis using the modal synthesis technique, which uses the data obtained in steps (1) and (2) with appropriate damping ratios for structure and soil subsystems. This method is based upon satisfaction of displacement compatibility and force equilibrium at the system interfaces and uses subsystem eigenvectors as internal generalized coordinates. This method results in a nonproportional damping matrix for the composite structure, and equations of motion have to be solved by direct integration or by uncoupling them by use of complex eigenvectors.

Other techniques for estimating the equivalent modal damping of a SSI model are reviewed on a case-by-case basis.

14. Determination of Seismic Overturning Moments and Sliding Forces for Seismic Category I Structures. To be acceptable, the determination of the design overturning moment and sliding force should incorporate the following items:
 - A. Three components of input motion.
 - B. Conservative consideration of the simultaneous action of vertical and horizontal seismic forces.

Additional information on load combinations is provided in SRP Section 3.8.5.

Technical Rationale

The technical rationale for application of these acceptance criteria to the areas of review addressed by this SRP section is discussed in the following paragraphs:

1. 10 CFR Part 50, General Design Criterion (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. These data shall be used to specify the design requirements of nuclear power plant components to be evaluated as part of construction permit (CP), operating license (OL), COL, early site permit reviews, or for site parameter envelopes in the case of design certifications, thereby ensuring that components important to safety will function in a manner that will maintain the plant in a safe condition.

SRP Section 3.7.2 describes acceptable methods for the seismic analysis and modeling of seismic Category I structures and major plant systems to assure that they accurately and/or conservatively represent the behavior of SSCs during postulated seismic events. These criteria include acceptable methods/procedures for performing a suitable dynamic analysis, including the effects of soil-structure interaction. For additional guidance reference is made to RGs 1.92, and 1.122. RG 1.92, provides various procedures acceptable to the staff for combining the three dimensional modal responses for both the response spectrum analysis approach and the time history analysis approach of nuclear power plant structures. Additionally, RG 1.122 describes methods acceptable to the NRC staff, as augmented in this SRP section, to be used in developing two horizontal and one vertical in-structure design response spectra at various floors or other equipment support locations of interest, from the time history motions resulting from the dynamic analysis of the supporting structure. Criteria and/or requirements are also described for considering the interaction of non-Category I structures with Category I SSCs, the treatment of torsional effects, the procedures for considering the effects of damping, and the determination of seismic overturning moments and sliding forces.

Meeting these requirements provides assurance that seismic Category I systems 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 100, Subpart A which is applicable to power reactor site applications before January 10, 1997, refers to appendix A of this part for seismic criteria. 10 CFR 100, Appendix A provides definitions for the OBE and the SSE, and requires that the engineering methods, used to ensure that the required safety functions are maintained during and after the vibratory ground motion associated with the SSE, involve the use of either a suitable dynamic analysis or an appropriate qualification test methodology. 10 CFR 100, Appendix A requires that the applicable levels of vibratory ground motion corresponding to the OBE and the SSE are properly defined, and that adequate

methods are used to demonstrate that SSCs important to safety can withstand the seismic and other concurrently applied loads.

10 CFR Part 100, Subpart B which is applicable to power reactor site applications on or after January 10, 1997, refers to 10 CFR 100.23 of this part for seismic criteria. 10 CFR 100.23 describes the criteria and nature of investigations required to obtain the geologic and seismic data necessary to determine the suitability of the proposed site and the plant design bases. 10 CFR 100.23 also indicates that applications to engineering design are contained in 10 CFR Part 50, Appendix S.

SRP Section 3.7.2 describes acceptable analytical methods for seismic evaluation of seismic Category I structures and systems. The criteria in SRP 3.7.2 provide methods acceptable to the staff for performing static and dynamic seismic analysis of systems. Criteria for the equivalent static load method and criteria for performing response spectrum or time history analyses for dynamic methods are provided.

Meeting these requirements provides assurance that appropriate engineering methods will be used to seismically qualify systems important to safety, and thereby ensure that they will be able to perform their intended safety function when subjected to the SSE and OBE (if applicable).

3. 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 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 response or design analysis 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.

SRP Section 3.7.2 describes acceptable analytical methods that are used to determine the seismic response of structures and systems in terms of stresses, strains, and deformations. These responses are combined with the structural responses from other loads in accordance with the criteria in SRP Section 3.8. The criteria in SRP Section 3.7.2 ensure that the effects of the three components of earthquake motion and the effects of soil-structure interaction are appropriately included in the evaluation. In addition, the use of these criteria allow 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 structural response of systems, under the SSE and OBE (if applicable), which will ensure that they will remain functional within applicable acceptance limits.

III. REVIEW PROCEDURES

The reviewer will select material from the procedures described below, as may be appropriate for a particular case.

These review procedures are based on the identified SRP 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. Seismic Analysis Methods. For all Category I SSCs, the applicable methods of seismic analysis (response spectra, time history, equivalent static load) are reviewed to confirm

that the techniques employed are in accordance with the acceptance criteria as given in subsection II.1 of this SRP section. If empirical methods or tests are used in lieu of analysis for any Category I structure, these are evaluated to determine whether or not the assumptions are conservative, and whether the test procedure adequately models the seismic response.

2. Natural Frequencies and Response Loads. The summary of natural frequencies and response loads is reviewed for compliance with the acceptance criteria in subsection II.2 of this SRP section.
3. Procedures Used for Analytical Modeling. The procedures used for modeling of seismic systems are reviewed to determine whether the three-dimensional characteristics of structures are properly modeled in accordance with the acceptance criteria of subsection II.3 of this SRP section and whether all significant degrees of freedom have been incorporated in the models. The criteria for decoupling of a structure, equipment, or component and analyzing it separately as a subsystem are reviewed for conformance with the acceptance criteria given in subsection II.3 of this SRP section.
4. Soil-Structure Interaction. The methods of SSI analysis used are examined to determine that the techniques employed are in accordance with the acceptance criteria as given in subsection II.4 of this SRP section. Typical mathematical models for SSI analysis are reviewed to ensure the adequacy of the representation in accordance with subsection II.4 of this SRP section. In addition, the methods used to assess the effects of adjacent structures on structural response in SSI analysis are reviewed to establish their acceptability.
5. Development of In-Structure Response Spectra. Procedures for developing the in-structure response spectra are reviewed to verify that they are in accordance with the acceptance criteria specified in subsection II.5 of this SRP section. If a direct generation method of analysis is used to develop the in-structure response spectra, its conservatism compared to that of a time history approach is reviewed.
6. Three Components of Earthquake Motion. The procedures by which the three components of earthquake motion are considered in determining the seismic response of SSCs are reviewed to determine compliance with the acceptance criteria of subsection II.6 of this SRP section.
7. Combination of Modal Responses. The procedures for combining modal responses are reviewed to determine compliance with the acceptance criteria of subsection II.7 of this SRP section.
8. Interaction of Non-Category I Structures with Category I SSCs. The design and analysis criteria for interaction of non-Category I structures with Category I SSCs are reviewed to ensure compliance with the acceptance criteria of subsection II.8 of this SRP section.
9. Effects of Parameter Variations on Floor Response Spectra. The seismic system analysis is reviewed to determine whether the analysis considered the effects of expected variations of structural properties, damping values, soil properties, and SSI on floor response spectra (e.g., peak width) and to determine compliance with the acceptance criteria of subsection II.9 of this SRP section. Among the various structural parameters analyzed, the effect of potential concrete cracking on structural stiffness should be addressed.
10. Use of Equivalent Vertical Static Factors. Use of constant static factors as response loads in the vertical direction for the seismic design of any Category I SSC, in lieu of a detailed dynamic method, is reviewed to determine compliance with the acceptance criteria of subsection II.10 of this SRP section.

11. Methods Used to Account for Torsional Effects. The methods of seismic analysis are reviewed to determine that the torsional effects of vibration are incorporated, in compliance with the acceptance criteria of subsection II.11 of the SRP section. Justification provided by the applicant for the use of any approximate method to account for torsional effects is reviewed, to ensure that it results in a conservative design.
12. Comparison of Responses. Where applicable, the responses obtained from both time history and response spectrum methods at selected points in major Category I structures are compared to judge the accuracy of the analyses conducted. The applicant should explain any significant discrepancies in the results of the two methods.
13. Analysis Procedure for Damping. The analysis procedure to account for differences in damping in different elements of the system structural model is reviewed to determine that it is in accordance with the acceptance criteria of subsection II.13 of this SRP section.
14. Determination of Seismic Overturning Moments and Sliding Forces for Category I Structures. The analysis methods to calculate seismic overturning moments and sliding forces are reviewed to determine compliance with the acceptance criteria of subsection II.14 of this SRP section.
15. Design Certification and COL Reviews. 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

(Combined for Sections 3.7.2 and 3.7.3)

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 plant design is acceptable and meets the requirements of 10 CFR Part 50, General Design Criterion (GDC) 2, 10 CFR Part 100, Subpart A (for applications received before January 10, 1997, and 10 CFR Part 100, Subpart B (for applications received on or after January 10, 1997). This conclusion is based on the following: The applicant has met the requirements of GDC 2 and 10 CFR Part 100, Appendix A or 10 CFR Part 50, Appendix S with respect to the capability of the structures to withstand the effects of earthquakes so that the design reflects:

1. Appropriate consideration for the most severe earthquake recorded for the site with an appropriate margin (GDC 2). Consideration of two levels of earthquakes (10 CFR Part 100, Appendix A or 10 CFR Part 50, Appendix S),

2. Appropriate combination of the effects of normal and accident conditions with the effect of the natural phenomena,
3. The importance of the safety functions to be performed (GDC 2), and
4. The use of a suitable dynamic analysis or a suitable qualification test to demonstrate that structures, systems, and components (SSCs) can withstand the seismic and other concurrent loads, except where it can be demonstrated that the use of an equivalent static load method provides adequate consideration (10 CFR Part 100, Appendix A or 10 CFR Part 50, Appendix S).

The applicant has met the requirements of item 1 listed above by use of the acceptable seismic design parameters as per SRP Section 3.7.1. The combination of earthquake-resultant loads with those resulting from normal and accident conditions in the design of Category I structures as specified in SRP Sections 3.8.1 through 3.8.5 will be in conformance with item 2 listed above.

The scope of review of the seismic system and subsystem analysis for the plant included the seismic analysis methods for all Category I SSCs. It included review of procedures for modeling, seismic SSI, development of floor response spectra, inclusion of torsional effects, seismic analysis of Category I concrete dams, evaluation of Category I structure overturning, and determination of composite damping. The review included design criteria and procedures for evaluation of the interaction of non-Category I structures with Category I structures and the effects of parameter variations on floor response spectra.

The review also included criteria and seismic analysis procedures for Category I buried piping outside containment and above-ground Category I tanks.

The system and subsystem analyses are performed by the applicant on an elastic and linear basis. Time history methods form the bases for the analyses of all major Category I SSCs. When the modal response spectrum method is used, the methods used in combining modal responses are in conformance with the regulatory positions in RG 1.92. If used, alternate methods have been evaluated and found to be acceptable. Floor spectra inputs to be used for design and test verifications of SSCs are generated from the time history method, and they are in conformance with the position of RG 1.122, as augmented in this SRP section. A vertical seismic system dynamic analysis is employed for all SSCs where analyses show significant structural amplification in the vertical direction. Torsional effects and stability against overturning are considered.

A coupled structure and soil model is used to evaluate SSI effects upon seismic responses. Appropriate nonlinear stress-strain and damping relationships for the soil are considered in the analysis. We conclude that the use of the seismic structural analysis procedures and criteria delineated above by the applicant provides an acceptable basis for the seismic design which is in conformance with the requirements of item 3 listed above.

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 SRP 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 following is intended to provide guidance to applicants and licensees regarding the NRC staff's plans for using this SRP section.

The staff will use this SRP section in performing safety evaluations of DC applications and license applications submitted by applicants pursuant to 10 CFR Part 50 or 10 CFR Part 52. Except when the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the staff will use the method described herein to evaluate conformance with Commission regulations.

The provisions of this SRP section apply to reviews of applications submitted six months or more after the date of issuance of this SRP section, unless superseded by a later revision.

Implementation schedules for conformance to parts of the method discussed herein are contained in the referenced regulatory guides.

Operating license (OL) and final design approval (FDA) applications, whose CP and PDA reviews were conducted after August of 1989 but prior to the issuance of Revision 3 to SRP Section 3.7.2, will be reviewed in accordance with the acceptance criteria given in the SRP Section 3.7.2, Revision 2, dated August 1989. Operating license (OL) and final design approval (FDA) applications, whose CP and PDA reviews were conducted prior to the issuance of this Revision 2 to SRP Section 3.7.2, will be reviewed in accordance with the acceptance criteria given in the SRP Section 3.7.2, Revision 1, dated July 1981.

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. Miller, C.A.; Costantino, C.J.; and Philippacopoulos, A.J.; "High Soil-Structure Damping Combined with Low Structural Damping," 7th Structural Mechanics in Reactor Technology (SMiRT) Paper K 10/10, Chicago, IL, 1985.
9. NUREG/CP-0054, "Proceedings of the Workshop on Soil-Structure Interaction," Bethesda, MD, June 16-18, 1986.
10. NUREG/CR-1161, "Recommended Revisions to Nuclear Regulatory Commission Seismic Design Criteria," May 1980.
11. Regulatory Guide 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants."
12. Regulatory Guide 1.70, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants."

13. Regulatory Guide 1.92, "Combining Modal Responses and Spatial Components in Seismic Response Analysis."
14. Regulatory Guide 1.122, "Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components."
15. Regulatory Guide 1.132, "Site Investigations for Foundations of Nuclear Power Plants"
16. Regulatory Guide 1.138, "Laboratory Investigations of Soils and Rocks for Engineering Analysis and Design of Nuclear Power Plants"
17. Regulatory Guide 1.206, "Combined License Applications for Nuclear Power Plants (LWR Edition)."

APPENDIX A

AUDIT GUIDELINES FOR SRP SECTION 3.7 SEISMIC DESIGN REVIEW

1. Introduction

This appendix provides guidelines for implementation of seismic design audits. The audit process is an important element of the staff's review activities. It provides an opportunity to review pertinent technical information that is not included in a license or certification application. It also serves as a forum for detailed face-to-face discussion with the applicant about unresolved technical issues. The audit results form part of the technical basis for the staff's final safety determination.

2. Audit Arrangements

Arrangements for the audit are made by the responsible Licensing Project Manager (LPM). The audit agenda, including specific areas of interest, is prepared by the NRC lead technical reviewer. The audit agenda is forwarded to the applicant by the LPM, at least two weeks prior to the start of the audit. The LPM should notify the appropriate regional office personnel, as well as any intervening parties, if applicable, about the forthcoming audit.

3. Audit Team

The audit team consists of the LPM, the NRC lead technical reviewer, and a number of technical experts, comprised of NRC staff and/or NRC contractor staff. The LPM acts as the contact between the NRC audit team and the applicant. The NRC lead technical reviewer is responsible for the resolution of all technical issues, and will determine the number of team members and the areas of expertise needed to accomplish the audit objectives.

4. Number and Duration of Audits

In general, two audits should be planned. The first audit is conducted after the staff's review of the applicant's initial responses to the staff's RAIs. The second audit is conducted near the end of the review process. At the end of the second audit, the remaining unresolved technical issues should be clearly defined by the staff and clearly understood by the applicant.

Usually, four working days should be planned for each audit, to allow sufficient time to complete the audit scope.

5. Audit Objectives

- (1) Obtain and review additional pertinent technical information that is not documented in the application (e.g., Sections 3.7.1 through 3.7.3 of the DCD).
- (2) Perform review of the applicant's seismic analyses and calculations.
- (3) Discuss the applicant's responses to the unresolved RAIs.
- (4) Obtain technical information (structural models, design site parameters, structural drawings, input ground motion time history, etc.) from the applicant, for use by the staff in performing its independent confirmatory seismic analyses. (first audit)

- (5) Resolve any discrepancies between the staff's independent confirmatory analysis results and the results of the applicant's analyses, after the confirmatory analyses are completed. (second audit)
- (6) Identify and document any new outstanding issues (new RAIs) resulting from (1) through (5) above.

6. Conduct of the Audit

(1) Entrance Meeting

An entrance meeting will be conducted at the beginning of the audit. The LPM will briefly summarize the purpose of the audit and introduce the NRC audit team members to the applicant. The NRC lead technical reviewer will discuss the purpose and scope of the audit in greater detail. The applicant will introduce its technical team that is available to support the staff during the audit. At its own discretion or as requested by the staff, the applicant may present an overview of its technical approach to seismic analysis of the Category I plant structures, including a description of assumptions, analysis methods, computer codes used, modeling techniques, and analysis results. The applicant should identify and discuss any changes in the technical approach from those identified and discussed in its application. The time allotted for the entrance meeting will vary from audit to audit, but should be limited to no more than three (3) hours. (The LPM determines whether the entrance meeting is a public meeting.)

(2) Audit Activities

There is no fixed format for conduct of the audit activities. The audit team may work as a single group, a number of smaller groups, or individually, at the direction of the NRC lead technical reviewer. Typically, at the end of each workday, the NRC lead technical reviewer compiles a summary of the audit team's activities and findings, assesses progress toward completion of the audit scope, and informs the applicant of the audit status. Any new technical issues and/or specific needs for additional information are communicated to the applicant.

Informal discussions between audit team members and the applicant's technical staff should be limited to exchanges of information. All important audit findings and conclusions should be communicated to the applicant's responsible manager by the NRC lead technical reviewer.

The audit team's activities should primarily focus on (a) review of pertinent technical information that the applicant referenced in its RAI responses; (b) confirmation, through review of formal calculations and design/analysis reports, that the applicant's technical approach to seismic analysis of the Category I plant structures, as identified and discussed in the application, has been appropriately implemented; and (c) as applicable, discussions related to the staff's independent confirmatory analyses.

Topics of special interest include

- Development of the ground motion time histories to match the design basis ground response spectrum.
- Modeling of soil properties.
- Modal properties of the structural models; confirmation of adequate refinement relative to the frequency content of the design basis ground response spectrum.

- Methodologies employed (computer codes, computer models) to conduct seismic analysis, including soil structure interaction (SSI) effects.
- In-structure response spectra

(3) **Exit Meeting**

An exit meeting will be conducted at the conclusion of the audit, to discuss and summarize the audit findings, the unresolved RAIs, any new outstanding issues identified, and the applicant's schedule for responding. One (1) hour is allotted for the exit meeting. (The LPM determines whether the exit meeting is a public meeting.)

7. **Audit Report**

The NRC lead technical reviewer will prepare a summary of progress toward resolution of technical issues, and a description of any new outstanding technical issues that emerged during the audit. The LPM is responsible for preparation of an audit summary report.

8. **Post-Audit Communications**

Review of the applicant's responses to the unresolved issues may necessitate additional meeting(s) or conference call(s) between the staff and the applicant, to obtain clarification of the responses.

9. **Input to the Safety Evaluation Report (SER)**

The audits are an integral part of the staff's review process. The audit results, the resolution of the RAIs and open items, and appropriate consideration of other safety aspects constitute the major basis for the staff's preparation of the SER.

PAPERWORK REDUCTION ACT STATEMENT

The information collections contained in the Standard Review Plan are covered by the requirements of 10 CFR Part 50 and 10 CFR Part 52, and were approved by the Office of Management and Budget, approval number 3150-0011 and 3150-0151.

PUBLIC PROTECTION NOTIFICATION

The NRC may not conduct or sponsor, and a person is not required to respond to, a request for information or an information collection requirement unless the requesting document displays a currently valid OMB control number.
