3.10 Seismic and Dynamic Qualification of Mechanical and Electrical Equipment

This section describes the acceptance criteria, code and standards, procedures, and methods applied to the seismic and dynamic qualification of mechanical and electrical equipment including instrumentation to provide reasonable assurance that they will withstand the effects of postulated events and accidents and still be capable of performing their safety-related functions under the full range of normal, transient, seismic, and accident loadings.

Safety-related equipment is the equipment necessary to provide reasonable assurance of the following:

a. The integrity of the reactor coolant pressure boundary

b. The capability to shut down the reactor and maintain it in a safe shutdown condition

c. The capability to prevent or mitigate the consequences of accidents that would result in potential offsite exposure in excess of the limits stated in 10 CFR 100

This safety-related equipment includes equipment associated with systems that are essential to emergency reactor shutdown, containment isolation, reactor core cooling, and containment reactor heat removal; equipment essential to preventing significant release of radioactive material to the environment, and instrumentation needed to assess plant and environs conditions during and after an accident as described in NRC RG 1.97 (Reference 1).

The safety-related equipment is identified as:

a. Equipment that performs the above functions automatically,

b. Equipment that operators use to perform the above functions manually,

c. Equipment for which failure can prevent satisfactory accomplishment of one or more of the above safety functions.

This includes equipment in the reactor protective system (RPS), the engineered safety features (ESF) Class 1E equipment, the emergency power system, and all auxiliary safety-related systems and supports.

Examples of mechanical equipment are valves, pumps, fans, and heat exchangers. Examples of electrical and I&C equipment are motor control centers, load centers, battery racks, and indicators. This equipment is divided into two categories:

a. Active Equipment – The equipment that must remain functional both during and after all postulated dynamic event such as fans, pumps, valves, motors, switches, relays, and transmitters.

b. Passive Equipment – The equipment whose safety-related function does not involve operability but that does require assurance of its structural and pressure integrity both during and after postulated dynamic events. Examples of some common items of equipment classified as passive include tanks, heat exchangers, and filter cabinets.

Seismic Category I SSCs are identified in Table 3.2-1. Safety-related mechanical and electrical equipment including instrumentation is designed to meet seismic Category I requirements to provide reasonable assurance of the ability to initiate required protective actions and to supply power, to components required to mitigate the consequences of events that require safety system operation during and after a safe shutdown earthquake (SSE).

Mechanical and electrical equipment including instrumentation designated as seismic Category II is shown to maintain its structural integrity and not adversely impact safety-related equipment during an SSE and during all static and dynamic loads from normal, transient, and accident conditions.

3.10.1 Seismic Qualification Criteria

The seismic and dynamic qualification of mechanical and electrical equipment demonstrates the safety system equipment's ability to perform its required function during and/or after the time it is subjected to the forces resulting from SSE and other related dynamic loads at the location of the equipment. For the purpose of equipment seismic qualification, the equipment is qualified with five one-half SSEs followed by one full SSE.

The SSE term is applicable to the site-independent earthquake or the site-specific earthquake. The expression "safe shutdown earthquake" used for seismic qualification of SSCs in this section refers to equipment qualified for the site-specific design. The seismic Category I SSCs are designed for the SSE. Since the operating basis earthquake (OBE) is defined as one third the SSE, an explicit analysis or design of the seismic Category I SSCs based on OBE is not required in accordance with Appendix S of 10 CFR 50 (Reference 2) as defined in Subsection 3.7.1.

When the OBE is defined as less than or equal to 1/3 SSE, explicit design or analysis is not required for the OBE. The COL applicant is to provide that the design of seismic Category I SSCs are analyzed for OBE, if OBE is higher than 1/3 SSE (COL 3.10(1)).

3.10.1.1 Qualification Codes and Standards

The seismic and dynamic qualification program provides reasonable assurance that equipment classified as seismic Category I meets functional performance requirements, as defined in design specification order of the equipment, during and after dynamic loadings due to normal operating, transient, seismic, and accident conditions.

The employed methods for the dynamic qualification described in Subsection 3.10.2 are in accordance with the requirements of GDC 1, GDC 2, GDC 4, GDC 14, GDC 30, and 10 CFR 50, Appendix S and Appendix B. The seismic and dynamic testing portion of the qualification program is performed in a sequence consistent with the requirements of Section 6 of IEEE Std. 323-2003 (Reference 3).

The recommended guidance and requirements in NRC RG 1.100 (Reference 4) and IEEE Std. 344-2004 (Reference 5) are used for the development and implementation of methods and procedures for seismic qualification of mechanical and electrical equipment.

The methods and procedures for seismic qualification of mechanical and electrical equipment are in accordance with the recommended guidance and requirements in NRC RG 1.100 and IEEE Std. 344-2004. The seismic or dynamic qualification based on test, analysis, or a combination of test and analysis are performed except an experience-based qualification. An experience-based qualification is not used for any equipment until it is endorsed by NRC RG 1.100.

The safety-related, seismic Category I mechanical equipment is designed to provide reasonable assurance of structural integrity of pressure boundary components for the intended service load conditions identified in the equipment's design specification, in accordance with the requirements in ASME Section III (Reference 6) described in Section 3.9. For seismic qualification of active mechanical equipment, the methods and guidance in ASME QME-1-2007 (Reference 7), including Appendix QR-A, with exceptions provided in NRC RG 1.100, are used.

For procurement of equipment, the dynamic requirements for the seismic qualification are specified in the equipment's design specifications. The equipment supplier is to submit a seismic qualification plan/procedure for review and approval prior to performing the seismic qualification. When test is employed, the equipment supplier is to submit a detailed test plan prior to conducting the test. When analysis is employed, the equipment supplier is to submit a detailed analysis procedure showing the methodology, approval, and description of the computer program used. If the plan/procedure is not acceptable, the seismic test plan or analysis procedure will be modified accordingly. The choice between testing and analysis may be made by the equipment supplier. However, the selected qualification program shall satisfy the requirements of the purchase specifications in accordance with the guidelines provided in IEEE Std 344-2004.

An existing seismic qualification is acceptable if it is properly documented, and if it meets all the requirements of the purchase specifications. The equipment supplier is to submit the seismic qualification documentation for review and approval prior to installation in the plant. The seismic qualification documentation is to include all the information stated in Subsection 3.10.4, to demonstrate that the equipment is qualified in accordance with the requirements of the purchase specifications.

3.10.1.2 Input Motion

The postulated dynamic loads related to the qualification of seismic Category I equipment are seismic loads (OBE and SSE), if applicable, hydrodynamic loads, and non-seismic loads (loads induced by pump trip, safety-relief valve open-case, etc.). The applicable loads are combined as part of the qualification of seismic Category I equipment.

These postulated dynamic loads are generally defined by the required response spectra (RRS). For in-line mounted equipment, they are defined by seismic coefficients. The location(s) in the plant will determine which spectra to use. Floor response spectra (FRS) are generated for specific buildings and elevations (floors) within a building as described in Subsection 3.7.2.5. When equipment is not directly mounted on floors, RRS reflects the amplification of the FRS due to the flexibility of equipment supporting structure. Selection of damping values for equipment to be qualified is made in accordance with NRC RG 1.61 (Reference 8) and IEEE Std. 344-2004. Higher damping values are used only if justified by documented test data with proper identification of the source and mechanism. Margins are added to RRS for testing. Section 6.3.2.5 of IEEE std. 323-2003 recommends a 10 percent margin.

In considering the high-frequency seismic effect, the COL applicant is to investigate if site-specific spectra generated for the COLA exceed the APR1400 design spectra in the high-frequency range. Accordingly, the COL applicant is to provide reasonable assurance of the functional performance of vibration-sensitive components in the high-frequency range (COL 3.10(2)).

3.10.1.3 Selection of Qualification Method

The dynamic qualification of equipment is performed by analysis, testing, or a combination of testing and analysis. The dynamic qualification of equipment is concerned with the following.

a. Identifying which equipment must be qualified

b. Identifying what the safety-related function(s) required of each piece of equipment is (are)

c. Defining the dynamic loads to be considered

d. Demonstrating the capability of the equipment to perform its safety-related function

e. Documenting that the process has been done in accordance with accepted regulatory and industry standards

In general, seismic Category I electrical equipment, for which functional operability must be demonstrated, is qualified by tests. Analysis alone is used for qualification of seismic Category I mechanical equipment if structural integrity alone can provide reasonable assurance of the design intended function.

For equipment whose functional operability cannot be demonstrated by analysis or testing because of its size, complexity, or the large number of similar configurations, a combination of test and analysis may be used.

3.10.2 Methods and Procedures for Qualifying Mechanical and Electrical Equipment and Instrumentation

Qualification of seismic Category I equipment and its supports meets the requirements of NRC RG 1.100 and IEEE Std. 344-2004. Qualification methods of testing and analysis for confirming the functionality of equipment during and after an SSE, and for all static and dynamic loads from normal, transient, and accident conditions, are presented in this section.

3.10.2.1 Qualification by Analysis

The seismic analysis methods are in accordance with the guidance of IEEE Std. 344-2004. Analysis without testing may be acceptable only if structural integrity alone can provide reasonable assurance of the design-intended function.

Procedures are presented that can be used to seismically qualify equipment by analysis for a number of OBEs followed by an SSE. Two approaches to seismic analysis are described. One approach is based on dynamic analysis, the other on static coefficient analysis.

a. Static coefficient analysis

This is an alternate method of analysis that allows a simpler technique in return for added conservatism. A determination of natural frequencies is not required. The acceleration response of the equipment is assumed to be the maximum acceleration in the amplified region peak of the RRS at a conservative and justifiable value of damping. A static coefficient of 1.5 has been established from experience to take into account the effects of multifrequency excitation and multimode response for linear frame-type structures, such as members physically similar to beams and columns, which can be represented by a simple model. A lower static coefficient may be used when it can be shown to yield conservative results. In a static coefficient analysis, the seismic forces on each component of the equipment are obtained by multiplying the values of the mass times the maximum peak of the RRS times the static coefficient. The resulting force should be distributed over the component in a manner proportional to its mass distribution. The stress at any point in the equipment can then be determined by combining the stress at that point due to the earthquake loading in each direction using the SRSS method.

b. Detailed dynamic analysis

Detailed dynamic analysis is basically finite element analysis. As such, it is generally used on equipment for which the simple models used in static-of-seismic-coefficient analysis are inadequate and/or on equipment for which a significant multimode response (when more than one resonant frequency is being excited simultaneously) or cross-coupling (when input in one direction results in response in one or more other directions) is anticipated.

c. Nonlinear equipment response

Nonlinearities may exist in addition to those associated with damping. These effects may be of a geometric nature, such as the closing of gaps, working of connections and rattling of components, or of a material source such as localized yielding. These effects may result in changing stiffness with increasing load. As frequency is also a function of stiffness, the frequencies may also change under increasing load. If a system exhibits significant nonlinearity, such behavior must be recognized and accounted for in any subsequent analysis so as to accurately predict the system response. If the nonlinearities cannot be adequately modeled, an alternative qualification method should be considered.

Nonlinearity may also occur as a result of local vibrations of equipment structure. One example is the high-frequency rattling of electrical cabinet doors that are not solidly secured in place. When such a condition exists and the operability of the mounted devices is deemed sensitive to this type of equipment nonlinear behavior, the analytic procedure must account for the behavior and must be properly validated.

d. Other dynamic loads

The analytical methodology described in this section for seismic loading is equally applicable to other dynamic loadings, such as hydrodynamic.

e. OBE and SSE analysis

The analysis must show that OBE events followed by an SSE will not result in failure of the equipment to perform its safety function. When the OBE is defined as less than or equal to 1/3 of the SSE, explicit design or analysis is not required for the OBE. With the elimination of the OBE, the guidance for determination of the earthquake cycles described in SECY-93-087 (Reference 9) is used. Alternatively, an equivalent number of fractional vibratory cycles to that of 20 full SSE vibratory cycles may be used (but with an amplitude not less than one-third (1/3) of the maximum SSE amplitude) when derived in accordance with Appendix D of IEEE Std. 344-1987.

For floor-level excitation, this should be approximated by demonstrating that each excitation waveform will produce a response that includes the equivalent of at least ten maximum peak-stress cycles. The number of OBEs and the fatigue-inducing potential per OBE are important only for low-cycle, fatigue-sensitive equipment. The analysis should determine that the structural integrity of the equipment is maintained in combination with other applicable loads during the OBE.

3.10.2.2 Qualification by Test

The seismic testing methods are performed in accordance with the guidance of IEEE Std. 344-2004. Seismic testing is the most effective way of demonstrating operability, especially for instrumentation and for electrical components. Seismic testing is thus used to qualify these items of equipment. Generally, the seismic qualification by testing is conducted for equipment that cannot be qualified with analysis alone or equipment having components that potentially cause any malfunctions related to their intended functions.

Seismic testing is performed by subjecting equipment to vibratory motion that conservatively simulates movement at the equipment mounting while the operating conditions are simulated, and monitoring the performance of these devices during the test.

These postulated dynamic loads are generally defined by response spectra. The location(s) in the plant will determine which spectra to use. Floor response spectra are generated for specific buildings and elevations (floors) within a building as described in Subsection 3.7.2.5.

Seismic ground motion occurs simultaneously in all directions in a random fashion. Single-axis, biaxial, and triaxial testing is allowed. The single-axis test should be done in a conservative manner to account for the absence of input motion in some of the orthogonal directions. Single-axis and biaxial tests should be applied in a number of directions relative to the equipment to account for potential failure modes. An additional factor to be considered is the dynamic nature of the equipment (flexible or rigid) and the degree of cross-coupling.

a. Single-axis tests can be performed successively in the three principal orthogonal axed of the equipment at these times:

    1) when it can be proved that the coupling is zero (or very low) between the three principal axes of the equipment, taken in pairs; or

    2) when the equipment, in a seismic event, is subjected to a single excitation that may be considered as single-axis because of equipment mounting conditions. For example, if a device is normally mounted on equipment that amplifies

motion in one direction, or if the method of mounting a device constrains its motion in a particular direction, single-axis testing may be adequate.

b. Biaxial testing is acceptable if the tests conservatively reflect the seismic event at the equipment mounting locations. Coupling in equipment is considered. Biaxial testing includes simultaneous input in horizontal and vertical axes. The selection of the horizontal axis may include the principal axes or some other direction selected to expose potential failure modes by testing the equipment in its most vulnerable direction.

   Independent random inputs are preferred, and the test should be performed in two steps, with the equipment rotated 90 degrees in the horizontal plane for the second step. Statistical independence of the input motions should be reasonably assured.

   If independent inputs are not used (i.e., pseudo-biaxial), four tests should be performed: Test 1 with the inputs in phase, Test 2 with one input 180 degrees out of phase, Test 3 with the equipment rotated 90 degrees horizontally and the inputs in phase, and Test 4 with the same equipment orientation as the third test but with one input 180 degrees out of phase.

c. Triaxial tests are desirable when significant couplings exist simultaneously between the three preferred axes of the equipment. Triaxial tests must be performed with a simulator capable of independent motions in all three orthogonal directions. The input motions should be statistically independent.

d. The transient response spectra (TRS) should envelop the RRS over the frequency range of interest. The TRS should be computed with a damping value equal to or greater than that of the RRS. The shake table maximum peak acceleration should equal or exceed the ZPA of the RRS. The total test duration and number of equivalent maximum peak cycles should be per the IEEE Std. 344-2004.

3.10.2.3 Operability of Active Equipment

The supplier is to prove the operability of all active equipment before, during, and after design basis events including seismic by test and/or analysis and provide the test or analysis report as a part of the dynamic qualification report.

3.10.2.3.1 Mechanical Equipment

The methods and procedures used for qualifying active mechanical equipment (i.e., valves and pumps) are described in Subsections 3.9.3, 3.10.2, and this subsection. Analysis, test, or a combination of test and analysis are used for qualification of seismic Category I active mechanical equipment to show it maintains structural integrity and functionality. The methods are used to provide reasonable assurance of equipment operability for its intended safety-related function under required plant conditions.

Seismic Category I active mechanical equipment is designed to withstand seismic and other dynamic loads, including the intended service load conditions in the equipment design specifications, in accordance with the requirements in ASME Section III described in Subsection 3.9.3.

Seismic qualification for active mechanical equipment is in accordance with IEEE std. 344-2004, ASME QME-1, and NRC RG 1.100 as stated in Subsection 3.10.2.

For mechanical equipment, the functionality by analysis and/or tests is proven as follows:

a. Pumps

   A static deflection analysis and/or test for the shaft and rotor (if applicable) should be performed under design basis loading, including the maximum allowable nozzle loads specified in the equipment design specification. The deflection is less than the allowable/recommended deflection by the equipment supplier.

b. Valves

   The following are the acceptable methods that can be applied to demonstrate valve operability:

1) Manual Valves

Active manual valves are those that should be opened or closed after DBA. In this case, the equipment supplier is to prove that the valve moving parts (stem, disc, etc.) are not permanently damaged due to DBA along with the maximum operating and nozzle loads by analysis and/or test.

2) Check Valves

The integrity of the valve and its parts, including disc, disc support, hinge, hinge-pin, hinge-arm, and seat is proven by test and/or analysis. The valve's operability verification document should address all possible worst loading conditions on the valve during and after seismic events.

3) Other Active Valves

For seismic qualification of all other active valves, the methods and guidance in ASME QME-1-2007 are used.

c. Mechanical Drive Turbines

The operability of the mechanical drive turbine focuses primarily on the operability of auxiliary active components (valves, pumps, instruments) associated with or mounted on the turbine. The operability is determined by analysis and/or test.

d. Fans

Shaft and bearing deflections when the fan is subjected to the external design base loads are determined. The resulting clearance between the shaft and bearing as a result of these loads will be smaller than the recommended clearance by the manufacturer.

e. Diesel Engine

For the operability of the diesel engine and its auxiliary active components (valves, pumps, instruments), the methods described in NRC RG 1.9 (Reference 10) and IEEE std. 387 (Reference 11) are used.

3.10.2.3.2 Electrical and Instrumentation

The supplier is to use the qualification test methods described in Subsection 3.10.2.2 to prove the operability of active electrical and instrumentation equipment.

3.10.3 Methods and Procedures of Analysis or Testing of Supports of Mechanical and Electrical Equipment and Instrumentation

Analyses or tests are performed for all supports of mechanical and electrical equipment to provide reasonable assurance of their structural capability.

The analytical results include the required input motions to the mounted equipment obtained with the manner stated in Subsection 3.10.1.2. Combined stresses of the designed component supports are maintained within the stress limits of the *[ANSI/AISC-N690]** (Reference 12). The loads, load combinations, combined stresses, and stress criteria to demonstrate the design adequacy of cable trays, conduits, and their supports are provided in Appendix 3.9A.

For supports of mechanical (ASME Section III) equipment, the analytical results include the loads, loading combinations, and combined stress limits described in Subsection 3.9.3 for ASME Section III Class 1, 2, and 3 component supports. The jurisdictional boundary between ASME Section III Class 1, 2, and 3 component supports and the building structure are established in accordance with ASME Section III, NF.

Supports are tested with equipment installed or with a dummy simulating the equivalent equipment inertial mass effects and dynamic coupling to the support. If the equipment is installed in a nonoperational mode for the support test, the response at the equipment mounting location is monitored and characterized in the manner as stated in Subsection 3.10.2.2. In such a case, equipment is tested separately for operability and the actual input motion to the equipment in this test is to be more conservative in amplitude and frequency content than the monitored response from the support test.

3.10.4 Test and Analyses Results and Experience Database

Complete and auditable records are maintained for the plant for the life of the plant at the plant administrative facilities. These records are updated and kept current as equipment is replaced, further tested, or otherwise further qualified.

The COL applicant is to develop the equipment seismic qualification files that summarize the component's qualification, including a list of equipment classified as seismic Category I in Table 3.2-1 and seismic qualification summary data sheets (SQSDS) for each piece of safety-related seismic Category I equipment (COL 3.10(3)). The SQSDS include the following information:

a. Identification of equipment, including vendor, model number and location within each building. Valves that are part of the RCPB are identified.

b. Physical description, including dimensions, weight, and field mounting condition

c. A description of the equipment's function within the system

d. Identification of all design (functional) specifications and qualification reports, and their locations

e. Description of the required loads and their intensities for which the equipment is qualified

f. If qualified by test, identification of the test methods and procedures, important test parameters, and a summary of the test results

g. If qualified by analysis, identification of the analysis methods and assumptions and comparisons between the calculated and allowable stresses and deflections for critical elements

h. The natural frequency (or frequencies) of the equipment

i. Identification of whether the equipment is affected by vibration fatigue cycle effects and a description of the methods and criteria used to qualify the equipment for such loading conditions

j. Indication whether the equipment has met the qualification requirements

k. A compilation of the required response spectra (or time history) and corresponding damping for each seismic and dynamic load specified for the equipment together with all other loads considered in the qualification and the method of combining all loads

3.10.4.1 Implementation Program and Milestones

The COL applicant is to perform equipment seismic qualification for seismic Category I equipment and provide milestones and completion dates of equipment seismic qualification program (COL 3.10(4)).

3.10.4.2 Experience-based Qualification

Experience-based qualification is not used for any equipment.

3.10.5 Combined License Information

COL 3.10(1) The COL applicant is to provide documentation that the designs of seismic Category I SSCs are analyzed for OBE, if OBE is higher than 1/3 SSE.

COL 3.10(2) The COL applicant is to investigate if site-specific spectra generated for the COLA exceed the APR1400 design spectra in the high-frequency range. Accordingly, the COL applicant is to provide reasonable assurance of the functional performance of vibration-sensitive components in the high-frequency range.

COL 3.10(3) The COL applicant is to develop the equipment seismic qualification files that summarize the component's qualification, including a list of equipment classified as seismic Category I in Table 3.2-1 and seismic qualification summary data sheets (SQSDS) for each piece of safety-related seismic Category I equipment.

COL 3.10(4) The COL applicant is to perform equipment seismic qualification for seismic Category I equipment and provide milestones and completion dates of equipment seismic qualification program.

3.10.6 References

1. NRC RG 1.97, "Criteria for Accident Monitoring Instrumentation for Nuclear Power Plants," Rev. 4, U.S. Nuclear Regulatory Commission, June 2006.

2. Title 10, Code of Federal Regulations, Part 50, Appendix S, "Earthquake Engineering Criteria for Nuclear Power Plants," U.S. Nuclear Regulatory Commission, Washington, DC.

3. IEEE Std. 323-2003, "IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations."

4. NRC RG 1.100, "Seismic Qualification of Electric and Mechanical Equipment for Nuclear Power Plants," Rev. 3, U.S. Nuclear Regulatory Commission, September 2009.

5. IEEE Std. 344-2004, "IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations."

6. American Society of Mechanical Engineers, "ASME Boiler and Pressure Vessel Code," Section III, Division 1, 2007 Edition with 2008 Addenda.

7. American Society of Mechanical Engineers, "Qualification of Active Mechanical Equipment Used in Nuclear Power Plants," ASME QME-1-2007.

8. NRC RG 1.61, "Damping Values for Seismic Design of Nuclear Power Plants," Rev. 1, U.S. Nuclear Regulatory Commission, March 2007.

9. SECY-93-087, "Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor (ALWR) Designs," U.S. Nuclear Regulatory Commission, April 2, 1993.

10. NRC RG 1.9, "Application and Testing of Safety-Related Diesel Generators in Nuclear Power Plants," Rev. 4, U.S. Nuclear Regulatory Commission, June 2007.

11. IEEE Std. 387-1995, "IEEE Standard Criteria for Diesel-Generator Units Applied as Standby Power Supplies for Nuclear Power Generating Stations."

12. *[ANSI/AISC N690-1994,]** "Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities."