Effect of High Frequency Content of Uniform Hazard Response Spectra on Nuclear Power Plant Structures, Systems and Components

Aman Usmani[1] and Paul D Baughman[2]

[1]Amec Foster Wheeler, 4th Floor, 393 University Avenue, Toronto, ON M5G 1E6, Canada
[2]Paul D. Baughman Consulting, 1 Split Rock Road, Exeter, NH 03833, USA

ABSTRACT

The Uniform Hazard Spectrum (UHS) is developed from a probabilistic seismic hazard assessment and represents a response spectrum for which the amplitude at each frequency has a specified and uniform (equal) probability of exceedance. The high spectral acceleration at high frequencies in the UHS can result mainly from small non-damaging low energy earthquakes. Historically Canadian and U.S. nuclear power plants have been designed using the standard shape spectrum given in CSA N289.3 or USNRC Regulatory Guide 1.60, which have maximum spectral accelerations in the lower (2-10 Hz.) frequency range. The impact of the high frequency content of UHS on the nuclear power plant SSCs is required to be assessed.

This paper briefly describes the methodologies used for screening and evaluation of the effects of UHS high frequency content on the nuclear power SSCs that have been designed using the CSA N289.3 standard shape spectrum.

1. Introduction

The issue of high frequency spectral amplification in seismic response spectra has been discussed for a long time. The termination of the amplified region of "Standard Shape" (CSA N 289.3 and USNRC REG 1.60) site-independent design spectra at 33 Hz was decided based on the fact that the US west coast recorded time histories available at the time did not indicate any significant amplification of seismic motion above about 33 Hz. and the vibration tests for ship–borne equipment were also limited up to around 33 Hz. More recent seismic hazard studies for Eastern North America (ENA) have indicated amplification at higher frequencies, especially for sites on hard rock. The uniform hazard spectrum (UHS) is developed from a probabilistic seismic hazard assessment and represents a response spectrum for which the amplitude at each frequency has a specified and uniform (equal) probability of non-exceedance. The high frequency spectral amplification in the UHS results mainly from small, non-damaging, low energy earthquakes occurring close to the site. Historically, Canadian and U.S. nuclear power plants have been designed using the standard shape spectra such as those in CSA N289.3 and USNRC REG 1.60, which have maximum amplification in the lower (2-10 Hz.) frequency range. The industry is currently addressing the impact of the high frequency amplification of ENA UHS on nuclear power plant SSCs.

This paper provides the overview of the research and studies [1-4] that have been undertaken to address the issue and the methodologies used for screening [3] and evaluation of the effects of UHS high frequency amplification on nuclear power plants Based on the findings of these research studies by EPRI and others on this subject it is concluded that for the nuclear plant SSCs designed using the standard shape DBE/SSE need not be evaluated for the impact of ENA UHS high frequency contents except for the high frequency sensitive electro-mechanical components such as relays, switches, measuring instruments that have the potential to change state or interrupt a signal under the seismic loading.

2. The Issue of High Frequency Amplification

As noted in [1,11], recent seismic hazard studies for CEUS plants in 1980s and 1990s concluded that the site-specific UHS spectral shapes for the western United States (WUS) and central and eastern United States (CEUS) were markedly different (see Figure 1). UHS for CEUS sites, especially for rock sites, tended to have maximum amplification in the 20-30 Hz range as opposed to the WUS sites where the maximum amplification occurs in the 1-10 Hz range. The UHS high frequency spectral accelerations were also higher in amplitude than lower frequency spectral accelerations, given the same peak ground acceleration. Canadian and U.S. seismic networks also recorded earthquake rock motions yielding high amplitudes at higher frequencies. These findings initiated the requirements to assess the impact of high frequency contents on the plants that were designed using the standard shape spectra.

3. Empirical Data on Effect of High Frequency Amplification on the Performance of NPPs

A few plants experienced high frequency spectral accelerations from small earthquakes [1] and also from nearby excavation blasting [1, 10] that exceeded the design basis spectral accelerations. Subsequent detailed examination of SSCs showed that the nuclear plant SSCs had the capability to withstand high frequency motions without damage, and exceeding design basis spectral accelerations in the high frequency range produced no significant effects.

4. Seismic Testing Considerations on Effect of High Frequency

The seismic qualification by shake table testing of nuclear components using multi-frequency random input motion normally produces a test response spectrum (TRS) that continues to high frequency range at the peak of the required response spectrum (RRS) as shown in Figure 2, from a typical shake table test. This is due to the fact that most test facilities find it expedient to continue in the higher frequency range with the peak amplitude rather than modifying the motion to remove the high frequency amplification. This indicates that in most cases of seismic qualification for DBE/SSE by testing, the effects of high frequency content are generally covered.

EPRI recently carried out a series of shake table tests [4] of 153 components considered potentially sensitive to high frequency spectral accelerations, such as relays and contactors. The tests used two sets of table motions: (1) motions that had maximum amplification in the 4-16 Hz range, the normal range for design basis required response spectra, and (2) motions that had maximum amplification in the 20-40 Hz range. The tests showed that components capable of withstanding without malfunction a given level of spectral accelerations in the lower frequency range could withstand the same level of spectral accelerations in the higher frequency range.

5. Analytical Consideration of the Impact of High Frequency on SSCs

The major SSCs in nuclear power plants are found to have dominant frequencies in the range of less than 10 Hz. In this range the spectral acceleration values from a typical standard shape spectrum are significantly higher (see Figure 1) than those for a typical UHS. As well the displacements in the UHS high frequency range will be small due to the spectral displacement being equal to the spectral acceleration divided by the square of the frequency. Small displacements will in turn produce small strains and corresponding small stresses. There is an issue of higher loading on the equipment support. However in most cases such small displacements due to the high frequency effects can easily be accommodated by normally found gaps without generating high support loads [1].

Take an example of a typical piping system in a nuclear power plant. These systems will have dominant contributing modes in the low frequency range, and, once the residual mass is accounted for the overall conservatism in calculation of seismic stresses using the standard shape spectra will compensate for the additional loading from the high frequencies. This indicates that the major failure modes of the SSCs are well addressed using the standard shape spectra.

6. Seismic Screening of Components Sensitive to High Frequency

Figure 3, from [2], shows the recommended process for screening of high frequency sensitive components.

7. USNRC Position on High Frequency Motion

For the conduct of the IPEEE program, the USNRC issued procedural guidance (USNRC, 1991). The following quote from NUREG-1407 provides the USNRC position on the consideration of high frequency ground motion effects [1]:

"Because recent ground motion estimates, such as those included in the LLNLand EPRI hazard studies, indicate relatively higher ground motion at frequencies greater than 10 Hz than shown in the NUREG/CR-0098 spectrum, the margin evaluation of only non-ductile components – for instance, relays – that are sensitive to high frequencies should be performed as discussed(below). No plant specific response analysis is anticipated to address concerns related to high frequency ground motion."

"Attempts to address the concerns related to high-frequency ground motion by analysis is very likely to entail extensive efforts, including the development of new and much more complex building models that transmit and amplify high frequency input and generate accurate and meaningful floor spectra at high frequencies. Estimates of high-frequency amplification in cabinets containing relays will also have to be developed. Rather than using analysis, the following approach is more suitable:

1. Prepare a list of relays that are known to have high-frequency sensitivity.

2. Screen relays that are known to have very high HCLPFs (that is, eliminate them from further consideration without performing specific response calculations).

3. Assume that the remaining relays will chatter at the review level earthquake.

4. Screen the remaining relays by showing either the circuitry is insensitive to high-frequency chatter or that they can be recovered from changes of state and associated false alarms.

Regulatory Precedents for the Acceptance of High Frequency Motion

5. Finally, replace the remaining relays with relays that are not sensitive to high frequency (an alternative approach is to show that the remaining relays are rugged by conducting tests)."

8. Summary and Conclusion

The issue of high frequency contents has been researched and studied [1, 4] over a few decades. The finding from these studies continue to support the conclusion that for the nuclear plant SSCs designed using the standard shape DBE/SSE need not be evaluated for the impact of ENA UHS high frequency contents except for the high frequency sensitive electro-mechanical components such as relays, switches, measuring instruments that have the potential to change state or interrupt a signal under the seismic loading.

9. References & Bibliography

[1] Program on Technology Innovation: The Effects of High Frequency Ground Motion on Structures, Components, and Equipment in Nuclear Power Plants. EPRI, Palo Alto, CA: 2007. 1015108.

[2] Program on Technology Innovation: Seismic Screening of Components Sensitive to High-Frequency Vibratory Motions. EPRI, Palo Alto, CA: 2007. 1015109.

[3] High Frequency Program: Phase 1 Seismic Test Summary. EPRI, Palo Alto, CA: 2013. 3002000706

[4] High Frequency Program: High Frequency Testing Summary. EPRI, Palo Alto, CA: 2014. 3002002997

[5] CAN3-N289.1, General Requirements for Seismic Qualification of CANDU Nuclear Power Plants

[6] CAN3-N289.2, Ground Motion Determination for Seismic Qualification of CANDU Nuclear Power Plants

[7] CAN3-N289.3, Design Procedures for Seismic Qualification of CANDU Nuclear Power Plants

[8] CAN3-N289.4, Testing Procedures for Seismic Qualification of CANDU Nuclear Power Plants

[9] CAN3-N289.5, Instrumentation, Inspection and Records for Seismic Qualification of CANDU Nuclear Power Plants

[10] A. Usmani, "Effects from Excavation Blasting on Nuclear Power Plant Operation", ASME PVP Conference, Pipe Dynamics, PVP Vol. 180. Honolulu Hawaii, July 1989

[11] G. Atkinson and M. Elgohary, "Typical uniform hazard spectra for eastern North American sites at low probability levels, Can. J. Civ. Eng. 34:12-18 (2007)

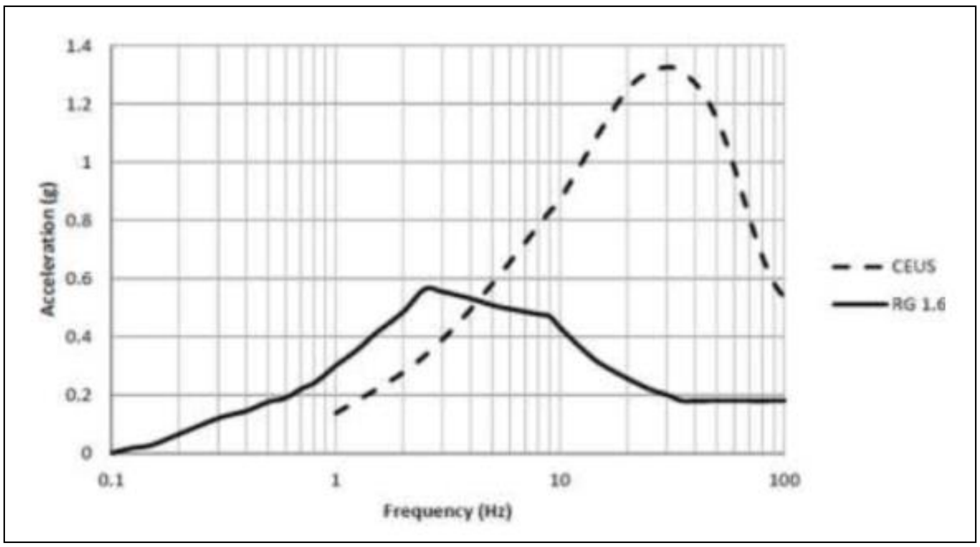

FIGURE 1: Comparison of a Typical UHS and standard shape DBE

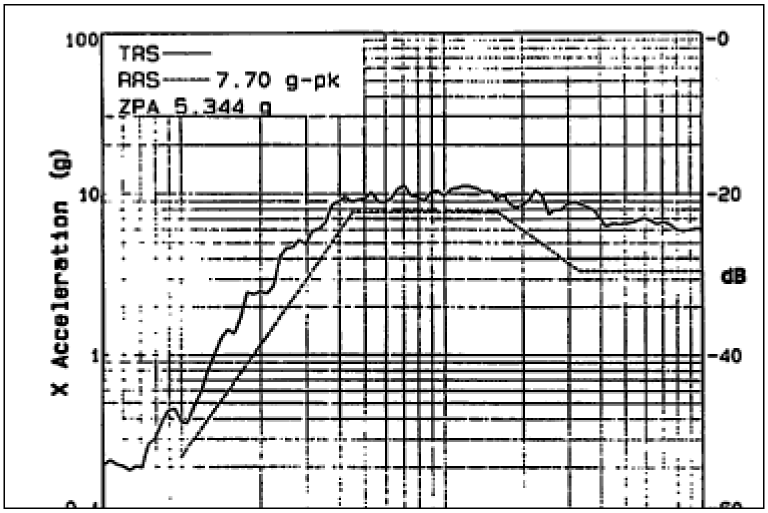

FIGURE 2: Typical Comparison of TRS and RRS from a Shake Table Test

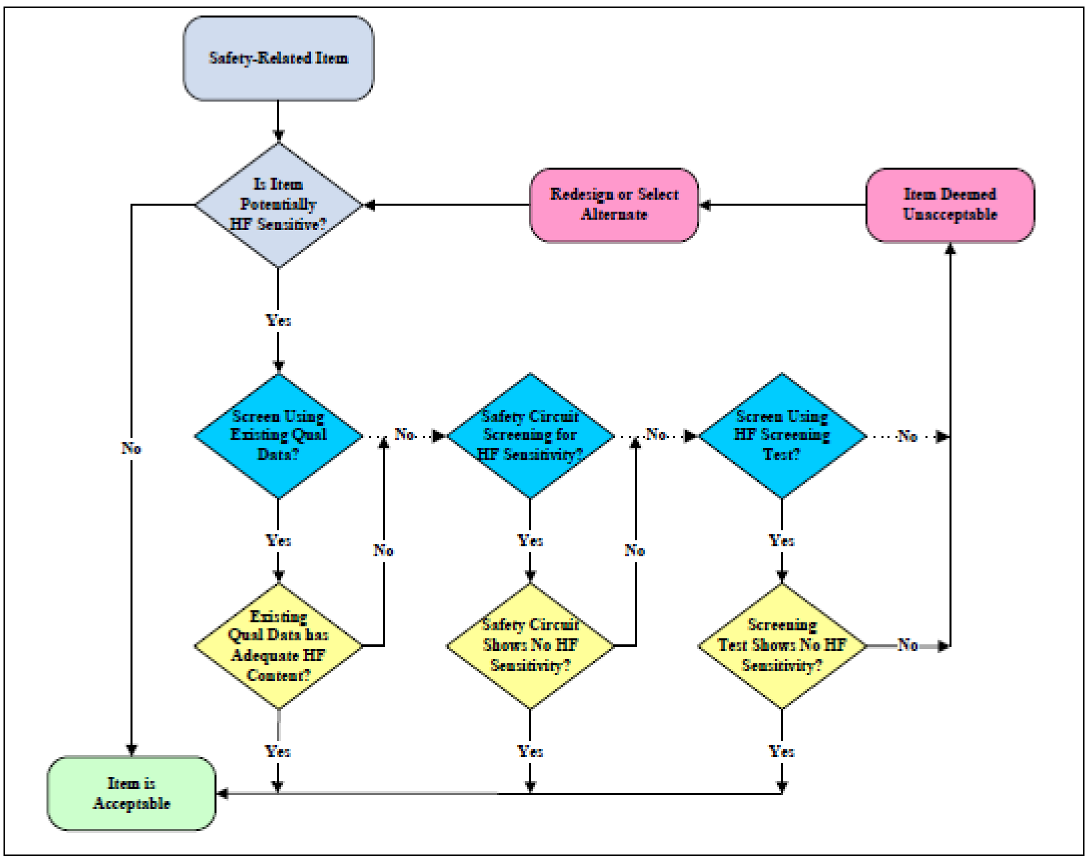

FIGURE 3: High Frequency Screening Process [2]