Soil Structure Interaction Effects on a Main Steam Valve House Structure

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EPRI Project Manager
R. Kassawara

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

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Bechtel Power Corporation
5275 Westview Drive
Frederick, MD 21703

Principal Investigator
L. Anderson

Bechtel National, Inc.
50 Beale Street
San Francisco, CA 94105

Principal Investigator
A. Hashemi

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ABSTRACT

This report provides a study of the effect of Soil-Structure Interaction (SSI) on a Main Steam Valve House (MSVH) structure subject to the Design Basis Earthquake (DBE) for the plant, the Combined Operating License Application (COLA) Ground Motion Response Spectra (GMRS) for a rock site, and a recorded Central and Eastern United States (CEUS) earthquake event. The current industry position is that structural dynamic analysis for existing plants that are rock-founded (i.e. with shear wave velocity > 3500 fps) may be completed without consideration of SSI effects. As a relatively stiff structure, with 1st mode natural frequencies of 9.9 Hz and 6.2 Hz in the X and Y directions, respectively, the structure considered provides an applicable example to evaluate this industry position.

In-Structure Response Spectra (ISRS) at various elevations of the structure due to all three input motions are generated and compared for the fixed-base, 3500 fps rock profile, and a site-specific rock profile representative of the CEUS rock conditions.

Keywords
SSI, soil-structure interaction, fixed-base.

EXECUTIVE SUMMARY

This report provides a study of the effect of Soil-Structure Interaction (SSI) on a Main Steam Valve House (MSVH) structure as an example to evaluate the industry position on the structural dynamic analysis approach for existing plants that are rock-founded.

The key findings of this report are summarized below. Note that given the limited accuracy of the Lumped-Mass and Stick Model (LMSM) above 10 Hz, and the applicable frequency range in the context of Seismic Probabilistic Risk Assessment (SPRA), the response of the structure below 10 Hz is emphasized.

1. The Soil-Structure Interaction (SSI) effects are noticeable for both rock profiles considered at frequencies of above 5 Hz. In general, these effects below 10 Hz are usually characterized by a small shift in frequency and amplification of the peak In-Structure Response Spectra (ISRS) up to 40% over a narrow band of frequencies. These effects are more noticeable at higher levels in the structure indicating some degree of foundation rocking.
2. The differences between the ISRS obtained from the site-specific rock profile (top Vs of 5200 ft/sec) and the Hard Rock profile below 10 Hz, for all three input ground motions, are not significant. This suggests that the use of fixed-base results (for the response below 10 Hz) for the subject structure on this profile is reasonable.
3. The comparison between the 3500 fps response and Hard Rock response below 10 Hz suggests that the peak ISRS from the SSI response maybe between 90% and 140% of the fixed-base ISRS. Also, a slight shift of frequency is observed in the spectral peaks. Nevertheless, the shapes of the ISRS in the entire frequency range remain about the same. These observations suggest that the use of fixed-base results (for the response below 10 Hz) for the subject structure on this profile is appropriate only if one can accept potential small frequency and amplitude shifts of the spectral peaks. The peak-broadening or peak-shifting of the ISRS can alleviate such frequency shift effects.
4. The consideration of different input time-histories does not significantly alter the findings above. However, a closer agreement between the results of different rock profiles is observed below 10 Hz when considering the representative Combined Operating License Application (COLA) input time-history. This is due to the high frequency nature of this ground motion with less energy content below 10 Hz.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1
INTRODUCTION

This report provides a study of the effect of Soil-Structure Interaction (SSI) on a Main Steam Valve House structure subject to the Design Basis Earthquake (DBE) for the plant, the Combined Operating License Application (COLA) Ground Motion Response Spectra (GMRS) for a rock site, and a recorded Central and Eastern United States (CEUS) earthquake event.. The current industry position is that structural dynamic analysis for existing plants that are rock-founded (i.e. with shear wave velocity > 3500 fps) may be completed without consideration of SSI effects. As a relatively stiff structure, with 1st mode natural frequencies of 9.9 Hz and 6.2 Hz in the X and Y directions, the structure considered will provide an example to evaluate this industry position.

In-Structure Response Spectra (ISRS) at various elevations of the structure will be generated for three different input time-histories and compared for the fixed-base, 3500 fps rock profile, and representative site-specific rock profile.

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Soil Structure Interaction Effects on a Nuclear Main Steam Valve House Structure. EPRI, Palo Alto, CA: <2012>. <070083>.

2
ASSUMPTIONS

The following assumptions are made throughout this report:

1. Lumped mass models cannot reflect flexibility of floors. Therefore, the model generated in this report assumes rigid floor systems.
2. The Lumped Mass and Stick Model (LMSM) uses a single stick at the center of rigidity to represent all structural walls in the building. This necessitates the assumption of a rigid foundation (using rigid beams) for the SSI analysis model to ensure proper connection of the LMSM to the foundation mesh.

3
METHODOLOGY

Lumped-Mass Stick Model Generation

The lumped-mass stick model of the structure is created using SAP2000, Version 15.0.0.

Modal analyses are completed and the frequencies corresponding to the dominant modes are shown in Table 1.

Table 1- Dominant Modes

Direction	Dominant Frequencies (Hz)
X	9.88
Y	6.16
Z	20.99

A complete listing of modal frequencies and mass participations is shown in Appendix A.

Soil-Structure Interaction Analysis

Structural Model

A mass-less shell representation of the foundation mat is added to the SAP2000 model, to prepare the model for use in subsequent SSI analysis. A series of rigid beam elements are added to the shell foundation, so as to rigidly transfer load from the lumped-mass stick model to the major shear wall locations. For the rigid beams a shear stiffness (EA) of 1000000 kips (1 kips = 4.45 MN) and a flexural stiffness (EI) of 10000000 kip-ft^2 (1 ft = 0.3048 m) is used. The shell elements are 4ft thick and assume an elastic modulus of 449570 ksf.

An isometric view of the SAP2000 model is shown in Figure 1. A plan view of the rigid shell foundation and the rigid beams used to connect the lumped-mass stick to the model are shown in Figure 2.

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Soil Structure Interaction Effects on a Nuclear Safety-Related Structure in the Central Eastern United States. EPRI, Palo Alto, CA: <2012>. <070083>.

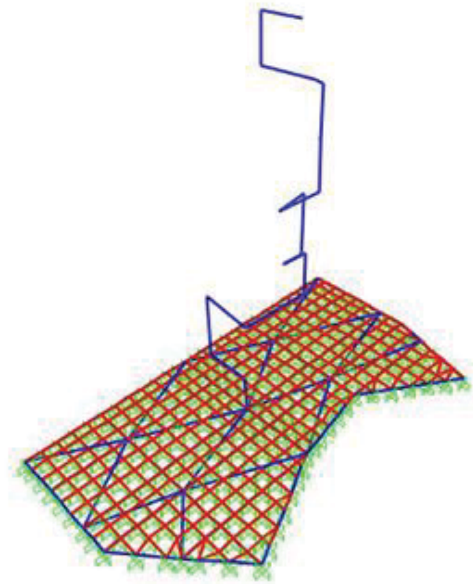

Figure 1 - Isometric View of SAP2000 Model

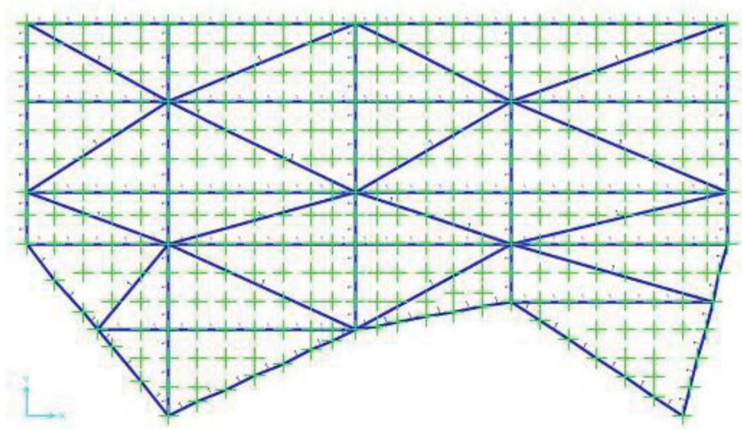

Figure 2 - Plan View of Rigid Shell Foundation Model

The SAP2000 model is then translated to SASSI2010 computer code. All nodes on the shell foundation are used as interaction points with the subsurface rock. In order to ensure the accuracy of the translation, a fixed-base condition is emulated in SASSI2010, using a Hard Rock (HR) profile. Note that the X, Y, and Z directions in the model refer to the East-West, North-South, and vertical directions in the MSVH structure, respectively.

For the HR profile, the shear wave velocity is taken as 20,000 fps, with a Poisson ratio of 0.30, and 1% damping ratio. The soil/rock density is taken as 0.15 kcf.

Transfer functions are computed for every lumped-mass node and post-processed using the SASSI Post-processing Toolbox developed using Matlab. The HR transfer functions are shown for response in the X, Y, and Z directions in Figures 3, 4, and 5, respectively. The analysis is carried out up to 50 Hz frequency with calculated frequencies indicated in each plot.

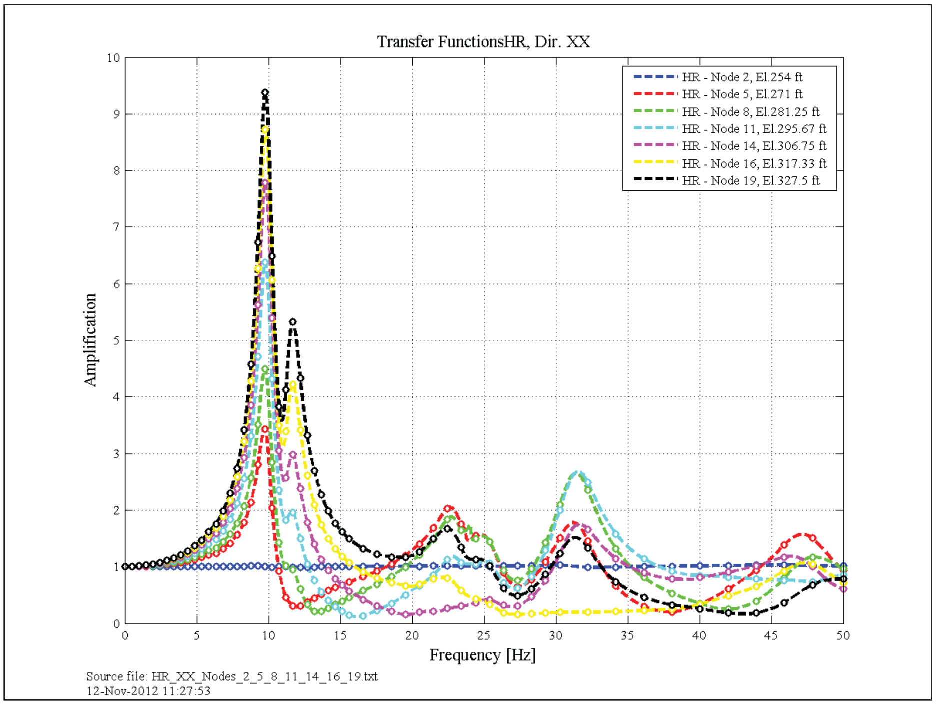

Figure 3 - Hard Rock X-Direction Transfer Functions

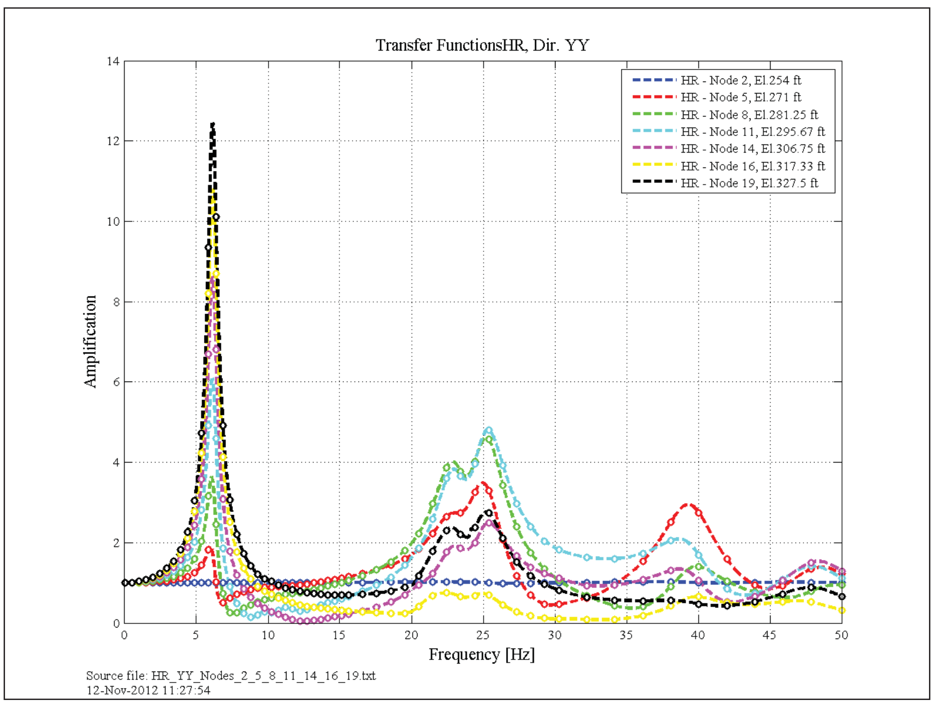

Figure 4 - Hard Rock Y-Direction Transfer Functions

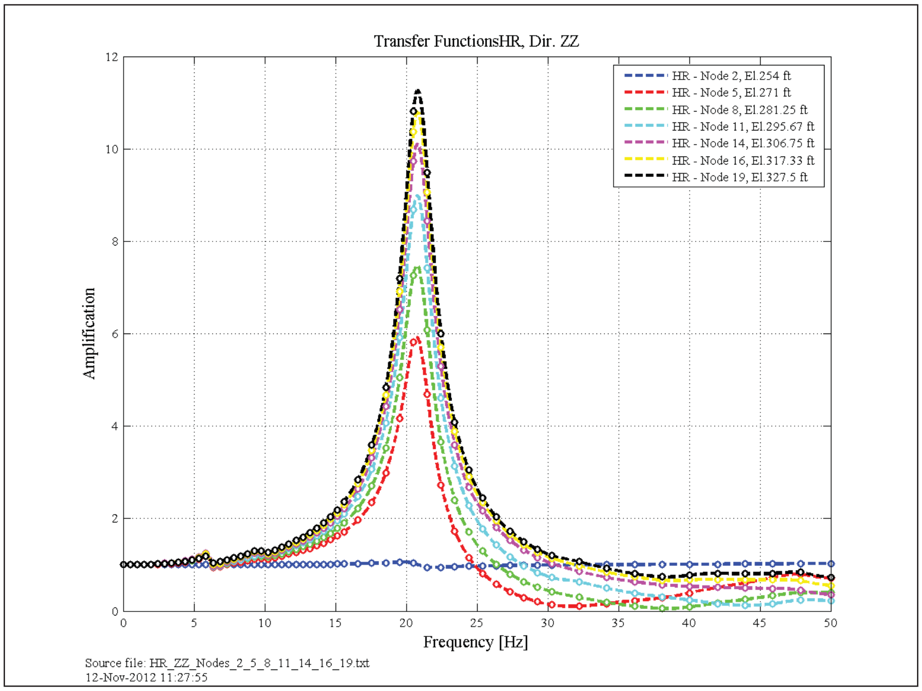

Figure 5 - Hard Rock Z-Direction Transfer Functions

The frequencies of the peaks of the HR transfer functions align with the corresponding dominant modal frequency resulting from the modal analyses. This confirms the accurate translation of the SAP2000 model to SASSI2010 computer code.

Also note that the transfer function amplitude for Node 2 (top of foundation) is unity for the frequency range of interest (below 50 Hz) which confirms the adequacy of the shear-wave velocity assumed for rock as well as adequate rigidity of the added foundation elements.

The HR transfer functions are shown for the coupling terms, X-Response due to Y-Motion (XY), Y-Response due to X-Motion (YX), Z-Response due to X-Motion (ZX), and Z-Response due to Y-Motion (ZY) in Figures 6, 7, 8, and 9, respectively.

The coupling transfer functions for the HR case identify the major structural torsional modes (XY and YX responses, e.g. at approximately 25 Hz) as well as important rocking modes (ZX and ZY responses). Also note that the response of Node 2 (top of foundation) is negligible which confirms the adequacy of the selected hard rock properties.

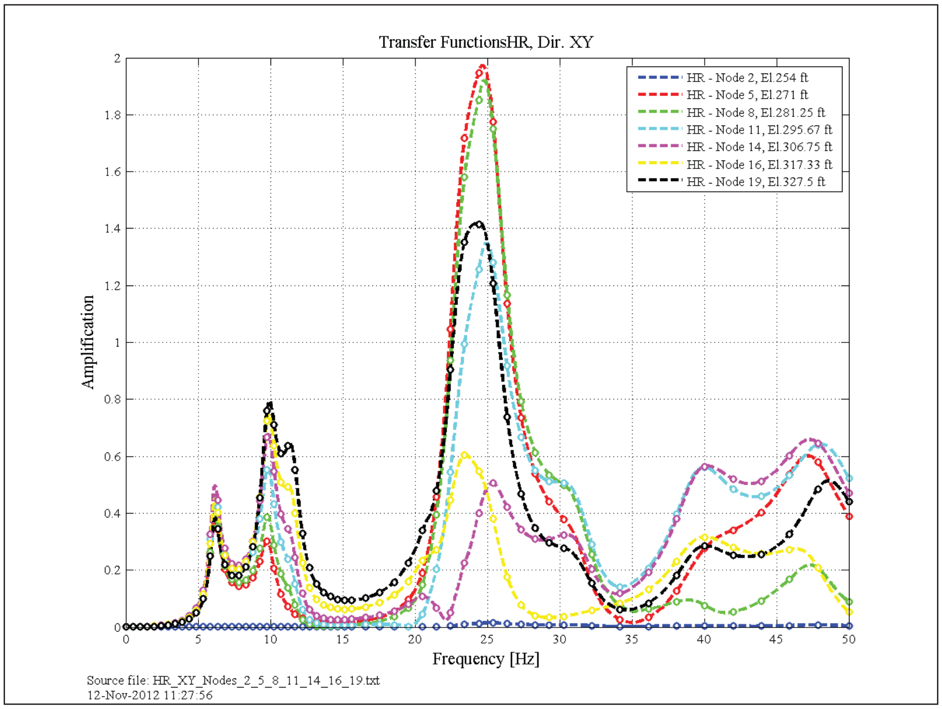

Figure 6 - Hard Rock XY Transfer Functions

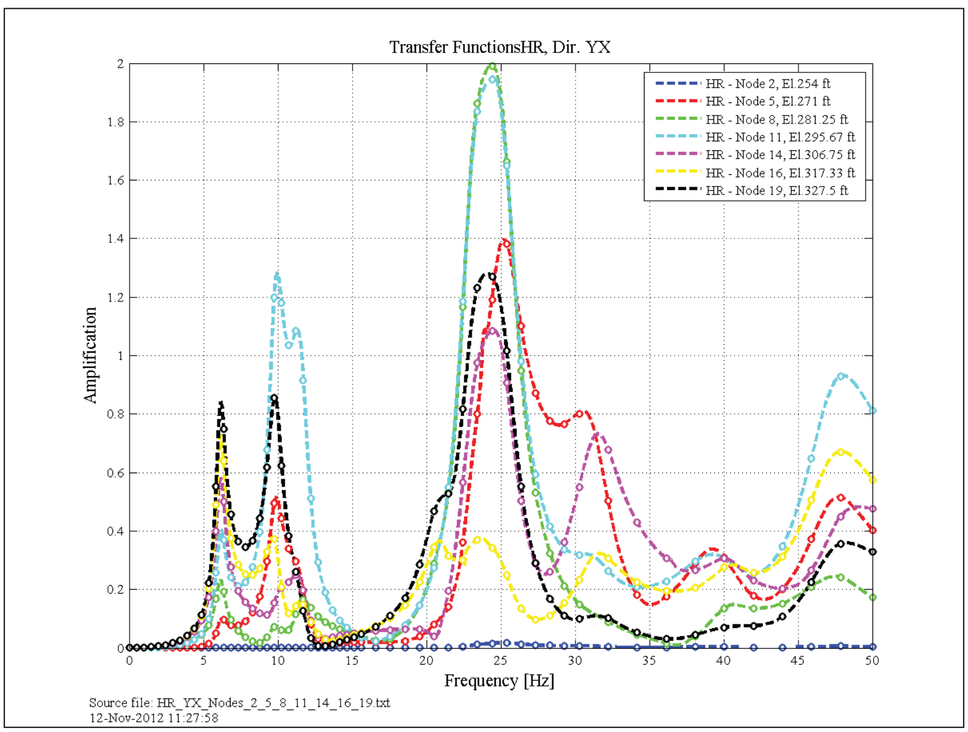

Figure 7 - Hard Rock YX Transfer Functions

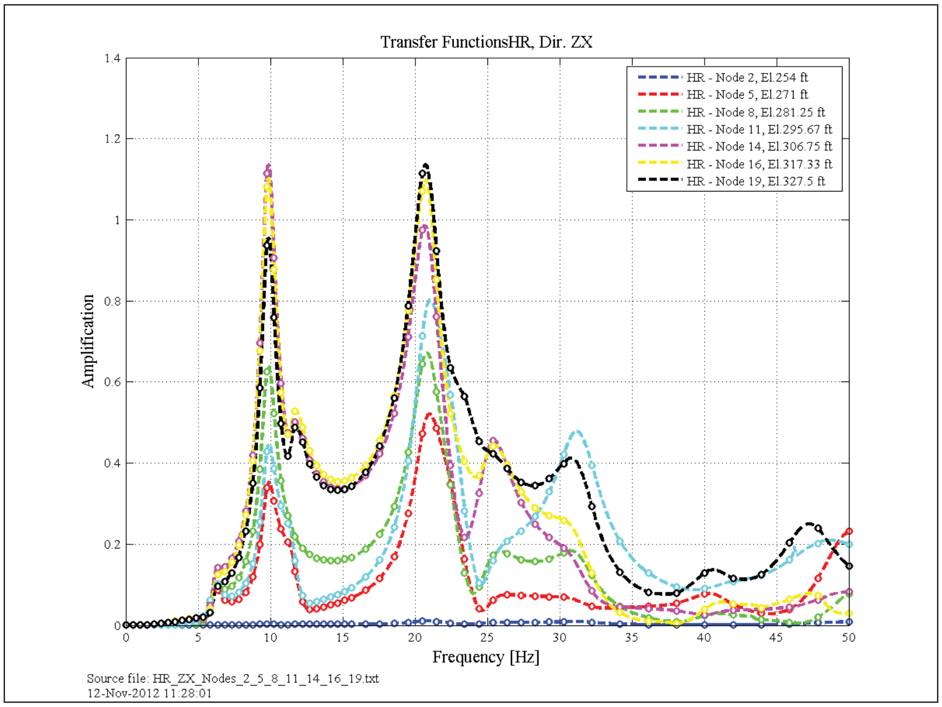

Figure 8 - Hard Rock ZX Transfer Functions

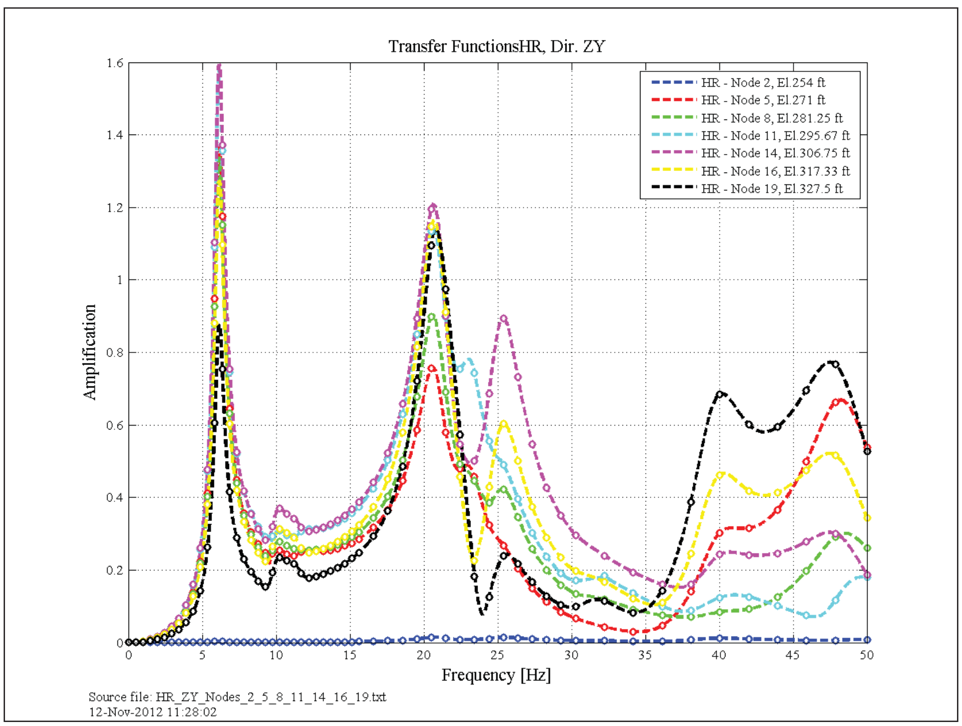

Figure 9 - Hard Rock ZY Transfer Functions

Soil Profiles

SSI analysis is completed with SASSI2010 computer code using the structural model created in Section 4.2.1 and three variations of soil profiles.

1. The first soil profile is the Hard Rock (HR) column, which emulates the fixed-base condition. For the HR column, the halfspace begins 100’-0” below grade. The properties of the half-space are equal to the HR properties.
2. The second profile is a uniform soil column considering 3,500 fps shear wave velocity (noted in the subsequent figures as 3500). As with the HR profile, a Poisson ratio of 0.30 is used with 1% soil damping and 0.15 kcf rock density. For the 3,500 fps column, the halfspace begins 100’-0” below grade. The halfspace shear wave velocity is assumed to be 9740 fps with 1% soil damping and density of 0.163 kcf.
3. The third profile represents the site-specific Rock Profile (RP). The average shear wave velocity is approximately 5,200 fps for the first 35 ft below the foundation and then increase to 8,800 fps below that. A rock damping of 1% is used with 0.163 kcf rock density. For the RP column, the halfspace begins 69’-5” below grade. The halfspace shear wave velocity is assumed to be 9740 fps with 1% rock damping and density of 0.163 kcf.

The three shear-wave velocity profiles used in this study are shown in Figure 10.

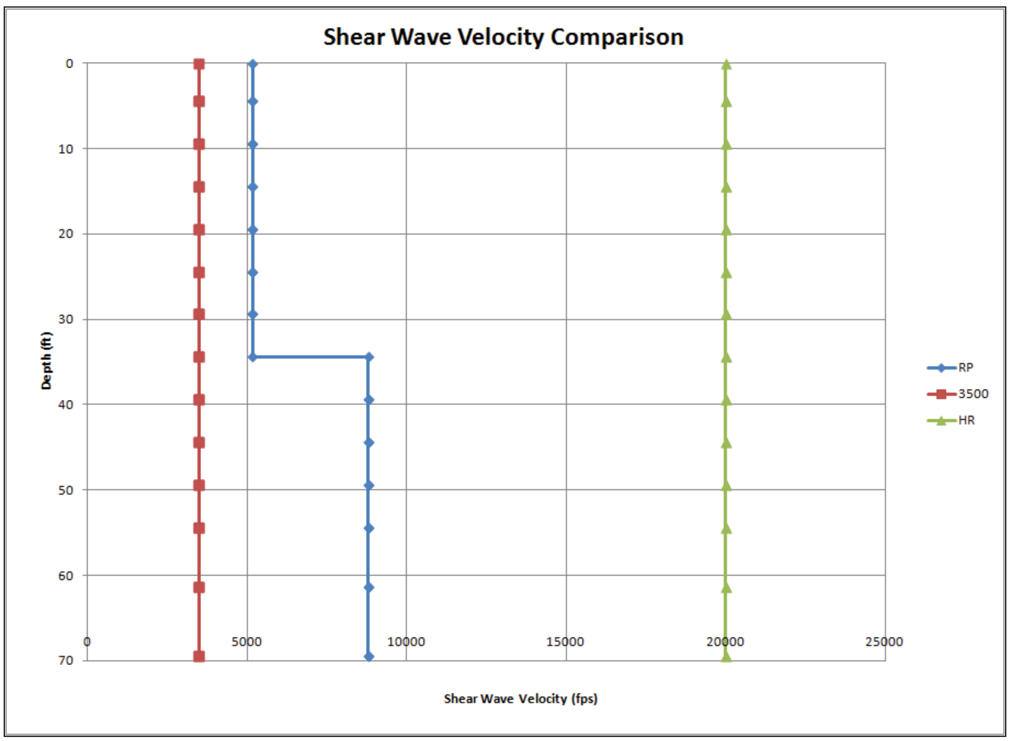

Figure 10 - Shear Wave Velocity Comparison (1 m/s = 3.28 fps)

Input Motions

In conjunction with the three rock profiles, results are presented for three different input motions, all applied in the free field at the same elevation as the bottom of the MSVH basemat.

1. The first ground motion (DBE) is the plant Design Basis Earthquake (DBE) time histories which is similar to that of the RG 1.60 and represents a typical broad band design spectra.

2. The second motion (COLA) represents a set of time-histories spectrally matched to a Combined Operating License Application (COLA) Ground Motion Response Spectra (GMRS) which is obtained from a recent PSHA and site response analysis for a CEUS rock site that contains high frequency content.
3. The third motion (CEUS) represents time-histories corresponding to a recorded Central Eastern United States (CEUS) earthquake event.

Generation of In-Structure Response Spectra

Raw Acceleration Response Spectra (ARS) are produced from each of the nine analysis cases (3 rock profiles × 3 input motions = 9) for each of the seven lumped-mass nodes representative of the major floor elevations, as indicated in Table 2.

Table 2 - Lumped-Mass Nodes at Major Elevations

Node ID	Elevation
2	254'-0"
5	271'-0"
8	281'-3"
11	295'-8"
14	306'-9"
16	317'-4"
19	327'-6"

The raw output includes nine component responses (e.g. XX: X-Response due to X-Motion, XY: X-Response due to Y-Motion, XZ: X-Response due to Z-Motion, etc.) for each node and each analysis case. Output is provided for six damping values: 1%, 2%, 3%, 4%, 5%, and 7%.

The SASSI Post-processing Tool is used to format the output data for comparison. The component responses are combined using the Square-Root-Sum of Squares (SRSS) method to produce three responses for each node and each analysis case.

Note that for production of final ISRS, broadening of +/- 15% would be applied to all curves and some degree of clipping may be allowed to the peak of applicable ARS. However, for the purposes of this comparison study, the ISRS are reported without broadening of peak clipping. For further simplification, only 5% damping curves are compared.

4
RESULTS

Sixty three ISRS comparison plots for the 5% damping ratio are presented in this report, for various combinations of soil and motion. Table 3 indicates the figure number and analysis conditions for each plot. Additional comparisons are shown in Appendix B. Complete results including ISRS at other damping ratios are provided in Appendix D.

Table 3 - ISRS Figure Numbers

Figure Number	Plot ID	Damping	Motion	Soil	Node	Direction*
11	DBE_All_N2_5_X	5%	DBE	All Soil	2	X
12	DBE_All_N2_5_Y	5%	DBE	All Soil	2	Y
13	DBE_All_N2_5_Z	5%	DBE	All Soil	2	Z
14	DBE_All_N5_5_X	5%	DBE	All Soil	5	X
15	DBE_All_N5_5_Y	5%	DBE	All Soil	5	Y
16	DBE_All_N5_5_Z	5%	DBE	All Soil	5	Z
17	DBE_All_N8_5_X	5%	DBE	All Soil	8	X
18	DBE_All_N8_5_Y	5%	DBE	All Soil	8	Y
19	DBE_All_N8_5_Z	5%	DBE	All Soil	8	Z
20	DBE_All_N11_5_X	5%	DBE	All Soil	11	X
21	DBE_All_N11_5_Y	5%	DBE	All Soil	11	Y
22	DBE_All_N11_5_Z	5%	DBE	All Soil	11	Z
23	DBE_All_N14_5_X	5%	DBE	All Soil	14	X
24	DBE_All_N14_5_Y	5%	DBE	All Soil	14	Y
25	DBE_All_N14_5_Z	5%	DBE	All Soil	14	Z
26	DBE_All_N16_5_X	5%	DBE	All Soil	16	X
27	DBE_All_N16_5_Y	5%	DBE	All Soil	16	Y
28	DBE_All_N16_5_Z	5%	DBE	All Soil	16	Z
29	DBE_All_N19_5_X	5%	DBE	All Soil	19	X
30	DBE_All_N19_5_Y	5%	DBE	All Soil	19	Y
31	DBE_All_N19_5_Z	5%	DBE	All Soil	19	Z
32	COLA_All_N2_5_X	5%	COLA	All Soil	2	X

Figure Number	Plot ID	Damping	Motion	Soil	Node	Direction*
33	COLA_All_N2_5_Y	5%	COLA	All Soil	2	Y
34	COLA_All_N2_5_Z	5%	COLA	All Soil	2	Z
35	COLA_All_N5_5_X	5%	COLA	All Soil	5	X
36	COLA_All_N5_5_Y	5%	COLA	All Soil	5	Y
37	COLA_All_N5_5_Z	5%	COLA	All Soil	5	Z
38	COLA_All_N8_5_X	5%	COLA	All Soil	8	X
39	COLA_All_N8_5_Y	5%	COLA	All Soil	8	Y
40	COLA_All_N8_5_Z	5%	COLA	All Soil	8	Z
41	COLA_All_N11_5_X	5%	COLA	All Soil	11	X
42	COLA_All_N11_5_Y	5%	COLA	All Soil	11	Y
43	COLA_All_N11_5_Z	5%	COLA	All Soil	11	Z
44	COLA_All_N14_5_X	5%	COLA	All Soil	14	X
45	COLA_All_N14_5_Y	5%	COLA	All Soil	14	Y
46	COLA_All_N14_5_Z	5%	COLA	All Soil	14	Z
47	COLA_All_N16_5_X	5%	COLA	All Soil	16	X
48	COLA_All_N16_5_Y	5%	COLA	All Soil	16	Y
49	COLA_All_N16_5_Z	5%	COLA	All Soil	16	Z
50	COLA_All_N19_5_X	5%	COLA	All Soil	19	X
51	COLA_All_N19_5_Y	5%	COLA	All Soil	19	Y
52	COLA_All_N19_5_Z	5%	COLA	All Soil	19	Z
53	CEUS_All_N2_5_X	5%	CEUS	All Soil	2	X
54	CEUS_All_N2_5_Y	5%	CEUS	All Soil	2	Y
55	CEUS_All_N2_5_Z	5%	CEUS	All Soil	2	Z
56	CEUS_All_N5_5_X	5%	CEUS	All Soil	5	X
57	CEUS_All_N5_5_Y	5%	CEUS	All Soil	5	Y
58	CEUS_All_N5_5_Z	5%	CEUS	All Soil	5	Z
59	CEUS_All_N8_5_X	5%	CEUS	All Soil	8	X
60	CEUS_All_N8_5_Y	5%	CEUS	All Soil	8	Y
61	CEUS_All_N8_5_Z	5%	CEUS	All Soil	8	Z
62	CEUS_All_N11_5_X	5%	CEUS	All Soil	11	X
63	CEUS_All_N11_5_Y	5%	CEUS	All Soil	11	Y

Figure Number	Plot ID	Damping	Motion	Soil	Node	Direction*
64	CEUS_All_N11_5_Z	5%	CEUS	All Soil	11	Z
65	CEUS_All_N14_5_X	5%	CEUS	All Soil	14	X
66	CEUS_All_N14_5_Y	5%	CEUS	All Soil	14	Y
67	CEUS_All_N14_5_Z	5%	CEUS	All Soil	14	Z
68	CEUS_All_N16_5_X	5%	CEUS	All Soil	16	X
69	CEUS_All_N16_5_Y	5%	CEUS	All Soil	16	Y
70	CEUS_All_N16_5_Z	5%	CEUS	All Soil	16	Z
71	CEUS_All_N19_5_X	5%	CEUS	All Soil	19	X
72	CEUS_All_N19_5_Y	5%	CEUS	All Soil	19	Y
73	CEUS_All_N19_5_Z	5%	CEUS	All Soil	19	Z

*The X, Y, and Z directions in the model refer to the East-West, North-South, and vertical directions, respectively.

Soil Comparisons

Comparisons are presented for all soil cases on one plot with each motion.

DBE Input Motion

The following comparisons consider the DBE input motion.

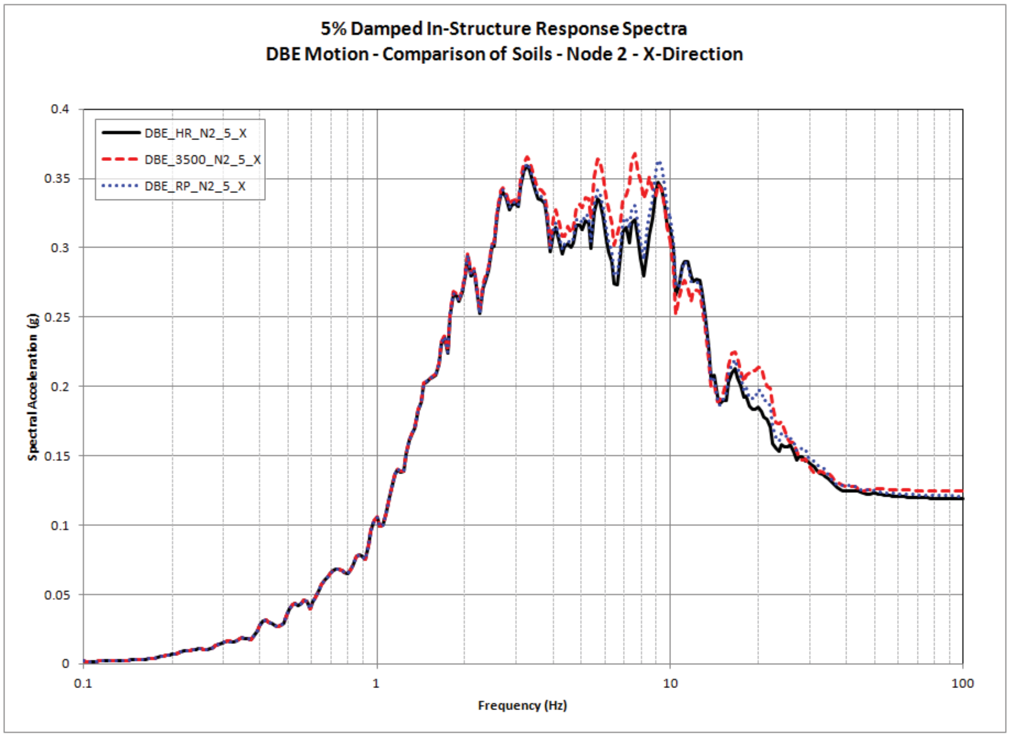

Figure 11 – 5% Damping ISRS - DBE Motion – All Soil – Node 2 – X (East-West) Direction

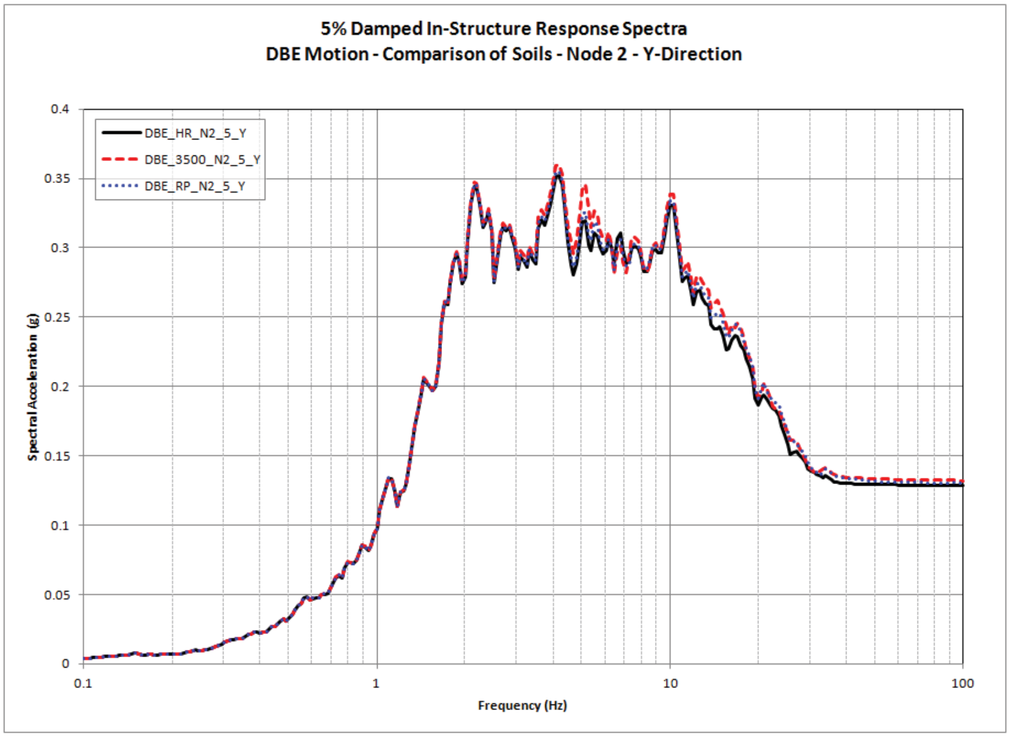

Figure 12 – 5% Damping ISRS - DBE Motion – All Soil – Node 2 – Y (North-South) Direction

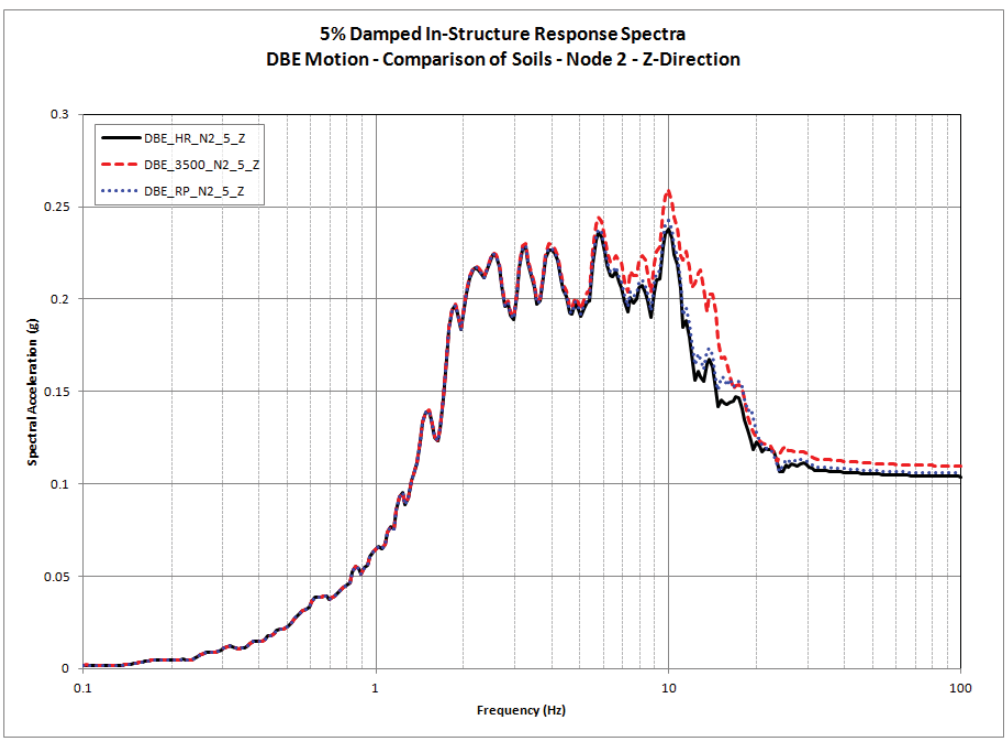

Figure 13 – 5% Damping ISRS - DBE Motion – All Soil – Node 2 – Z (Vertical) Direction

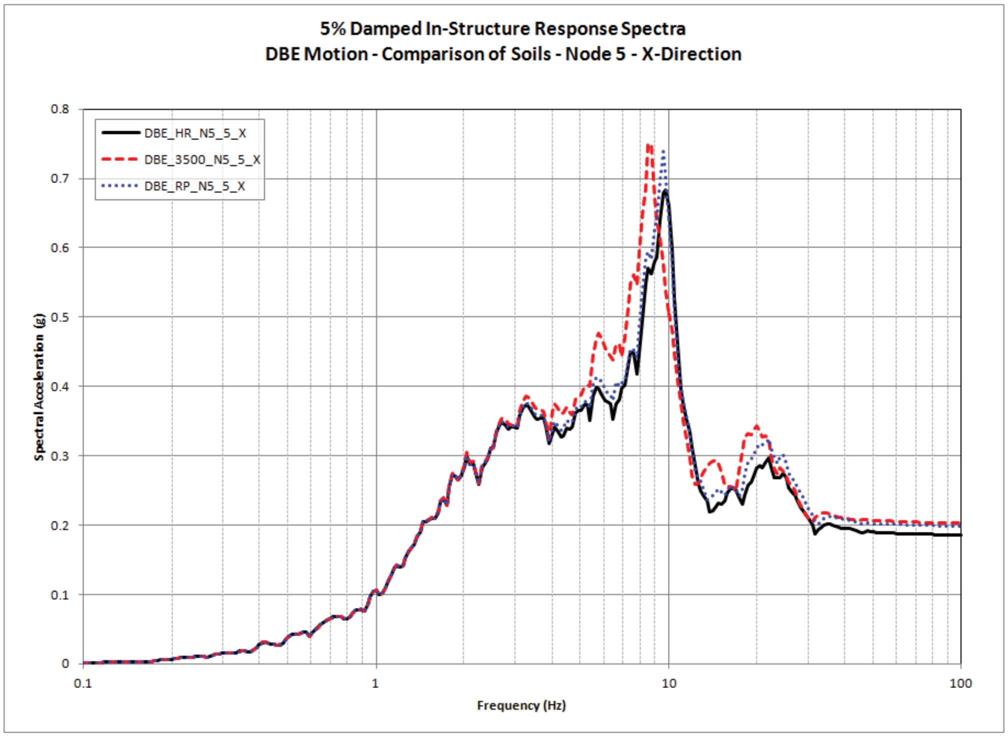

Figure 14 – 5% Damping ISRS - DBE Motion – All Soil – Node 5 – X (East-West) Direction

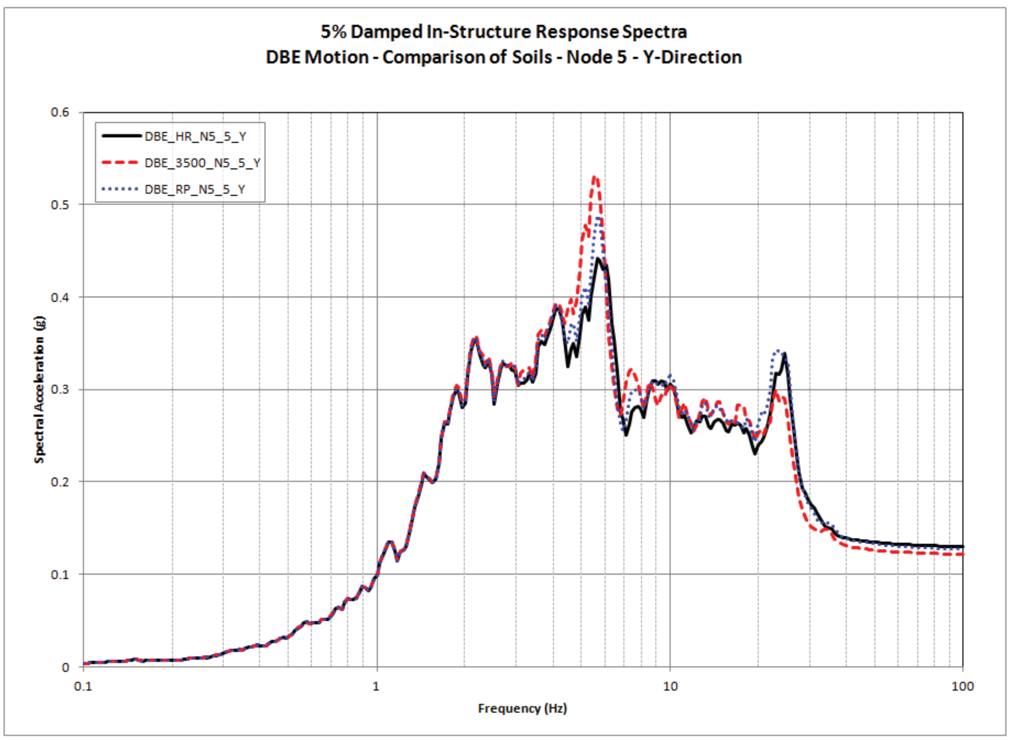

Figure 15 – 5% Damping ISRS - DBE Motion – All Soil – Node 5 – Y (North-South) Direction

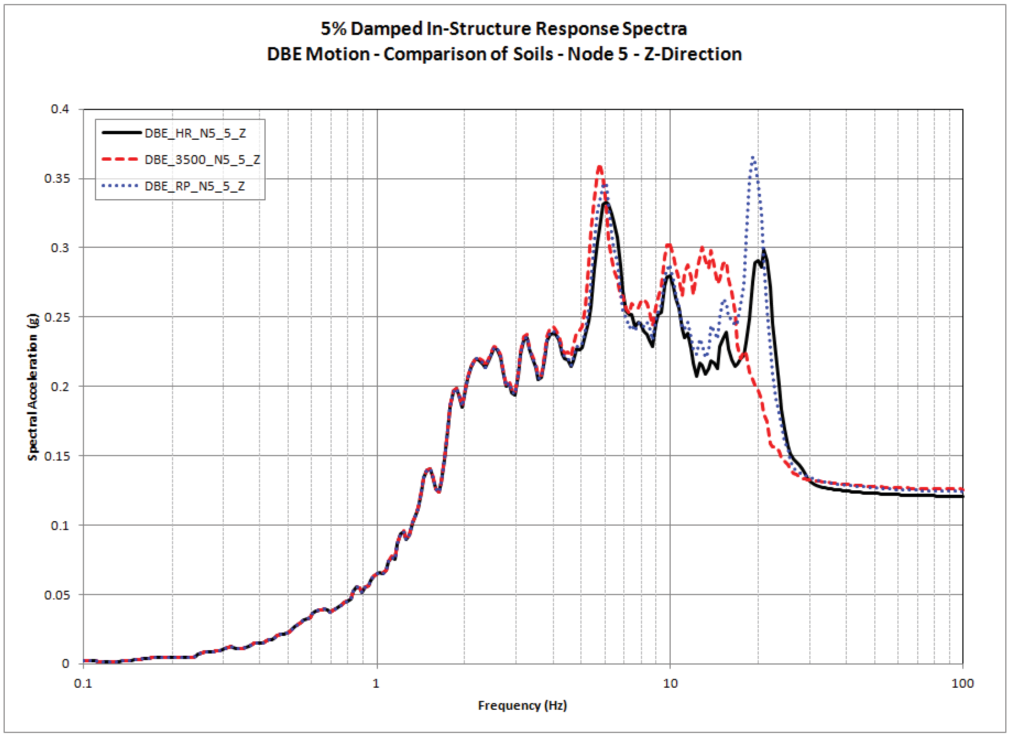

Figure 16 – 5% Damping ISRS - DBE Motion – All Soil – Node 5 – Z (Vertical) Direction

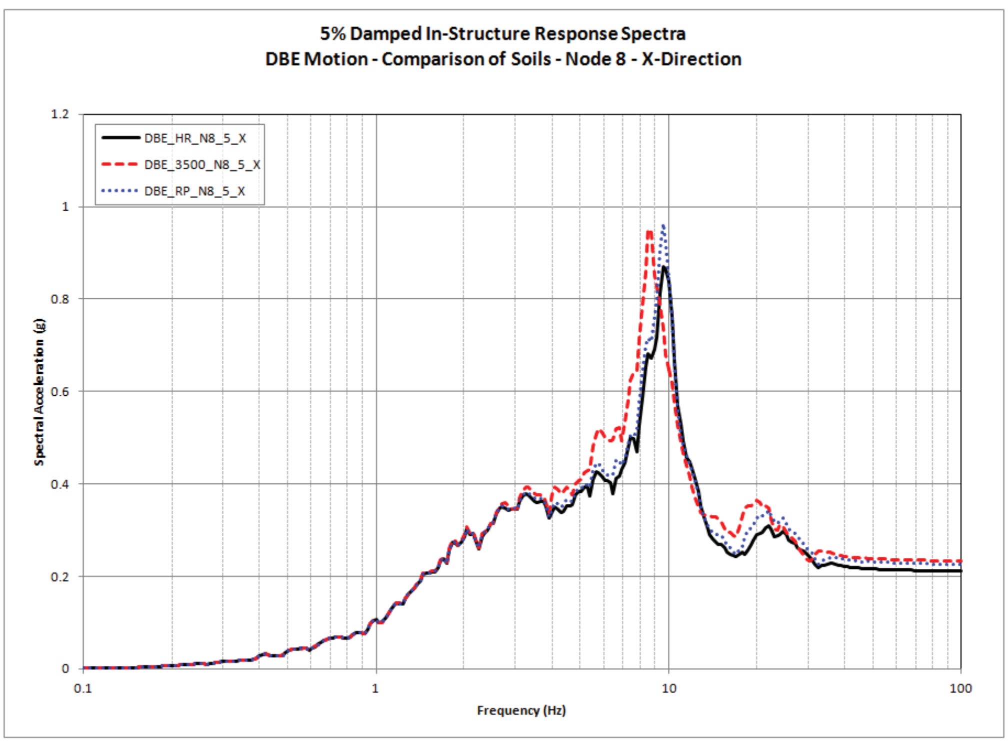

Figure 17 – 5% Damping ISRS - DBE Motion – All Soil – Node 8 – X (East-West) Direction

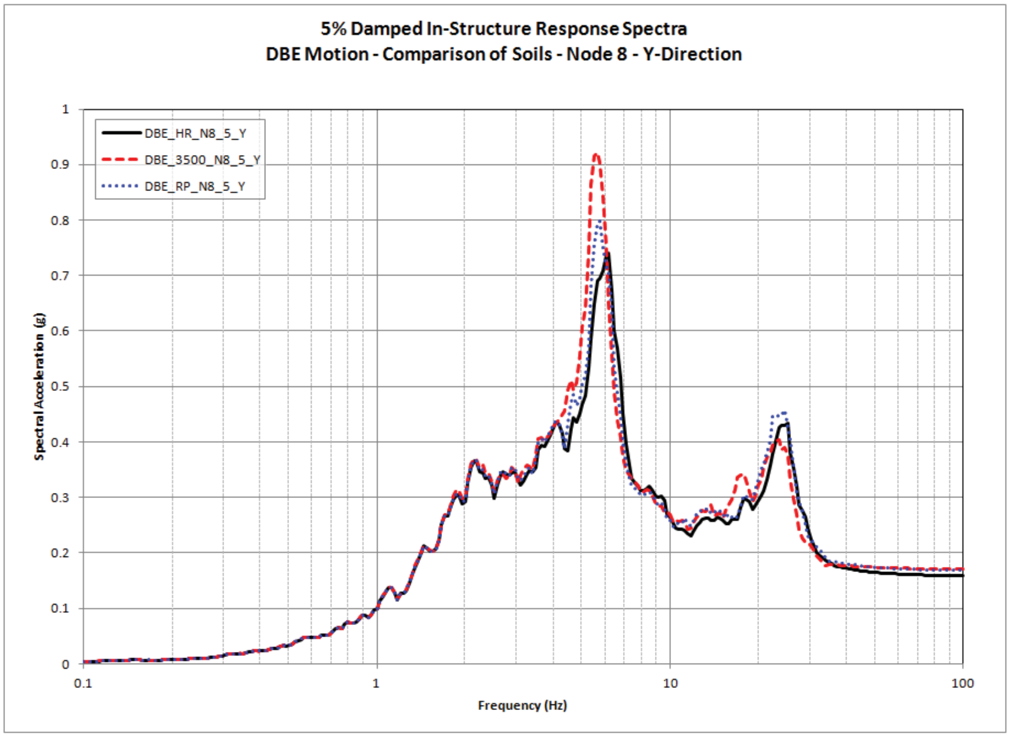

Figure 18 – 5% Damping ISRS - DBE Motion – All Soil – Node 8 – Y (North-South) Direction

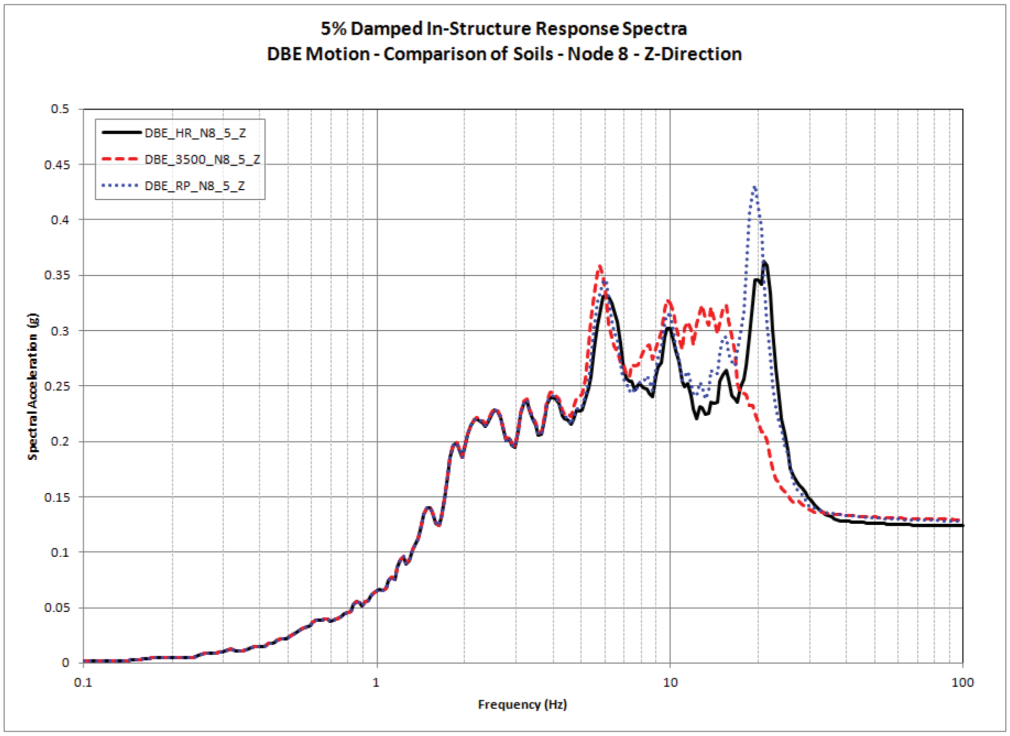

Figure 19 – 5% Damping ISRS - DBE Motion – All Soil – Node 8 – Z (Vertical) Direction

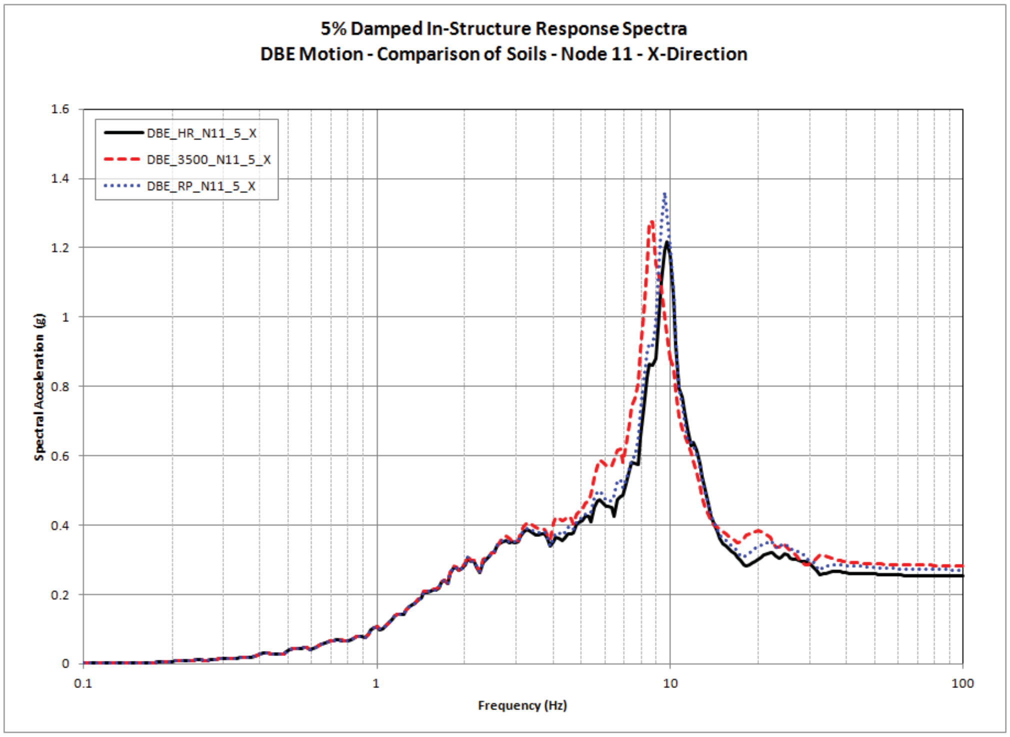

Figure 20 – 5% Damping ISRS - DBE Motion – All Soil – Node 11 – X (East-West) Direction

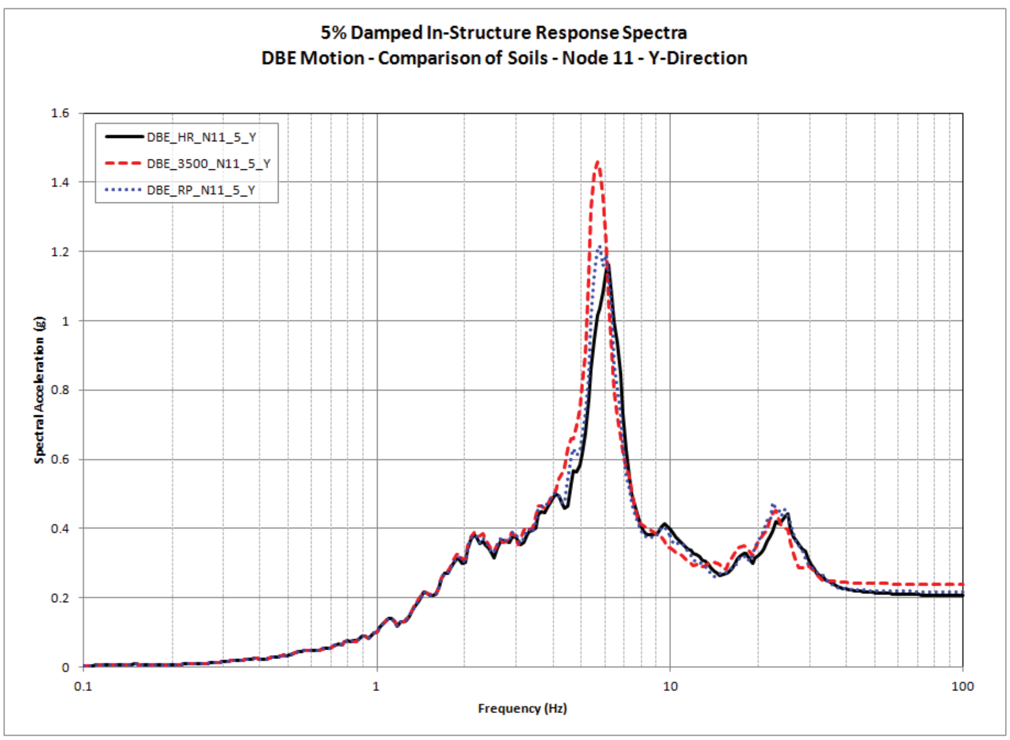

Figure 21 – 5% Damping ISRS - DBE Motion – All Soil – Node 11 – Y (North-South) Direction

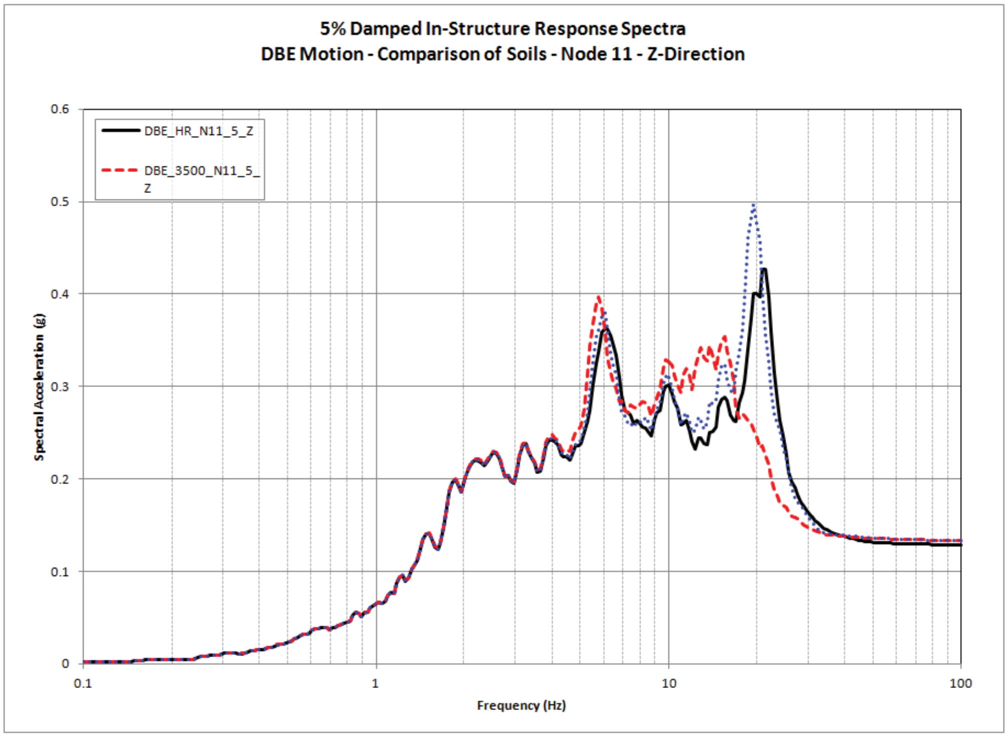

Figure 22 – 5% Damping ISRS - DBE Motion – All Soil – Node 11 – Z (Vertical) Direction

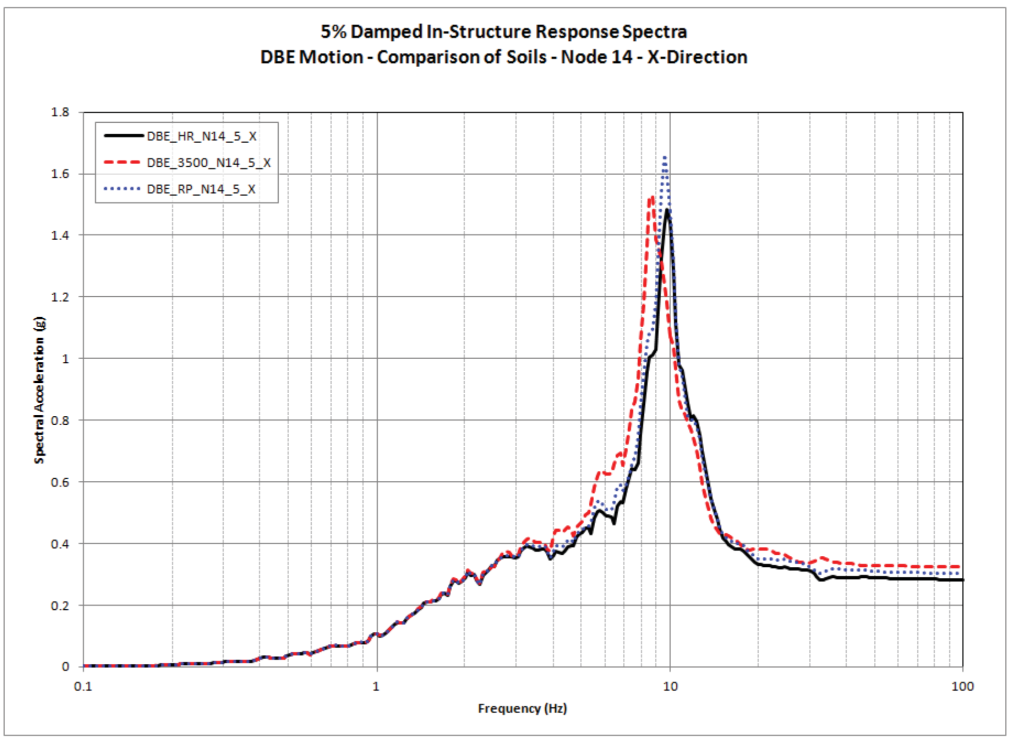

Figure 23 – 5% Damping ISRS - DBE Motion – All Soil – Node 14 – X (East-West) Direction

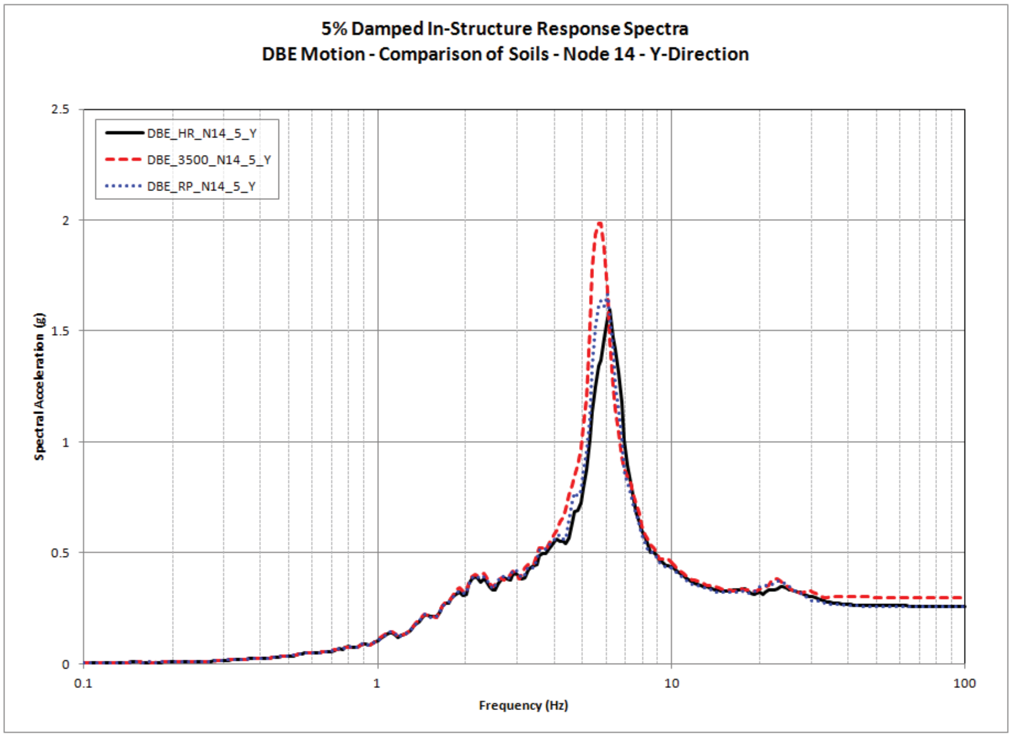

Figure 24 – 5% Damping ISRS - DBE Motion – All Soil – Node 14 – Y (North-South) Direction

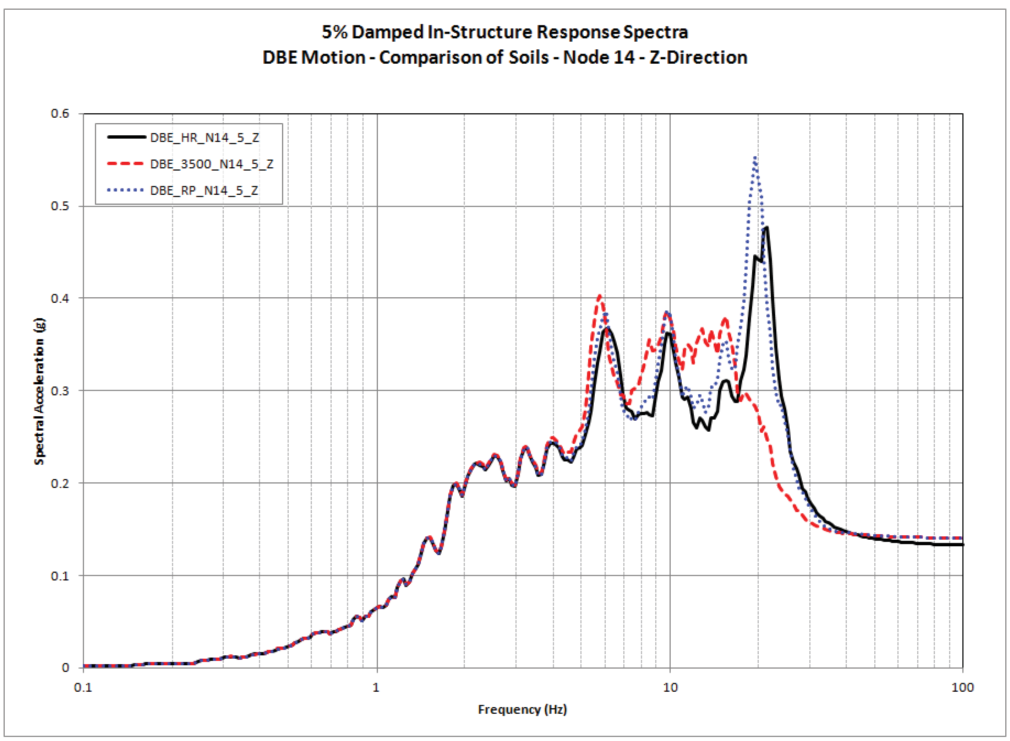

Figure 25 – 5% Damping ISRS - DBE Motion – All Soil – Node 14 – Z (Vertical) Direction

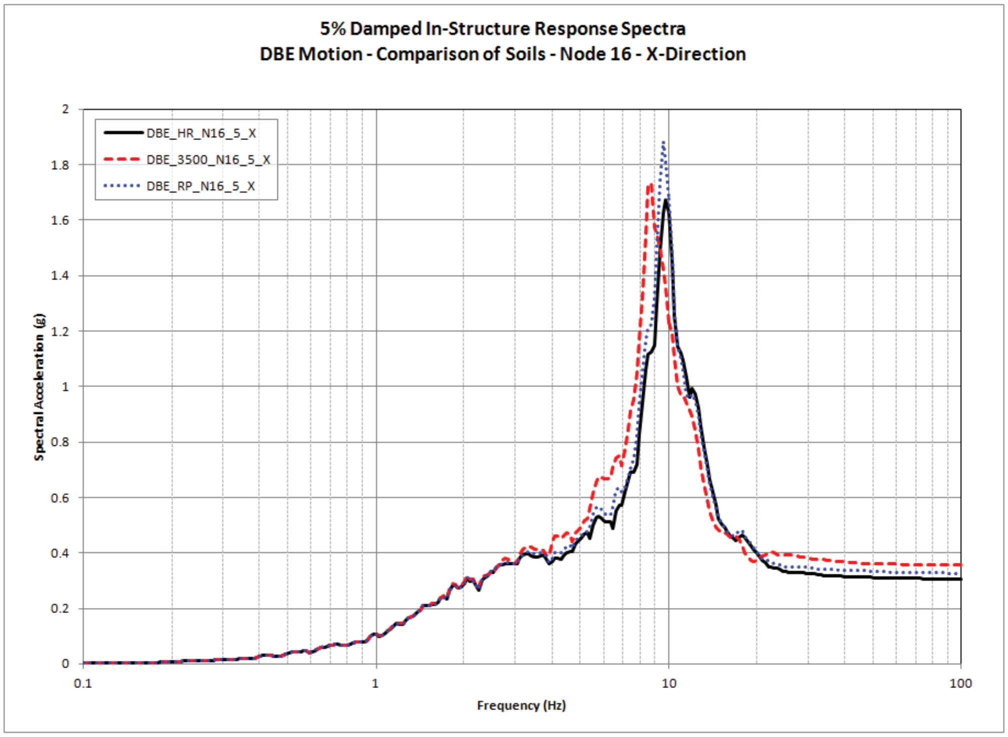

Figure 26 – 5% Damping ISRS - DBE Motion – All Soil – Node 16 – X (East-West) Direction

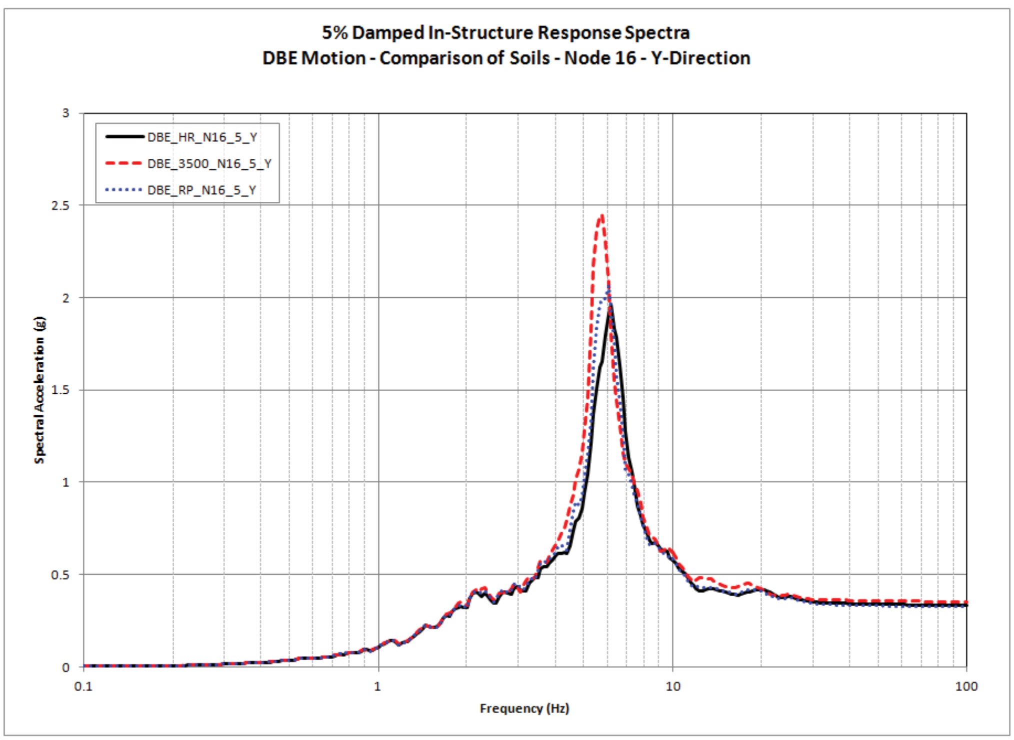

Figure 27 – 5% Damping ISRS - DBE Motion – All Soil – Node 16 – Y (North-South) Direction

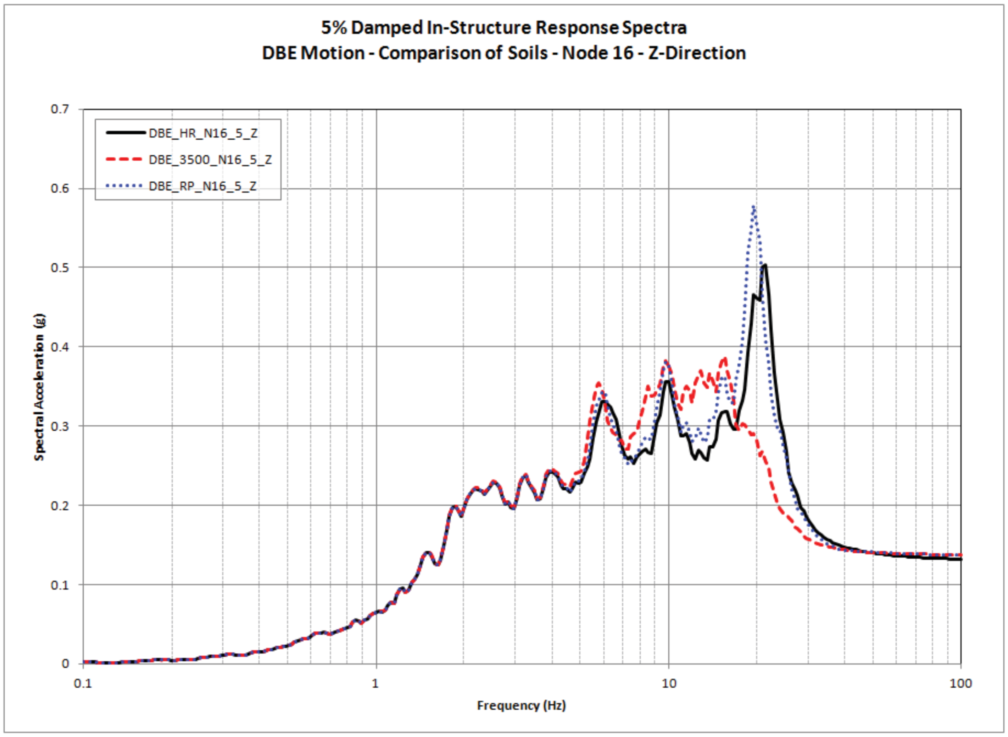

Figure 28 – 5% Damping ISRS - DBE Motion – All Soil – Node 16 – Z (Vertical) Direction

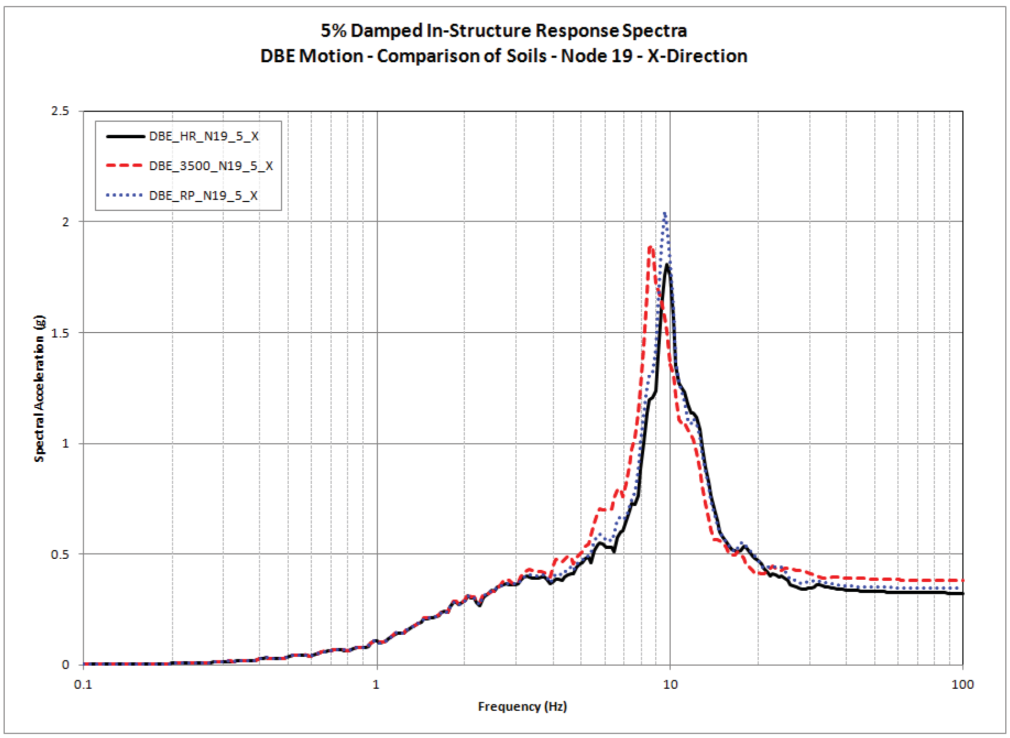

Figure 29 – 5% Damping ISRS - DBE Motion – All Soil – Node 19 – X (East-West) Direction

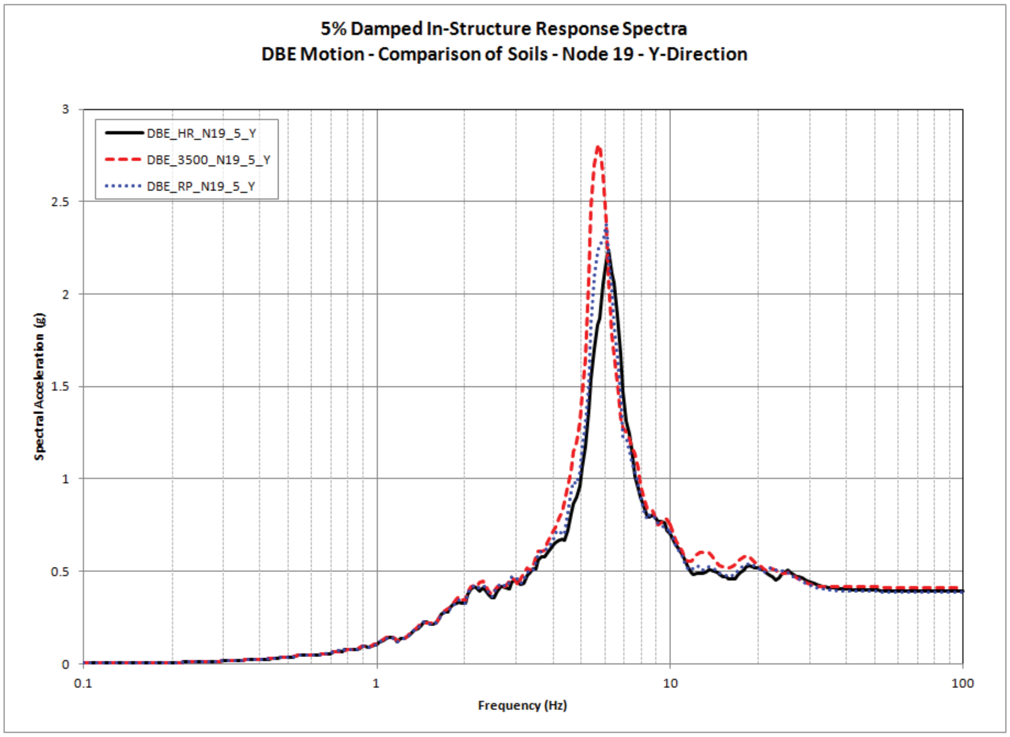

Figure 30 – 5% Damping ISRS - DBE Motion – All Soil – Node 19 – Y (North-South) Direction

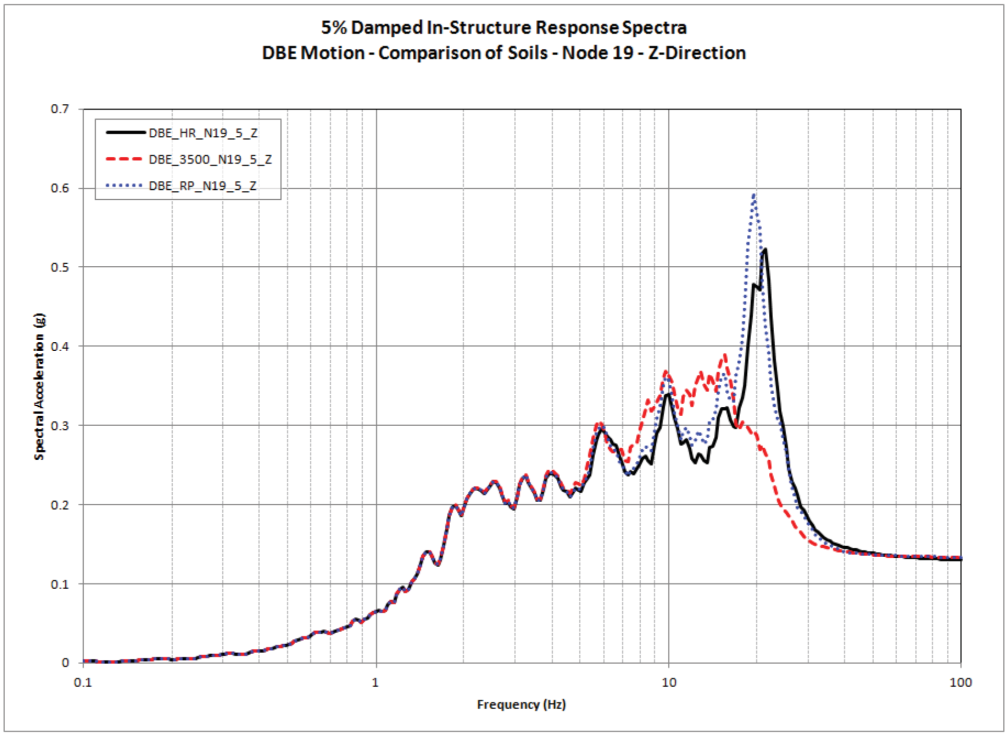

Figure 31 – 5% Damping ISRS - DBE Motion – All Soil – Node 19 – Z (Vertical) Direction

COLA Input Motion

The following comparisons consider the COLA input motion.

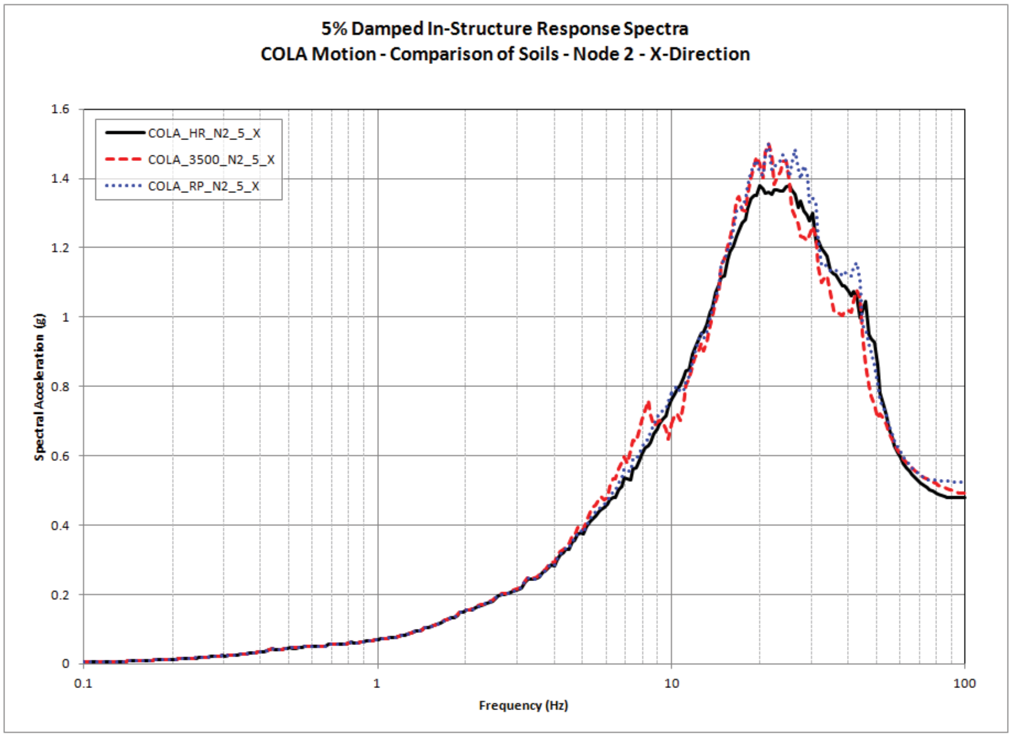

Figure 32 – 5% Damping ISRS - COLA Motion – All Soil – Node 2 – X (East-West) Direction

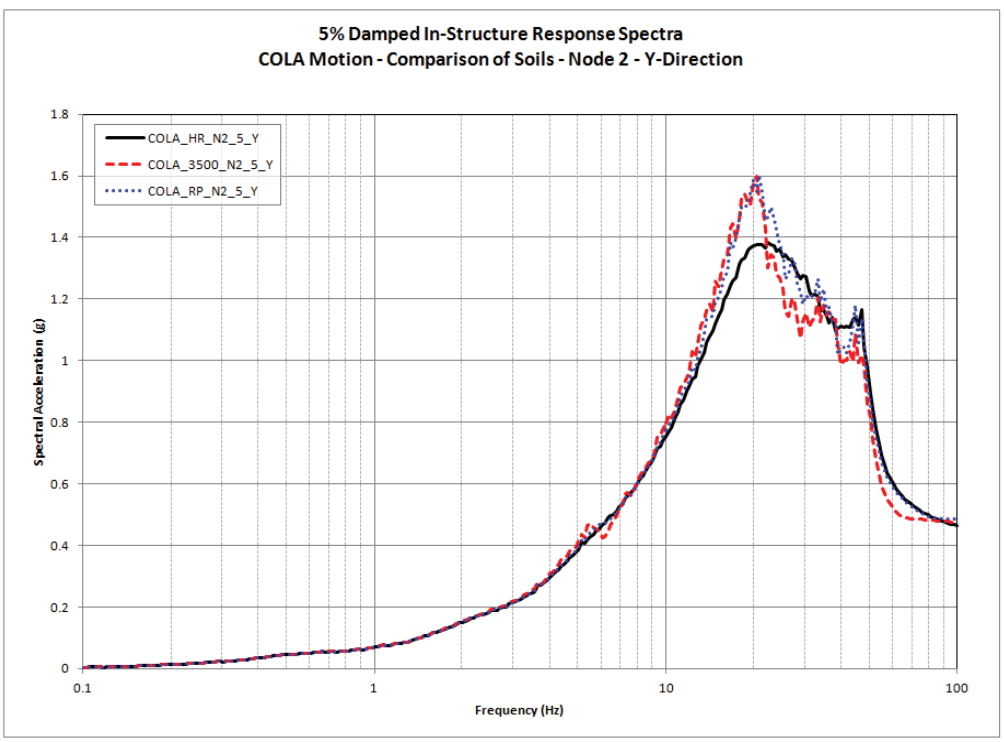

Figure 33 – 5% Damping ISRS - COLA Motion – All Soil – Node 2 – Y (North-South) Direction

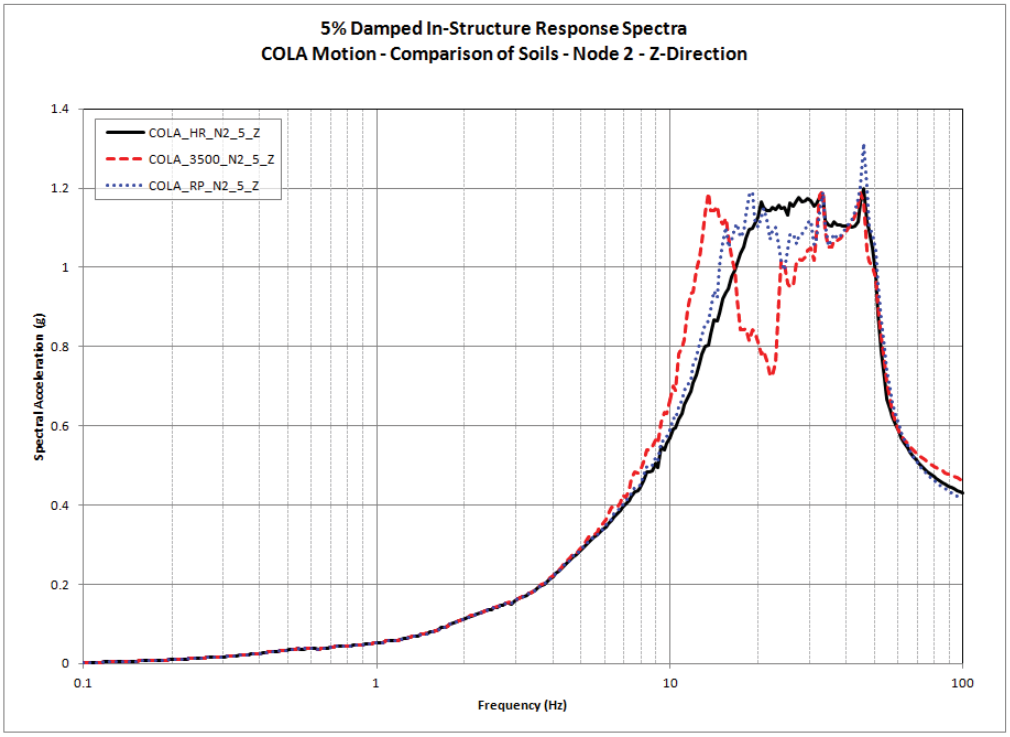

Figure 34 – 5% Damping ISRS - COLA Motion – All Soil – Node 2 – Z (Vertical) Direction

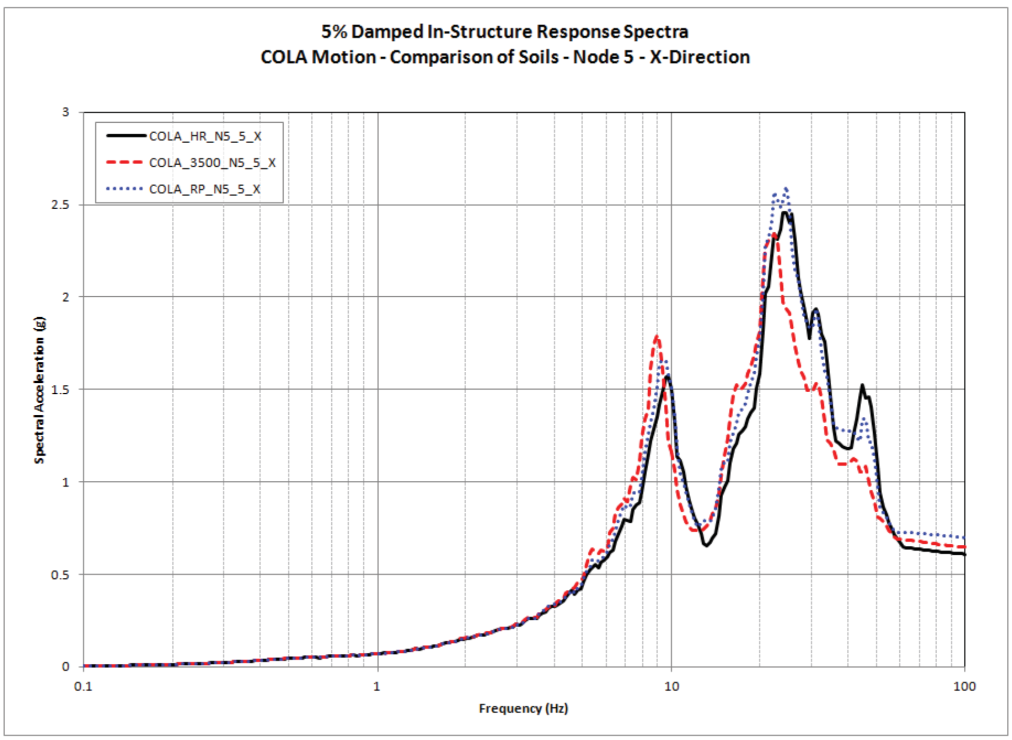

Figure 35 – 5% Damping ISRS - COLA Motion – All Soil – Node 5 – X (East-West) Direction

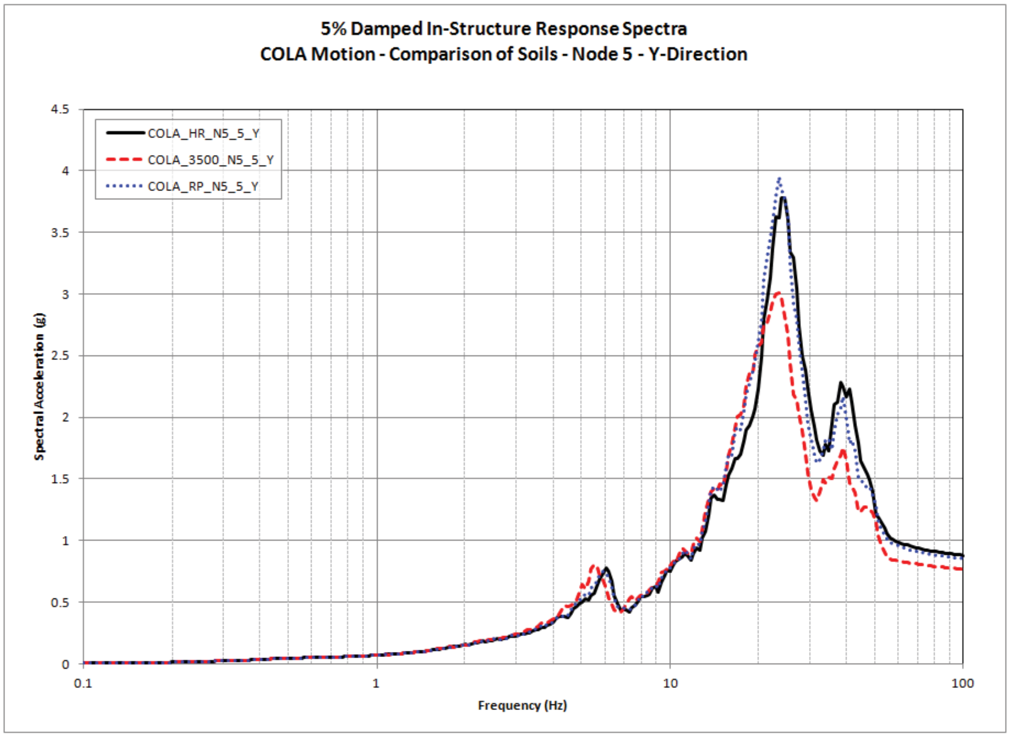

Figure 36 – 5% Damping ISRS - COLA Motion – All Soil – Node 5 – Y (North-South) Direction

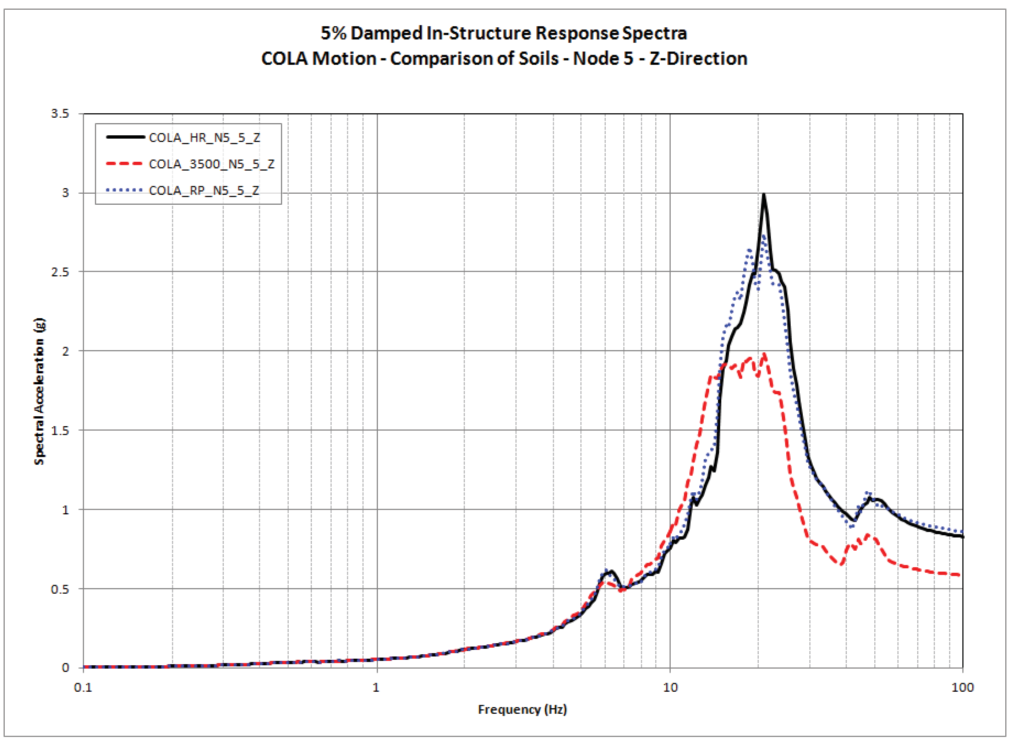

Figure 37 – 5% Damping ISRS - COLA Motion – All Soil – Node 5 – Z (Vertical) Direction

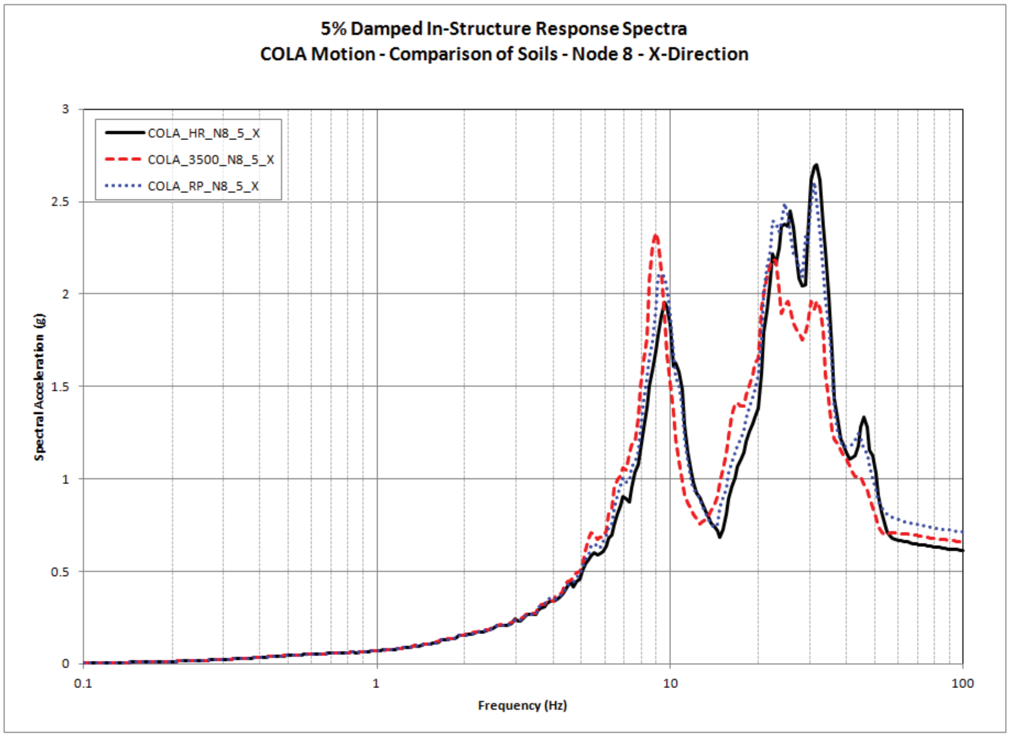

Figure 38 – 5% Damping ISRS - COLA Motion – All Soil – Node 8 – X (East-West) Direction

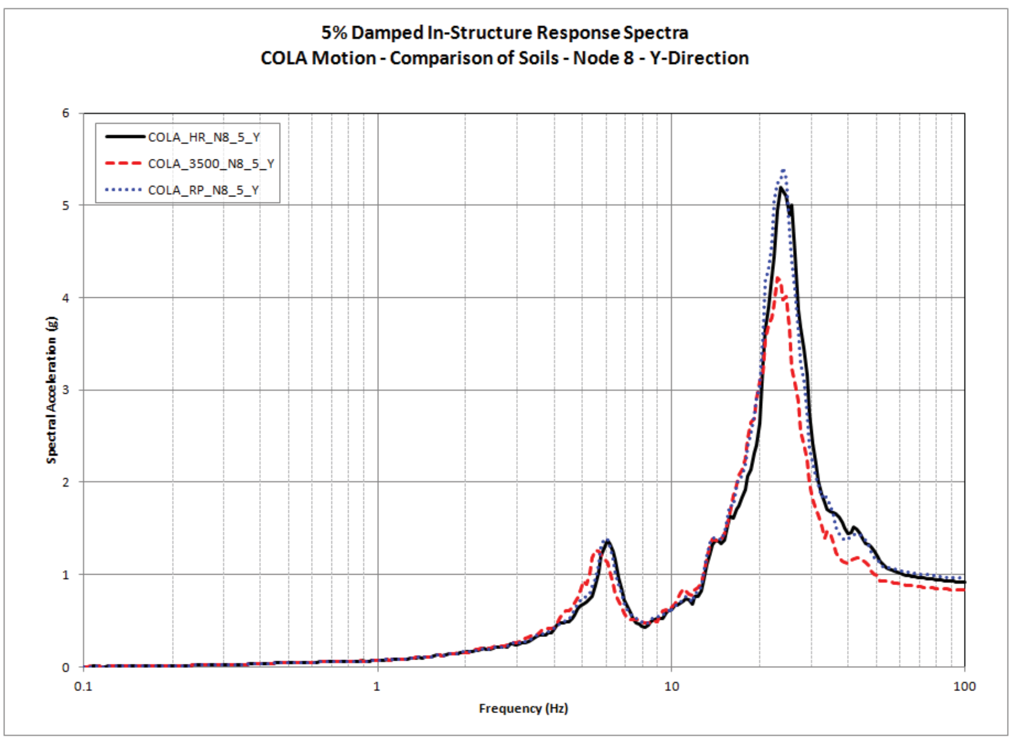

Figure 39 – 5% Damping ISRS - COLA Motion – All Soil – Node 8 – Y (North-South) Direction

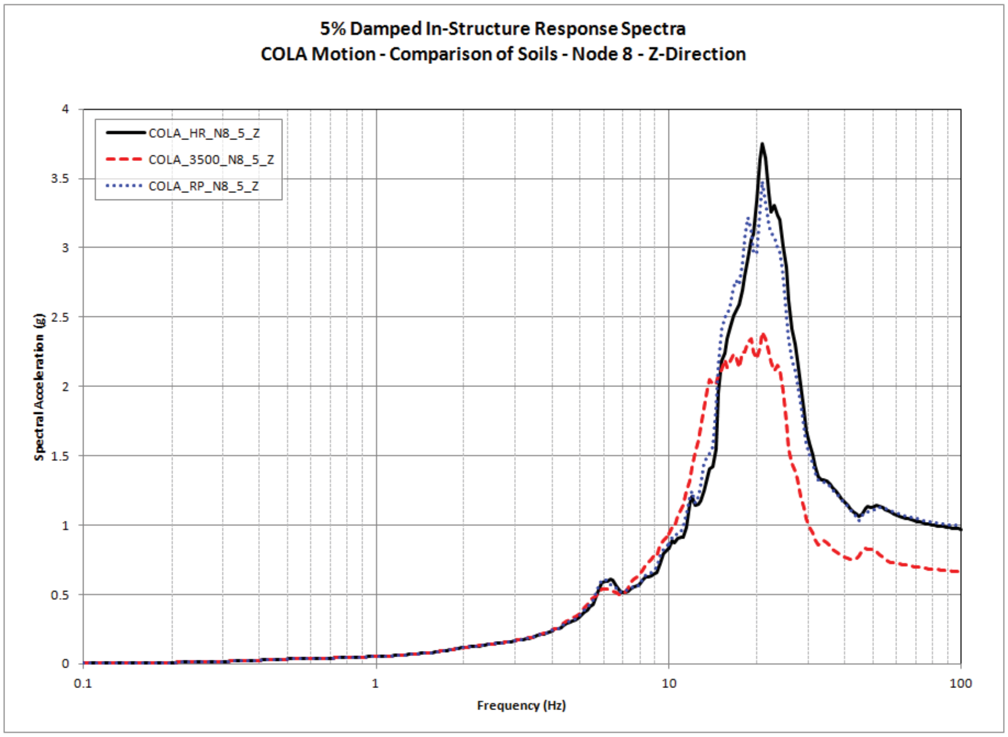

Figure 40 – 5% Damping ISRS - COLA Motion – All Soil – Node 8 – Z (Vertical) Direction

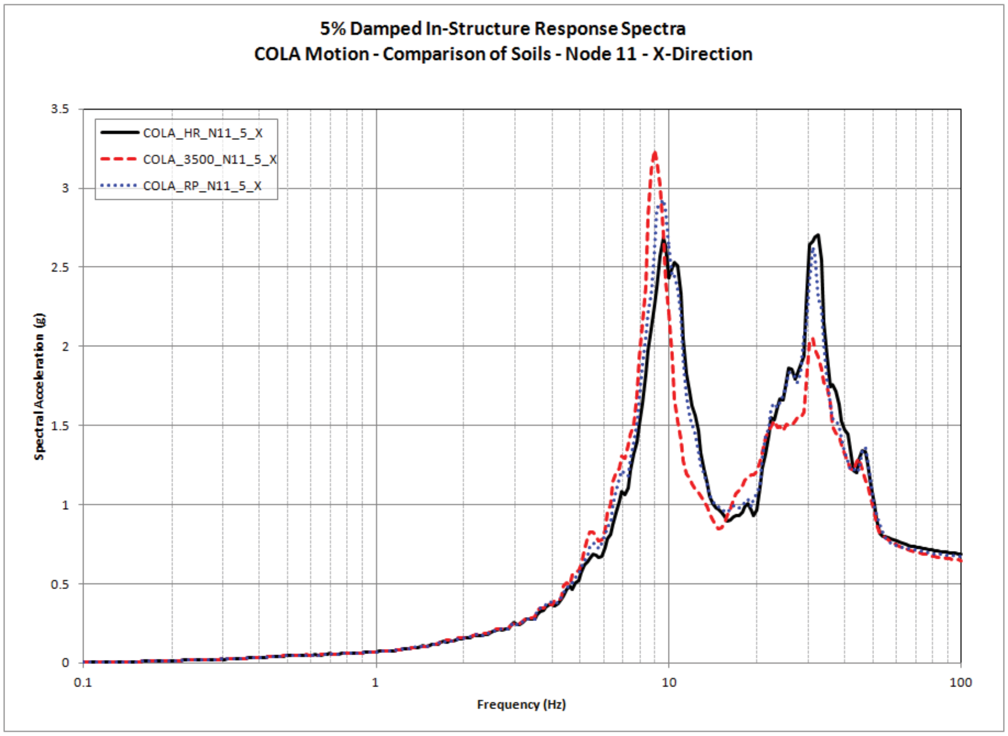

Figure 41 – 5% Damping ISRS - COLA Motion – All Soil – Node 11 – X (East-West) Direction

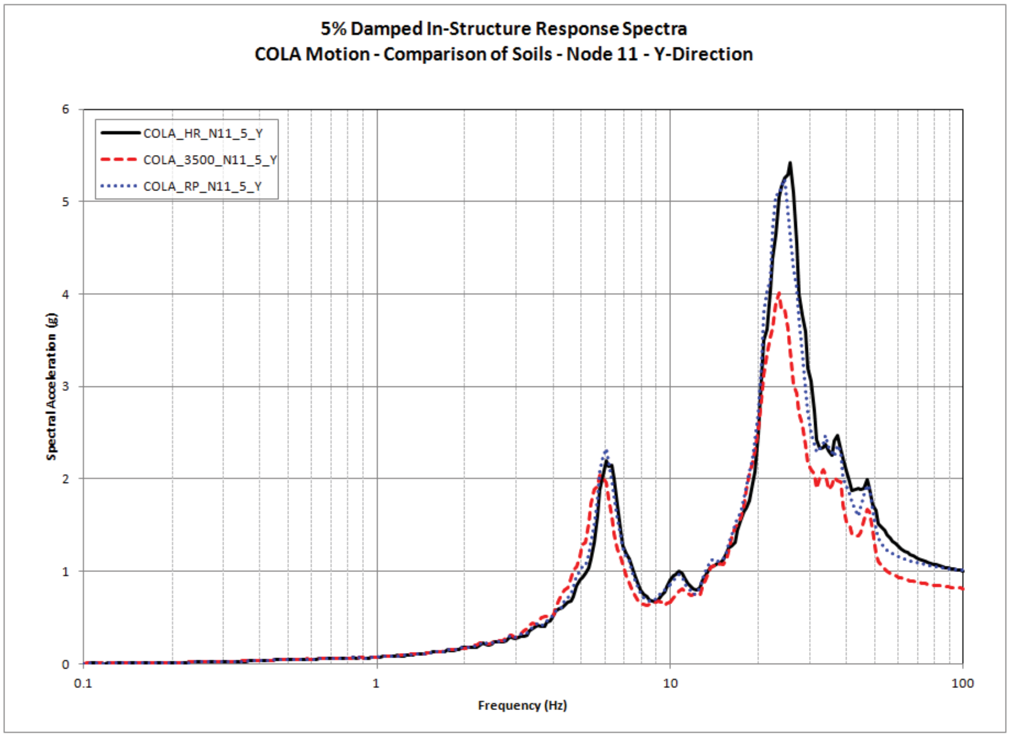

Figure 42 – 5% Damping ISRS - COLA Motion – All Soil – Node 11 – Y (North-South) Direction

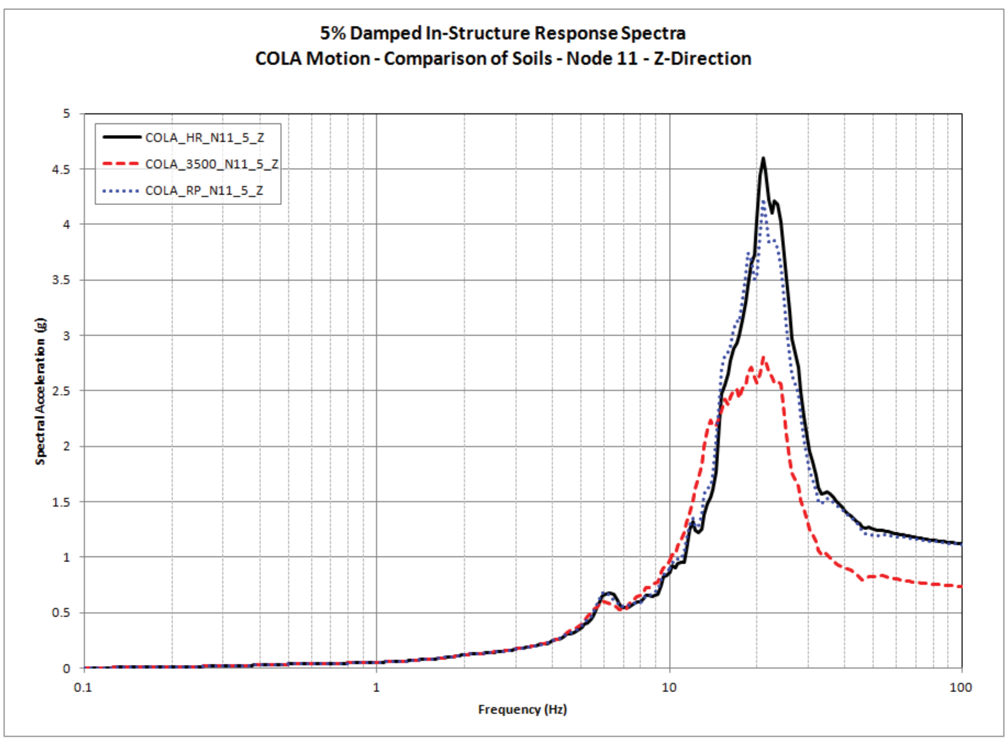

Figure 43 – 5% Damping ISRS - COLA Motion – All Soil – Node 11 – Z (Vertical) Direction

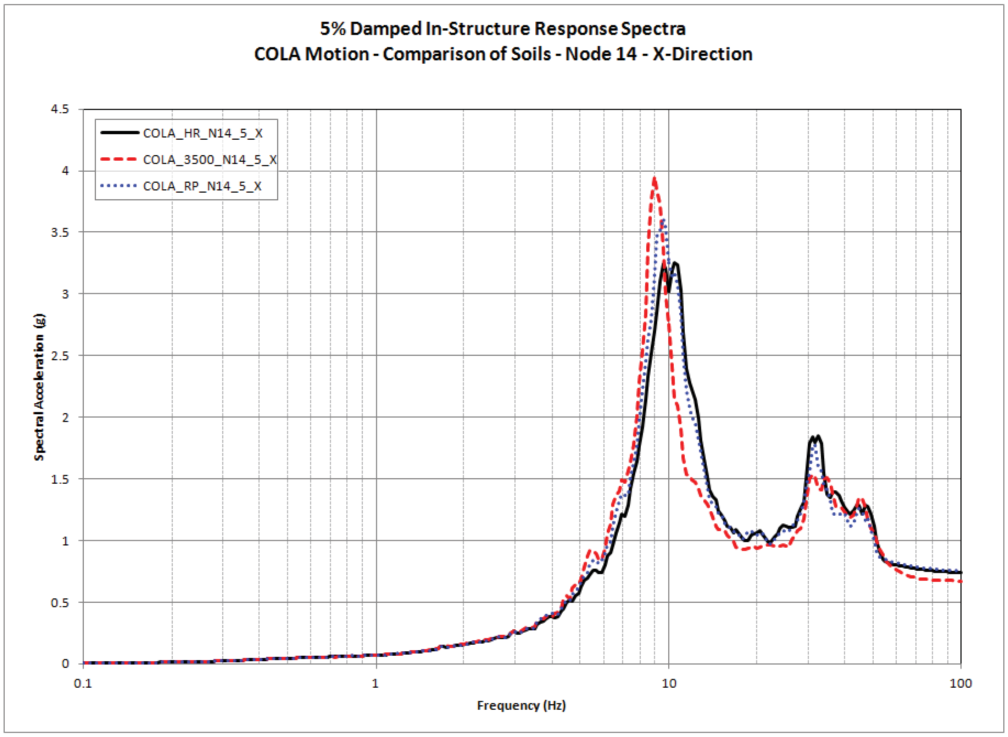

Figure 44 – 5% Damping ISRS - COLA Motion – All Soil – Node 14 – X (East-West) Direction

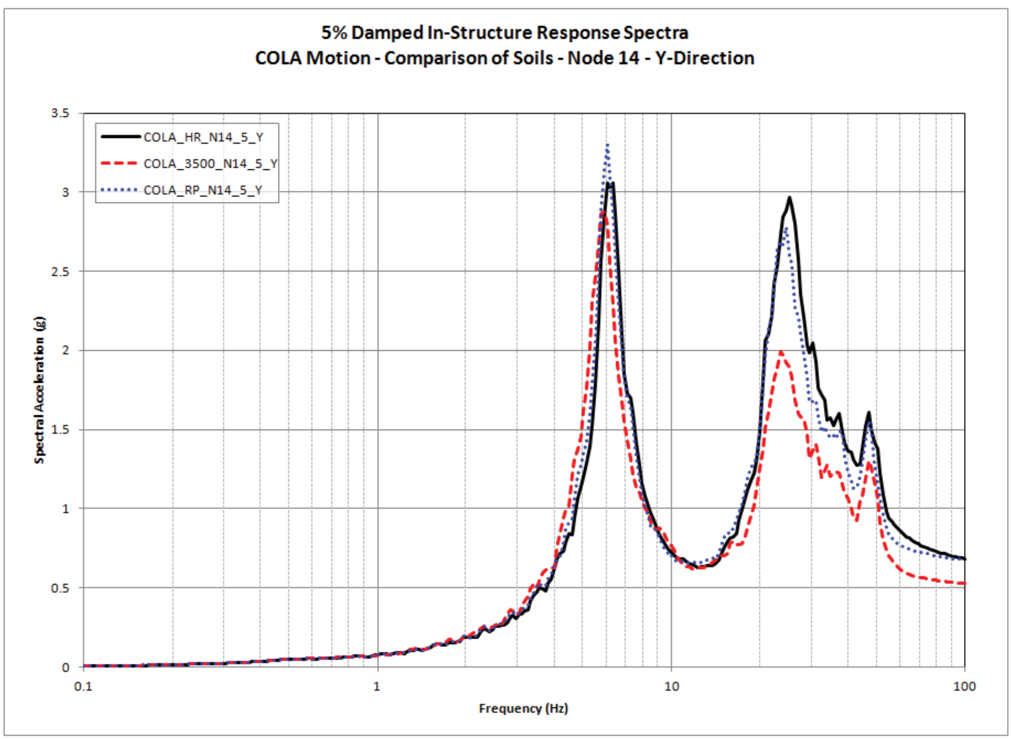

Figure 45 – 5% Damping ISRS - COLA Motion – All Soil – Node 14 – Y (North-South) Direction

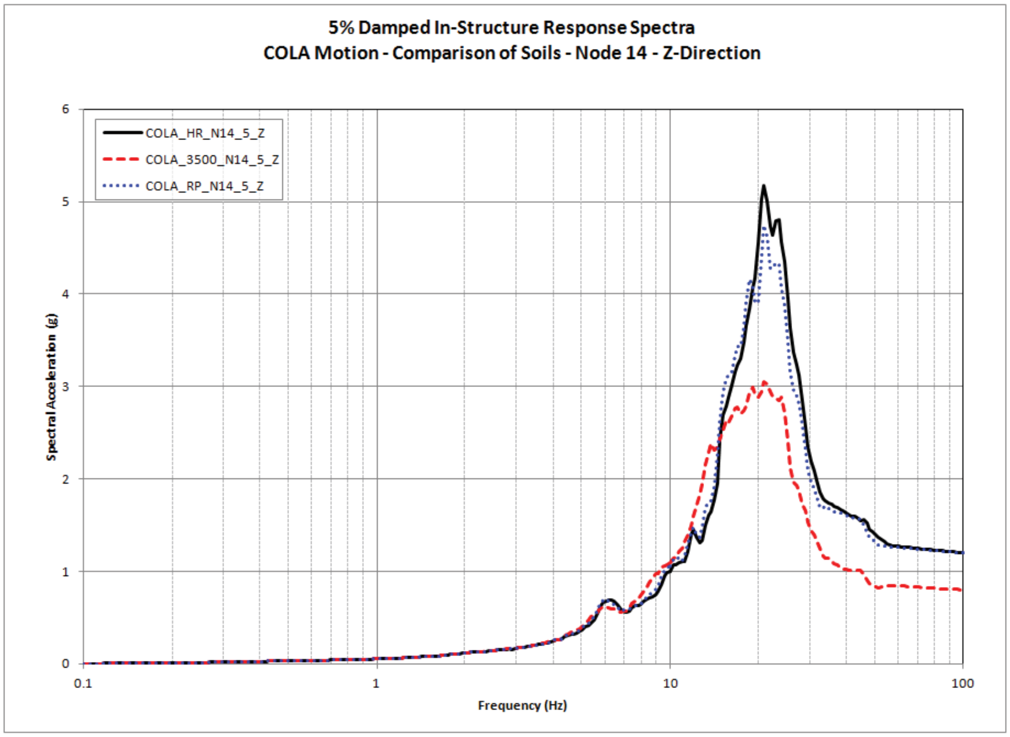

Figure 46 – 5% Damping ISRS - COLA Motion – All Soil – Node 14 – Z (Vertical) Direction

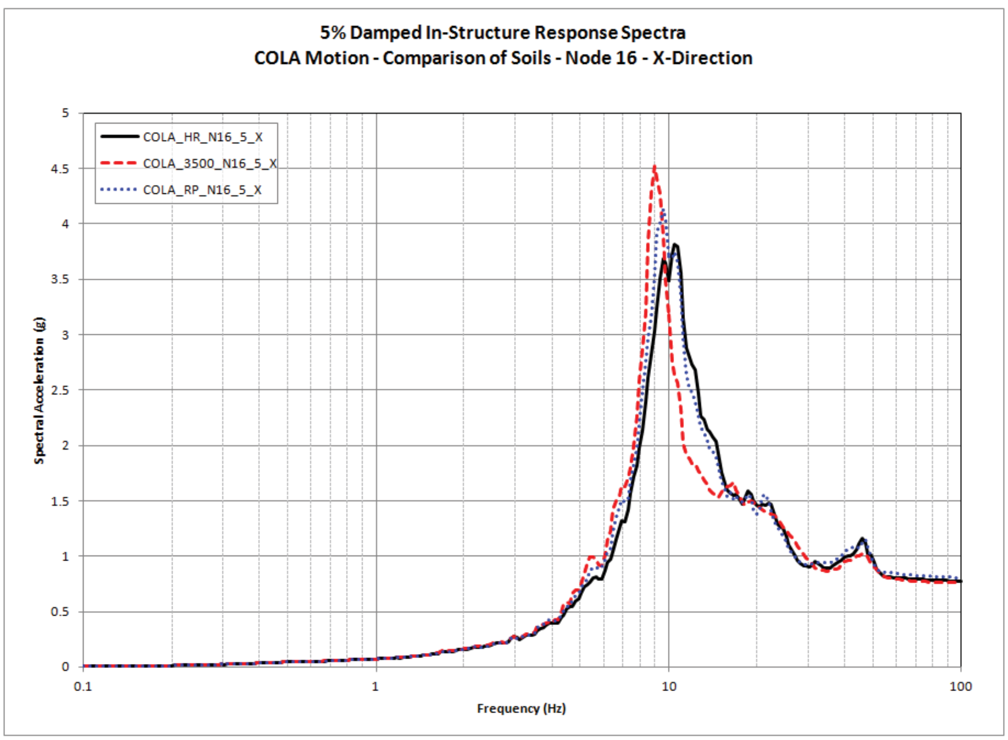

Figure 47 – 5% Damping ISRS - COLA Motion – All Soil – Node 16 – X (East-West) Direction

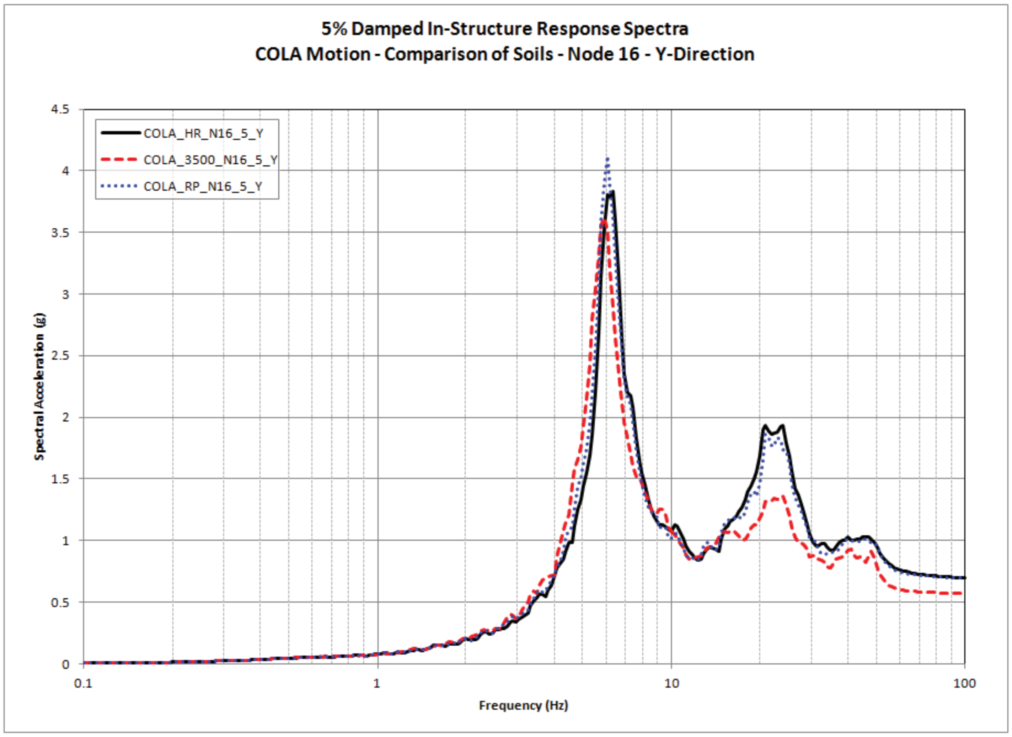

Figure 48 – 5% Damping ISRS - COLA Motion – All Soil – Node 16 – Y (North-South) Direction

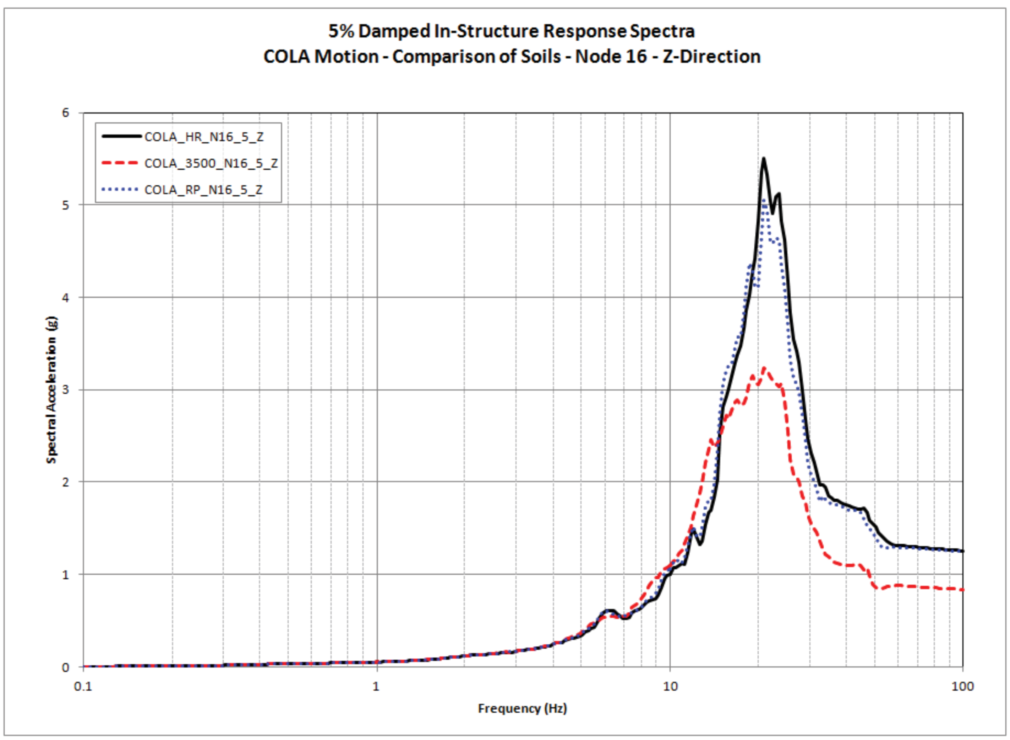

Figure 49 – 5% Damping ISRS - COLA Motion – All Soil – Node 16 – Z (Vertical) Direction

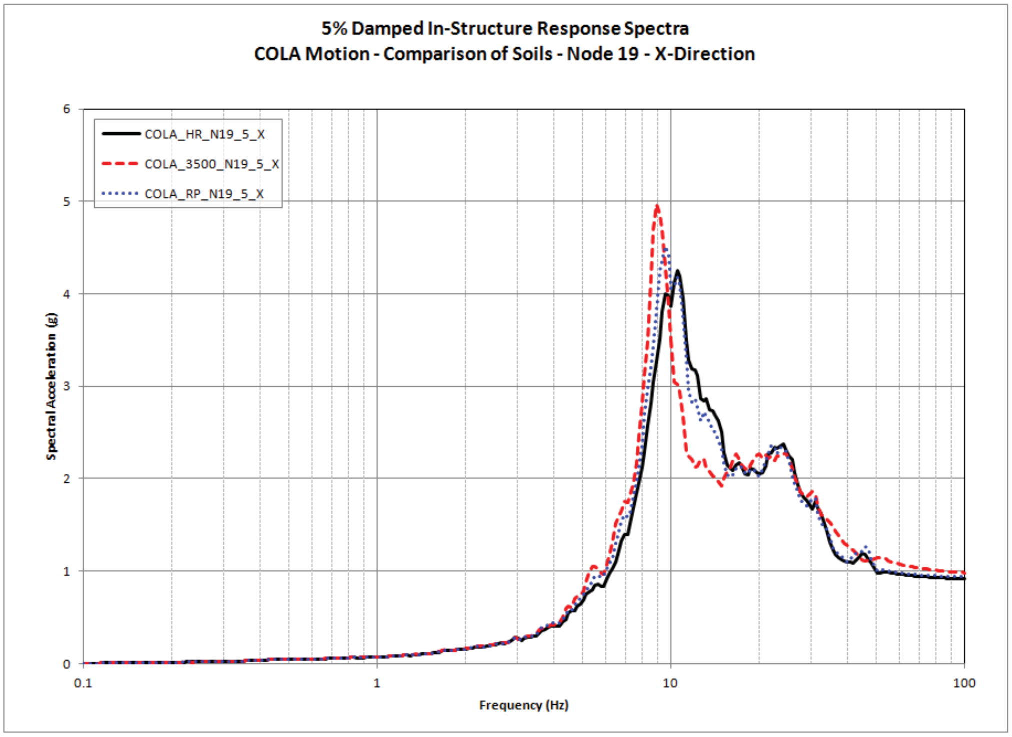

Figure 50 – 5% Damping ISRS - COLA Motion – All Soil – Node 19 – X (East-West) Direction

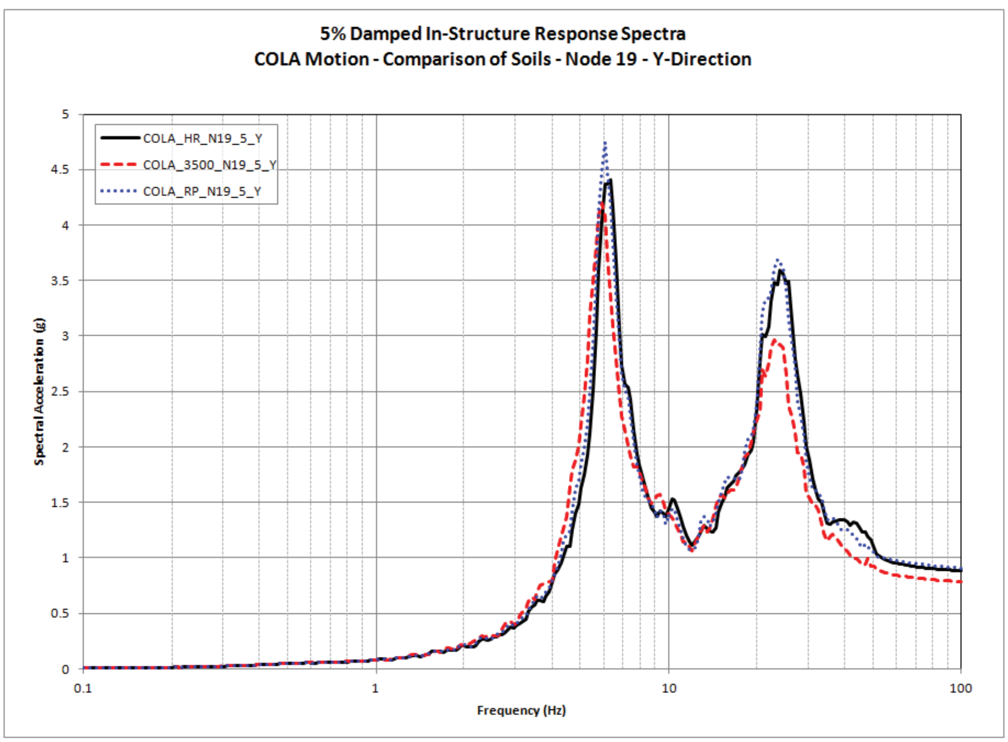

Figure 51 – 5% Damping ISRS - COLA Motion – All Soil – Node 19 – Y (North-South) Direction

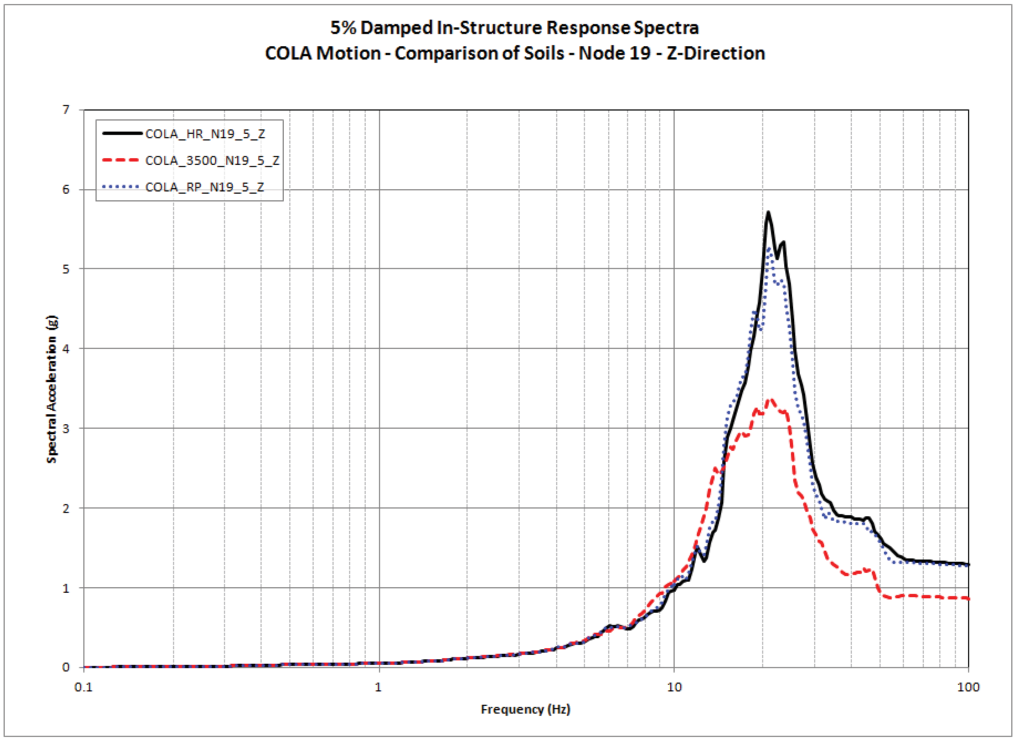

Figure 52 – 5% Damping ISRS - COLA Motion – All Soil – Node 19 – Z (Vertical) Direction

CEUS Input Motion

The following comparisons consider the CEUS input motion.

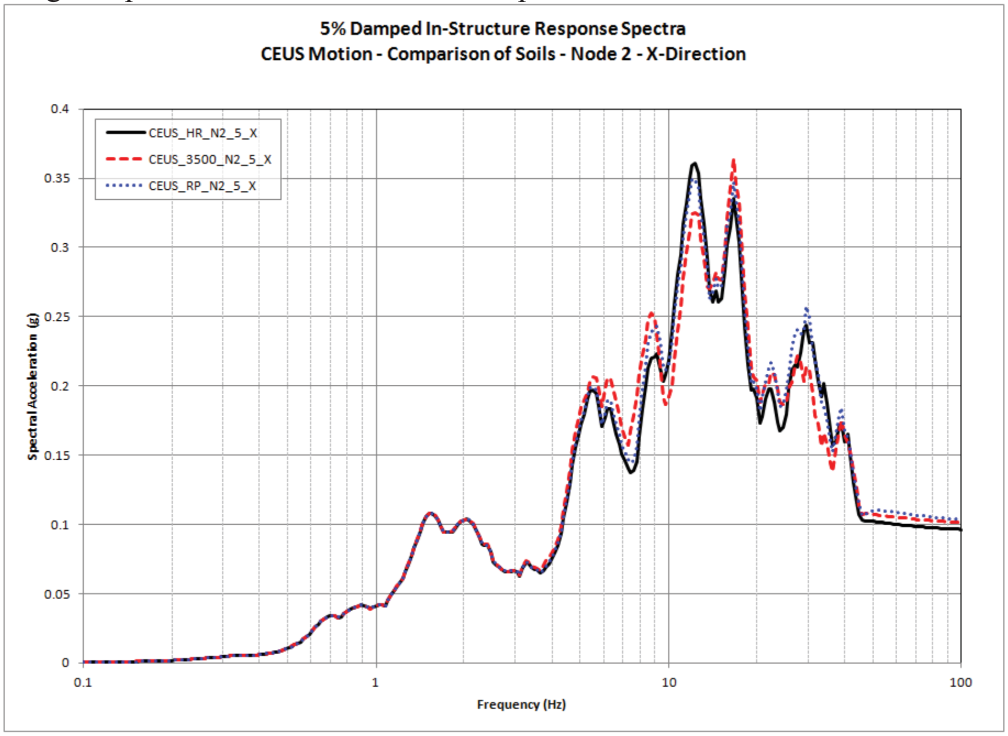

Figure 53 – 5% Damping ISRS - CEUS Motion – All Soil – Node 2 – X (East-West) Direction

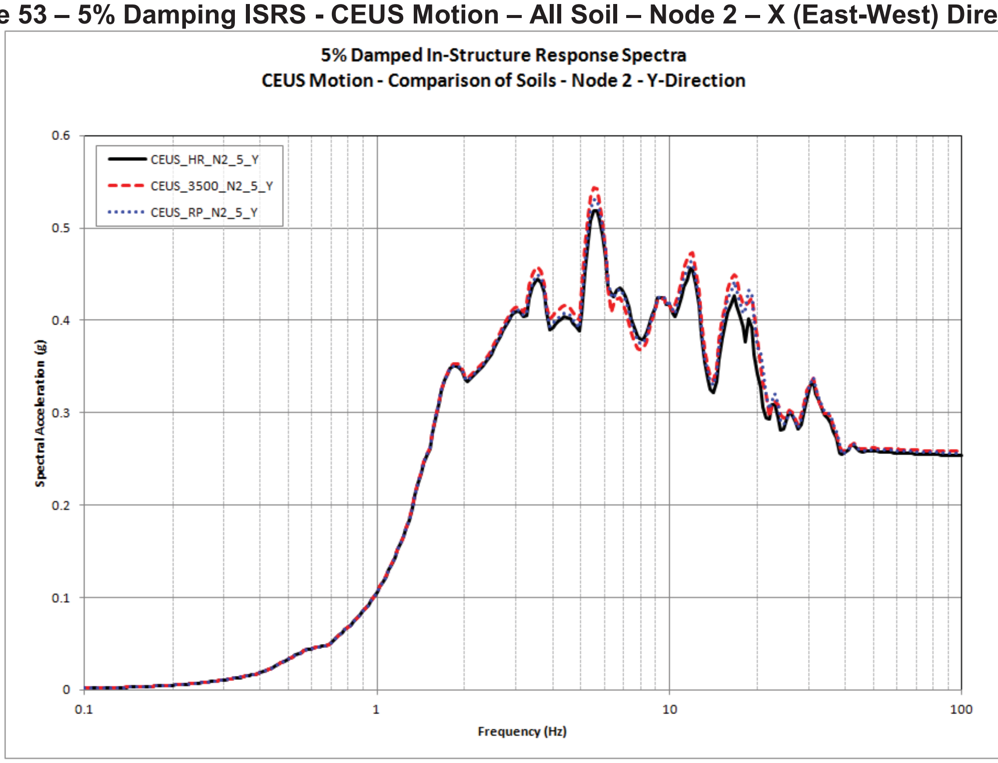

Figure 54 – 5% Damping ISRS - CEUS Motion – All Soil – Node 2 – Y (North-South) Direction

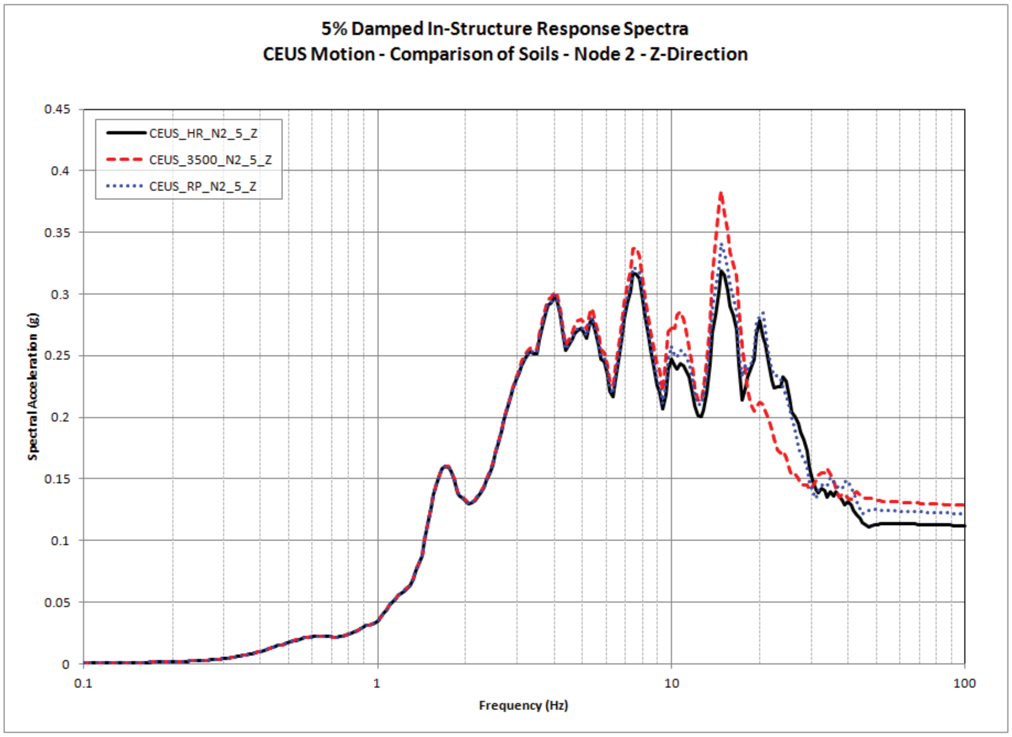

Figure 55 – 5% Damping ISRS - CEUS Motion – All Soil – Node 2 – Z (Vertical) Direction

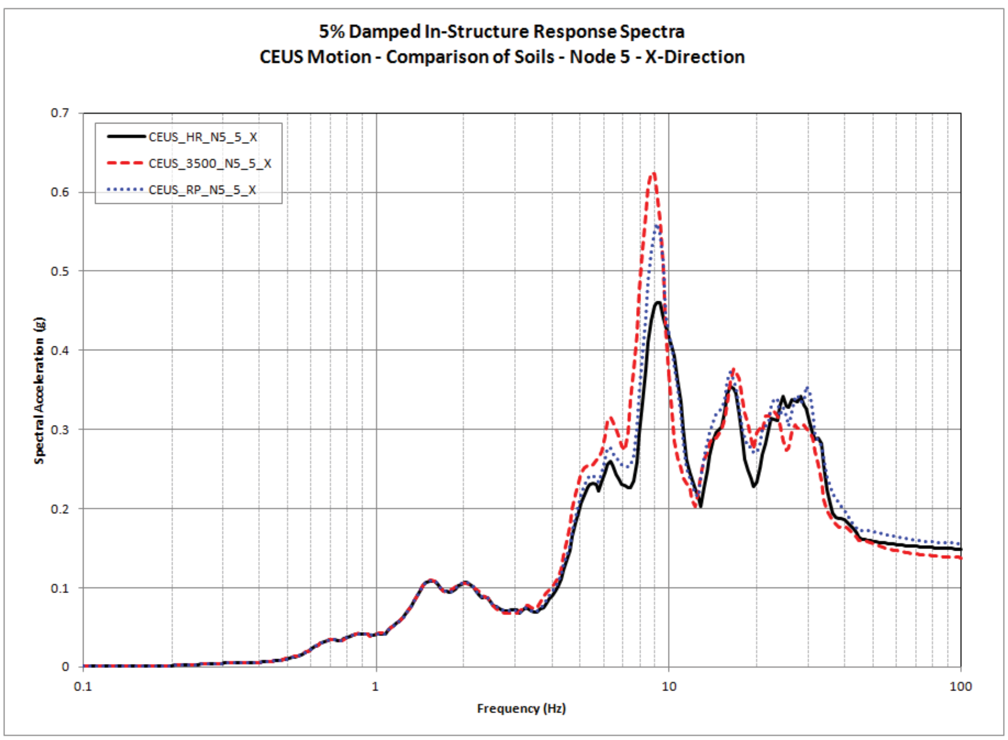

Figure 56 – 5% Damping ISRS - CEUS Motion – All Soil – Node 5 – X (East-West) Direction

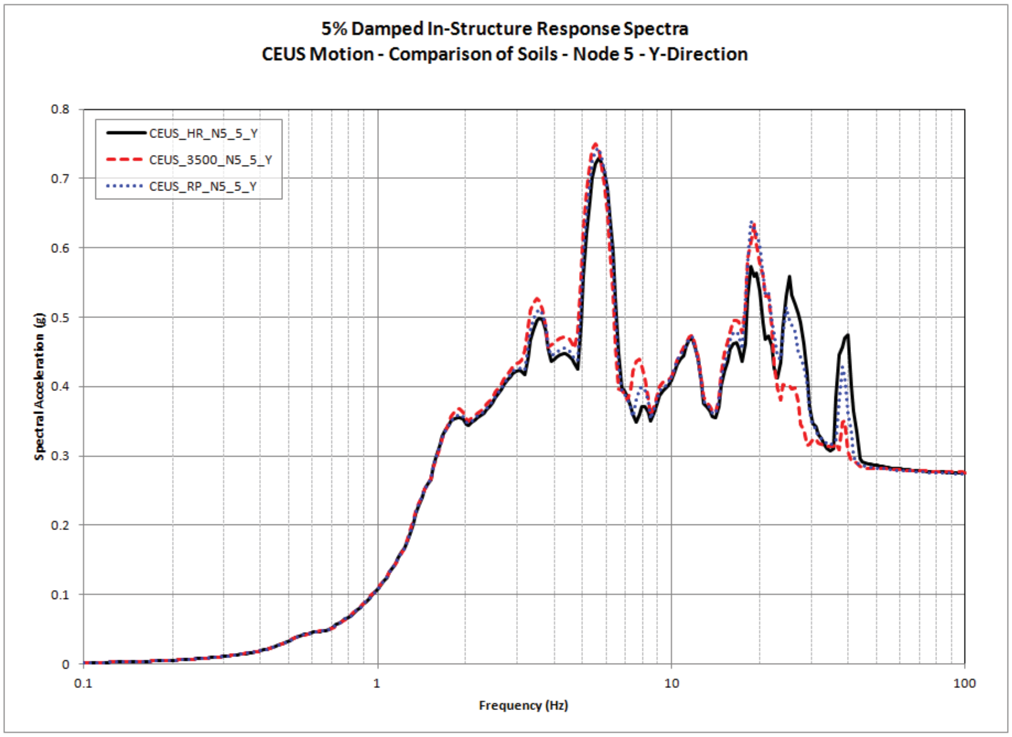

Figure 57 – 5% Damping ISRS - CEUS Motion – All Soil – Node 5 – Y (North-South) Direction

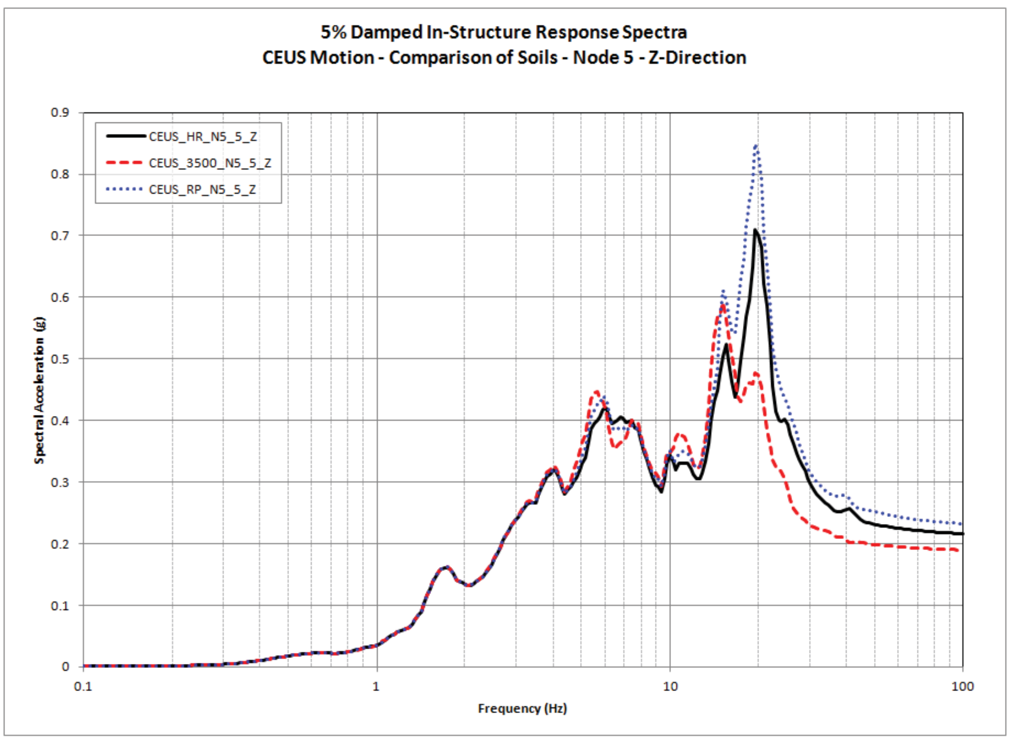

Figure 58 – 5% Damping ISRS - CEUS Motion – All Soil – Node 5 – Z (Vertical) Direction

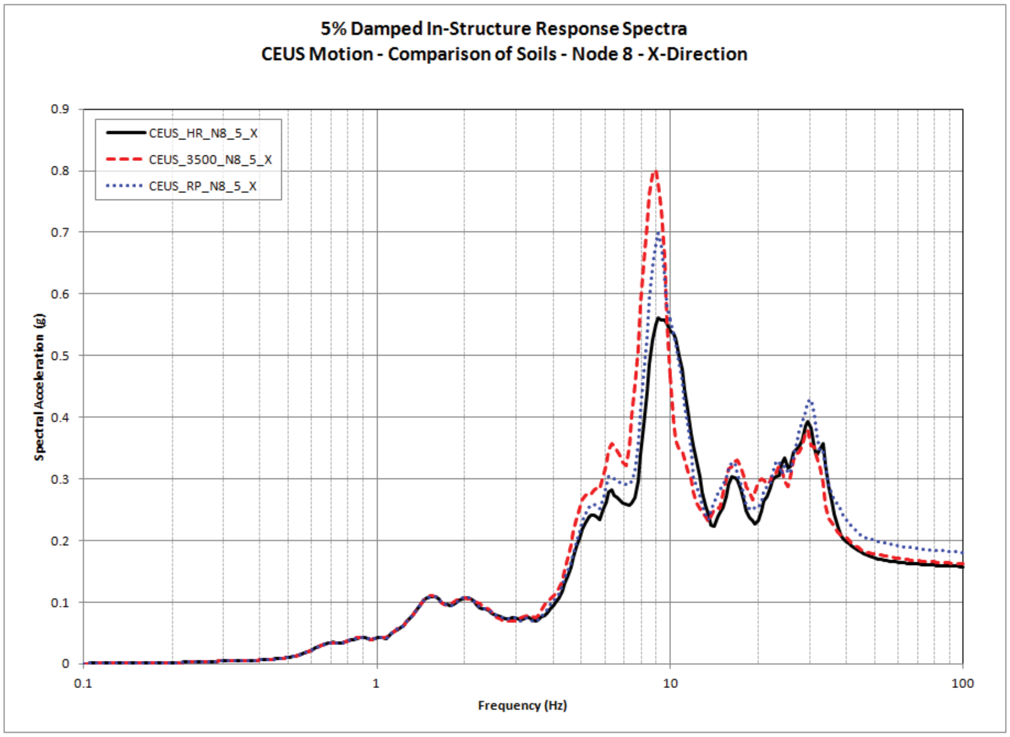

Figure 59 – 5% Damping ISRS - CEUS Motion – All Soil – Node 8 – X (East-West) Direction

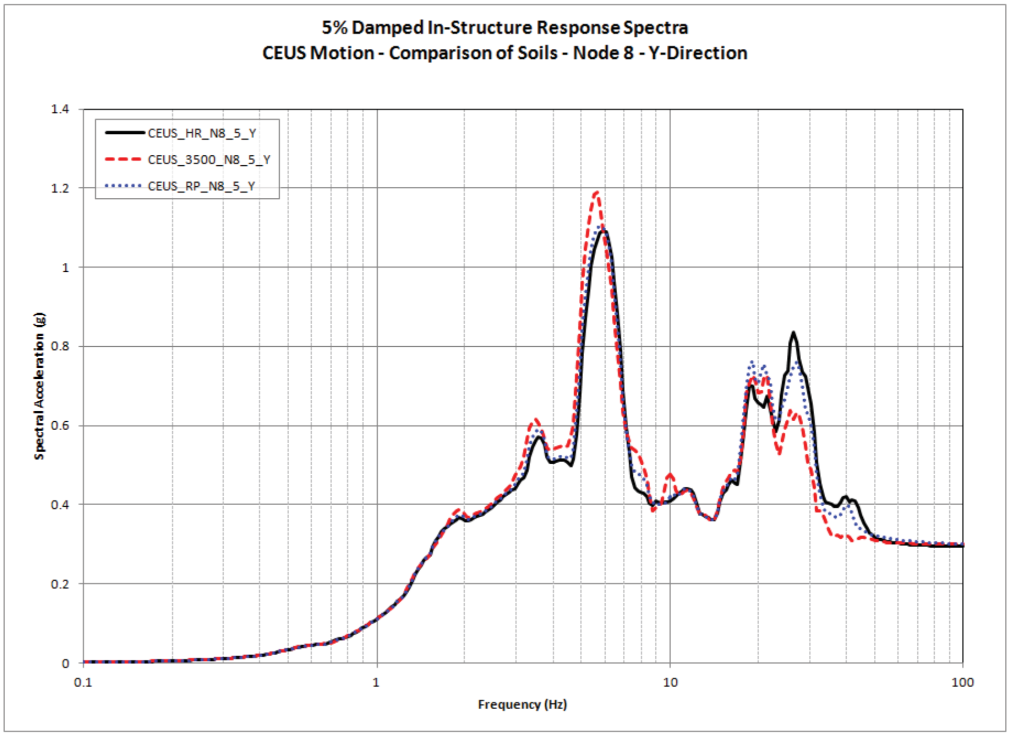

Figure 60 – 5% Damping ISRS - CEUS Motion – All Soil – Node 8 – Y (North-South) Direction

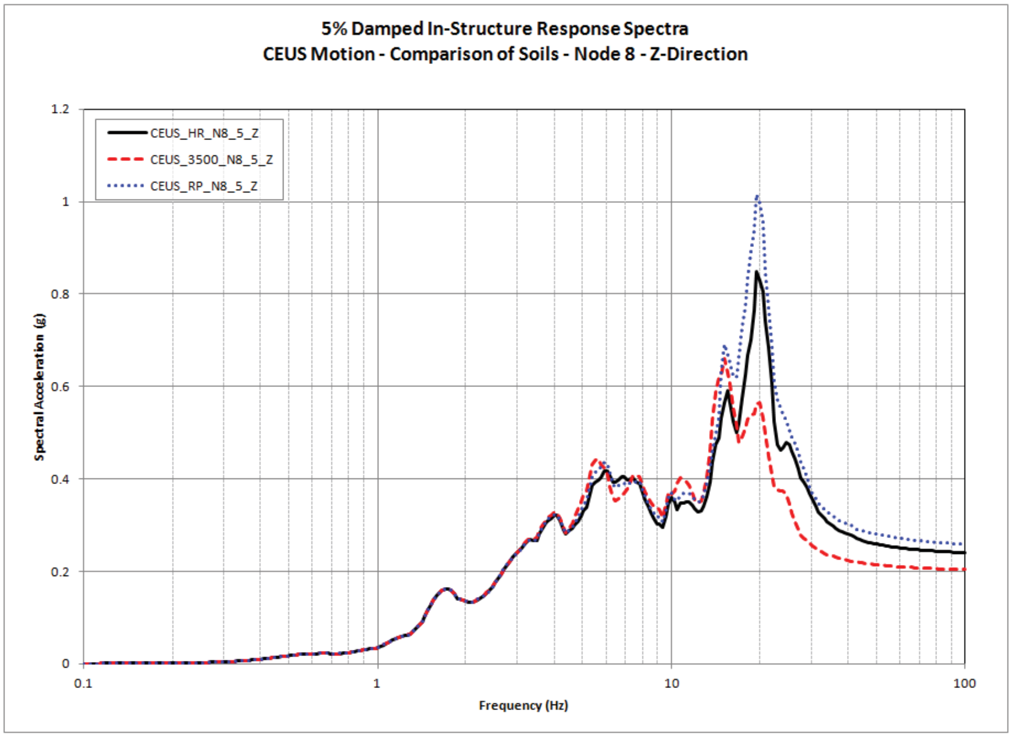

Figure 61 – 5% Damping ISRS - CEUS Motion – All Soil – Node 8 – Z (Vertical) Direction

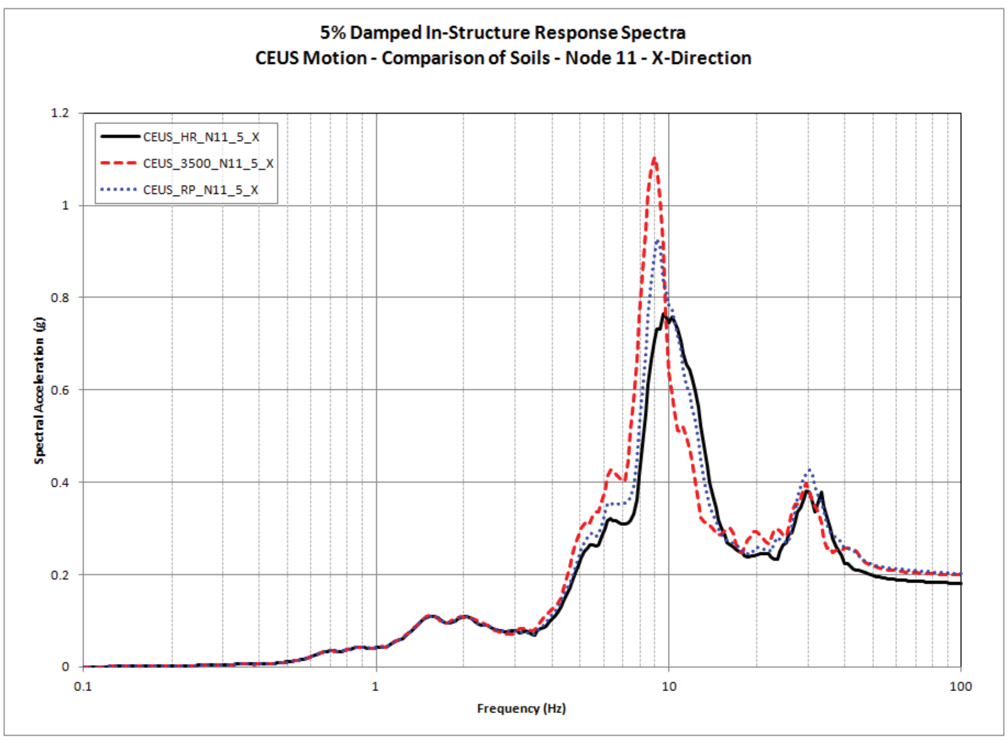

Figure 62 – 5% Damping ISRS - CEUS Motion – All Soil – Node 11 – X (East-West) Direction

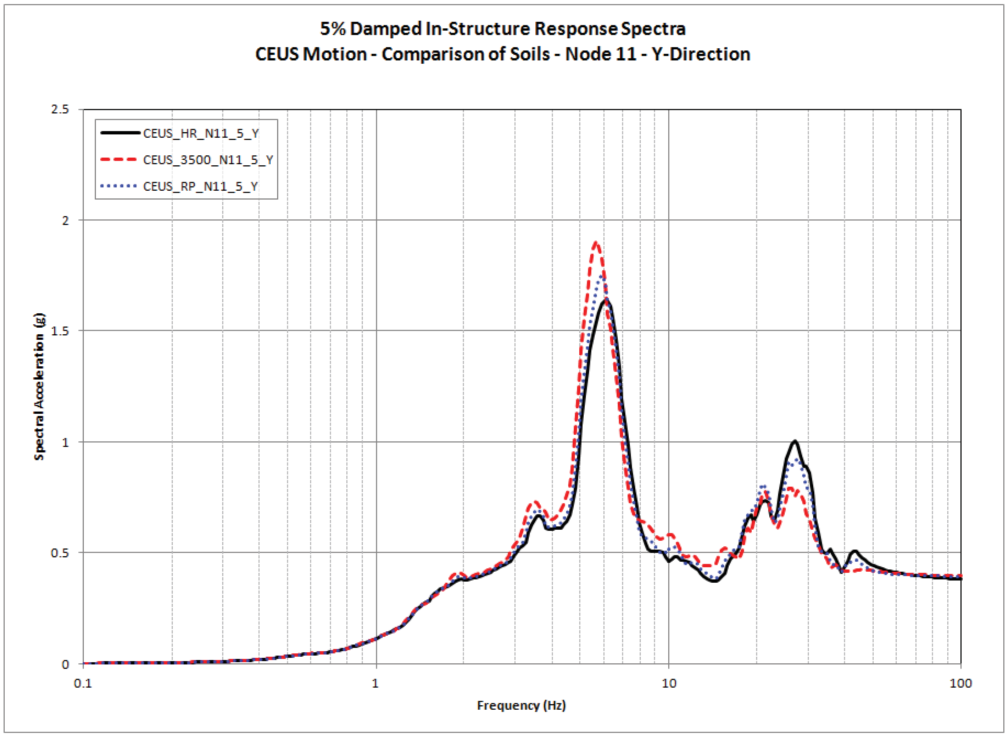

Figure 63 – 5% Damping ISRS - CEUS Motion – All Soil – Node 11 – Y (North-South) Direction

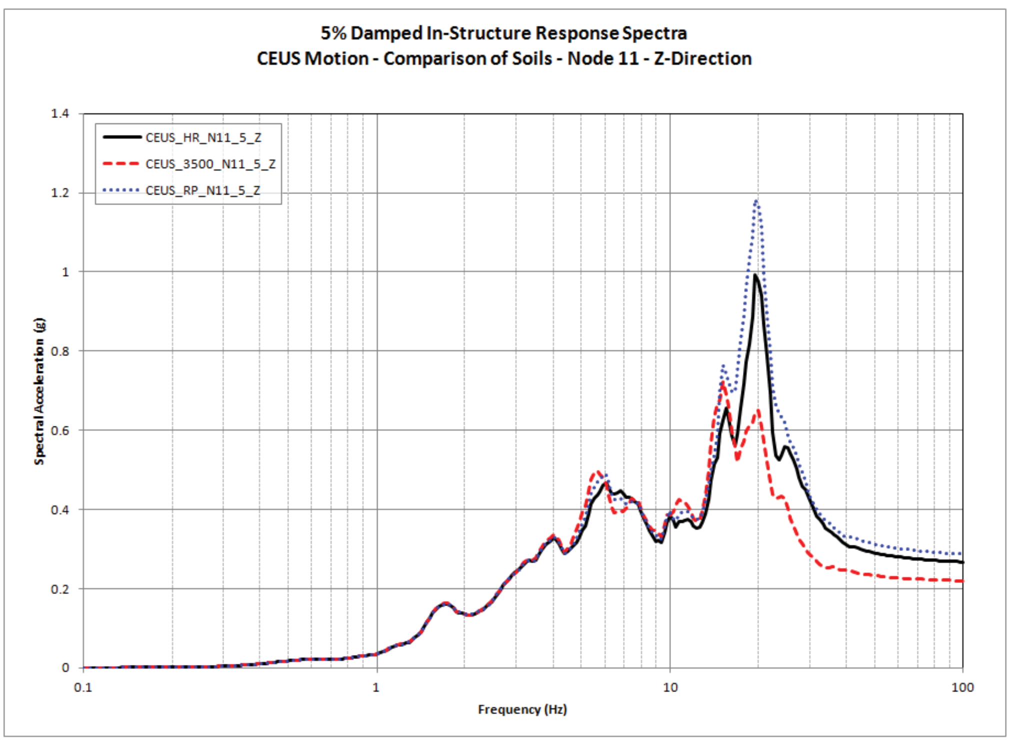

Figure 64 – 5% Damping ISRS - CEUS Motion – All Soil – Node 11 – Z (Vertical) Direction

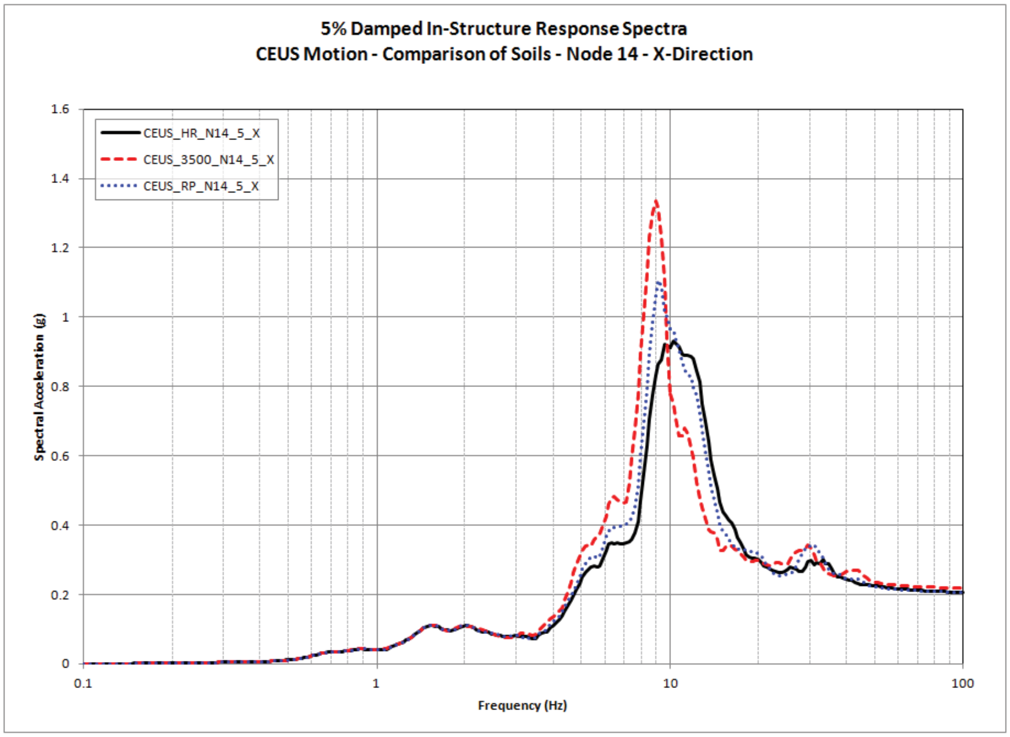

Figure 65 – 5% Damping ISRS - CEUS Motion – All Soil – Node 14 – X (East-West) Direction

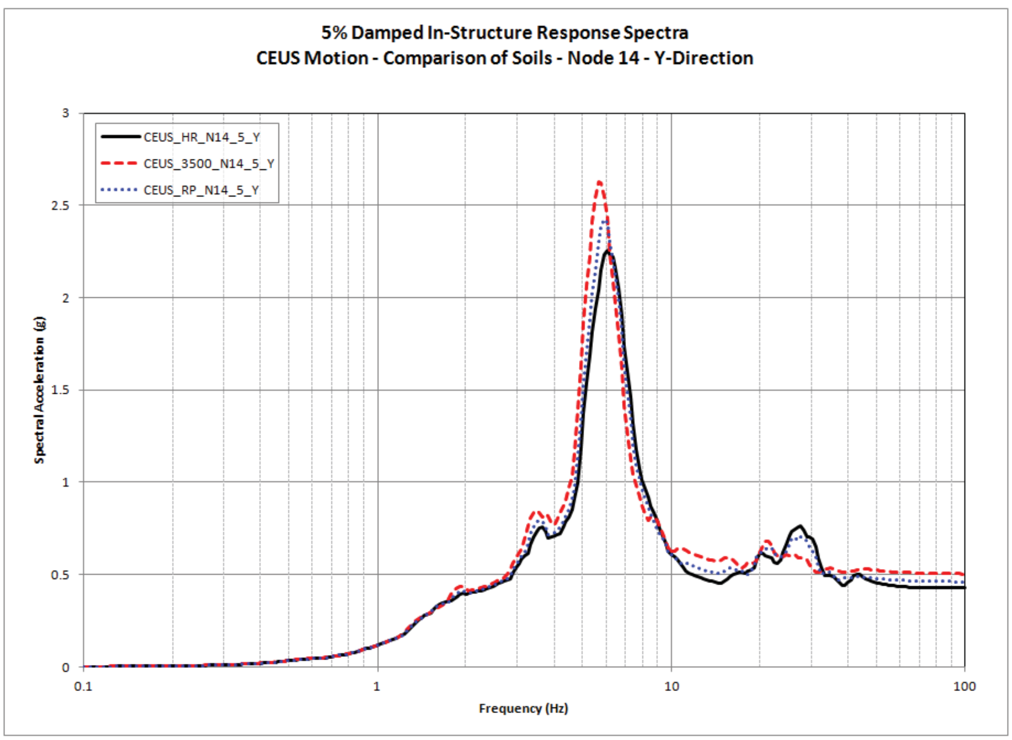

Figure 66 – 5% Damping ISRS - CEUS Motion – All Soil – Node 14 – Y (North-South) Direction

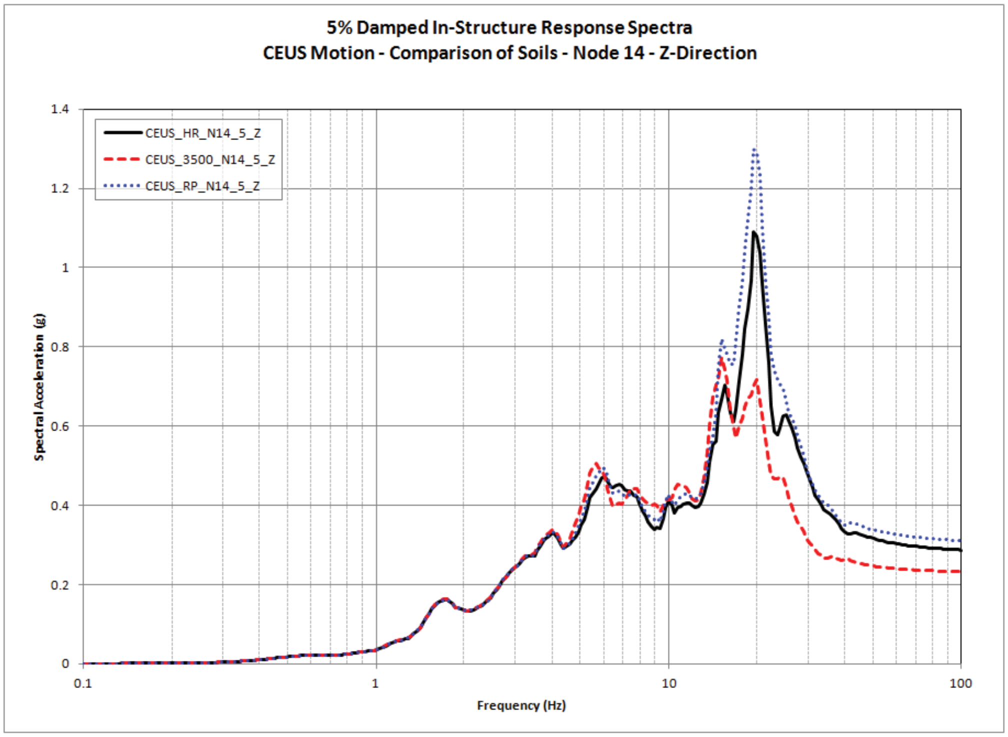

Figure 67 – 5% Damping ISRS - CEUS Motion – All Soil – Node 14 – Z (Vertical) Direction

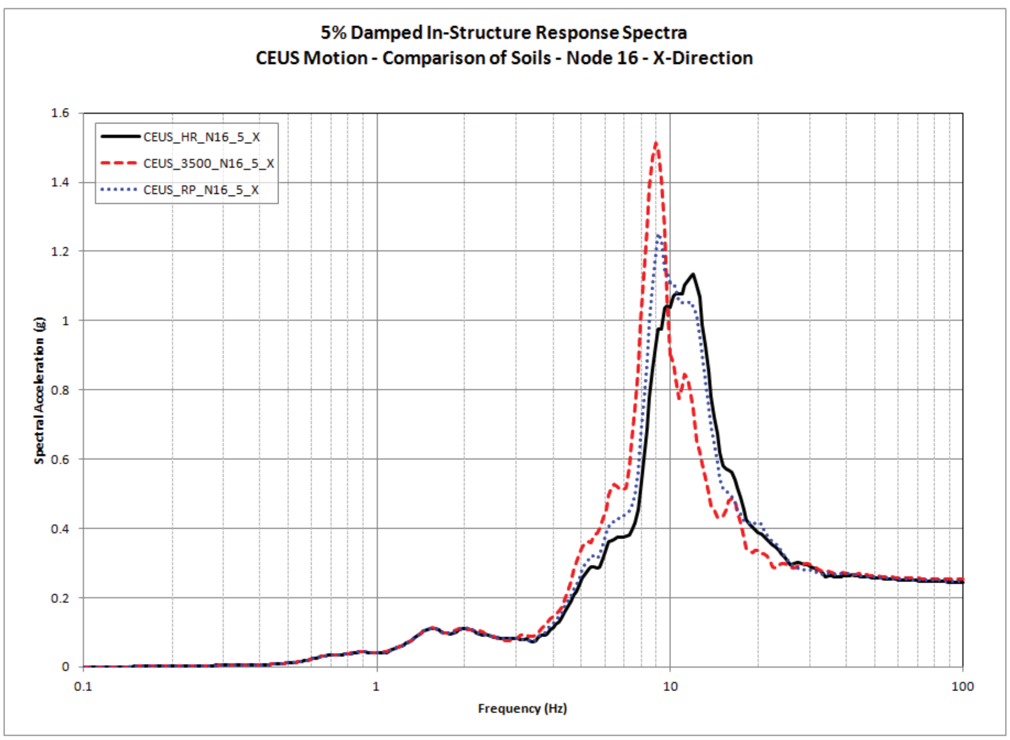

Figure 68 – 5% Damping ISRS - CEUS Motion – All Soil – Node 16 – X (East-West) Direction

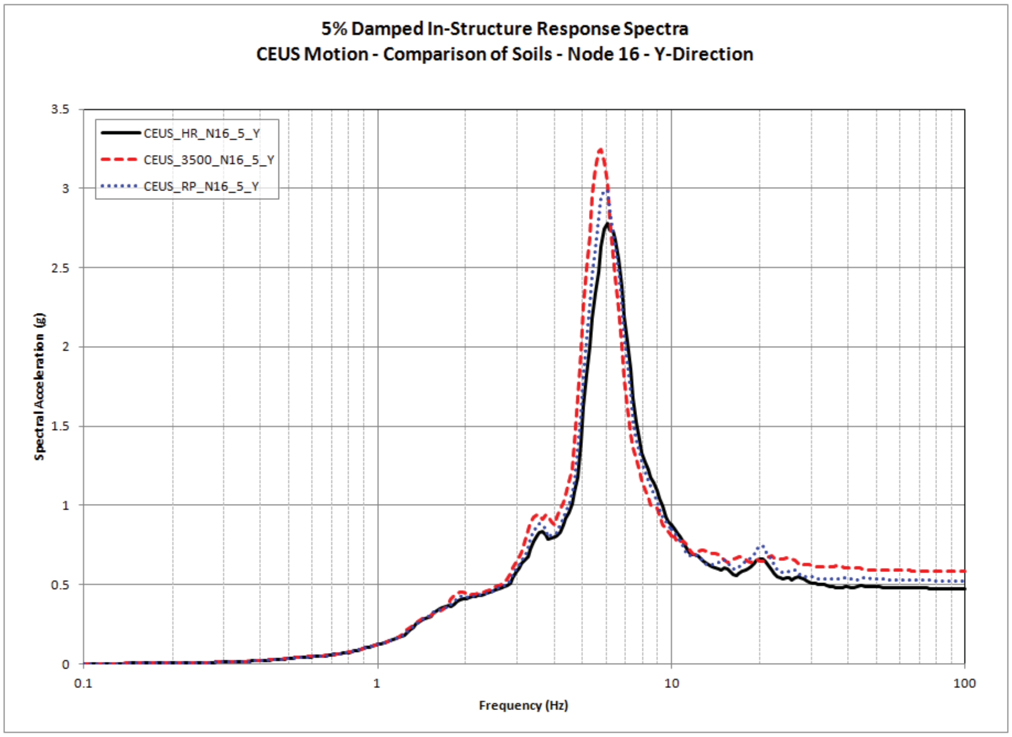

Figure 69 – 5% Damping ISRS - CEUS Motion – All Soil – Node 16 – Y (North-South) Direction

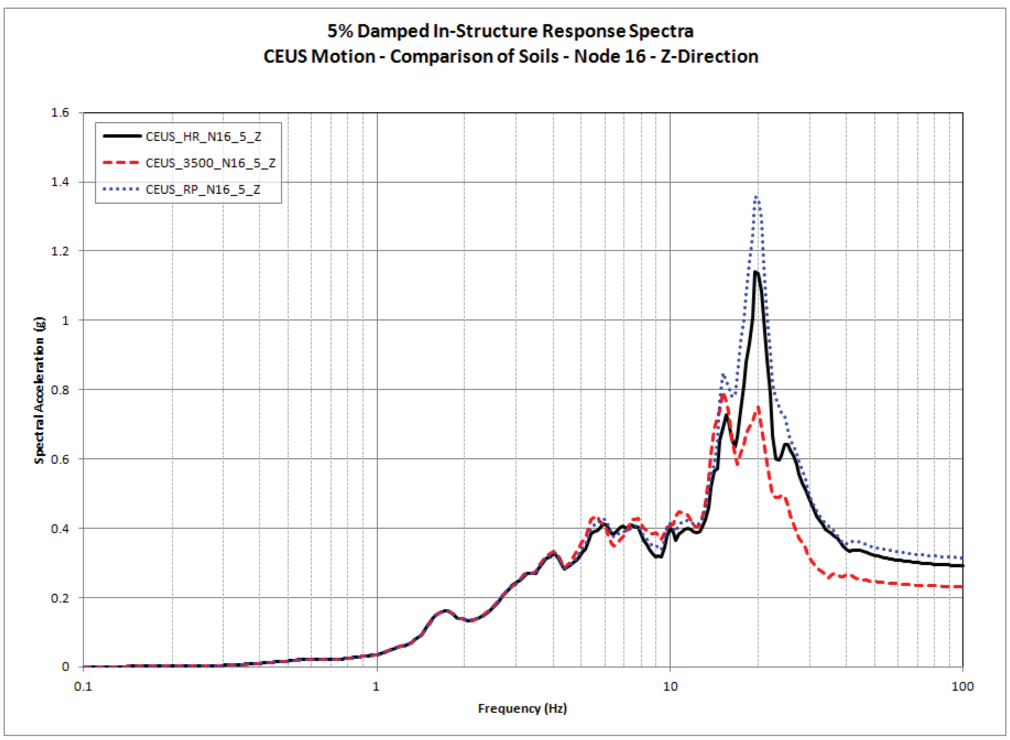

Figure 70 – 5% Damping ISRS - CEUS Motion – All Soil – Node 16 – Z (Vertical) Direction

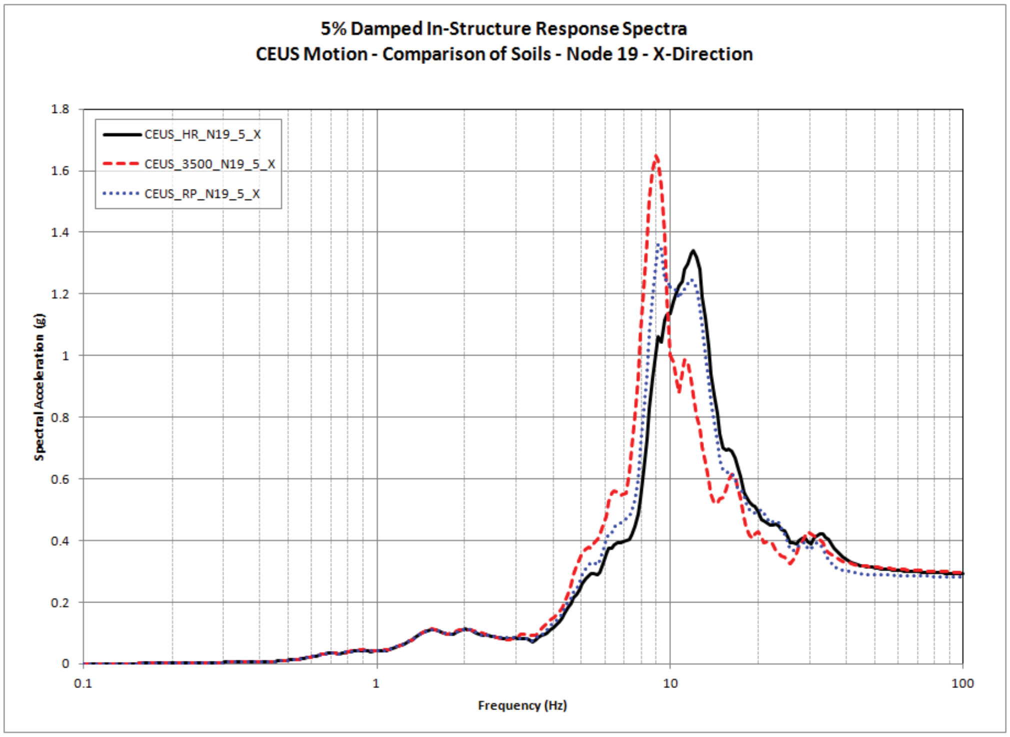

Figure 71 – 5% Damping ISRS - CEUS Motion – All Soil – Node 19 – X (East-West) Direction

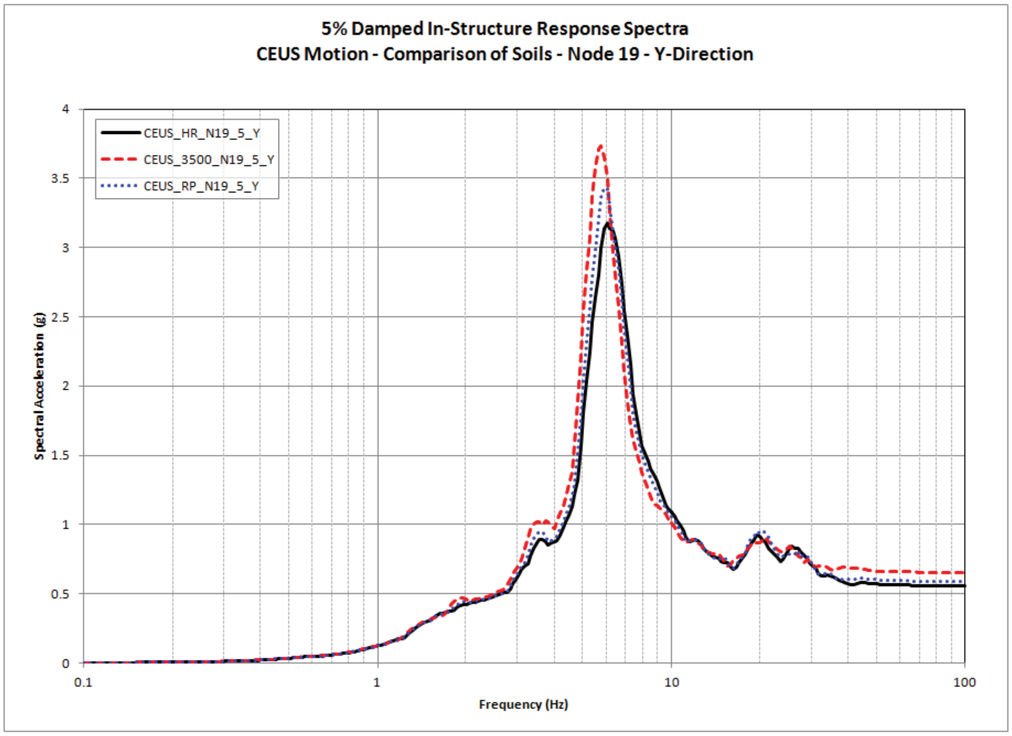

Figure 72 – 5% Damping ISRS - CEUS Motion – All Soil – Node 19 – Y (North-South) Direction

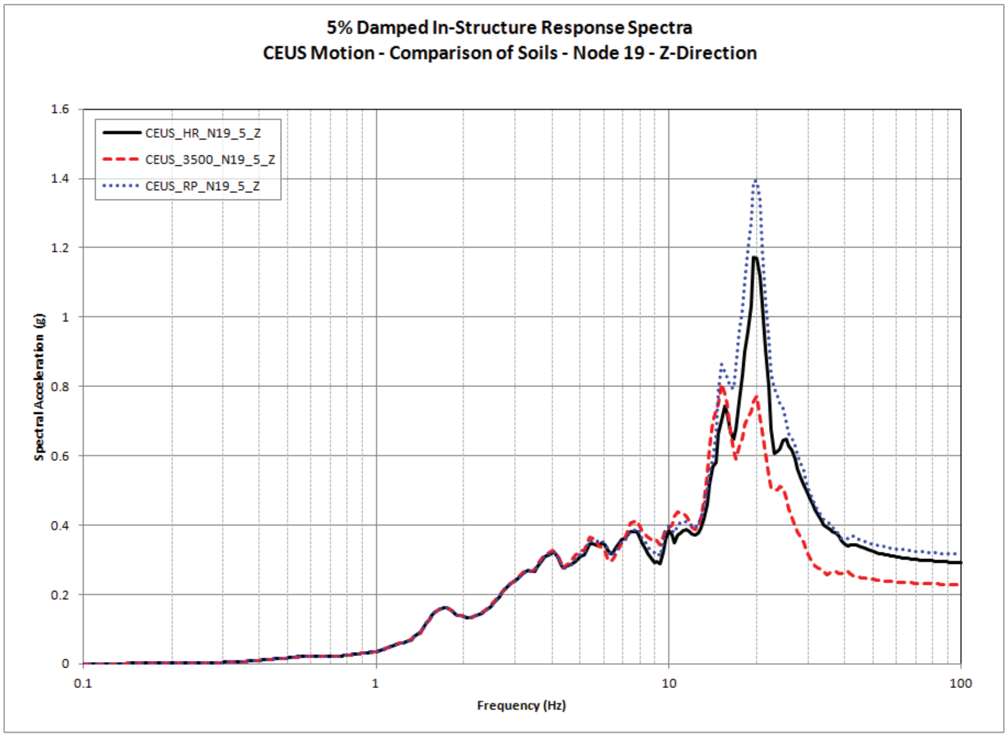

Figure 73 – 5% Damping ISRS - CEUS Motion – All Soil – Node 19 – Z (Vertical) Direction

5
SUMMARY AND CONCLUSIONS

The following summarizes the observations and findings of this report. Note that given the limited accuracy of the Lumped-Mass and Stick Model (LMSM) above 10 Hz, and the applicable frequency range in the context of Seismic Probabilistic Risk Assessment (SPRA), the response of the structure below 10 Hz is emphasized.

The comparison between fixed-base (Hard Rock profile) results and two rock profiles with shear wave velocities of 3500 fps and 5200 fps are presented in this report. A sample of these comparisons is repeated in Figure 74 through Figure 79 for convenience.

- The Soil-Structure Interaction (SSI) effects are noticeable for both rock profiles considered at frequencies of above 5 Hz. In general, these effects below 10 Hz are usually characterized by a small shift in frequency and amplification of the peak In-Structure Response Spectra (ISRS) up to 40% over a narrow band of frequencies. These effects are more noticeable at higher levels in the structure indicating some degree of foundation rocking.
- The differences between the ISRS obtained from the site-specific rock profile (top Vs of 5200 fps) and the Hard Rock profile below 10 Hz, for all three input ground motions, are not significant. This suggests that the use of fixed-base results (for the response below 10 Hz) for the subject structure on this profile is reasonable.
- The comparison between the 3500 fps response and Hard Rock response below 10 Hz suggests that the peak ISRS from the SSI response maybe between 90% and 140% of the fixed-base ISRS. Also, a slight shift of frequency is observed in the spectral peaks. Nevertheless, the shapes of the ISRS in the entire frequency range remain about the same. These observations suggest that the use of fixed-base results (for the response below 10 Hz) for the subject structure on this profile is appropriate only if one can accept potential small frequency and amplitude shifts of the spectral peaks. The peak-broadening or peak-shifting of the ISRS can alleviate such frequency shift effects.
- The consideration of different input time-histories does not significantly alter the findings above. However, a closer agreement between the results of different rock profiles is observed below 10 Hz when considering the representative Combined Operating License Application (COLA) input time-history. This is due to the high frequency nature of this ground motion with less energy content below 10 Hz.

The SSI effects above 10 Hz are generally more significant and cannot be discounted. This is especially manifested in the large differences between the vertical (Z direction) ISRS at and above 20 Hz and in the results of COLA time-history.

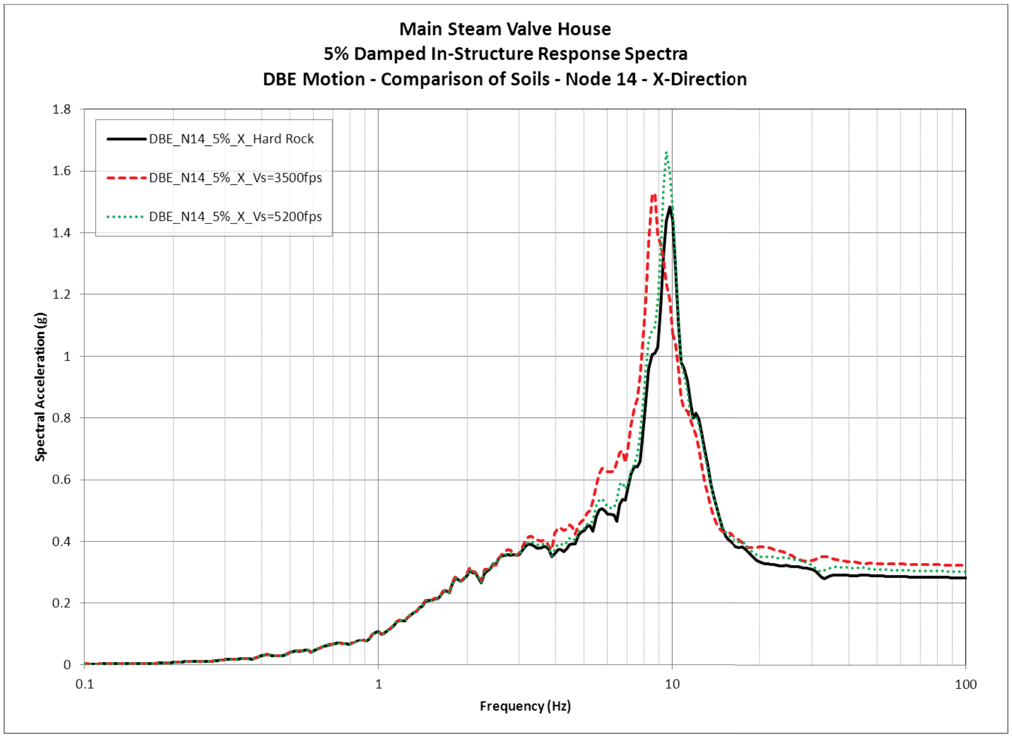

Figure 74 – Main Steam Valve House, Elevation 306’-9”, 5% Damping ISRS - DBE Motion – X (East-West) Direction

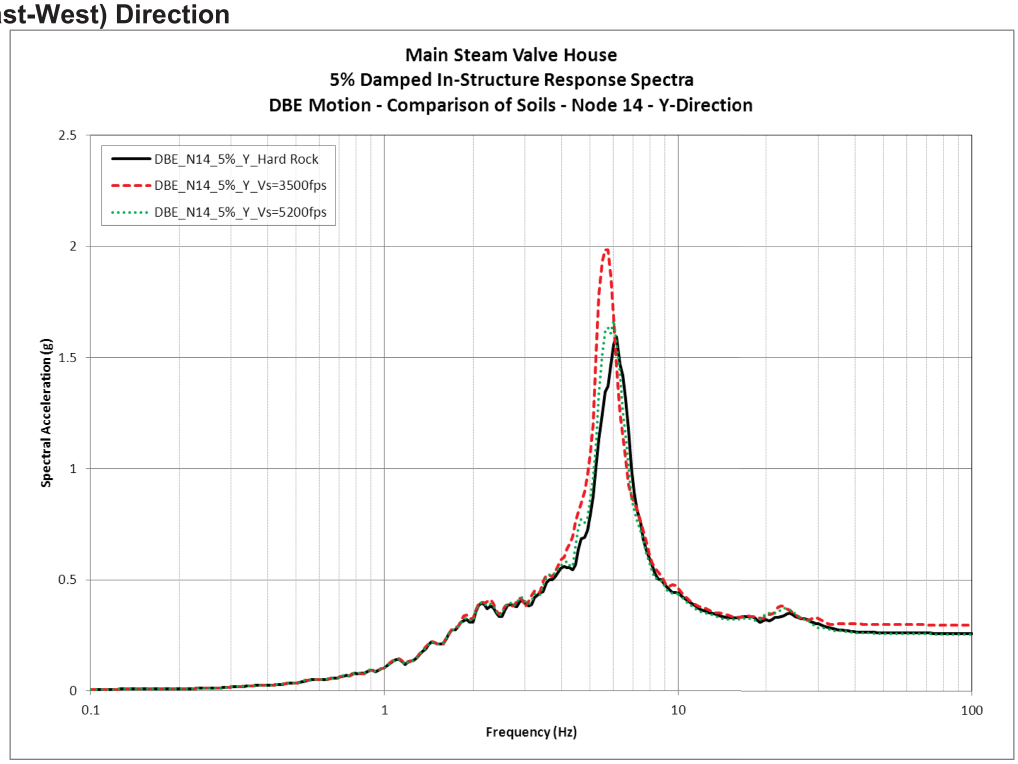

Figure 75 – Main Steam Valve House, Elevation 306’-9”, 5% Damping ISRS - DBE Motion – Y (North-South) Direction

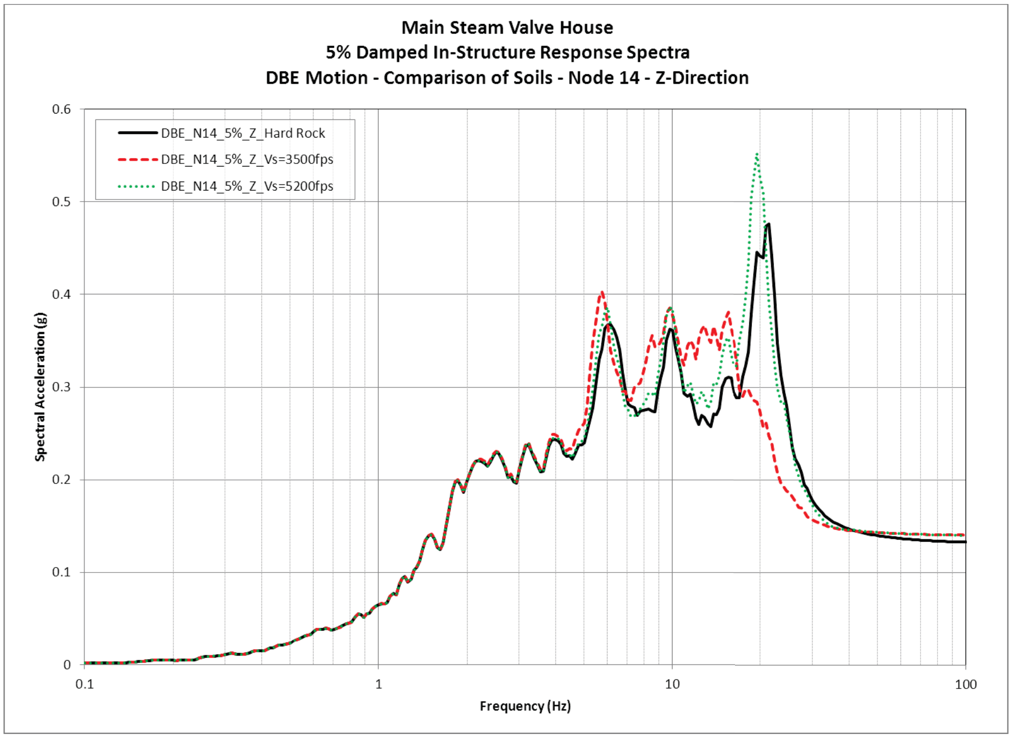

Figure 76 – Main Steam Valve House, Elevation 306’-9”, 5% Damping ISRS - DBE Motion – Z (Vertical) Direction

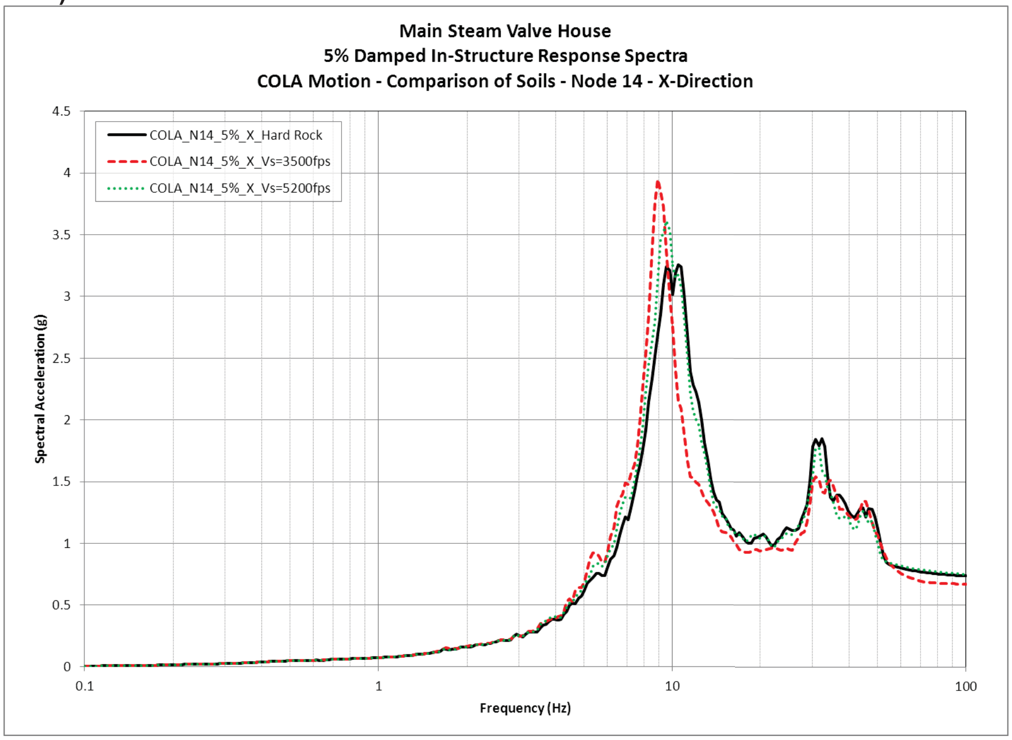

Figure 77 – Main Steam Valve House, Elevation 306’-9”, 5% Damping ISRS - COLA Motion – X (East-West) Direction

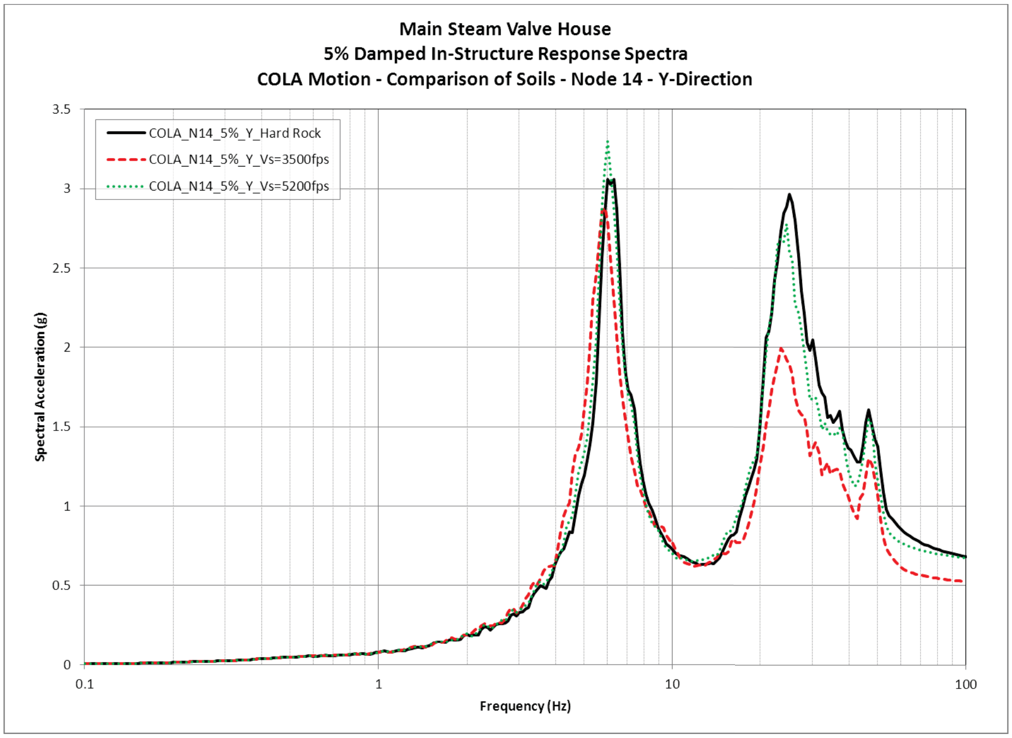

Figure 78 – Main Steam Valve House, Elevation 306'-9", 5% Damping ISRS - COLA Motion – Y (North-South) Direction

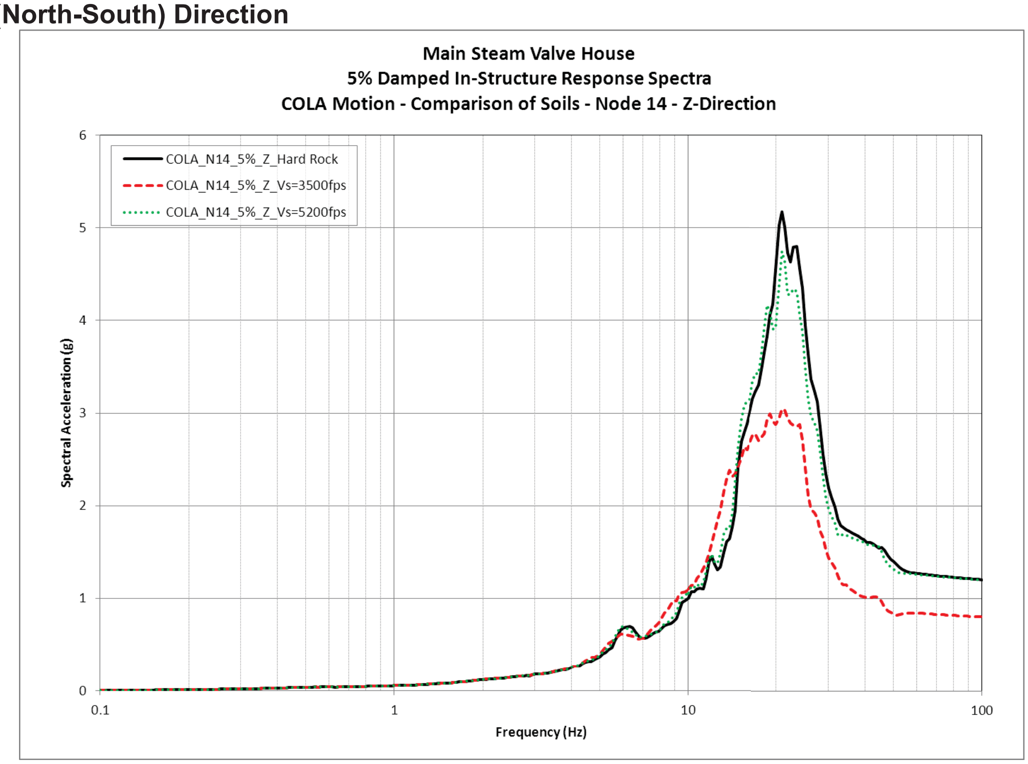

Figure 79 – Main Steam Valve House, Elevation 306'-9", 5% Damping ISRS - COLA Motion – Z (Vertical) Direction

A
MODAL FREQUENCIES AND MASS PARTICIPATIONS

The modal frequencies and corresponding mass participations are shown in Table 4 below.

Table 4 – Modal Frequencies and Mass Participations

Mode	Frequency (Hz)	Mass Participation (%)		
		X	Y	Z
1	6.15886	0.19	41.94	1.91
2	9.88278	39.01	0.36	0.53
3	11.59590	10.77	0.28	0.00
4	20.98944	0.52	0.57	57.71
5	23.04184	3.01	5.48	0.22
6	25.27333	3.12	12.65	0.34
7	31.43676	7.84	0.17	0.28
8	39.56552	0.05	4.25	0.08
9	41.03711	0.02	0.02	0.01
10	47.51002	1.66	0.56	0.21
11	48.49165	0.12	1.16	0.29
12	55.40802	1.32	0.05	1.28
13	61.93570	0.14	0.01	1.03
14	64.01123	0.01	0.25	0.05
15	73.51847	0.03	0.00	0.00
16	74.28253	0.03	0.06	0.11
17	82.15926	0.03	0.07	0.37
18	85.28392	0.02	0.01	0.77
19	88.38605	0.06	0.05	0.53
20	91.93731	0.01	0.00	0.93
21	98.37846	0.01	0.00	0.15
22	109.40040	0.02	0.00	0.00
23	115.23629	0.00	0.01	0.24
24	126.74190	0.00	0.00	0.06
25	130.21918	0.00	0.00	0.27
26	137.02551	0.00	0.01	0.51
27	159.10845	0.00	0.00	0.00
28	165.71847	0.00	0.00	0.02
29	174.56493	0.00	0.00	0.03
30	192.84299	0.00	0.00	0.09

Mode	Frequency (Hz)	Mass Participation (%)		
		X	Y	Z
31	195.74910	0.00	0.00	0.01
32	211.96391	0.00	0.00	0.00
33	231.83704	0.00	0.00	0.01
34	256.63996	0.00	0.00	0.00
35	270.06345	0.00	0.00	0.00
36	320.94518	0.00	0.00	0.00
37	342.09146	0.01	0.02	0.04
38	433.36492	0.36	0.17	0.03
39	752.42911	0.00	0.19	1.58
40	2310.36557	20.30	10.17	0.95
41	2353.21303	0.02	3.11	26.99

B

MOTION COMPARISONS FOR DIFFERENT SOIL CASES

Comparisons are presented for all motions on one plot with each soil profile. Figure numbers are indicated in Table 5.

Table 5 - Motion Comparison Figure Numbers

Figure Number	Plot ID	Damping	Motion	Soil	Node	Direction
80	All_3500_N2_5_X	5%	All Motions	3500	2	X
81	All_3500_N2_5_Y	5%	All Motions	3500	2	Y
82	All_3500_N2_5_Z	5%	All Motions	3500	2	Z
83	All_3500_N19_5_X	5%	All Motions	3500	19	X
84	All_3500_N19_5_Y	5%	All Motions	3500	19	Y
85	All_3500_N19_5_Z	5%	All Motions	3500	19	Z
86	All_HR_N2_5_X	5%	All Motions	HR	2	X
87	All_HR_N2_5_Y	5%	All Motions	HR	2	Y
88	All_HR_N2_5_Z	5%	All Motions	HR	2	Z
89	All_HR_N19_5_X	5%	All Motions	HR	19	X
90	All_HR_N19_5_Y	5%	All Motions	HR	19	Y
91	All_HR_N19_5_Z	5%	All Motions	HR	19	Z
92	All_RP_N2_5_X	5%	All Motions	RP	2	X
93	All_RP_N2_5_Y	5%	All Motions	RP	2	Y
94	All_RP_N2_5_Z	5%	All Motions	RP	2	Z
95	All_RP_N19_5_X	5%	All Motions	RP	19	X
96	All_RP_N19_5_Y	5%	All Motions	RP	19	Y
97	All_RP_N19_5_Z	5%	All Motions	RP	19	Z

3500 Soil Profile

The following comparisons consider the 3500 soil profile.

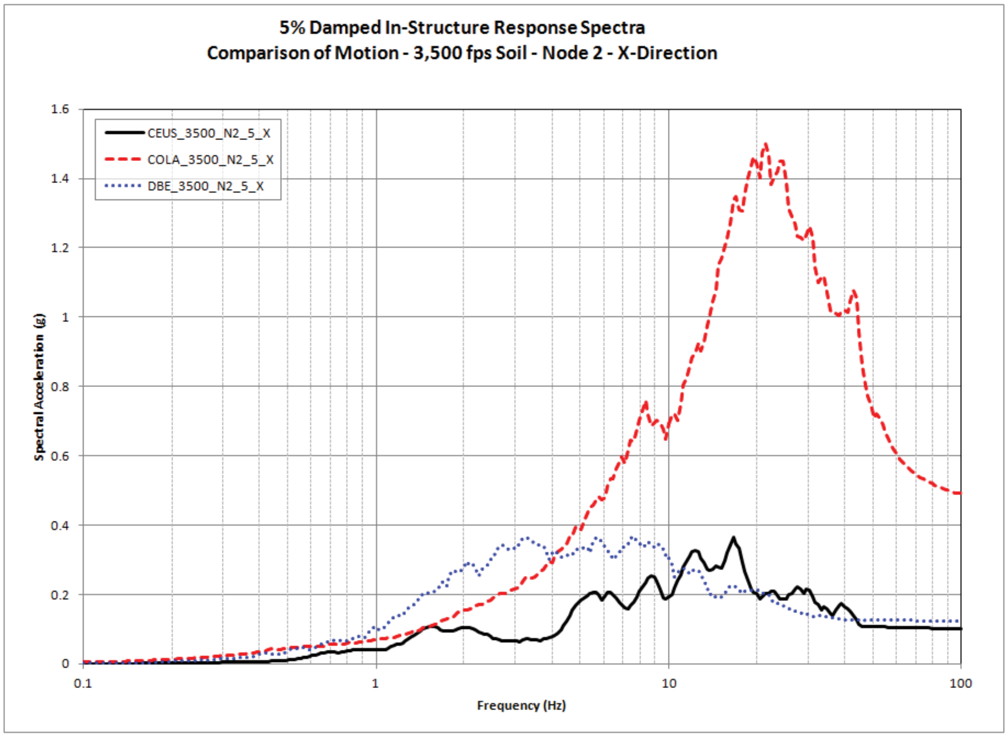

Figure 80 – 5% Damping ISRS – All Motions – 3500 Soil – Node 2 – X (East-West) Direction

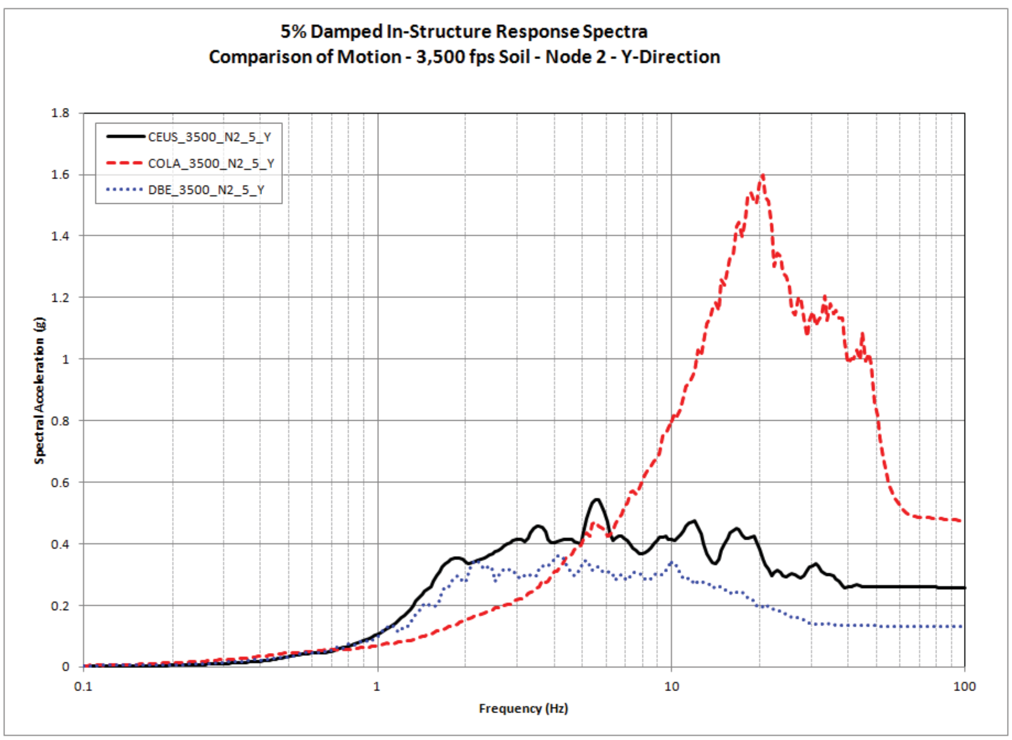

Figure 81 – 5% Damping ISRS – All Motions – 3500 Soil – Node 2 – Y (North-South) Direction

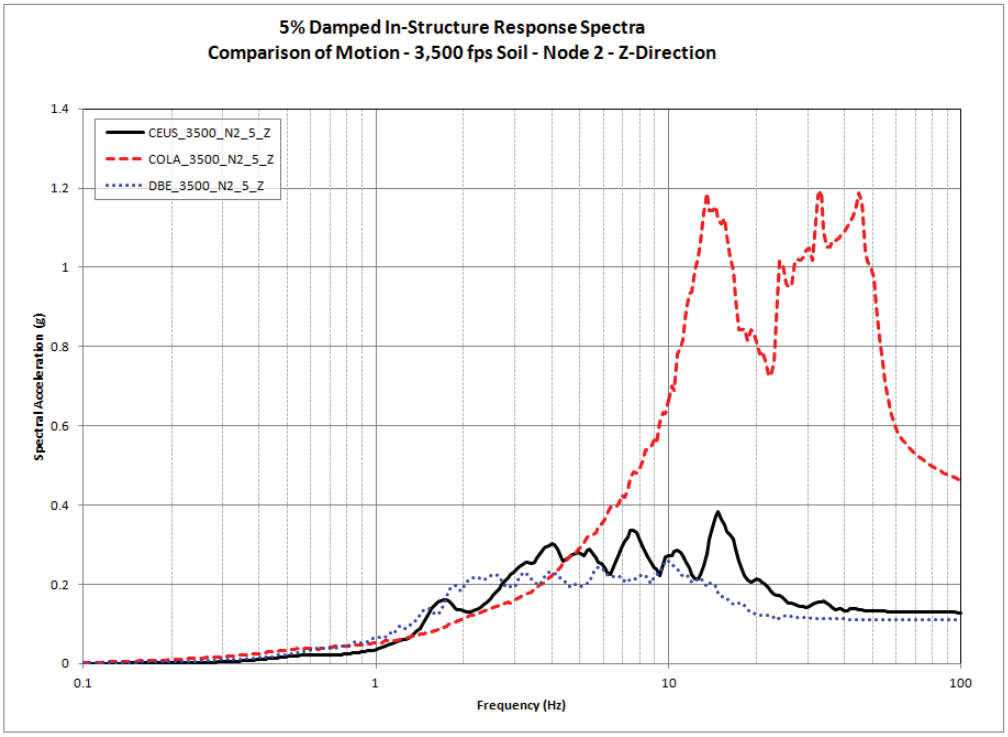

Figure 82 – 5% Damping ISRS – All Motions – 3500 Soil – Node 2 – Z (Vertical) Direction

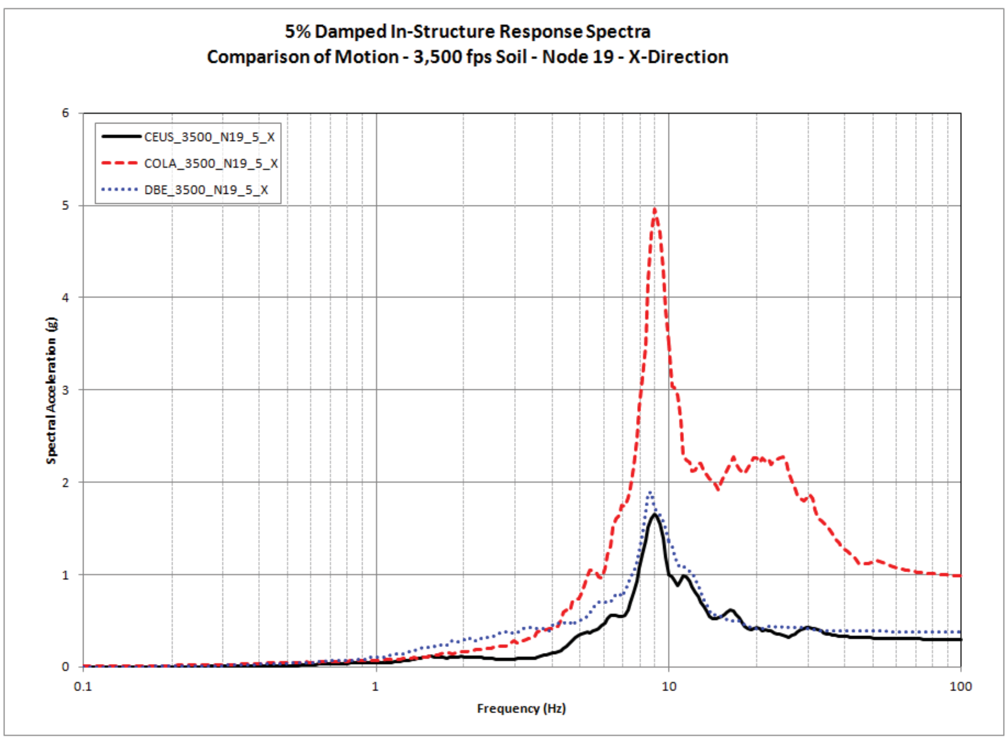

Figure 83 – 5% Damping ISRS – All Motions – 3500 Soil – Node 19 – X (East-West) Direction

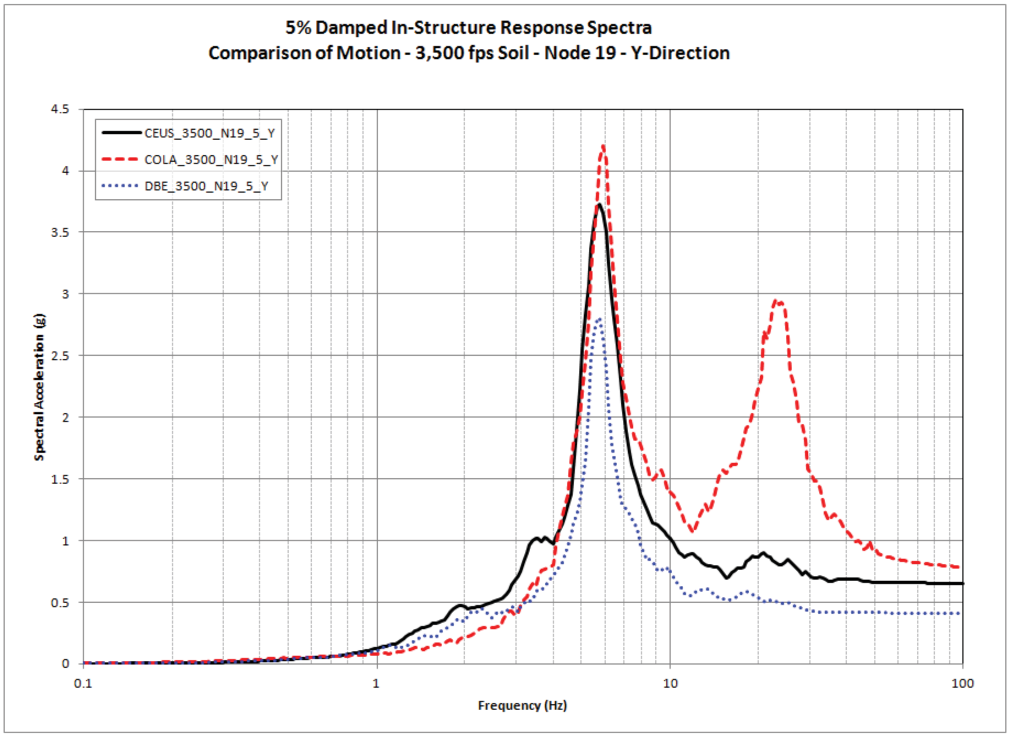

Figure 84 – 5% Damping ISRS – All Motions – 3500 Soil – Node 19 – Y (North-South) Direction

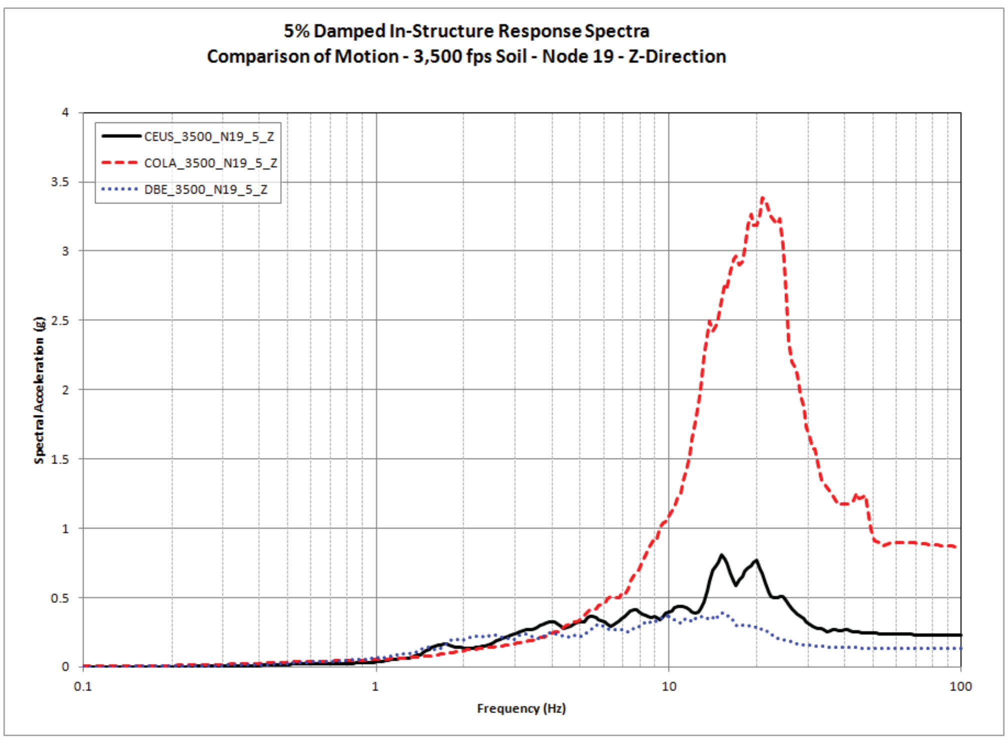

Figure 85 – 5% Damping ISRS – All Motions – 3500 Soil – Node 19 – Z (Vertical) Direction

HR Soil Profile

The following comparisons consider the HR soil profile.

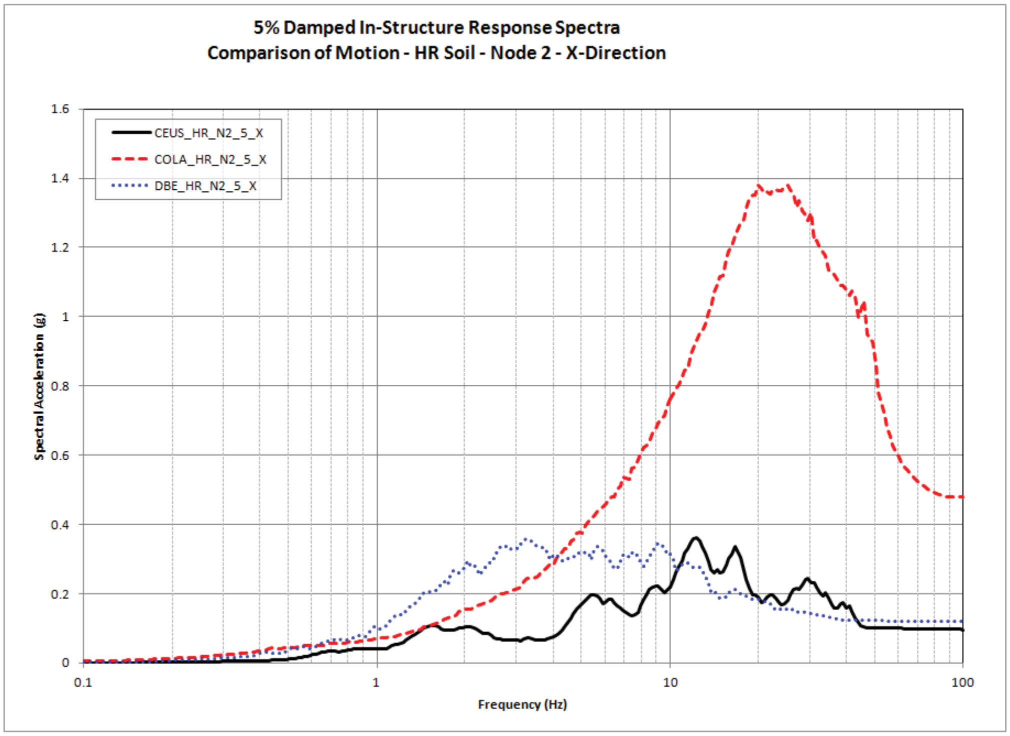

Figure 86 – 5% Damping ISRS – All Motions – HR Soil – Node 2 – X (East-West) Direction

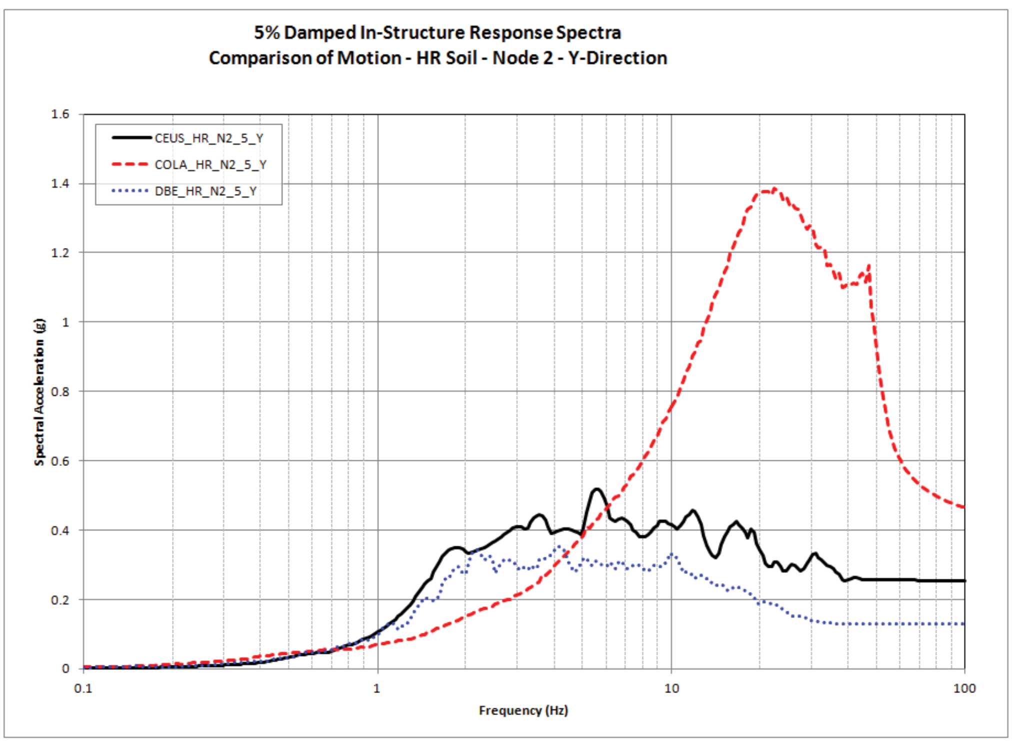

Figure 87 – 5% Damping ISRS – All Motions – HR Soil – Node 2 – Y (North-South) Direction

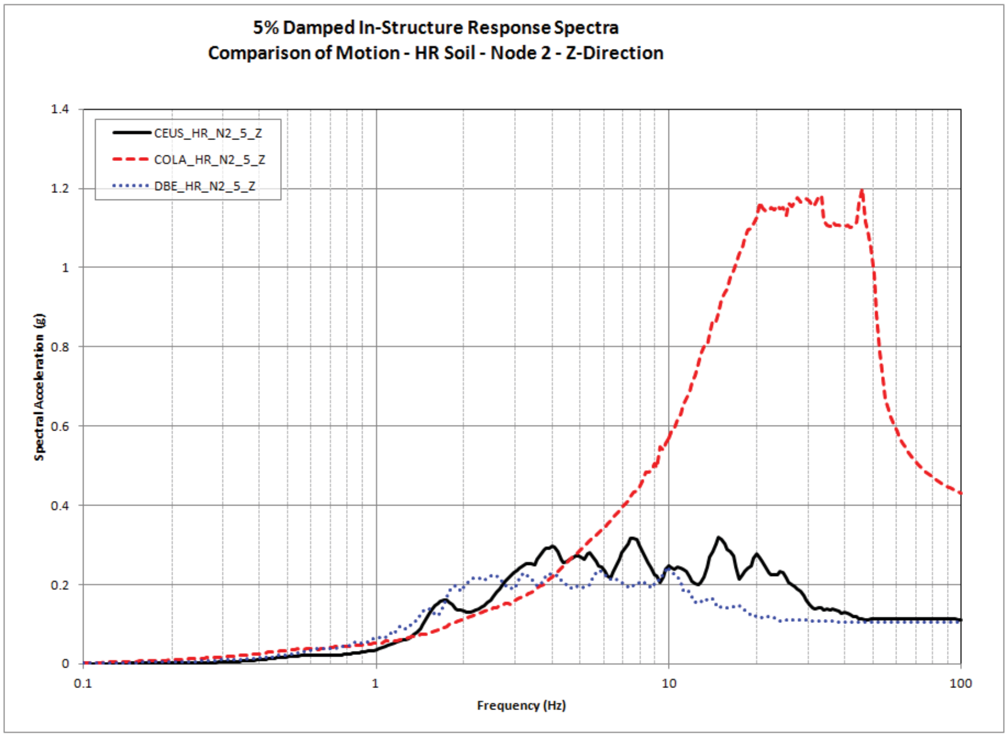

Figure 88 – 5% Damping ISRS – All Motions – HR Soil – Node 2 – Z (Vertical) Direction

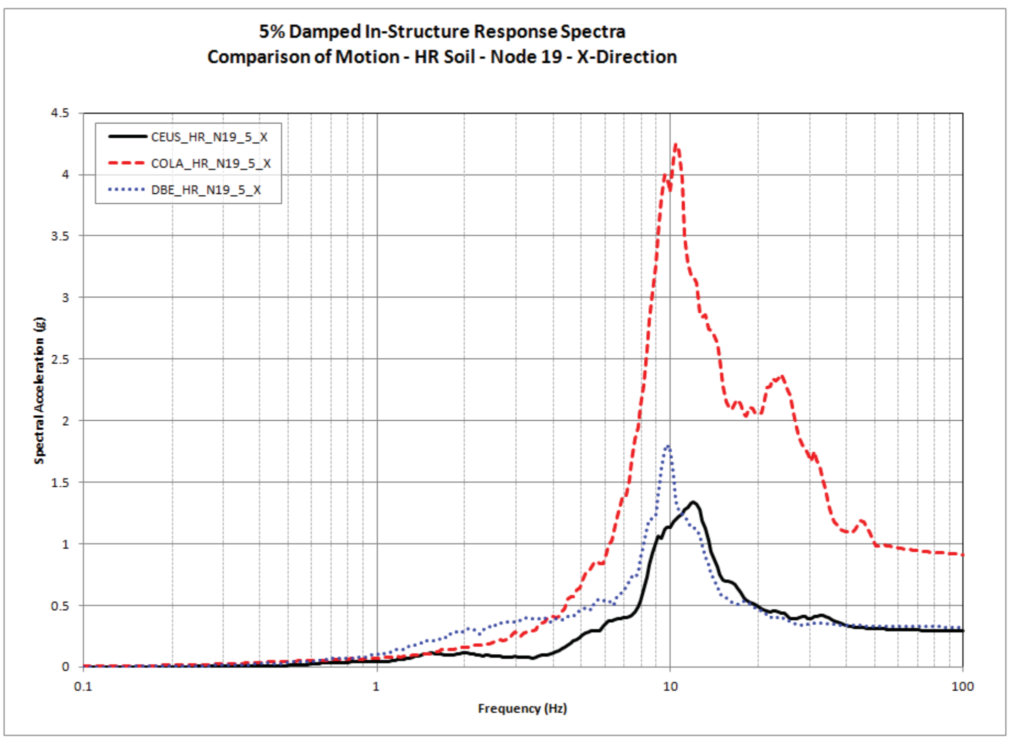

Figure 89 – 5% Damping ISRS – All Motions – HR Soil – Node 19 – X (East-West) Direction

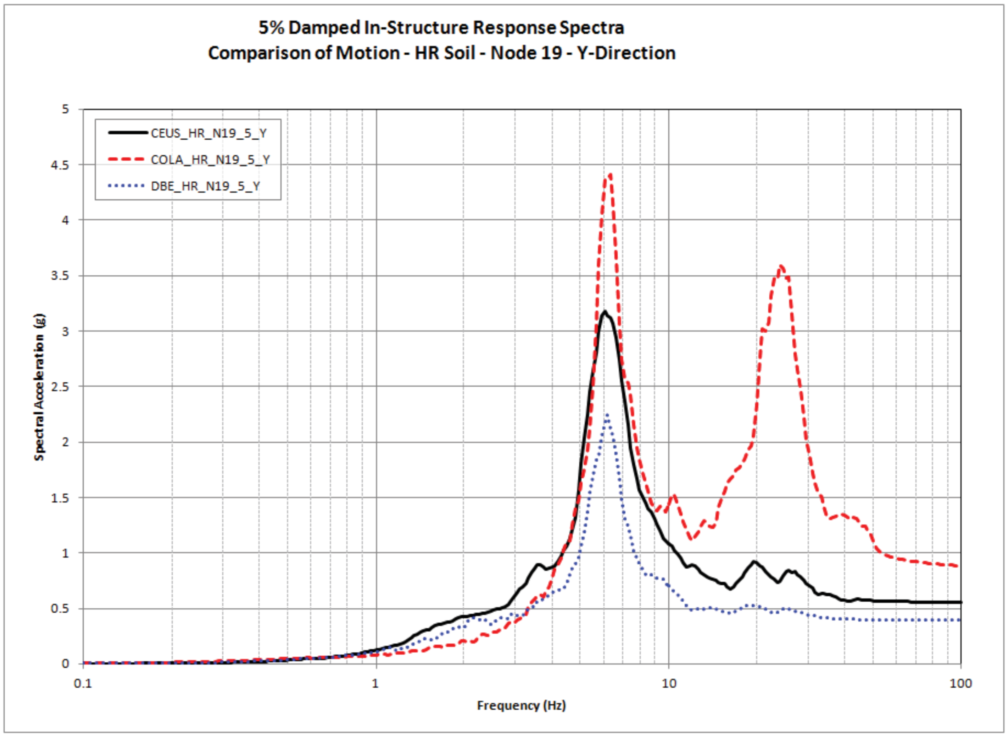

Figure 90 – 5% Damping ISRS – All Motions – HR Soil – Node 19 – Y (North-South) Direction

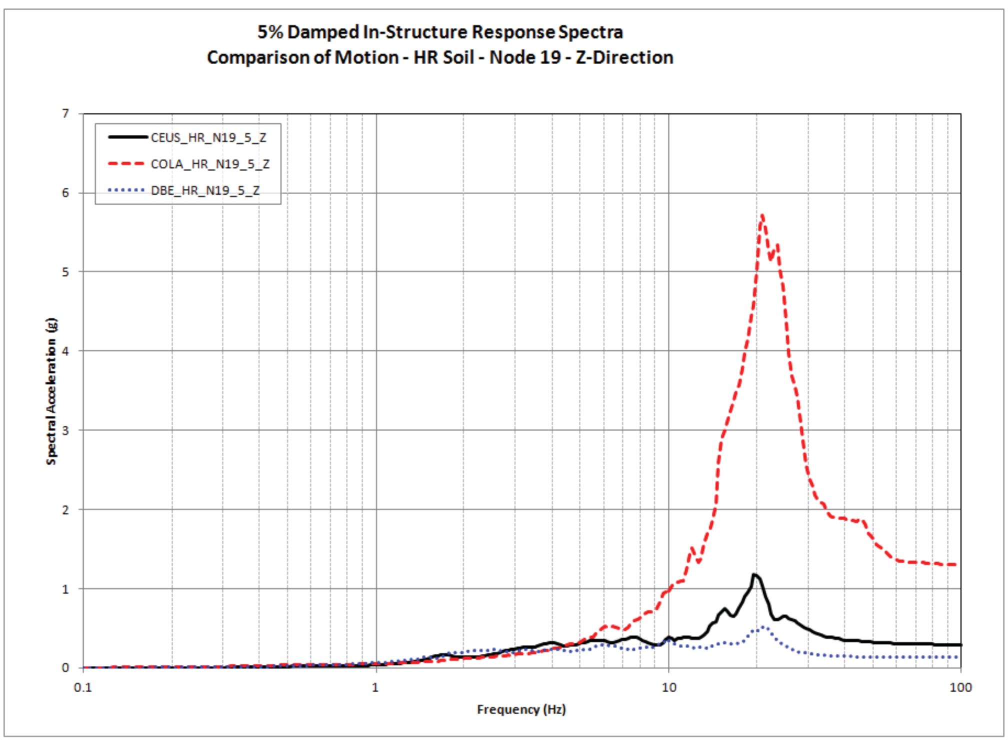

Figure 91 – 5% Damping ISRS – All Motions – HR Soil – Node 19 – Z (Vertical) Direction

RP Soil Profile

The following comparisons consider the RP soil profile.

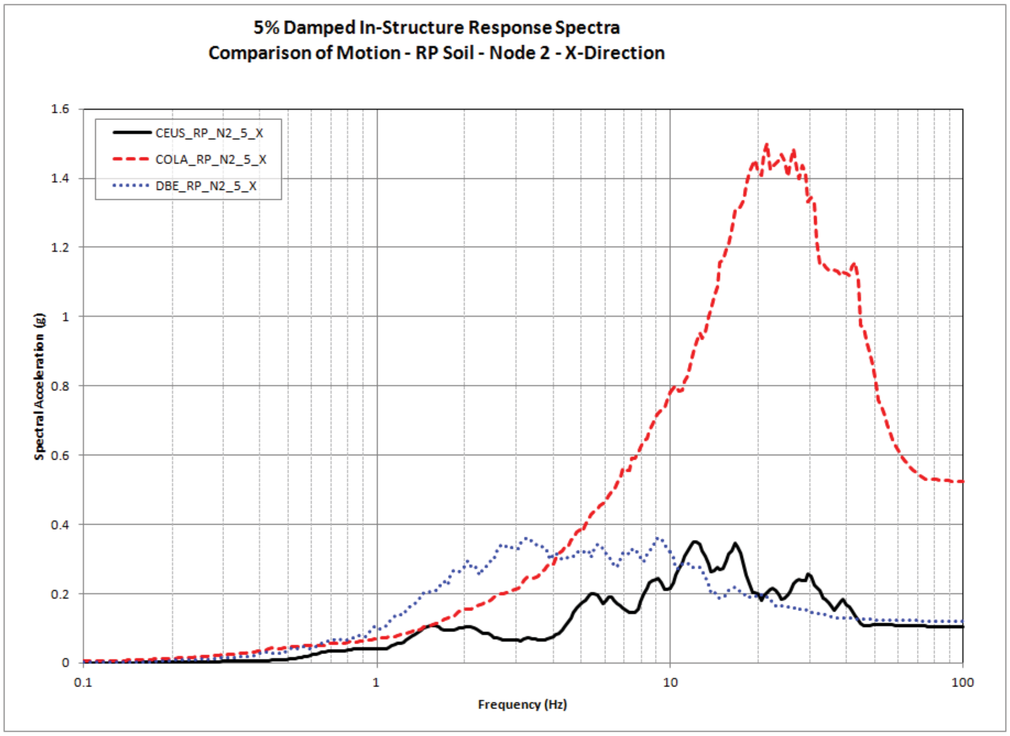

Figure 92 – 5% Damping ISRS – All Motions – RP Soil – Node 2 – X (East-West) Direction

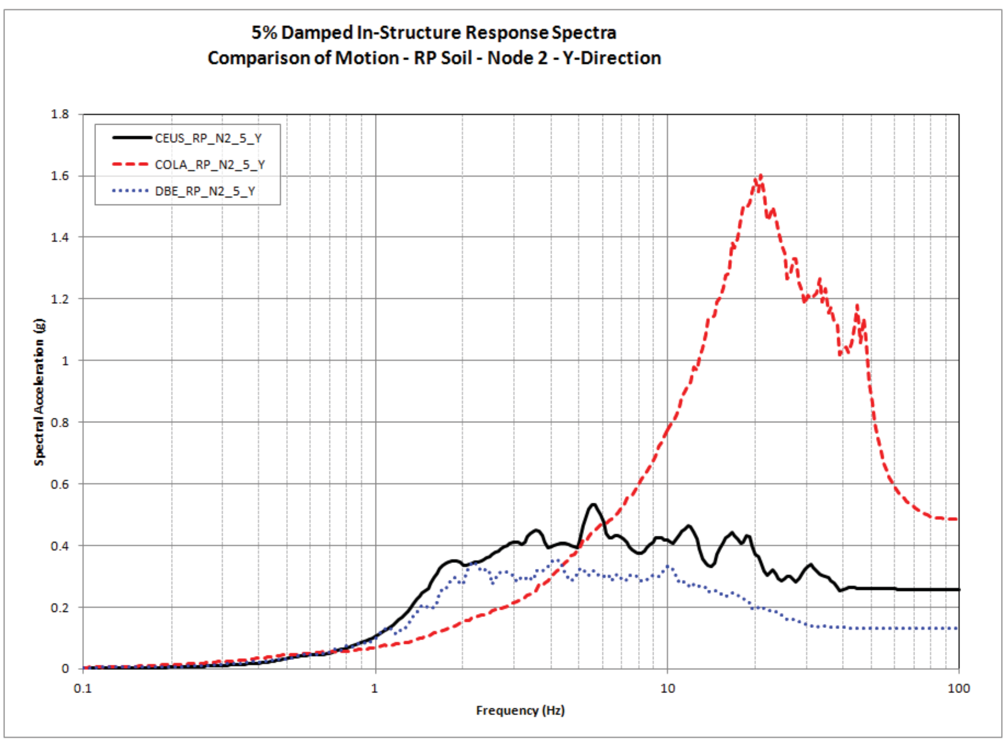

Figure 93 – 5% Damping ISRS – All Motions – RP Soil – Node 2 – Y (North-South) Direction

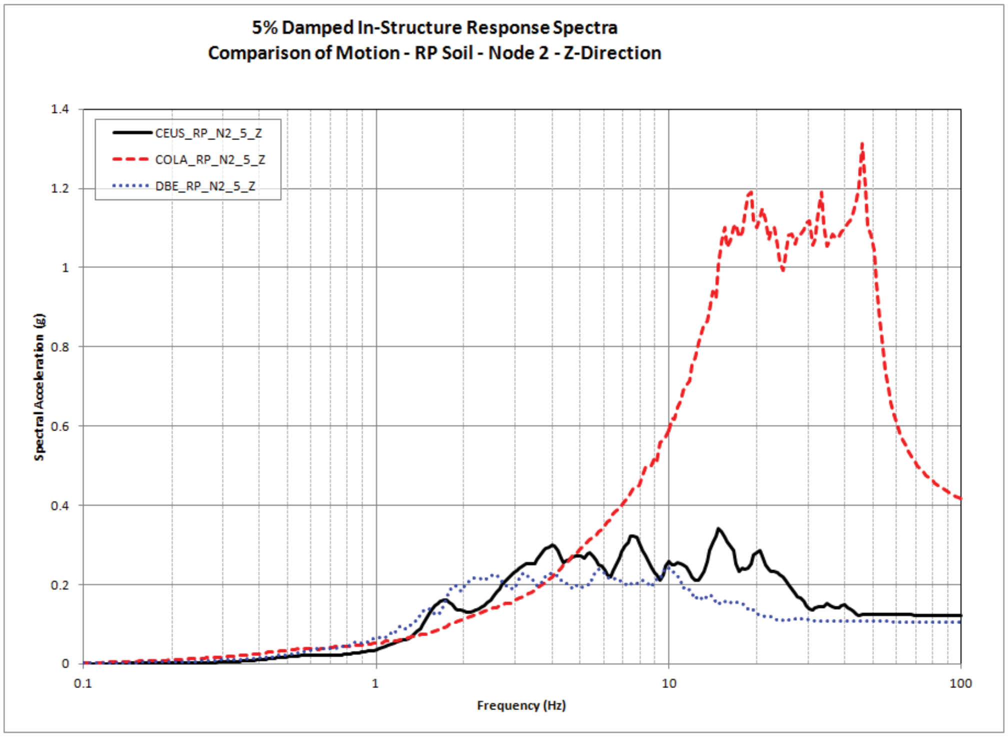

Figure 94 – 5% Damping ISRS – All Motions – RP Soil – Node 2 – Z (Vertical) Direction

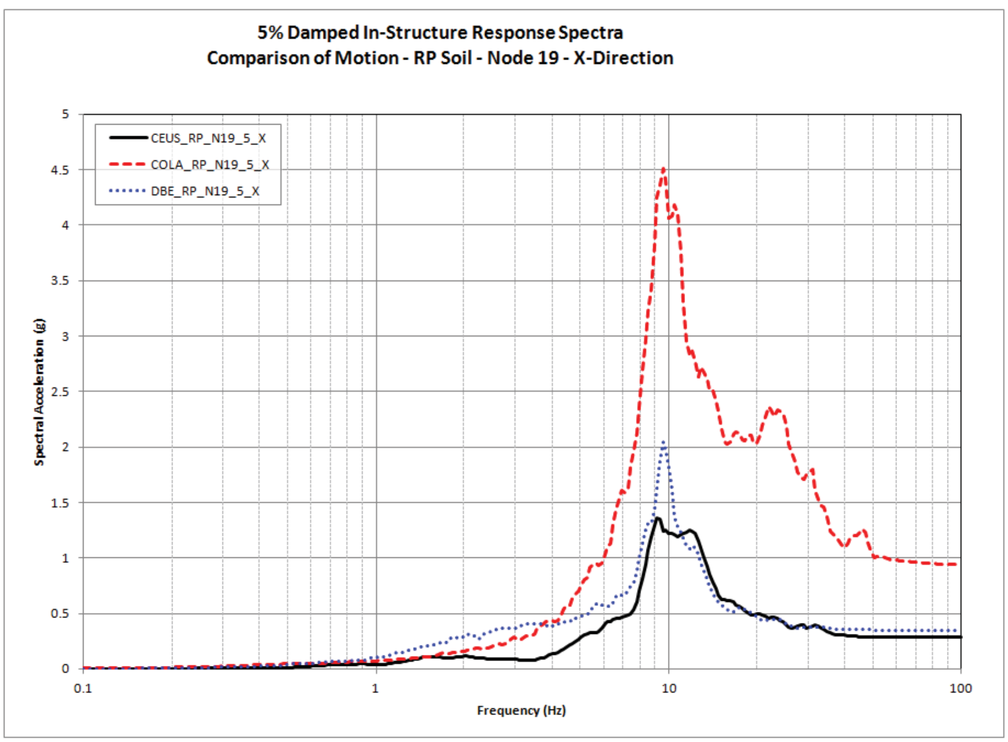

Figure 95 – 5% Damping ISRS – All Motions – RP Soil – Node 19 – X (East-West) Direction

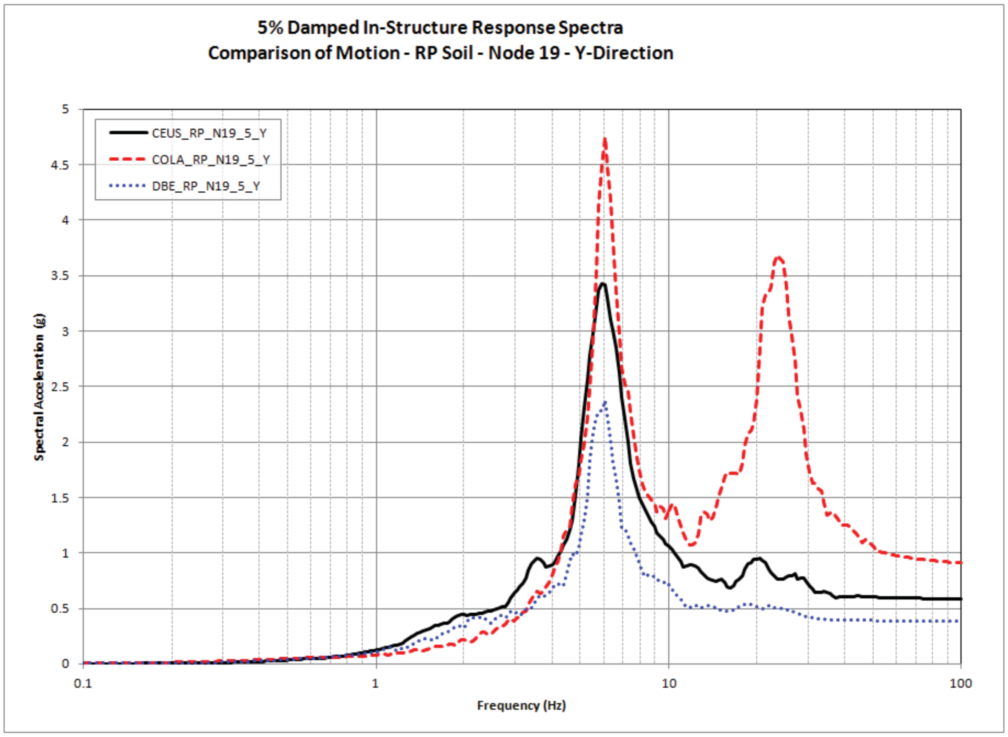

Figure 96 – 5% Damping ISRS – All Motions – RP Soil – Node 19 – Y (North-South) Direction

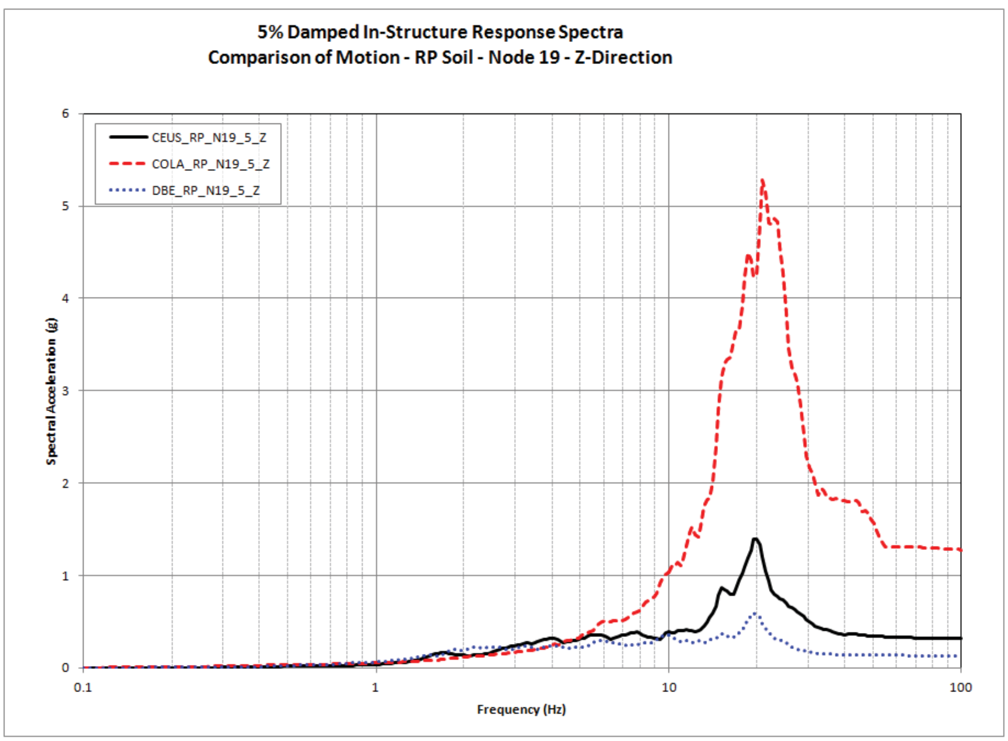

Figure 97 – 5% Damping ISRS – All Motions – RP Soil – Node 19 – Z (Vertical) Direction