CERTIFIED SEISMIC DESIGN RESPONSE SPECTRA AND TIME HISTORY GENERATION FOR ADVANCED REACTOR LICENSE SUBMITTAL

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ABSTRACT

This paper presents a summary of the work performed to develop certified seismic design response spectra (CSDRS) and compatible acceleration time histories for designing small modular reactors (SMRs) developed by NuScale Power. The intent is to submit the design to the United States Nuclear Regulatory Commission (NRC), and the CSDRS will be used to design the systems, structures, and components (SSCs) for a generic site design control document (DCD).

Historically, when submitting a license for generic nuclear power plant (NPP) design vendors utilized the response spectra described in Regulatory Guide 1.60 and anchored the zero period acceleration (ZPA) at 0.3g. This approach, while technically sound typically resulted in some rework when actual site specific data was available, usually in the combined operating license process; the spectral shape from generic spectra varied from the spectral shape of the site specific spectra. As such an effort was undertaken to envelope actual site specific spectra with the intent to develop a more realistic and bounding CSDRS for the licensing of new nuclear power plants (NPPs) at generic sites. In addition, the reactor building for the NuScale power plant is a deeply embedded structure. For performing seismic soil-structure interaction (SSI) analysis to determine the seismic design responses, synthetic time histories need to be developed to match the target seismic response spectra. For the design, the target response spectra are the CSDRS and Generic High Frequency Hard Rock Response Spectra (GHFHRRS). The synthetic time histories are based on criteria from ASCE/SEI 43-05 and the NRC Standard Review Plan (NUREG 0800) Section 3.7.1. The spectral amplitudes resulting from the synthetic time histories are compared with the target spectra for 5% damping and found acceptable to meet the criteria. The range of frequencies considered is from 0.1 Hz to 100 Hz for the CSDRS and 0.1 Hz to 120 Hz for GHFHRRS. The total duration of the synthetic time history is 24 seconds. All three orthogonal (North-South, East-West and Vertical) synthetic time histories are statistically independent, meeting the cross coupling coefficients to be far less than the acceptable value of 0.16.

INTRODUCTION

Described herein is the methodology used to develop conservative generic ground response spectra to be employed in the design of the NuScale nuclear power plant. Recent design response spectra from numerous proposed new plant sites were utilized to prepare the response spectra. Each response spectrum is a product of a comprehensive effort in the geo-science area and is in accordance with the most recent regulatory requirements. The NuScale design has the benefit of using data not available a few years ago. The development of NuScale Certified Seismic Design Response Spectra (CSDRS) utilizes "high-level" (ZPA greater than 0.5g) representative ground response spectra to cover most of the proposed plant sites (i.e. soft sites, hard/rock, and Western sites) in the U.S. In addition, the information from a U.S. Department of Energy (DOE) site and one operating nuclear power plant site (Diablo Canyon) was selected. These ground spectra were digitized and enveloped.

Once the response spectra were established the next step was to generate the synthetic acceleration time histories which closely match the target response spectra for the NuScale nuclear power plant. The synthetic time histories are generated to be compatible with both the horizontal and vertical CSDRS and GHFHRRS. In general, response spectrum compatible acceleration time histories are not available. Therefore, a process of generating a time history to match the target response spectrum was used. The computer program MICRO-SEIM, provided a method of obtaining the synthetic time history for a given target response spectrum [1, 2, and 5]. The spectrum compatible synthetic acceleration time histories are required for performing seismic soil-structure interaction analysis to produce seismic design response accelerations, seismic design forces and moments, and In-structure Response Spectra (ISRS) for the seismic analysis of the NuScale SSCs.

DEVELOPMENT OF GENERIC GROUND MOTION RESPONSE SPECTRA

Collection of Response Spectra

The first step we took in establishing the generic ground motion response spectra was to research the response spectra data available for proposed new nuclear power plant sites. The NRC's website provides a map of the new project sites in the United State and we used that as a starting point for establishing data. Our objective was to create conservative ground motion response spectra that will allow the NuScale plant to be designed adequately in the design certification stage so that little rework would be required when a site is established. Consideration was also given to a variety of soil types to ensure that an appropriate envelope would be developed. It was decided that the response spectra used in the proposed designs of selected new U.S. plant sites, a DOE site, and an operating nuclear power plant located in the coastal high seismic zone in California would be used to develop the generic response spectra, which is also defined as Certified Seismic Design Response Spectra (CSDRS). Ten (10) selected sets of response spectra from eight (8) locations were chosen to provide the highest response spectra for the various site characteristics representative of most of the U.S. and many international sites. The selected sites and generic response spectra selected are summarized in Table 1.

Table 1-Selected Sites and Response Spectra

No.	Site Description	Site Characteristic	PGA
1	Southern US	Soil Site	0.30g
2	South East US	Soil Site	0.30g
3	Southern US	Soil Site	0.30g
4	North East US	Soft Site, Medium Site, Hard Site	0.30g
5	Mid West US	Hard/Rock Site	0.25g
6	DOE Site (North West US)	Soil Site	0.26g Horizontal; 0.19g Vertical
7	Modified Newmark-Hall Generic Response Spectra	Covers Most Soft and Medium Soil Sites	0.50g (vertical is increased from 0.33g to 0.50g)
8	North East US	Hard/Rock Site	0.52g
9	South East US	Soft & Hard/Rock Sites	0.30g
10	Diablo Canyon Nuclear Power Plant	-	0.83g Horizontal; 0.70g Vertical

Envelope Response Spectra

All of the selected horizontal and vertical response spectra for the development of the envelope spectra are shown together in Figure 1 and Figure 2, respectively.

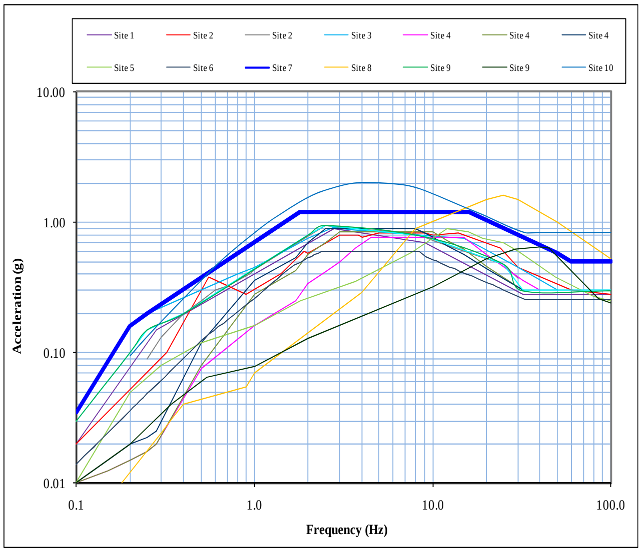

Figure 1-Plots of All Selected Horiz. Response Spectra

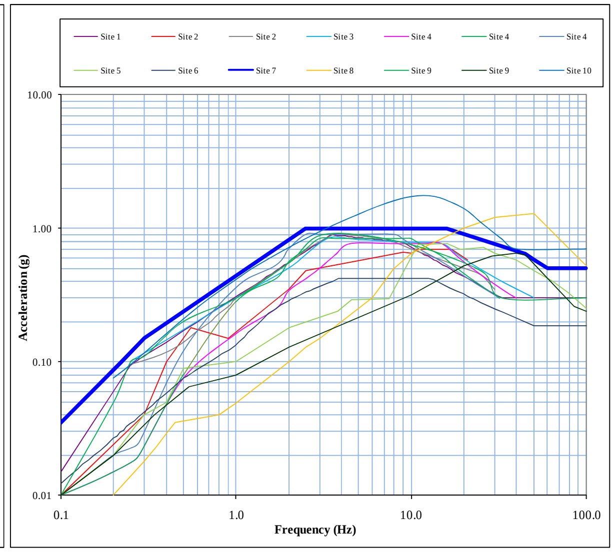

Figure 2-Plots of All Selected Vert. Response Spectra

From these selected response spectra, four sets of generic envelope response spectra were developed:

- Set #1- to envelope all sites,
- Set #2- to envelope all sites except the high seismic west coast sites,
- Set #3- to envelope all sites except the high seismic west coast sites and hard/rock sites,
- Set #4- to envelope all horizontal and vertical high frequency hard/rock sites.

Response Spectra Chosen for Design

Since the proposed response spectra were obtained by enveloping the response spectra from the existing DCDs submitted by several new plant licensees to the NRC and other hard/rock and west coast site (see Table 1), the proposed sets of response spectra can be used for the majority of the U.S. new nuclear power plant sites.

Set #1 was developed to cover all U.S. sites and most international sites. However, this high seismic response spectrum set could result in excessive cost ramifications and therefore should not be used. Set #2 is determined to be too unrealistic, due to its unusual spectrum shapes, to be representative of real earthquakes. Thus, we decided that this set will not be considered for the NuScale design.

After a careful review of all four sets of response spectra, it was determined that the response spectra Set #3 will be used as the final Certified Seismic Design Response Spectra (CSDRS). Set #3 covers most of the U.S. sites except west coastal sites and some high seismic regions in California. This set is considered as the optimum response spectra for the NuScale design. The horizontal and vertical CSDRS can be seen in Figure 3 and Figure 4, respectively.

A separate evaluation will be performed for the high frequency hard/rock sites using the response spectra Set #4. These generic high frequency hard/rock response spectra (GHFHRRS) will not include the low frequency content of the CSDRS which is applicable for the softer or western US sites. The benefits of high frequency incoherency of the input ground motion will be considered as a separate evaluation for the GHFHRRS. The horizontal and vertical spectra can be seen in Figures 5 and 6, respectively.

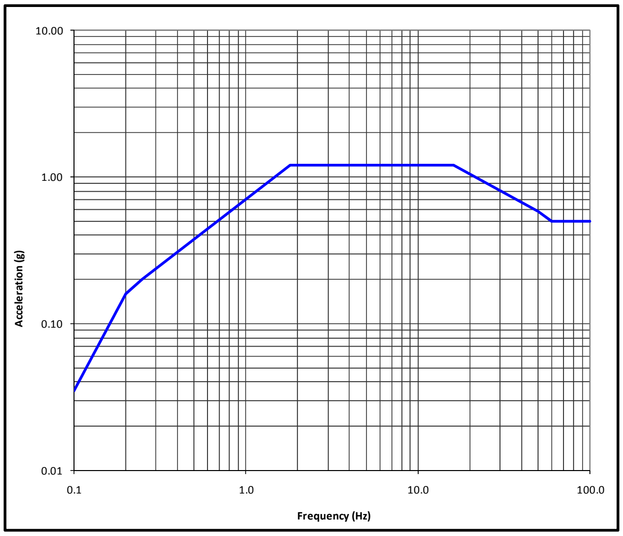

Figure 3-Set #3-Horizontal CSDRS

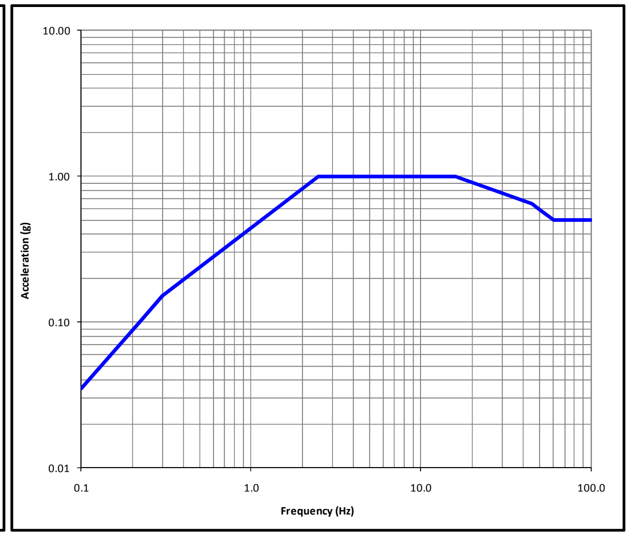

Figure 4-Set #3-Vertical CSDRS

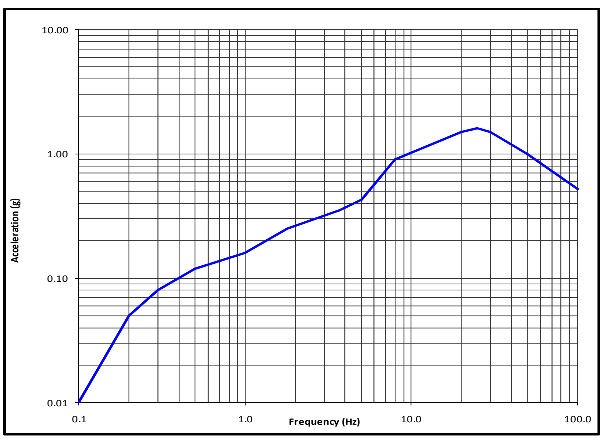

Figure 5-Set #4-Horizontal GHFHRS

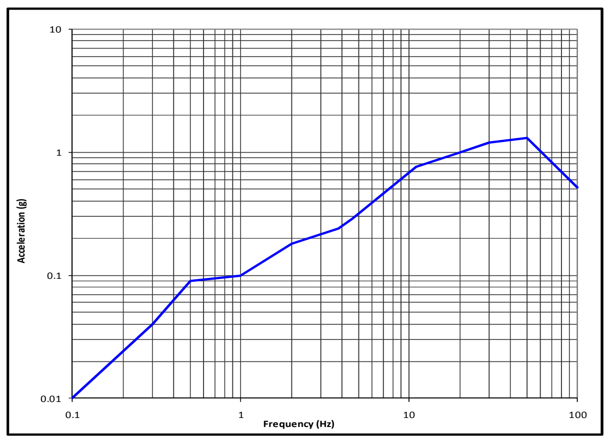

Figure 6-Set #4-Vertical GHFHRS

SYNTHETIC TIME HISTORY GENERATION

Development of Synthetic Seismic Acceleration Time Histories

The development of the synthetic spectrum compatible time histories using the CSDRS and GHFHRRS as the target spectra are required to comply with the criteria or requirements set forth by the two following documents:

- ASCE/SEI 43-05 [3], Section 2.4 (a) through (f); and
- NUREG-0800 [4], SRP 3.7.1 II ACCEPTANCE CRITERIA. SRP Acceptance Criteria. 1 Design Ground Motion. B. Design Time Histories. Option 1: Single Set of Time Histories. Ii. Approach 2 (a) through (d).

The objective was to generate synthetic time histories which achieve a mean based fit to the target response spectrum and do not have significant gaps in the Fourier amplitude spectrum or the response spectrum.

The MICRO-SEIM computer program was used to generate the synthetic time histories in each of the three mutually orthogonal directions, namely North-South, East-West and Vertical directions for each of the two target response spectra sets, CSDRS and GHFHRRS. The verification of generation of intermediate response spectrum values for each time history is performed by independent analyses using the SAP2000 computer program [6].

Spectrum Compatible Time History Generation Results for CSDRS Target Spectra

The details for the development of the synthetic time histories for the Certified Seismic Design Response Spectra (CSDRS) are provided as follows:

- CSDRS for 5% damping were used for the development of synthetic time histories in the North-South, East-West, and Vertical directions.
- All three time histories were statistically independent with cross-correlation coefficients less than 0.16.
- Baseline correction was applied to each time history.
- Time history duration was 24 seconds.
- Frequency range was 1 to 100 Hz.
- Time history time step was 0.002 seconds.
- Total number of acceleration data points for each time history was 12,000.

Figure 7 through Figure 12 provide the plots for all three CSDRS response spectrum compatible synthetic time histories and comparison between the target response spectra and those obtained from the corresponding synthetic time histories.

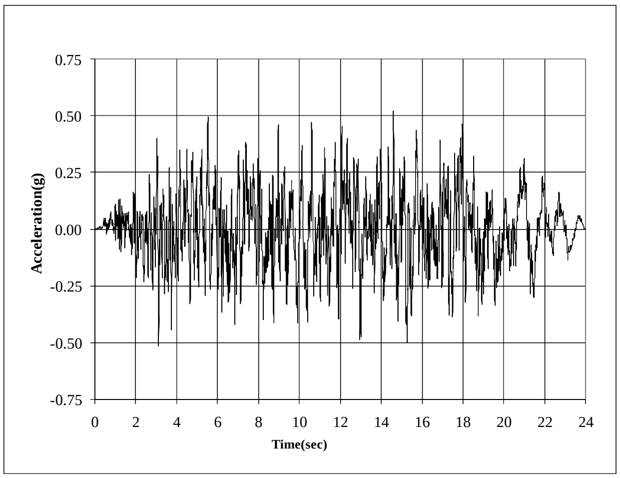

Figure 7-N/S CSDRS Acceleration Time History

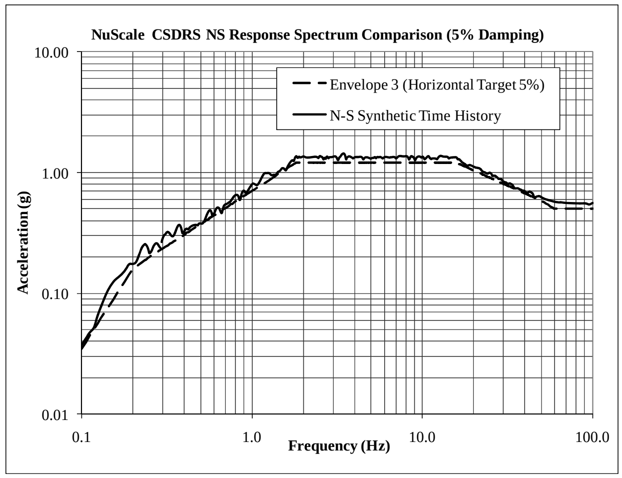

Figure 8-N/S CSDRS Response Spectrum

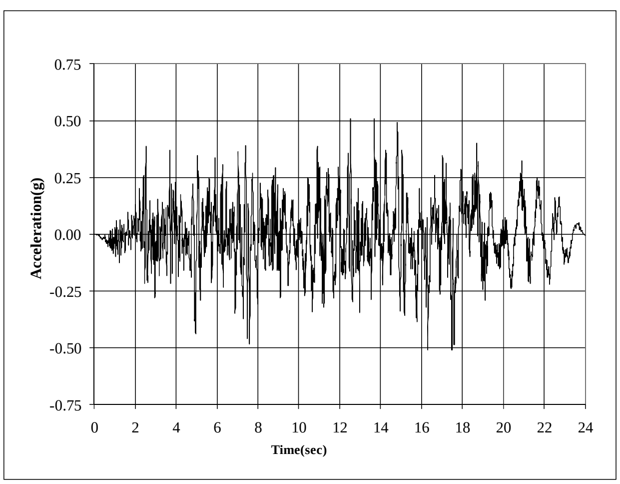

Figure 9-E/W CSDRS Acceleration Time History

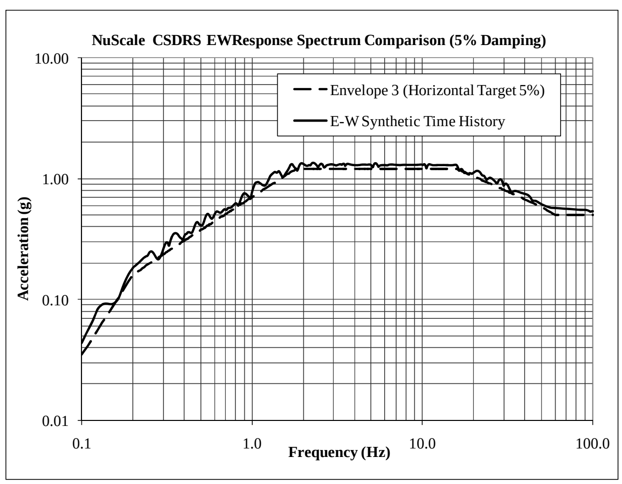

Figure 10-E/W CSDRS Response Spectrum

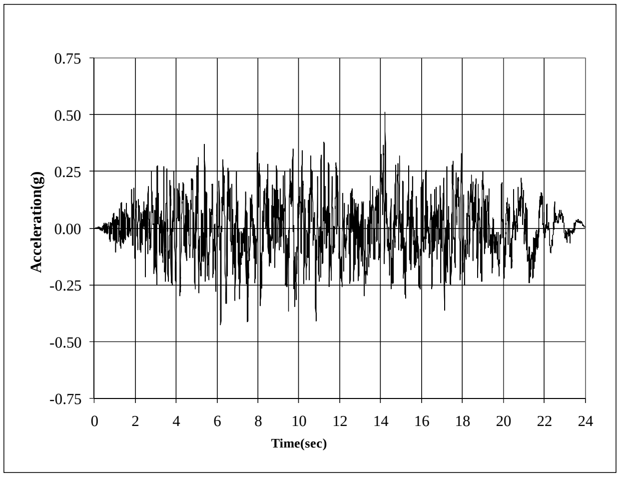

Figure 11-Vertical CSDRS Acceleration Time History

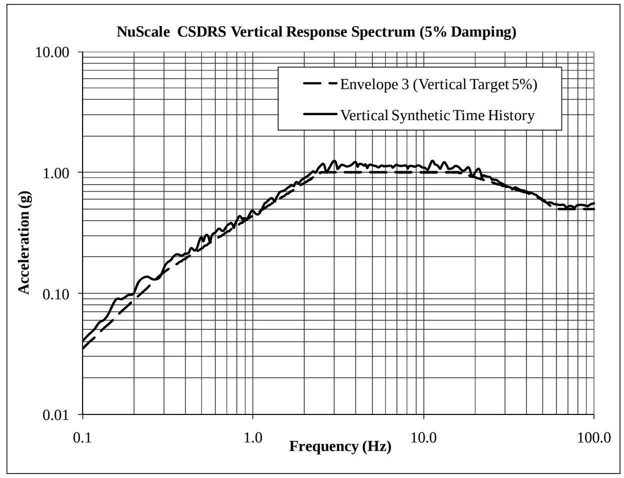

Figure 12-Vertical CSDRS Response Spectrum

Spectrum Compatible Time History Generation Results for GHFHRRS Target Spectra

The details for the development of the synthetic time histories for the Generic High Frequency Hard/Rock Response Spectra (GHFHRRS) are provided as follows:

- GHFHRRS for 5% damping were used for the development of synthetic time histories in the North-South, East-West, and Vertical directions.
- All three time histories were statistically independent with cross-correlation coefficients less than 0.16.
- Baseline correction was applied to each time history.
- Time history duration was 24 seconds.
- Frequency range was 1 to 120 Hz.
- Time history time step was 0.001667 seconds.
- Total number of acceleration data points for each time history was 14,400.

Figure 13 through Figure 18 provide the plots for all three GHFHRRS response spectrum compatible synthetic time histories and comparison of the target response spectra and those obtained from the corresponding synthetic time histories.

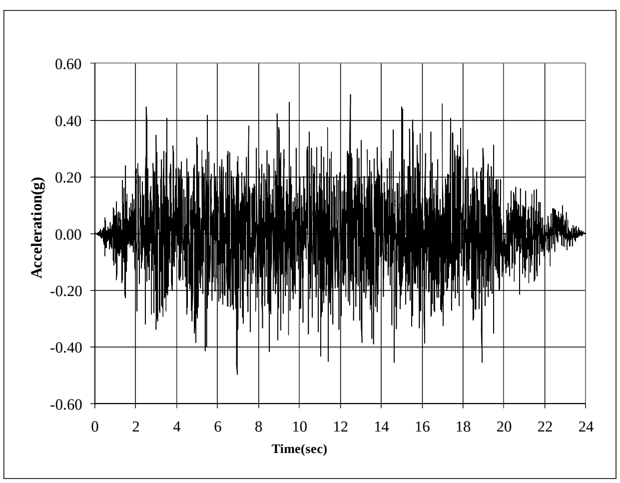

Figure 13-N/S GHFHRRS Acceleration Time History

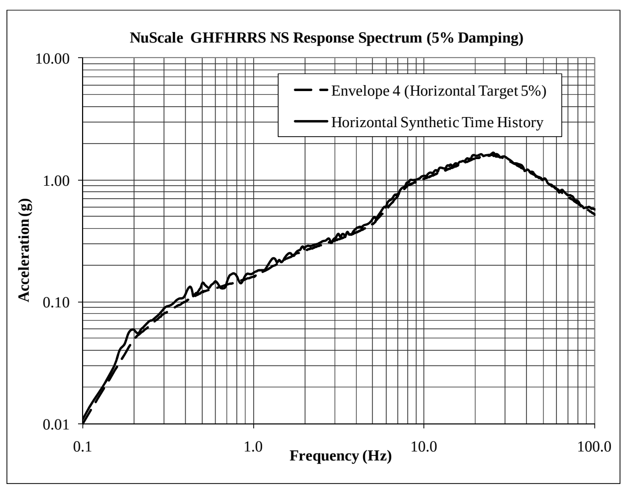

Figure 14-N/S GHFHRRS Response Spectrum

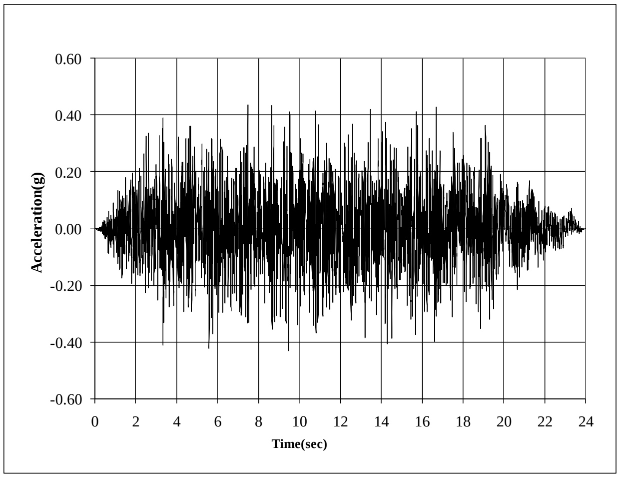

Figure 15-E/W GHFHRRS Acceleration Time History

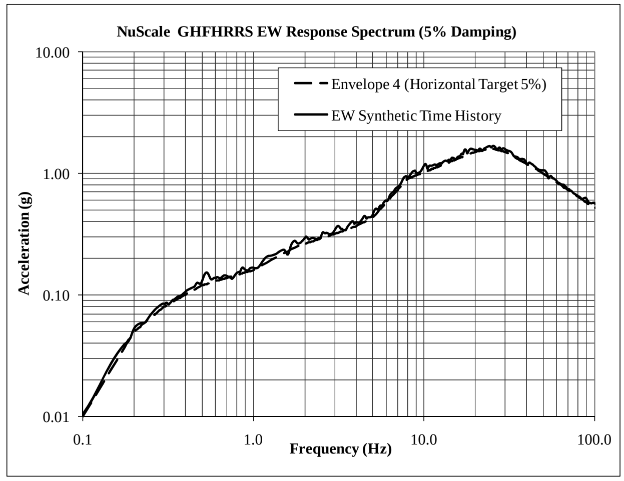

Figure 16-E/W GHFHRRS Response Spectrum

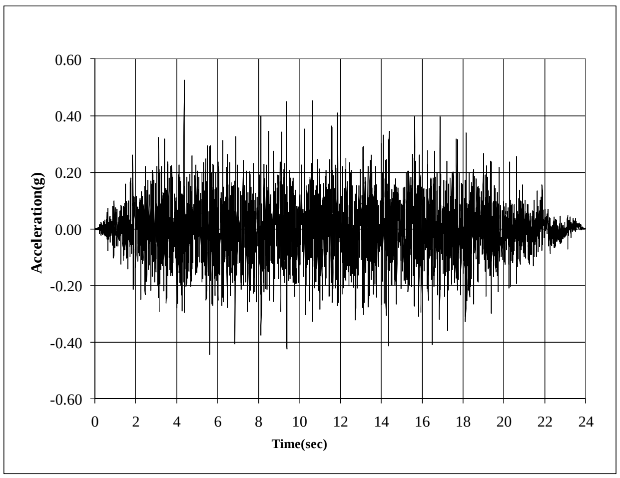

Figure 17-Vertical GHFHRRS Acceleration Time History

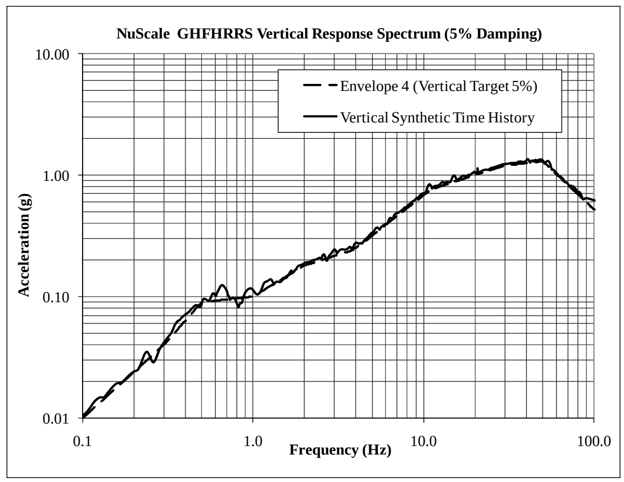

Figure 18-Vertical GHFHRRS Response Spectrum

Cross-Correlation Coefficients

The cross-correlation coefficients of the spectrum-compatible synthetic time histories are listed in Table-2. All cross-correlation coefficients are much less than the maximum allowed value of 0.16 [4] to imply that any two components are statistically independent.

Table 2-Cross-Correlation Coefficients

Coupling Components	CSDRS	GHFHRRS
North-South/East-West	0.016	0.015
East-West/Vertical	0.094	0.013
North-South /Vertical	0.064	0.043

CONCLUSION

To develop generic ground response spectra for the NuScale power plant, a conservative methodology was developed in which several ground motion response spectra were analyzed to form composite enveloping spectra. The intent was to encompass a significant portion of the United States such that a NuScale Power Plant could be sited in a variety of locations. The result was a robust and broad CSDRS and GHFHRRS.

Additionally, we generated synthetic time histories in each of the three mutually orthogonal directions. The process for generating the synthetic time histories is described in ASCE/SEI 43-05 and NRC Standard Review Plan NUREG-0800 Section 3.7.1. The synthetic time histories will be used in future analyses for the NuScale design.

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