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U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

OFFICE OF NUCLEAR REACTOR REGULATION

SECTION 3.7.3 SEISMIC SUBSYSTEM ANALYSIS

REVIEW RESPONSIBILITIES

Primary - Structural and Geosciences Branch (ESGB)

Secondary - None

I. AREAS OF REVIEW

The following areas related to the seismic subsystem analysis are reviewed:

1. Seismic Analysis Methods

The information reviewed is similar to that described in subsection I.1 of Standard Review Plan (SRP) Section 3.7.2 but as applied to seismic Category I subsystems.

2. Determination of Number of Earthquake Cycles

Criteria or procedures used to establish the number of earthquake cycles during one seismic event and the maximum number of cycles for which applicable Category I subsystems and components are designed are reviewed.

3. Procedures Used for Analytical Modeling

The criteria and procedures used for modeling the seismic subsystems are reviewed.

4. Basis for Selection of Frequencies

As applicable, criteria or procedures used to separate fundamental frequencies of components and equipment from the forcing frequencies of the support structure are reviewed.

5. Analysis Procedure for Damping

The information reviewed is similar to that described in subsection I.13 of SRP Section 3.7.2 but as applied to Category I subsystems.

6. Three Components of Earthquake Motion

The information reviewed is similar to that described in subsection I.6 of SRP Section 3.7.2 but as applied to Category I subsystems.

7. Combination of Model Responses

The information reviewed is similar to that described in subsection I.7 of SRP Section 3.7.2 but as applied to Category I subsystems.

8. Interaction of Other Systems With Category I Systems

The seismic analysis procedures to account for the seismic motion of non-Category I systems in the seismic design of Category I systems are reviewed.

9. Multiply-Supported Equipment and Components with Distinct Inputs

The criteria and procedures for seismic analysis of equipment and components supported at different elevations within a building and between buildings with distinct inputs are reviewed.

10. Use of Equivalent Vertical Static Factors

The information reviewed is similar to that described in subsection 1.10 of SRP Section 3.7.2 but as applied to Category I subsystems.

11. Torsional Effects of Eccentric Masses

The criteria and procedures that are used to consider the torsional effects of eccentric masses in seismic subsystem analyses are reviewed.

12. Category I Buried Piping, Conduits, and Tunnels

For Category I buried piping, conduits, tunnels, and auxiliary systems, the seismic criteria and methods which consider the compliance characteristics of soil media, dynamic pressures, settlement due to earthquake and differential movements at support points, penetrations, and entry points into structures provided with anchors are reviewed.

13. Methods for Seismic Analysis of Category I Concrete Dams

The analytical methods and procedures that will be used for seismic analysis of Category I concrete dams are reviewed. The assumptions made, the boundary conditions used, the hydrodynamic effects considered, and the procedures by which strain-dependent material properties of foundation are incorporated in the analysis are reviewed.

14. Methods for Seismic Analysis of Above-Ground Tanks

For Category I above-ground tanks, the seismic criteria and methods that consider hydrodynamic forces, tank flexibility, soil-structure interaction, and other pertinent parameters are reviewed.

II. ACCEPTANCE CRITERIA

The acceptance criteria for the areas of review described in subsection I of this SRP section are given below. Other criteria which can be justified to be equivalent to or more conservative than the stated acceptance criteria may be used. The staff accepts the design of subsystems that are important to safety and must withstand the effects of earthquakes if the relevant requirements of General Design Criterion (GDC) 2 (Ref. 1) and Appendix A to 10 CFR Part 100 (Ref. 2) concerning material phenomena are complied with. The relevant requirements of GDC 2 and Appendix A to 10 CFR Part 100 are:

1. General Design Criterion 2 - The design basis shall reflect appropriate consideration of the most severe earthquakes reported to have affected 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. Appendix A to 10 CFR Part 100 - Two earthquake levels, the safe shutdown earthquake (SSE) and the operating basis earthquake (OBE), shall be considered in the design of safety-related structures, components, and systems. Appendix A to 10 CFR Part 100 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 safe shutdown earthquake shall involve the use of either a suitable dynamic analysis or a suitable qualification test to demonstrate that structures, systems, and components 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.

Specific criteria necessary to meet the relevant requirements of GDC 2 and Appendix A to Part 100 are as follows:

1. Seismic Analysis Methods

   The acceptance criteria provided in SRP Section 3.7.2, subsection II.1, are applicable.

2. Determination of Number of Earthquake Cycles

   During the plant life at least one safe shutdown earthquake (SSE) and five operating basis earthquakes (OBEs) should be assumed. The number of cycles per earthquake should be obtained from the synthetic time history (with a minimum duration of 10 seconds) used for the system analysis, or a minimum of 10 maximum stress cycles per earthquake may be assumed.

3. Procedures Used for Analytical Modeling

   The acceptance criteria provided in SRP Section 3.7.2, subsection II.3, are applicable.

4. Basis for Selection of Frequencies

To avoid resonance, the fundamental frequencies of components and equipment should preferably be selected to be less than 1/2 or more than twice the dominant frequencies of the support structure. Use of equipment frequencies within this range is acceptable if the equipment is adequately designed for the applicable loads.

5. Analysis Procedure for Damping

The acceptance criteria provided in SRP Section 3.7.2, subsection II.13, are applicable.

6. Three Components of Earthquake Motion

The acceptance criteria provided in SRP Section 3.7.2, subsection II.6, are applicable.

7. Combination of Modal Responses

The acceptance criteria provided in SRP Section 3.7.2, subsection II.7, are applicable.

8. Interaction of Other Systems With Category I Systems

To be acceptable, each non-Category I system should be designed to be isolated from any Category I system by either a constraint or barrier, or should be remotely located with regard to the seismic Category I system. If it is not feasible or practical to isolate the Category I system, adjacent non-Category I systems should be analyzed according to the same seismic criteria as applicable to the Category I system. For non-Category I systems attached to Category I systems, the dynamic effects of the non-Category I systems should be simulated in the modeling of the Category I system. The attached non-Category I systems, up to the first anchor beyond the interface, should also be designed in such a manner that during an earthquake of SSE intensity it will not cause a failure of the Category I system.

9. Multiply-Supported Equipment and Components With Distinct Inputs

Equipment and components in some cases are supported at several points by either a single structure or two separate structures. The motions of the primary structure or structures at each of the support points may be quite different.

A conservative and acceptable approach for equipment items supported at two or more locations is to use an upper bound envelope of all the individual response spectra for these locations to calculate maximum inertial responses of multiply-supported items. In addition, the relative displacements at the support points should be considered. Conventional static analysis procedures are acceptable for this purpose. The maximum relative support displacements can be obtained from the structural response calculations or, as a conservative approximation, by using the floor response spectra. For the latter option the maximum displacement of each support is predicted by $S_d = S_a g/\omega^2$, where S_a is the spectral acceleration in "g's" at the high-frequency end of the spectrum curve (which, in turn, is equal to the maximum floor acceleration), g is the gravity constant, and ω is the fundamental frequency of the primary support structure in radians per second. The support displacements can then be imposed on the supported item in the most unfavorable combination. The responses due to the inertia effect and relative displacements should be combined by the absolute sum method.

In the case of multiple supports located in a single structure, an alternative acceptable method using the floor response spectra involves determination of dynamic responses due to the worst single floor response spectrum selected from a set of floor response spectra obtained at various floors and applied identically to all the floors, provided there is no significant shift in frequencies of the spectra peaks. In addition, the support displacements should be imposed on the supported item in the most unfavorable combination using static analysis procedures.

In lieu of the response spectrum approach, time histories of support motions may be used as excitations to the subsystems. Because of the increased analytical effort compared to the response spectrum techniques, usually only a major equipment system would warrant a time history approach. The time history approach does, however, provide more realistic results in some cases as compared to the response spectrum envelope method for multiply-supported systems.

10. Use of Equivalent Vertical Static Factors

The acceptance criteria provided in SRP Section 3.7.2, subsection II.10, are applicable.

11. Torsional Effects of Eccentric Masses

For seismic Category I subsystems, when the torsional effect of an eccentric mass is judged to be significant, the eccentric mass and its eccentricity should be included in the mathematical model. The criteria for judging the significance will be reviewed on a case-by-case basis.

12. Category I Buried Piping, Conduits, and Tunnels

For Category I buried piping, conduits, tunnels, and auxiliary systems, the following items should be considered in the analysis:

a. Two types of groundshaking-induced loadings must be considered for design.

(i) Relative deformations imposed by seismic waves traveling through the surrounding soil or by differential deformations between the soil and anchor points.

(ii) Lateral earth pressures and ground-water effects acting on structures.

b. The effects of static resistance of the surrounding soil on piping deformations or displacements, differential movements of piping anchors, bent geometry and curvature changes, etc., should be adequately considered. Procedures using the principles of the theory of structures on elastic foundations are acceptable.

c. When applicable, the effects due to local soil settlements, soil arching, etc., should also be considered in the analysis.

d. Actual methods used for determining the design parameters associated with seismically induced transient relative deformations are reviewed and accepted on a case-by-case basis. Additional information, for guidance purposes only, can be found on page 26 of Reference 3 and in Section 3.5.2 of Reference 4.

13. Methods for Seismic Analysis of Category I Concrete Dams

For the analysis of all Category I concrete dams, an appropriate approach that takes into consideration the dynamic nature of forces (due to both horizontal and vertical earthquake loadings), the behavior of the dam material under earthquake loadings, soil-structure interaction (SSI) effects, and nonlinear stress-strain relations for the soil, should be used. Analysis of earthen dams is reviewed under Section 2.5.6.

14. Methods for Seismic Analysis of Above-Ground Tanks

Most above-ground fluid-containing vertical tanks do not warrant sophisticated, finite element, fluid-structure interaction analyses for seismic loading. However, the commonly used alternative of analyzing such tanks by the "Housner-method" (Ref. 5) may be inadequate in some cases. The major problem is that direct application of this method is consistent with the assumption that the combined fluid-tank system in the horizontal impulsive mode is sufficiently rigid to justify the assumption of a rigid tank. For flat-bottomed tanks mounted directly on their bases, or tanks with very stiff skirt supports, the assumption leads to the usage of a spectral acceleration equal to the zero-period base acceleration. Recent studies (Refs. 6, 7, 8, 9, and 10) have shown that for typical tank designs the frequency for this fundamental horizontal impulsive mode of the tank shell and contained fluid is such that the spectral acceleration may be significantly far greater than the zero-period acceleration. Thus, the assumption of a rigid tank could lead to inadequate design loadings. The SSI effects may also be very important for tank responses, and they may be considered for both horizontal and vertical motions.

The acceptance criteria below are based upon the information contained in References 1 through 3 and Reference 5. These references also contain acceptable calculational techniques for the implementation of these criteria. The use of other approaches meeting the intent of these criteria can also be considered if adequate justification is provided.

a. A minimum acceptable analysis must incorporate at least two horizontal modes of combined fluid-tank vibration and at least one vertical mode of fluid vibration. The horizontal response analysis must include at least one impulsive mode in which the response of the tank shell and roof are coupled together with the portion of the fluid contents that moves in unison with the shell. Furthermore, at least the fundamental sloshing (convective) mode of the fluid must be included in the horizontal analysis.

b. The fundamental natural horizontal impulsive mode of vibration of the fluid-tank system must be estimated giving due consideration to the flexibility of the supporting medium and to any uplifting tendencies for the tank. It is unacceptable to assume a rigid tank unless the assumption can be justified. The horizontal impulsive-mode spectral acceleration, S_{a1}, is then determined using this frequency and the appropriate damping for the fluid-tank system. Alternatively, the maximum spectral acceleration corresponding to the relevant damping may be used.

c. Damping values used to determine the spectral acceleration in the impulsive mode shall be based upon the system damping associated with the tank shell material as well as with the SSI, as specified in References 3 and 10.

d. In determining the spectral acceleration in the horizontal convective mode, S_{a2}, the fluid damping ratio shall be 0.5 percent of critical damping unless a higher value can be substantiated by experimental results.

e. The maximum overturning moment, M_o, at the base of the tank should be obtained by the modal and spatial combination methods discussed in subsection II of SRP Section 3.7.2. The uplift tension resulting from M_o must be resisted either by tying the tank to the foundation with anchor bolts, etc., or by mobilizing enough fluid weight on a thickened base skirt plate. The latter method of resisting M_o must be shown to be conservative.

f. The seismically induced hydrodynamic pressures on the tank shell at any level can be determined by the modal and spatial combination methods in SRP Section 3.7.2. The maximum hoop forces in the tank wall must be evaluated with due regard for the contribution of the vertical component of ground shaking. The beneficial effects of soil-structure interaction may be considered in this evaluation (Refs. 4, 11, 12, and 13). The hydrodynamic pressure at any level must be added to the hydrostatic pressure at that level to determine the hoop tension in the tank shell.

g. Either the tank top head must be located at elevation higher than the slosh height above the top of the fluid or else must be designed for pressures resulting from fluid sloshing against this head.

h. At the point of attachment, the tank shell must be designed to withstand the seismic forces imposed by the attached piping. An appropriate analysis must be performed to verify this design.

i. The tank foundation (see also SRP Section 3.8.5) must be designed to accommodate the seismic forces imposed on it. These forces include the hydrodynamic fluid pressures imposed on the base of the tank as well as the tank shell longitudinal compressive and tensile forces resulting from M_o.

j. In addition to the above, a consideration must be given to prevent buckling of tank walls and roof, failure of connecting piping, and sliding of the tank.

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. The review procedures are such as to satisfy the requirements of acceptance criteria stated in subsection II.

1. Seismic Analysis Methods

   The seismic analysis methods are reviewed to determine that these are in accordance with the acceptance criteria of SRP Section 3.7.2, subsection II.1.

2. Determination of Number of Earthquake Cycles

   Criteria or procedures used to establish the number of earthquake cycles are reviewed to determine that they are in accordance with the acceptance criteria as given in subsection II.2 of this SRP section. Justification for deviating from the acceptance criteria is requested from the applicant, as necessary.

3. Procedures Used for Analytical Modeling

   The criteria and procedures used for modeling for the seismic subsystem analysis are reviewed to determine that these are in accordance with the acceptance criteria of SRP Section 3.7.2, subsection II.3.

4. Basis for Selection of Frequencies

   As applicable, criteria or procedures used to separate fundamental frequencies of components and equipment from the forcing frequencies of the support structure are reviewed to determine compliance with the acceptance criteria of subsection II.4 of this SRP section.

5. Analysis Procedure for Damping

   The analysis procedure to account for damping in different elements of the model of a coupled system is reviewed to determine that it is in accordance with the acceptance criteria of SRP Section 3.7.2, subsection II.13.

6. Three Components of Earthquake Motion

The procedures by which the three components of earthquake motion are considered in determining the seismic response of subsystems are reviewed to determine compliance with the acceptance criteria of SRP Section 3.7.2, subsection II.6.

7. Combination of Modal Responses

The procedures for combining modal responses are reviewed to determine compliance with the acceptance criteria of SRP Section 3.7.2, subsection II.7 when a response spectrum modal analysis method is used.

8. Interaction of Other Systems with Category I Systems

The criteria used to design the interfaces between Category I and non-Category I systems are reviewed to determine compliance with the acceptance criteria of subsection 11.8 of this SRP section.

9. Multiply-Supported Equipment and Components With Distinct Inputs

The criteria for the seismic analysis of multiply-supported equipment and components with distinct inputs are reviewed to determine that the criteria are in accordance with the acceptance criteria of subsection II.9 of this SRP section.

10. Use of Equivalent Vertical Static Factors

Use of equivalent static factors as response loads in the vertical direction for the seismic design of any Category I subsystems in lieu of a detailed dynamic method is reviewed to determine that constant static factors are used only if the structure is rigid in the vertical direction.

11. Torsional Effects of Eccentric Masses

The procedures for seismic analysis of Category I subsystems are reviewed to determine compliance with the acceptance criteria of subsection II.11 of this SRP section.

12. Category I Buried Piping, Conduits, and Tunnels

The analysis procedures for Category I buried piping, conduits, tunnels, and auxiliary systems are reviewed to determine that they are in accordance with the acceptance criteria of subsection II.12 of this SRP section. The analysis includes review of the procedures used to consider the inertial effects of soil media and the differential displacements at structural penetrations, etc. Any procedures that are not adequately justified are so identified, and the applicant is requested to provide additional justification.

13. Methods for Seismic Analysis of Category I Concrete Dams

Methods for the seismic analysis of Category I concrete dams are reviewed to determine compliance with the acceptance criteria of subsection II.13 of this SRP section.

14. Method for Seismic Analysis of Above-Ground Tanks

Methods for seismic analysis of Category I above-ground tanks are reviewed to determine compliance with the acceptance criteria of subsection II.14 of this SRP section.

IV. EVALUATION FINDINGS

Evaluation findings for SRP Section 3.7.3 have been combined with those of SRP Section 3.7.2 and are given under SRP Section 3.7.2, subsection IV.

V. IMPLEMENTATION

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

Except in those cases in which the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the method described herein will be used by the staff in its evaluation of conformance with the Commission's regulations.

The provisions of this SRP section apply to reviews of construction permit (CP), preliminary design approval (PDA), final design approval (FDA), and combined license (CP/OL) applications docketed after the date of issuance of this SRP section. Operating license (OL) and final design approval (FDA) applications, whose CP and PDA reviews were conducted prior to the issuance of this revision to SRP Section 3.7.3, will be reviewed in accordance with the acceptance criteria given in the SRP Section 3.7.3, Revision 1, dated July 1981.

VI. REFERENCES

1. 10 CFR Part 50, Appendix A, General Design Criterion 2, "Design Bases for Protection Against Natural Phenomenon."

2. 10 CFR Part 100, Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants."

3. D. W. Coats, "Recommended Revisions to Nuclear Regulatory Commission Seismic Design Criteria," NUREG/CR-1161, May 1980.

4. ASCE Standard 4-86, "Seismic Analysis of Safety-Related Nuclear Structures and Commentary on Standard for Seismic Analysis of Safety-Related Nuclear Structures," American Society of Civil Engineers, September 1986.

5. TID-7024, "Nuclear Reactors and Earthquakes," Division of Reactor Development, U.S. Atomic Energy Commission, August 1963.

6. A. S. Veletsos, "Seismic Effects in Flexible Liquid Storage Tanks," Proceedings of Fifth World Conference on Earthquake Engineering, Rome, 1974.

7. A. S. Veletsos and J. Y. Yang, "Earthquake Response of Liquid Storage Tanks," Advances in Civil Engineering Through Engineering Mechanics, Proceedings of the Engineering Mechanics Division Specialty Conference, ASCE, Raleigh, North Carolina, pp. 1-24, 1977.

8. M. A. Haroun and G. W. Housner, "Seismic Design of Liquid Storage Tanks," Journal of the Technical Councils, ASCE, Vol. 107, No. TC1, pp. 191-207, 1981.

9. A. S. Veletsos, "Seismic Response and Design of Liquid Storage Tanks," Guidelines for the Seismic Design of Oil and Gas Pipeline Systems, Technical Council on Lifeline Earthquake Engineering, ASCE, pp. 255-370 and 443-461, 1984.

10. A. S. Veletsos and Y. Tang, "Soil-Structure Interaction Effects for Laterally Excited Liquid-Storage Tanks," to appear as an EPRI Technical Report, Palo Alto, California, 1989.

11. M. A. Haroun and M. A. Tayel, "Axisymmetrical Vibrations of Tanks--Numerical," Journal of Engineering Mechanics Division, ASCE, Vol. 111, No. 3, pp. 329-345, 1985.

12. A. S. Veletsos and Y. Tang, "Dynamics of Vertically Excited Liquid Storage Tanks," Journal of Structural Engineering, ASCE, Vol. 112, No. 6, pp. 1228-1246, 1986.

13. A. S. Veletsos and Y. Tang, "Interaction Effects in Vertically Excited Steel Tanks," Dynamic Response of Structures, G. C. Hart and R. B. Nelson, Editors, ASCE, pp. 636-643, 1986.