Seismic Qualification by Testing for Electrical and Active Mechanical Equipment to be Installed in Hard-Rock High Frequency Sites (PVP-2009-77098)

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Abstract

All electric and active mechanical equipment important to safety must be seismically qualified by either analysis, testing, or a combination of both. The general requirements for seismic qualification of electric and active mechanical equipment in nuclear power plants are delineated in Appendix S to Title 10, Part 50, of the Code of Federal Regulations (10 CFR Part 50), item 52.47(20) of 10 CFR 52.47, and Appendix A to 10 CFR Part 100. The staff at the US Nuclear Regulatory Commission (NRC) has recognized that the Certified Design Ground Motion may be exceeded by the site-specific ground motion. The exceedances are generally in the high-frequency range for the Central and Eastern US sites. For equipment seismic qualification consideration, the exceedances must be addressed at both the ground level and the floor level where the equipment is located. Thus, the in-structure response spectra at some locations may exceed those in-structure response spectra generated by the certified seismic design response spectra. The U.S. nuclear industry and the NRC have initiated activities to address this issue. Two scenarios that revealed themselves during the review activities of the design certification and combined license applications for new reactors will be expounded upon in the paper. In Case I, equipment seismic qualification has been approved for a certified design and equipment is to be installed

at a hard-rock high frequency (HRHF) site with certified seismic design response spectra (CSDRS) exceeded by the Ground Motion Response Spectra (GMRS) of the hard-rock site. In Case II, equipment seismic qualification has not been approved for a design certification and there is an application with GMRS exceeding the not-yet-approved CSDRS. In the paper, the staff will begin the discussion with the regulatory requirements for seismic qualification of electric and mechanical equipment. The focus of the paper is to identify the staff concern and illustrate the resolution between the NRC staff and an applicant on the seismic qualification of equipment by testing, in particular for equipment to be installed in hard-rock high frequency sites, to meet the regulatory requirements.

Introduction

The purpose of seismic qualification of equipment in nuclear power plants (NPPs) is to ensure that certain mechanical and electrical equipment (includes instrumentation and controls) will be able to perform its intended safety function during and after a postulated earthquake. For more than three decades, the nuclear industry has achieved this goal by following the guidelines provided in the industry standards developed by the Institute of Electrical and Electronics Engineers (IEEE) in the United States, such as IEEE Standard (Std) 344, "IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations."

Traditional seismic qualification of equipment for nuclear power plants is to ensure seismic adequacy of equipment subjected to simulated earthquake motions at the equipment location. These in-structure response spectra (ISRS) are generated based on either the site-independent design spectrum shape from Regulatory Guide (RG) 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants" [1] issued by the Nuclear Regulatory Commission (NRC) or other site-independent spectral shapes. These spectral shapes normally consider the frequencies up to 33 Hz [2]. More recent probabilistic hazard-based site spectral shapes for Central and Eastern United States (CEUS) may contain spectral amplification at higher frequencies and exceed the spectral amplification contained in the traditional standard RG 1.60 spectral shape. As a result, the required response spectra (RRS) (i.e, the

ISRS at the equipment locations) for the equipment seismic qualification may exceed those RRS generated by CSDRS. This paper discusses how seismic qualification by testing for equipment to be installed in hard-rock high frequency sites can be accomplished in a manner that satisfies the regulatory requirements for seismic qualification of equipment for planned CEUS nuclear power plants.

The general requirements for seismic qualification of electric and active mechanical equipment in nuclear power plants are delineated in Appendix S, "Earthquake Engineering Criteria for Nuclear Power Plants," to Title 10, Part 50 of the Code of Federal Regulations (10 CFR Part 50) [3], Item 52.47(20) of 10 CFR 52.47, "Contents of Applications; Technical Information," [4] and Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants," to 10 CFR Part 100 [5]. The vibratory ground motion includes Safe Shutdown Earthquake (SSE) Ground Motion and Operating Basis Earthquake (OBE) Ground Motion. OBE is the vibratory ground motion at which those features of the nuclear power plant necessary for continued operation without undue risk to the health and safety of the public will remain functional. SSE is the vibratory ground motion at which certain structures, systems, and components must be designed to remain functional.

In Appendix S to 10 CFR Part 50, it is stated that the OBE must be characterized by response spectra. The value of OBE must be set to one of the following choices:

(A) One-third or less of the SSE design response spectra. The requirements associated with this OBE definition can be satisfied without the applicant performing explicit responses or design analyses.

(B) A value greater than one-third of the SSE design response spectra. Analysis and design must be preformed with this OBE to demonstrate that those features of the nuclear power plant necessary for continued operation will remain functional.

Based on Case (A) above, the NRC Commissioners, in its Staff Requirements Memoranda (SRM) for the Commission Paper SECY-93-087 [6], approved the NRC staff's recommendation to eliminate the OBE evaluation analyses from design of structures, systems, and components (SSC) in nuclear power plants. However, with the elimination of the OBE, two alternatives exist that essentially maintain the requirements provided in IEEE Standard 344-1987 [7] to qualify equipment by testing with the equivalent of five OBE events followed by one SSE event (with 10 maximum stress cycles per event). Of these alternatives, the staff concluded that equipment should be qualified with five one-half SSE events followed by one full SSE event. Alternatively, a number of fractional peak cycles equivalent to the maximum peak cycles for five one-half SSE events may be used in accordance with Appendix D of IEEE Standard 344-1987 followed by one full SSE.

Regulatory and Industry Guidelines for Seismic Qualification of Equipment

One of the regulatory acceptance criteria for licensing of NPPs in the United States requires that certain safety-related equipment and systems be designed to perform their safety function during and after a postulated safe-shutdown earthquake and qualified to five OBE and one SSE [2]. All electrical and active mechanical equipment important to safety must be seismically qualified by either analysis, testing or a combination of the two. The general guidelines for accomplishing seismic qualification of equipment are delineated in Standard Review Plan (SRP) Section 3.10, “Seismic and Dynamic Qualification of Mechanical and Electrical Equipment,” [2] and supplemented by Regulatory Guide (RG) 1.100, “Seismic Qualification of Electric and Mechanical Equipment for Nuclear Power Plants.” [8]

The most commonly used methods in the nuclear industry, and acceptable to the NRC staff, for seismic qualification of mechanical and electrical equipment in NPPS could be grouped into three general categories:

(1) Predict and evaluate the equipment’s performance by analysis;

(2) Test the equipment under simulated seismic conditions;

(3) Qualify the equipment by a combination of test and analysis.

Detailed seismic qualification methods and procedures can be found in IEEE Standard 344-1987. Seismic qualification by testing is the subject of discussion in this paper.

Interim Staff Guidance on Seismic Qualification of High Frequency Sensitive Equipment

The results of recent seismic hazard studies conducted for the CEUS indicate that site-specific GMRS have relatively large high-frequency (HF) spectral acceleration content above or in exceedance of the certified seismic design response spectra. The staff recognized that, for seismic qualification of equipment, the certified design ISRS may be exceeded by the site specific ISRS for the CEUS sites and the exceedances are generally in the high frequency range.

To help address the HF seismic issues, the NRC staff provided an Interim Staff Guidance (ISG) document titled, "Interim Staff Guidance on Seismic Issues Associated with High Frequency Ground Motion in Design Certification and Combined License Applications," May 2008 [9]. The ISG provides technical positions defining specific acceptance criteria or an acceptable approach to address HF exceedances, and identifies information to be included in the design certification (DC) and combined license (COL) applications to adequately address the HF issue. Section 4 of the ISG provides staff guidance/position on addressing HF ground motion evaluations, in particular, guidance for identification and evaluation of HF sensitive mechanical and electrical equipment/components. For those cases where the GMRS-based ISRS exceed the CSDRS-based ISRS, further equipment and component functionality evaluation is needed and a screening approach is considered appropriate. These evaluations are in addition to the CSDRS-based seismic qualification program as stipulated in the approved certified design. This is considered Case I, and the purpose of the evaluation of HF sensitive equipment/component is to demonstrate that their safety-related functionality and structural integrity of the equipment are adequate to be installed at a hard-rock HF (HRHF) sites. A HF screening test is used to identify HF sensitive equipment.

In Case II, equipment seismic qualification has not been approved for a design certification and there is a COL application with site-specific GMRS exceeding CSDRS in the high frequency range. Described below are three approaches for this case.

<u>Approach I</u>: Assume that the seismic qualification of equipment for the CSDRS will be approved without modification. The HF exceedance would be addressed using the approach for Case I.

Approach II: Revise the not-yet-approved CSDRS to envelop all known site-specific GMRS. Obtain approval for seismic qualification of equipment using the revised CSDRS.

Approach III: Modify the DC equipment qualification program and qualify the plant equipment using the site-specific GMRS-based ISRS in the COL application.

Resolution of NRC Staff Concerns

The guidelines for seismic qualification of mechanical and electrical equipment by testing for equipment to be installed in hard-rock high frequency sites are delineated in the ISG. As described in the ISG section 4, in addition to the CSDRS-based seismic qualification program as stipulated in an approved certified design, for those COL applications where the GMRS-based ISRS exceed the CSGRS-based ISRS, further equipment and component functionality evaluation is needed. The screening procedure can be used to identify and evaluate HF sensitive mechanical and electrical equipment/components. Currently, an HF screening test using SSE spectra alone is used by the industry for Case I to identify screened-in or screened-out equipment and components.

During a review of this high frequency exceedance issue for Case I, the industry proposed that a successful HF screening test using one SSE of GMRS-based ISRS alone constitutes the seismic qualification of equipment for plants to be built on HRHF sites. The staff has a concern that the industry's solution fails to test the equipment with five OBEs of GMRS-based ISRS prior to the one full SSE or to provide a basis to justify the equipment was qualified for the HRHF site. As delineated in Reference 2, the equipment should be qualified with five one-half SSE events followed by one full SSE event to meet the equipment seismic qualification requirements of Appendix S to 10 CFR Part 50 and Appendix A to 10 CFR Part 100.

The industry indicated that the five OBE (one-half SSE) events and a minimum of one SSE of the CSDRS-based ISRS test runs preceding the HRHF screening test are in compliance with IEEE 344-1987. The industry further indicated that all of the CSDRS test runs can be used to address seismic aging of the equipment in the high frequency exceedance region.

In response to the NRC staff's request, the industry successfully provided justifications including the results from calculations that showed seismic qualification of electrical/electronic equipment by tests for the particular design CSDRS can be considered as equivalent to, or more than, five OBE peak stress cycles for HRHF spectra. The staff found that the justification showed that the equipment was qualified per the regulations. With a description of this in the Design Control Document of the DC, the staff can conclude that equipment potentially sensitive to HRHF satisfy the seismic qualification by tests of five OBEs (one-half SSE) and followed by one SSE HRHF spectra.

Conclusion

To satisfy the regulatory acceptance criteria for seismic qualification by testing, the equipment must be qualified to five OBEs and one SSE. When a COL application indicates that the GMRS-based ISRS exceeded the CSDRS-based ISRS, the industry should work with the NRC staff to address the HF exceedance issue. In the case when the CSDRS has not been approved (Case II), the high frequency issues can be addressed by one of the three approaches: use HF screening test to supplement the CSDRS-based qualification, modify CSDRS to envelop all sites, or qualify the equipment using site-specific spectra. In the case when the CSDRS has been approved (Case I), an acceptable approach for the seismic qualification by testing for equipment to be installed in hard-rock high frequency sites can be accomplished by the following two steps: (1) perform one successful HRHF SSE spectra screening testing, and (2) provide justifications, including calculations and demonstration, that the qualification test performed for the CSDRS can be considered as equivalent to, or more than, five OBE (one-half SSE) peak stress cycles for HRHF spectra.

References

[1] Regulatory Guide 1.60, 1973, "Design Response Spectra for Seismic Design of Nuclear Power Plants," Revision 1, U.S. Nuclear Regulatory Commission, Washington, DC.

[2] NUREG-0800, 2007, Section 3.10, "Seismic and Dynamic Qualification of Mechanical and

Electrical Equipment," Revision 3, U.S. Nuclear Regulatory Commission, Washington, DC.

[3] Title 10, Part 50, Code of Federal Regulations, "Domestic Licensing of Production and Utilization Facilities," U.S. Nuclear Regulatory Commission, Washington, DC.

[4] Title 10, Part 52, Code of Federal Regulations, "License, Certification, and Approval for Nuclear Power Plants," U.S. Nuclear Regulatory Commission, Washington, DC.

[5] Title 10, Part 100, Code of Federal Regulations, "Reactor Site Criteria," U.S. Nuclear Regulatory Commission, Washington, DC.

[6] SECY-93-087, 1993, "Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor Designs," U.S. Nuclear Regulatory Commission, Washington, DC.

[7] IEEE Std. 344-1987, 1987, "IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations," Institute of Electrical and Electronics Engineers, Inc., New York, NY.

[8] Regulatory Guide 1.100, 1988, "Seismic Qualification of Electric and Mechanical Equipment for Nuclear Power Plants," Revision 2, U.S. Nuclear Regulatory Commission, Washington, DC.

[9] Interim Staff Guidance COL/DC-ISG-1, 2008 "Interim Staff Guidance on Seismic Issues Associated with High Frequency Ground Motion in Design Certification and Combined License Applications," U.S. Nuclear Regulatory Commission, Washington, DC.