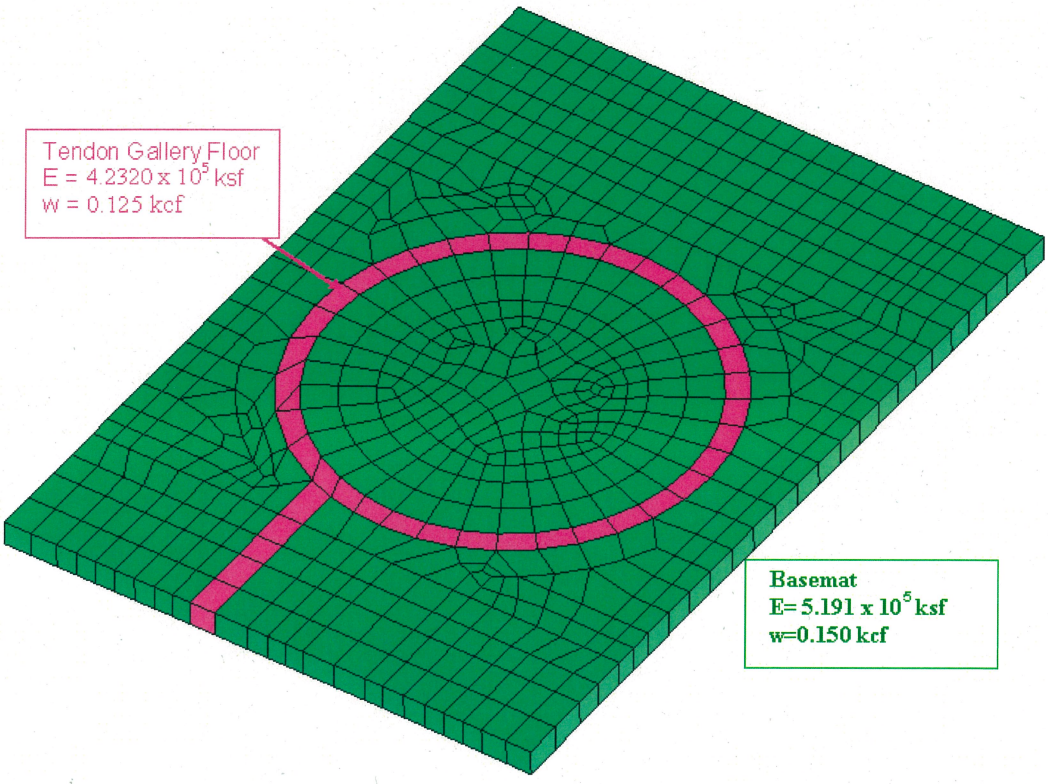

Figure 5.3.2-1 Basemat Solid Elements

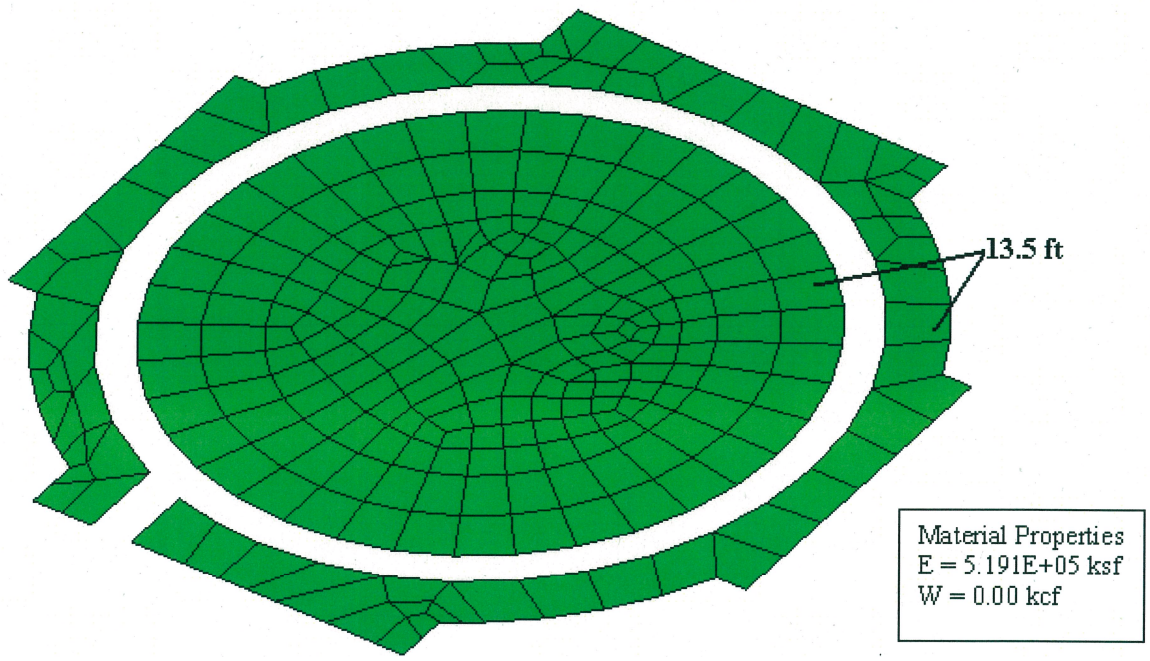

Figure 5.3.2-2 Plate Elements Modeling Additional Stiffness of the Central Reactor Mat

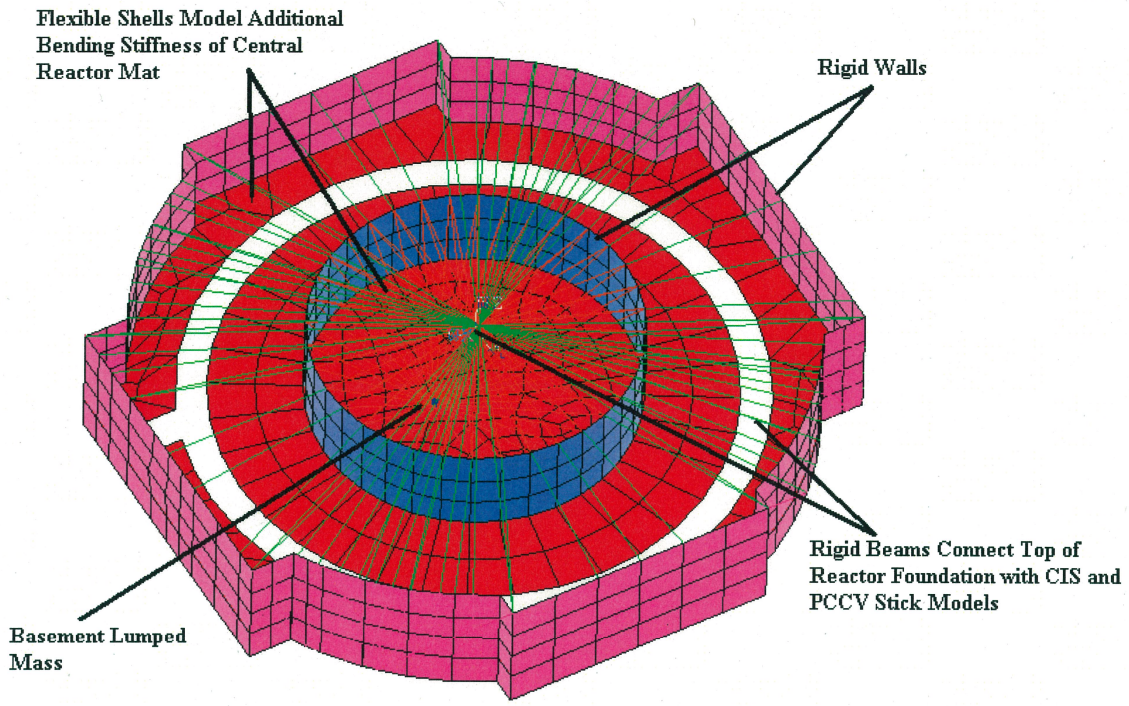

Figure 5.3.2-3 FE Model Components Under the PCCV

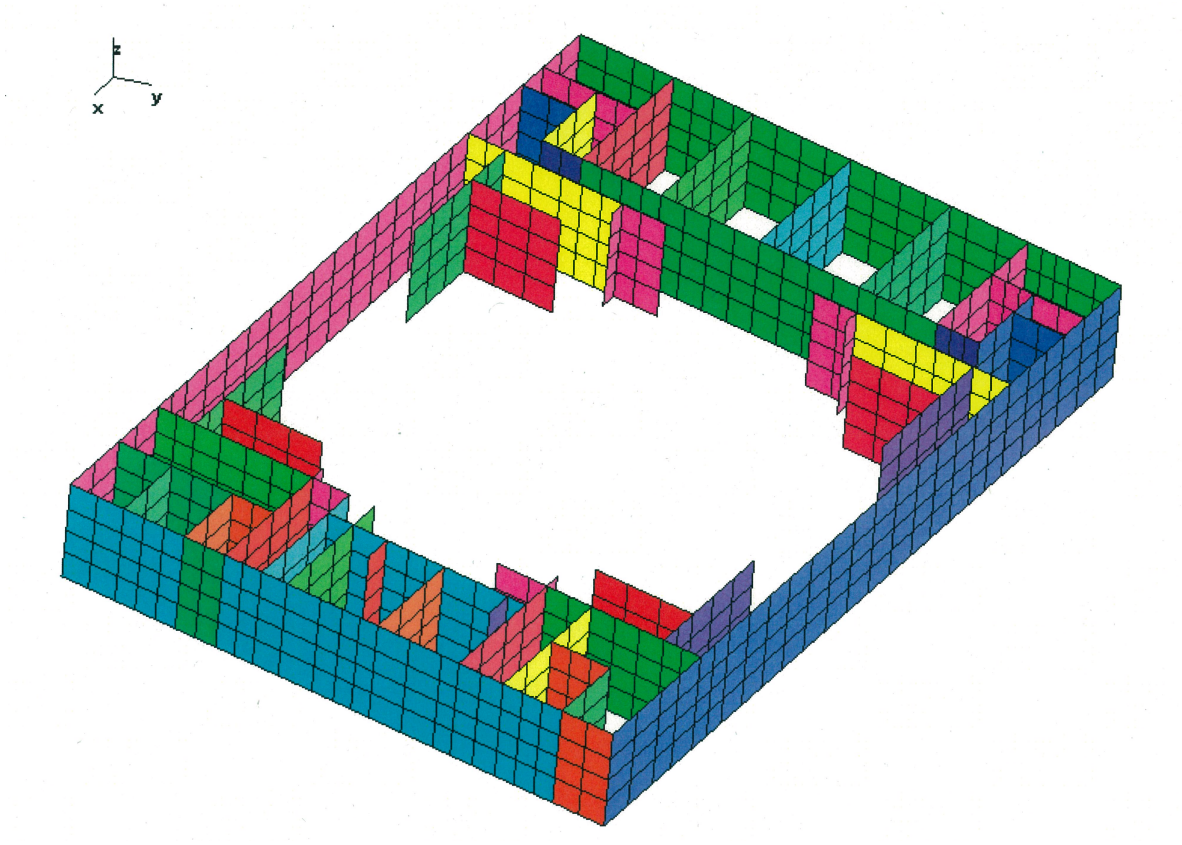

Figure 5.3.2-4 FE Model Shear Wall Elements

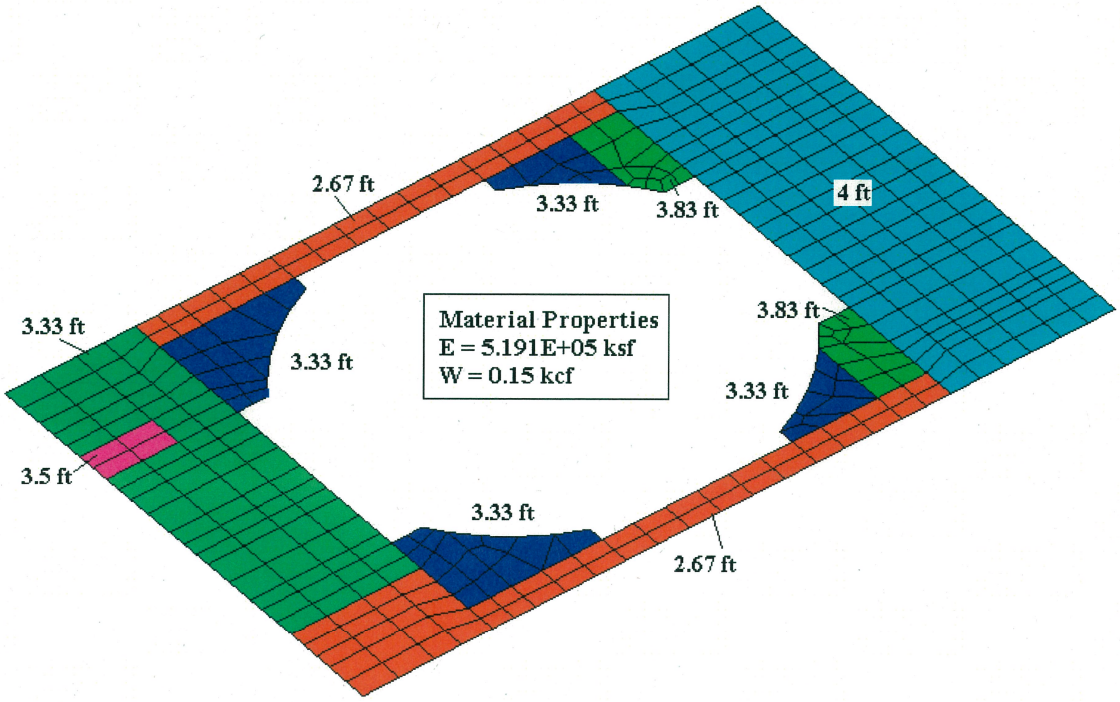

Figure 5.3.2-5 FE Model Plate Elements at Ground Elevation

5.3.3 PCCV Verification Results

5.3.3.1 1g Static Analysis

It is noted that the 3-D FE Model utilizes uncracked concrete material properties. Therefore, for comparison and validation purposes, uncracked concrete material properties are also assigned to the PCCV Stick model.

A 1g static analysis in the vertical (Z) direction with full constraints at the bottom of the Containment structure is performed on both PCCV models to verify their overall static weight.

The total weight of the Stick Model is found to be 78,607 kips.

The total weight of the 3-D FE Model is 77,667 kips.

This represents a difference of 1.2% between the total weights of both models.

A 1g static analysis in the horizontal (X) direction with full constraints at the bottom of the PCCV structure is also performed on both models. The displacement results from both static analyses are used to compare the structure stiffness of the two models in all directions. The displacement distributions along the height of the PCCV are plotted in the following figures and indicate that the stick model stiffness is comparable to that of the 3-D FE Model.

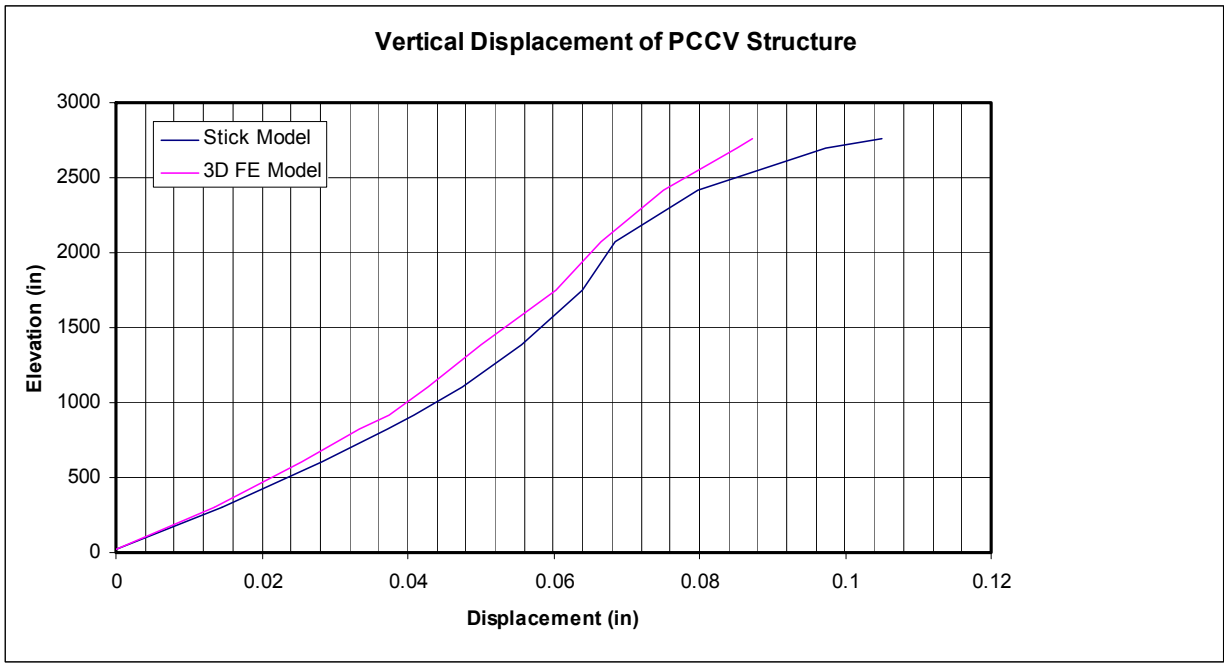

Figure 5.3.3.1-1 Vertical Displacement Results Under 1g Load in Vertical Direction (Z)

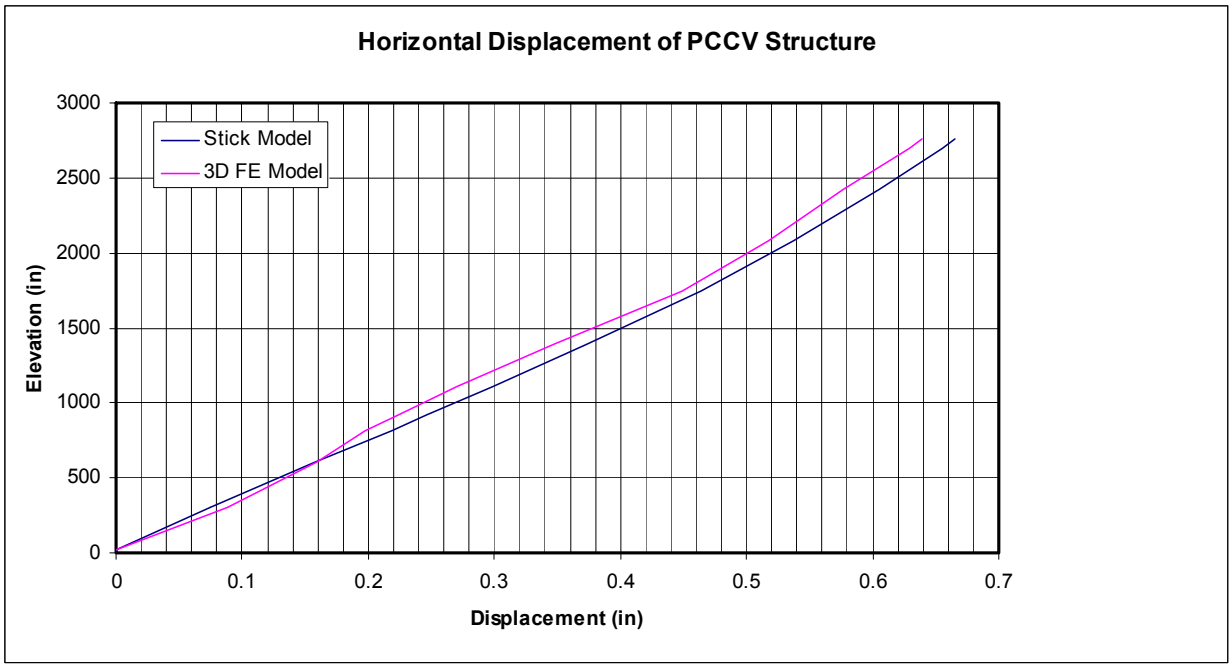

Figure 5.3.3.1-2 Horizontal Displacement Results Under 1g Load in Horizontal Direction (X)

5.3.3.2 Modal Analysis

A modal analysis using ANSYS is performed on the 3-D FE model. The dominant natural frequencies and effective masses obtained from these analyses are shown in the following tables:

Table 5.3.3.2-1 Modal Properties of First 3 Modes, X-Direction (NS)

MODE	FREQUENCY (HZ)	PERIOD (sec)	PARTIC.FACTOR	EFFECTIVE MASS (lbs*sec^2/ft)
1	4.597	0.218	373.47	139477
16	13.274	0.0753	177.11	31367

Table 5.3.3.2-2 - Modal Properties of First 3 Modes, Y-Direction (EW)

MODE	FREQUENCY (HZ)	PERIOD (sec)	PARTIC.FACTOR	EFFECTIVE MASS (lbs*sec^2/ft)
2	4.613	0.217	376.34	141628
13	13.000	0.0769	136.57	18651.3

Table 5.3.3.2-3 - Modal Properties of First 3 Modes, Z-Direction (Vertical)

MODE	FREQUENCY (HZ)	PERIOD (sec)	PARTIC.FACTOR	EFFECTIVE MASS (lbs*sec^2/ft)
12	12.766	0.0783	368.16	135545
39	21.223	0.0471	-96.286	9270

An SSI analysis is performed on the SASSI model with the model resting on the surface of a half-space with hard-rock properties. This is to simulate the response of the structure under a fixed base condition. Transfer functions at selected nodes are obtained from the SSI analysis and are presented in the following figures. These figures indicate amplification spikes at or close to the dominant frequency points shown in Tables 5.3.3.2-1 through 5.3.3.2-3. This shows that the stick model captures the structure response to dynamic loading in all directions properly.

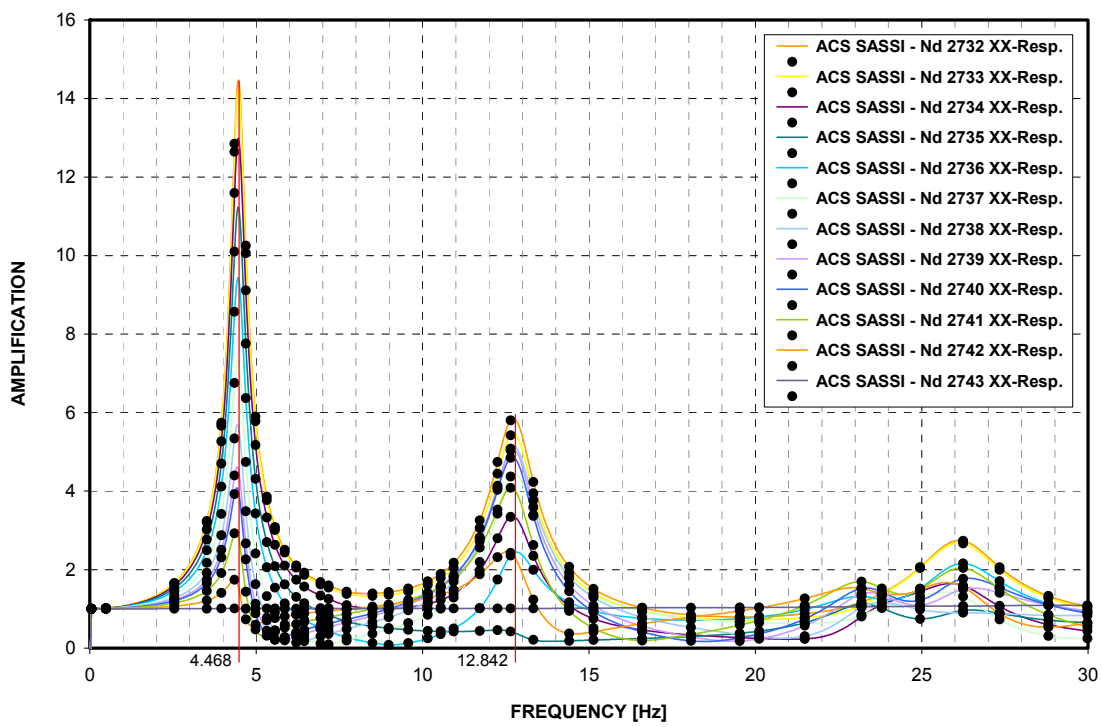

Figure 5.3.3.2-1 PCCV Lumped Mass Stick Model Transfer Functions, X-Direction

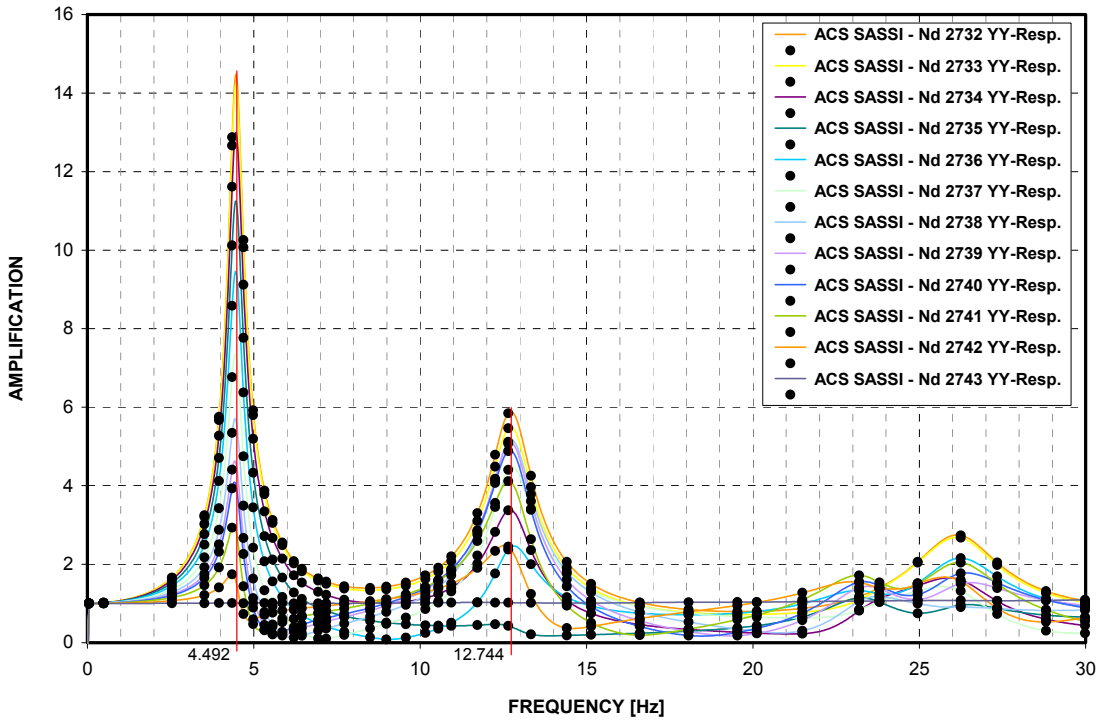

Figure 5.3.3.2-2 PCCV Lumped Mass Stick Model Transfer Functions, Y-Direction

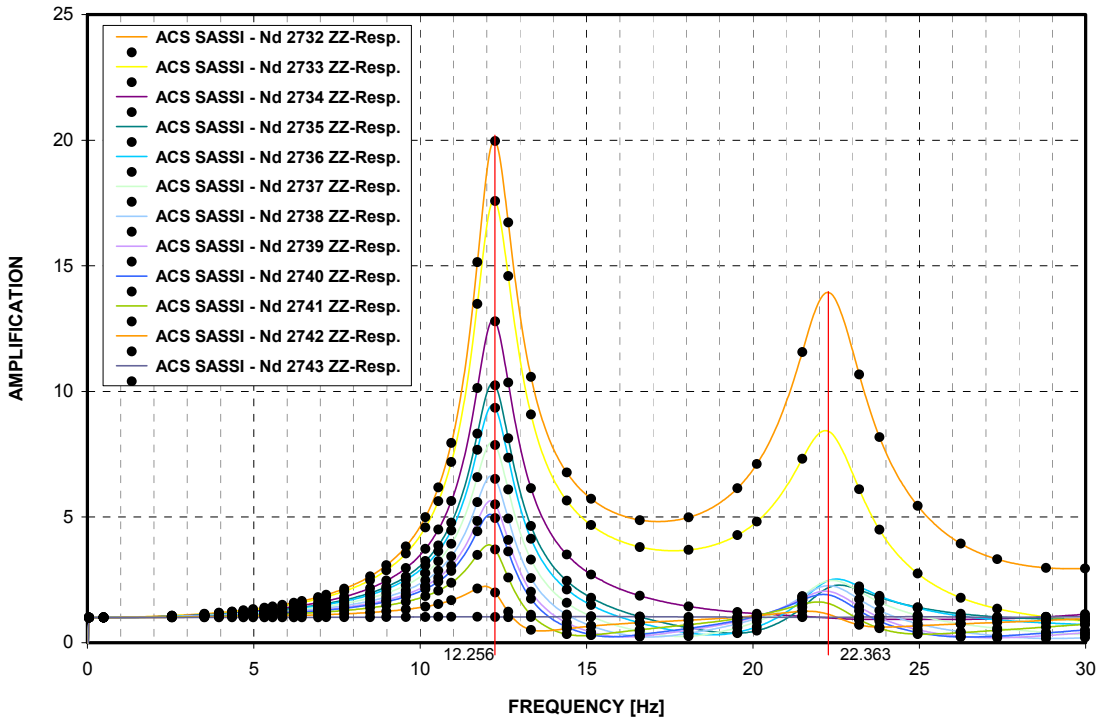

Figure 5.3.3.2-3 PCCV Lumped Mass Stick Model Transfer Functions, Z-Direction

5.3.3.3 Mode-Superposition Transient Dynamic Analysis

A dynamic Time-History response analysis using modal superposition is performed on the PCCV models using ANSYS and SASSI. Acceleration response spectra (ARS) with 5 % damping are generated for each model at lumped mass locations. These acceleration response spectra indicate that the stick model captures the structure response to dynamic loads in all directions properly.

The following are some of the accelerations response spectra generated for representative nodes CV11, CV09, CV06, CV03 and CV01 (Figure 5.3.3.3-1 through Figure 5.3.3.3-10)

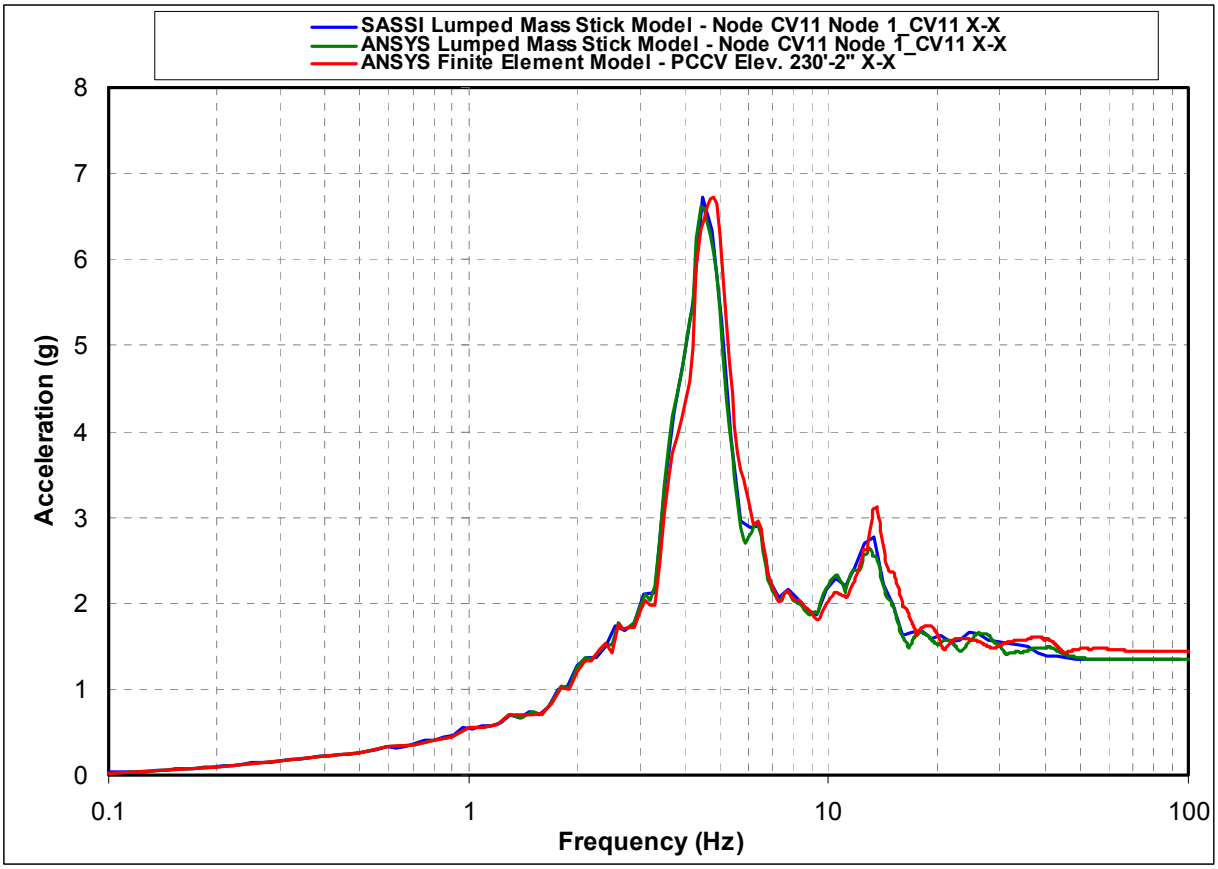

Figure 5.3.3.3-1 ARS, Node CV11, Horizontal Direction

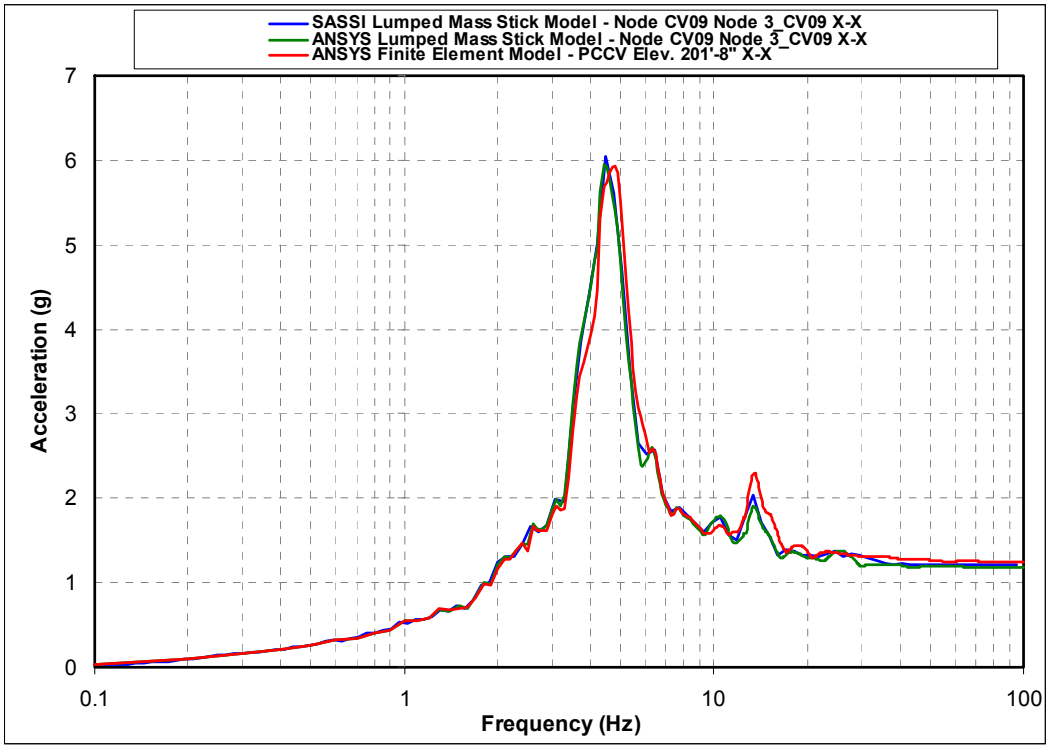

Figure 5.3.3.3-2 ARS, Node CV09, Horizontal Direction

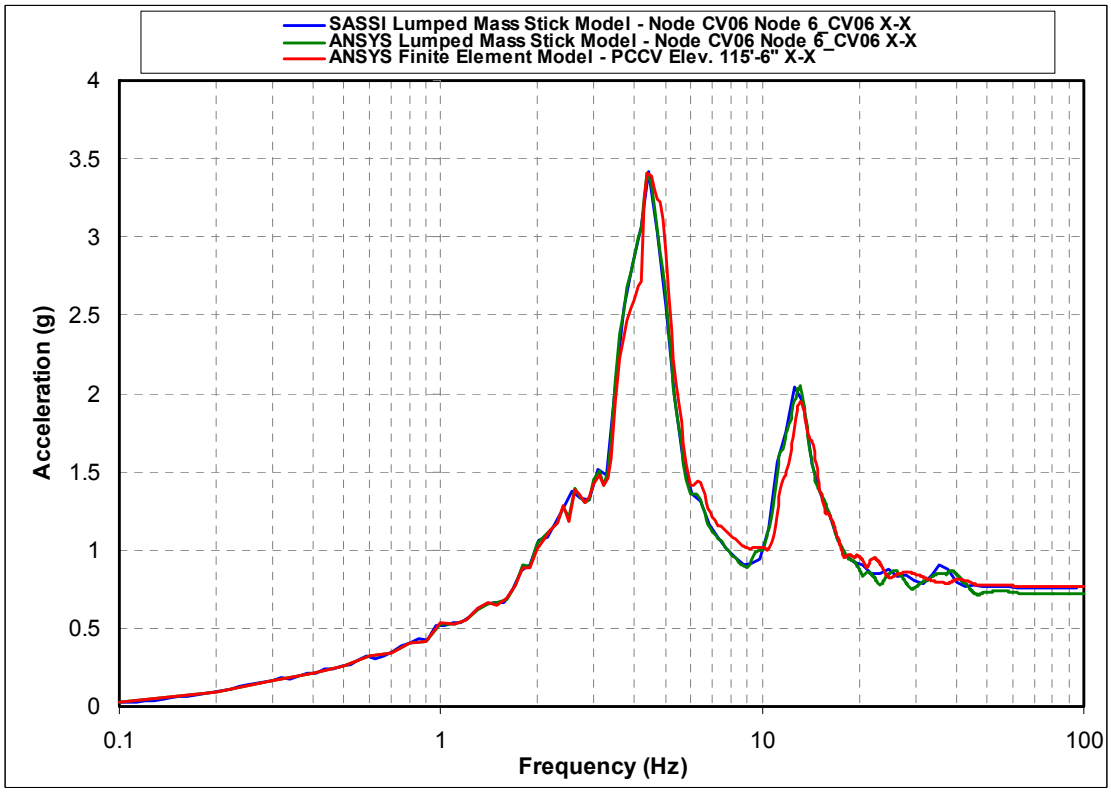

Figure 5.3.3.3-3 ARS, Node CV06, Horizontal Direction

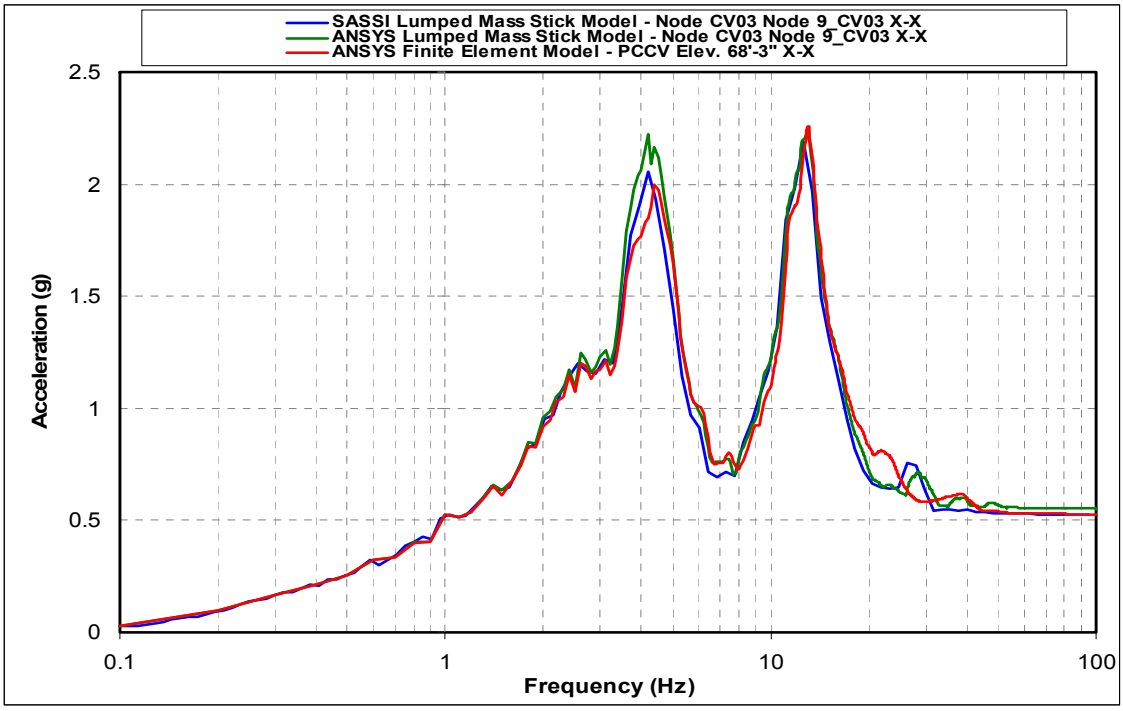

Figure 5.3.3.3-4 ARS, Node CV03, Horizontal Direction

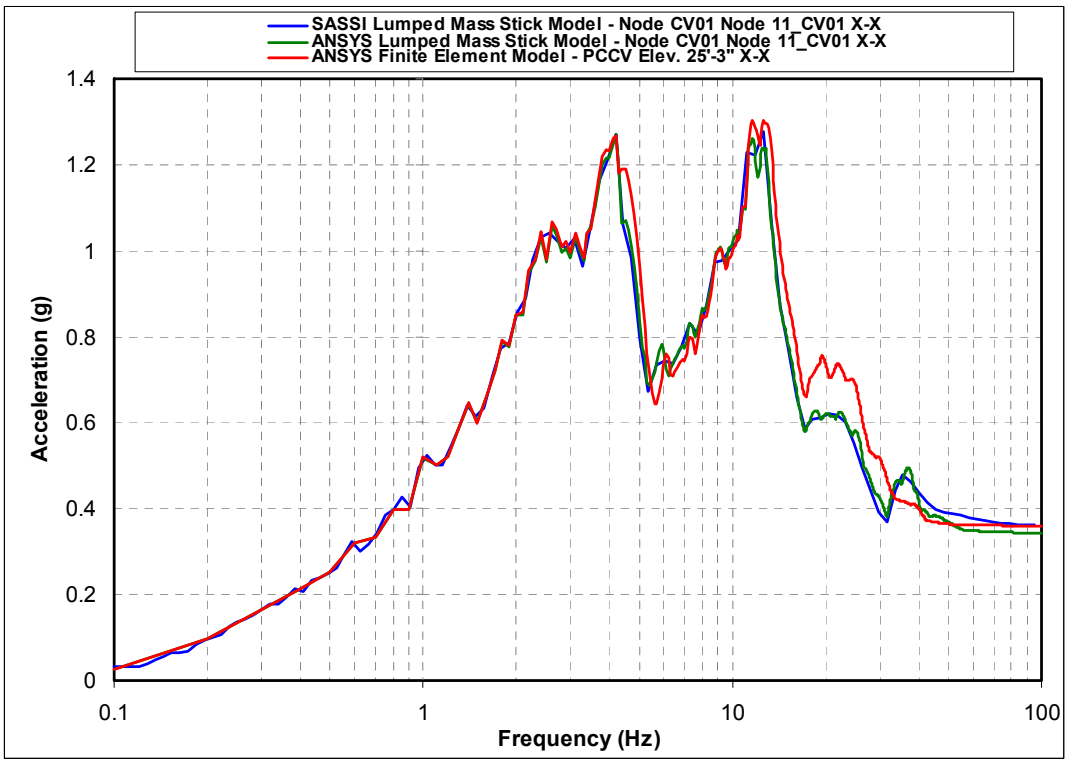

Figure 5.3.3.3-5 ARS, Node CV01, Horizontal Direction

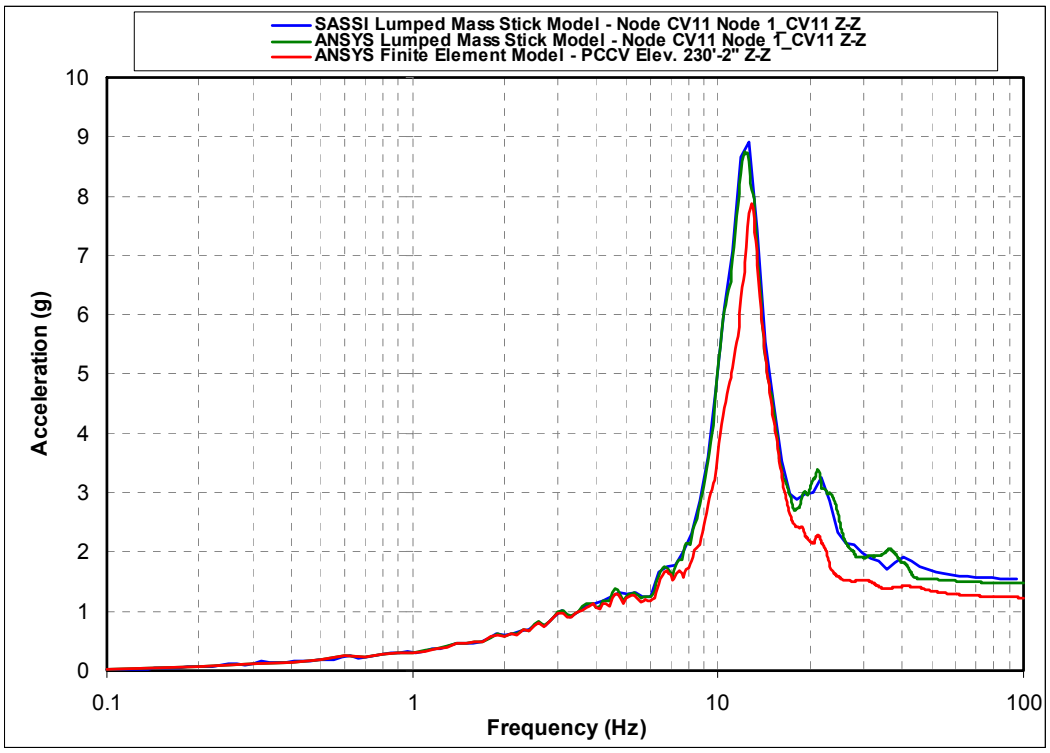

Figure 5.3.3.3-6 ARS, Node CV11, Vertical Direction

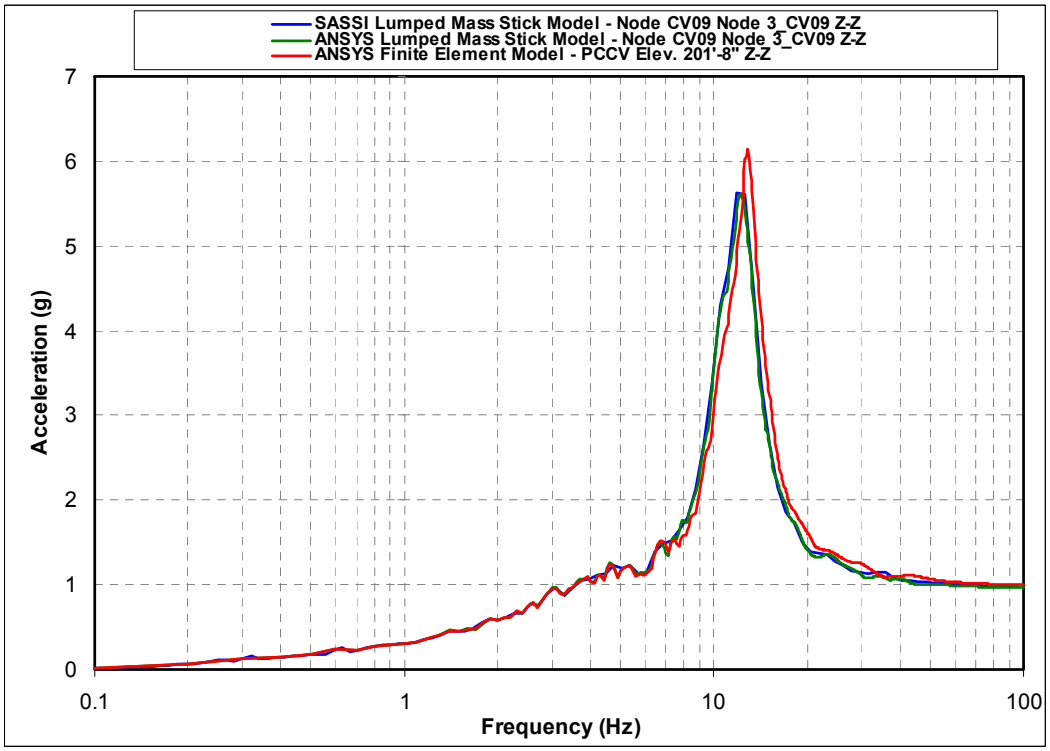

Figure 5.3.3.3-7 ARS, Node CV09, Vertical Direction

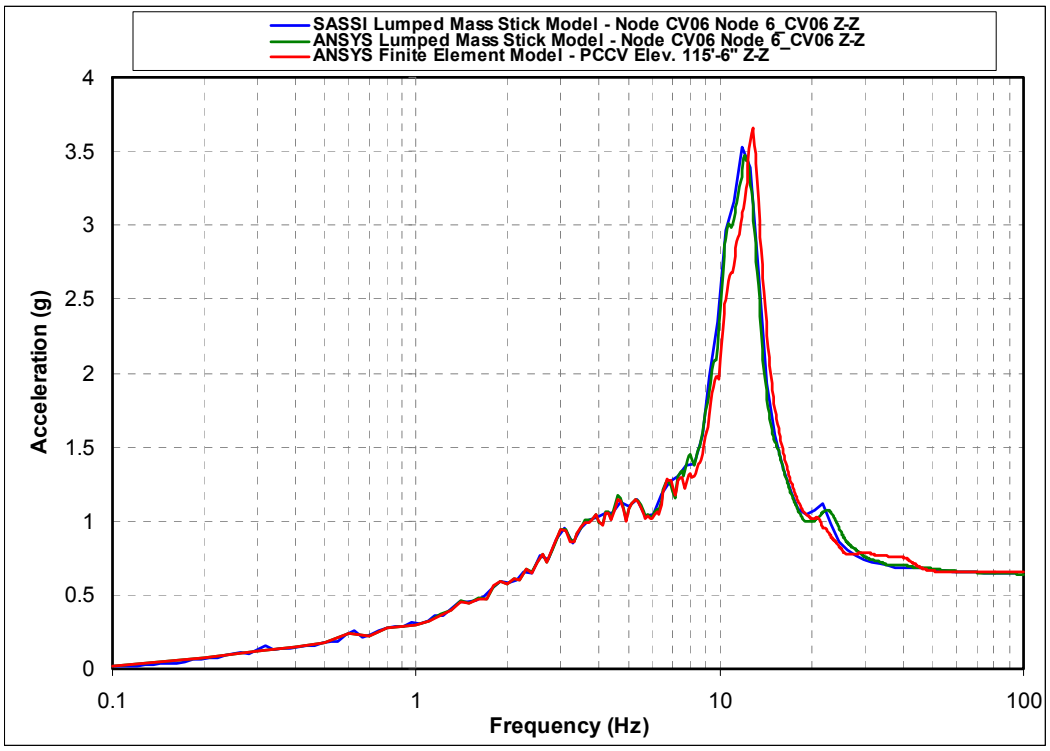

Figure 5.3.3.3-8 ARS, Node CV06, Vertical Direction

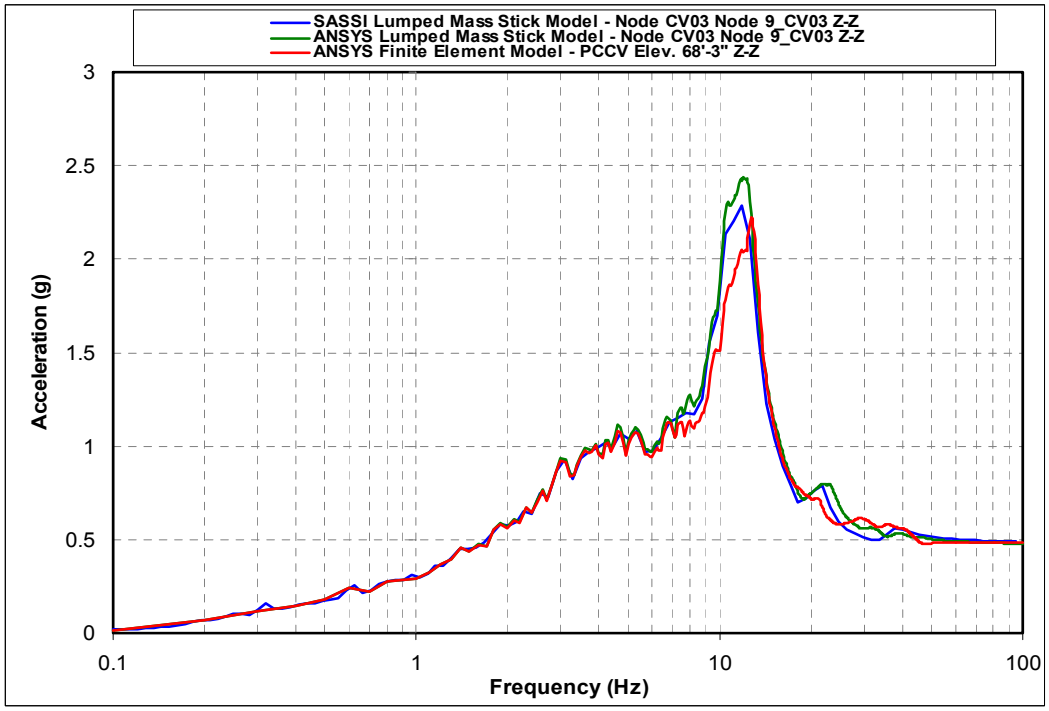

Figure 5.3.3.3-9 ARS, Node CV03, Vertical Direction

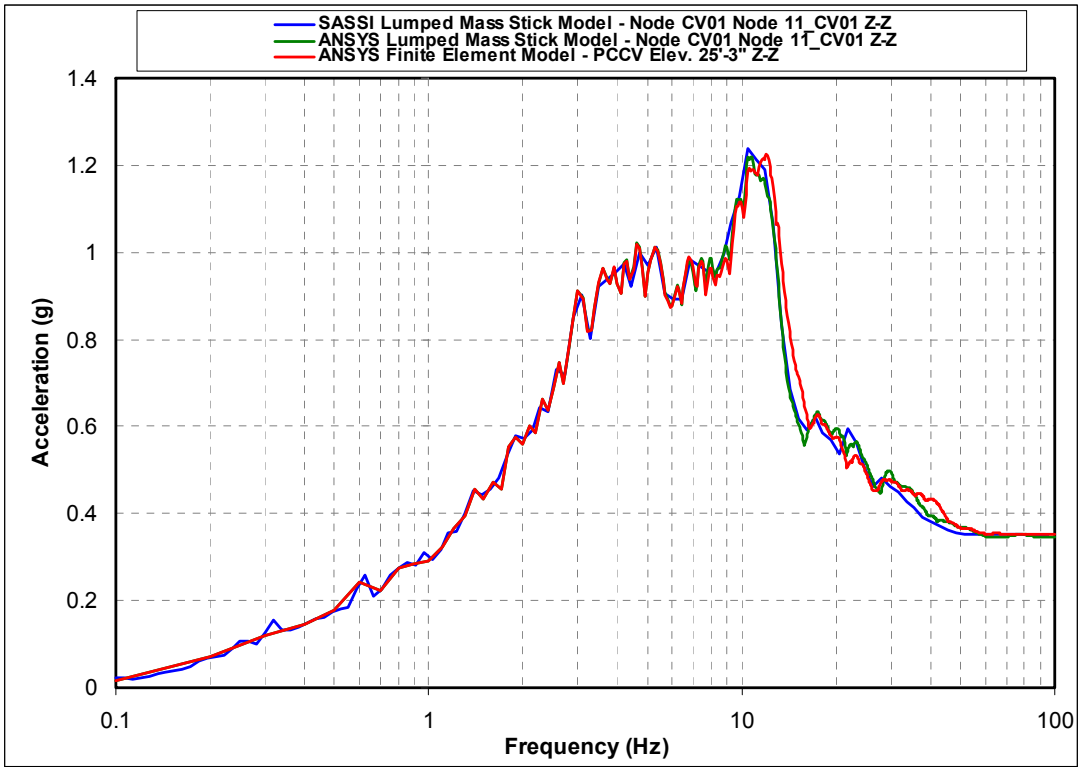

Figure 5.3.3.3-10 ARS, Node CV01, Vertical Direction

5.3.4 R/B and FH/A Verification Results

5.3.4.1 1g Static Analysis

The validation of the R/B and FH/A ACS SASSI Lumped-Mass Stick Model utilizes cracked concrete material properties. See Section 7.2 for discussion of the effects of concrete cracking.

A 1g static analysis in the vertical direction (Z) with full constraints at the bottom of the Reactor Building structure is performed on both R/B models (Lumped-Mass Stick and 3-D FE) in ANSYS to verify their overall static weight.

The total weight of the Lumped-Mass Stick Model is 372,000 kips.

The total weight of the 3-D FE Model is 354,625 kips.

This represents a difference of 4.67% between the total weights of both models. The weight of the Lumped-Mass Stick model is slightly higher than the weight of the 3-D FE Model due to node RE00 of the Stick Model incorporating additional weight from the basemat.

A 1g static analysis is performed on each R/B model in both horizontal (X and Y) directions with full constraints at the bottom of each model. The displacement results from both static analyses are used to compare the structure stiffness of the two models in all directions. The displacement distributions along the height of the R/B at each corner of the structure are plotted in Figures 5.3.4.1-1 through 5.3.4.1-8 below. Although the displacements vary in magnitude due to the different boundary conditions, the shape of the diagrams of the lateral deformations obtained from the ANSYS analyses of the lumped-mass stick model and the detailed FE model presented in Figures 5.3.4.1-1 to 8 are used as an indicator of the ability of the lumped-mass stick model to represent the stiffness of the structure. The comparison of the results presented in Figures 5.3.4.1-1 to 4 indicate that the displacements in NS direction are consistent in shape for all but the NE corner of the fuel handling area (FH/A) located above R/B operational floor elevation. The comparison of the shapes of the deformations in EW direction calculated from the ANSYS analyses of both models indicates that they are consistent for all areas of the building but the FH/A portion. For the FH/A, the stiffness of the crane steel support and concrete exterior walls in the SASSI stick model is lumped together in a single stick element, so the local effects are not explicitly captured when modeling the overall lateral stiffness of the FH/A.

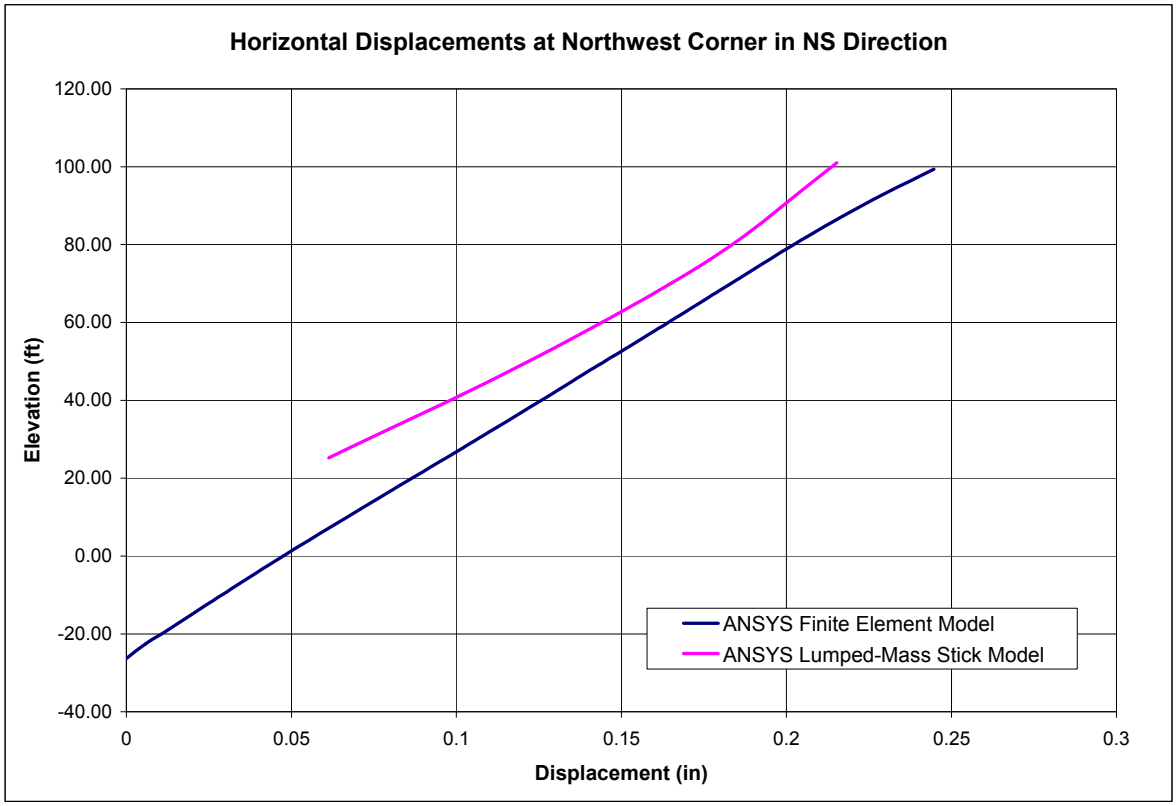

Figure 5.3.4.1-1 Horizontal Displacement Results At Northwest Corner of Reactor Building Under 1g Load in Horizontal Direction (X)

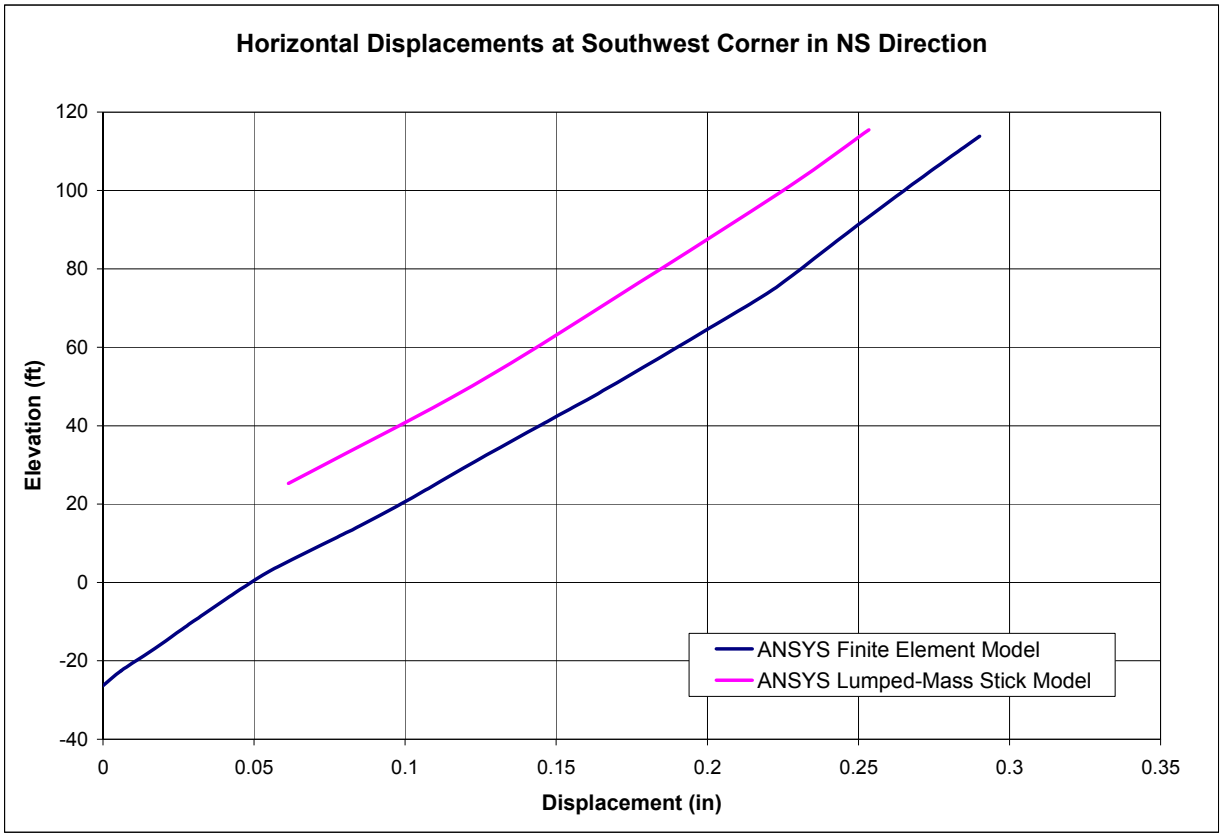

Figure 5.3.4.1-2 Horizontal Displacement Results At Southwest Corner of Reactor Building Under 1g Load in Horizontal Direction (X)

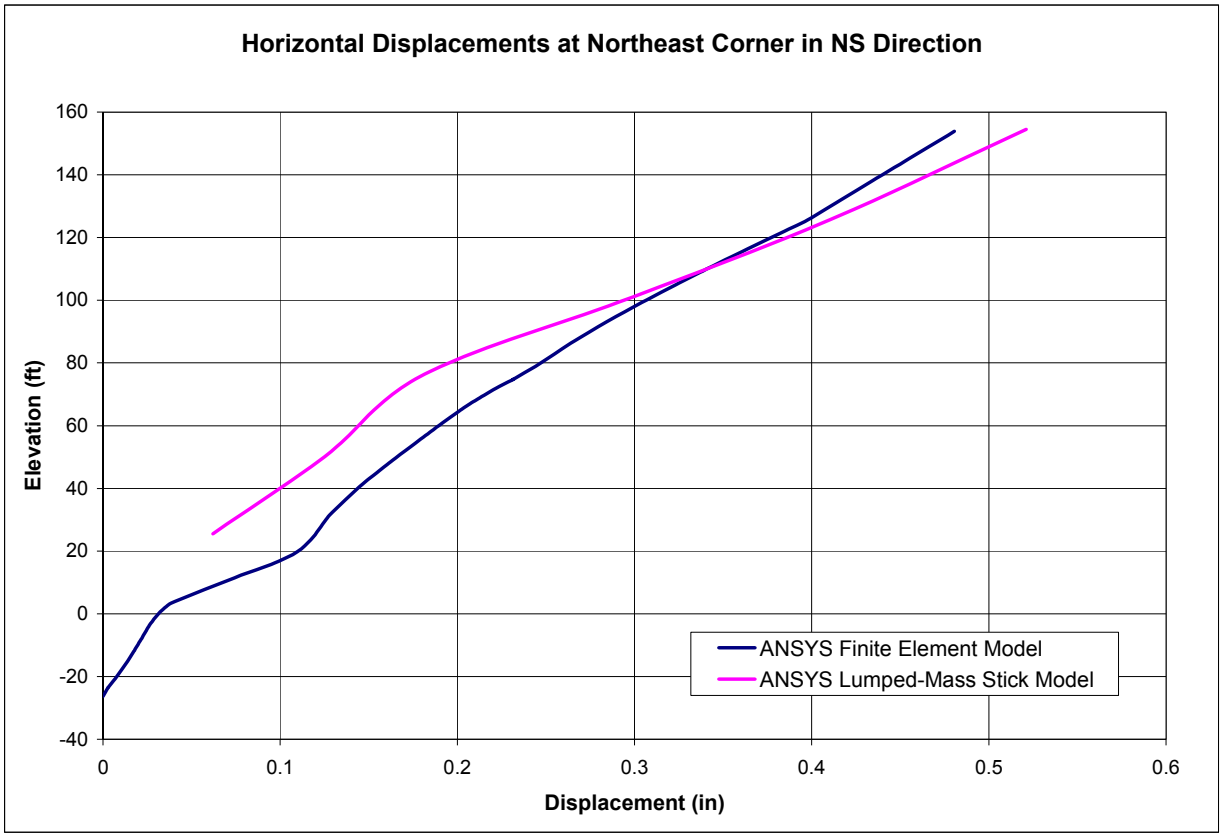

Figure 5.3.4.1-3 Horizontal Displacement Results At Northeast Corner of Reactor Building Under 1g Load in Horizontal Direction (X)

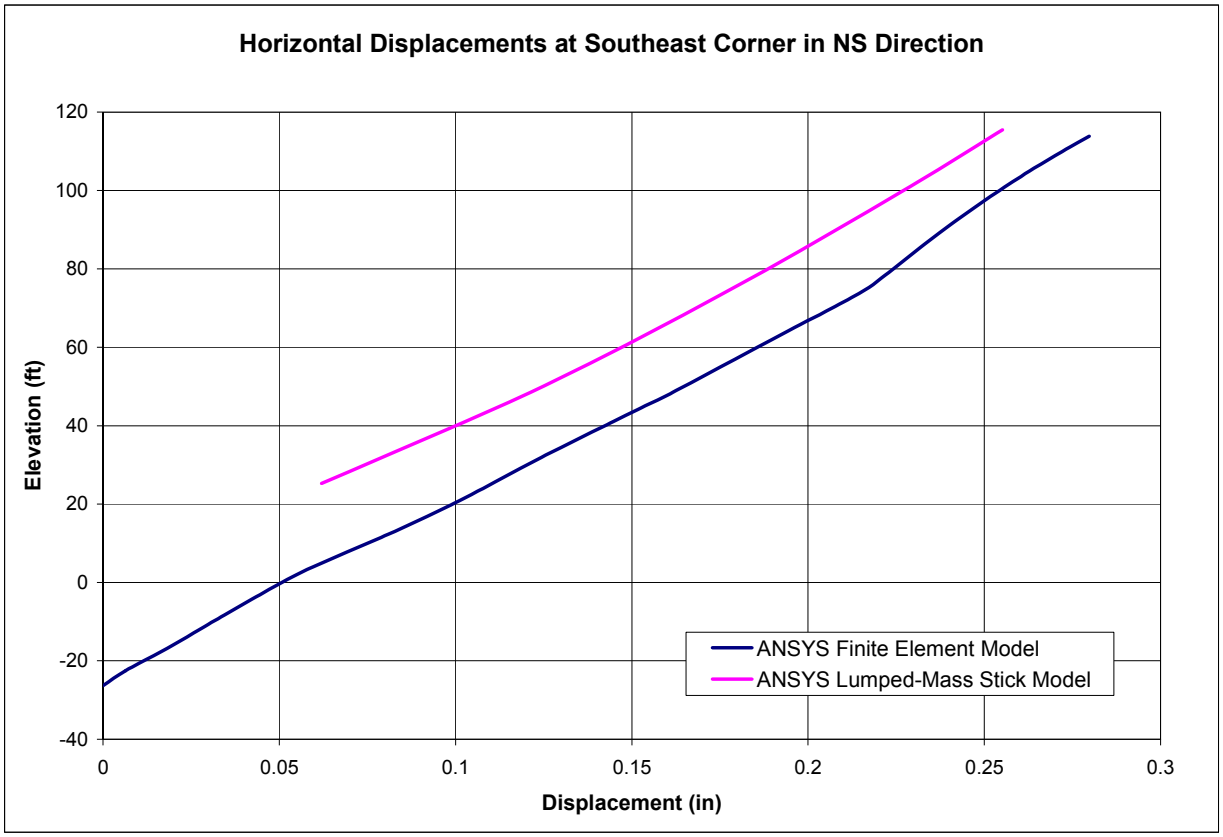

Figure 5.3.4.1-4 Horizontal Displacement Results At Southeast Corner of Reactor Building Under 1g Load in Horizontal Direction (X)

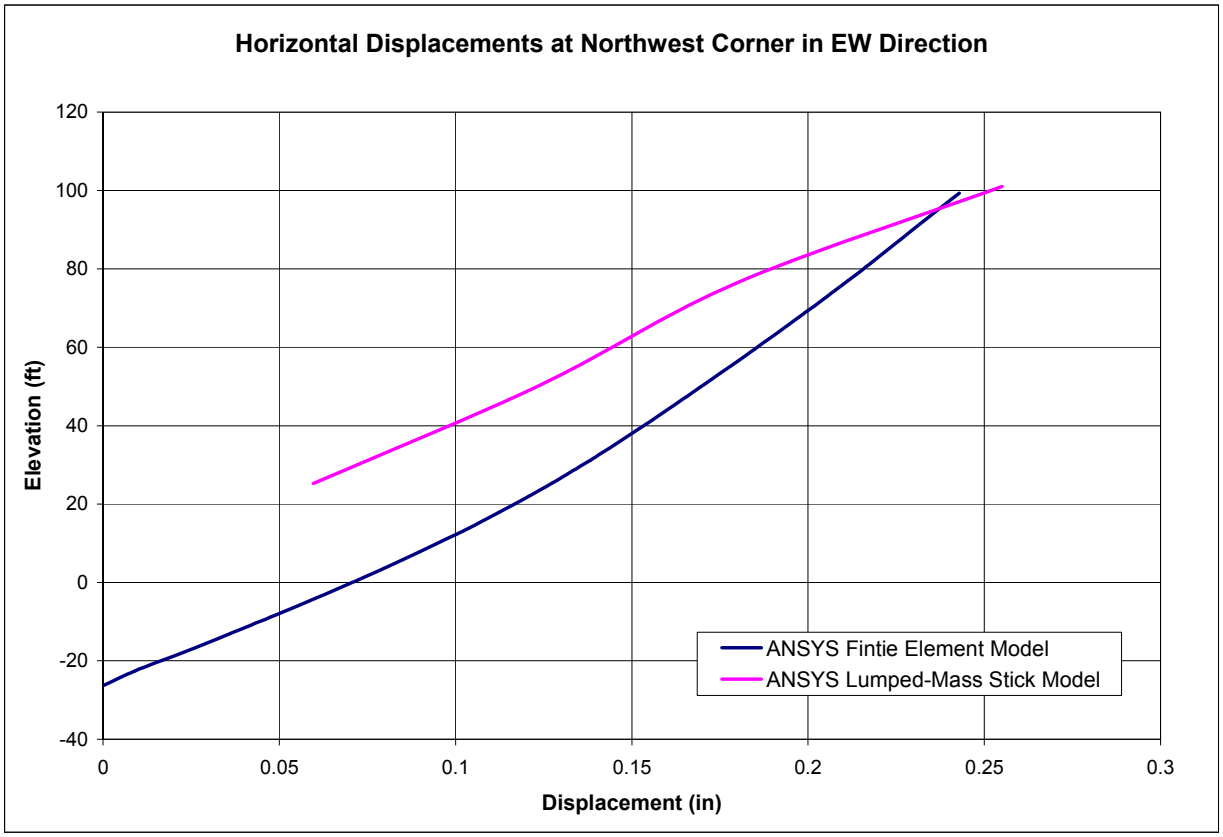

Figure 5.3.4.1-5 Horizontal Displacement Results At Northwest Corner of Reactor Building Under 1g Load in Horizontal Direction (Y)

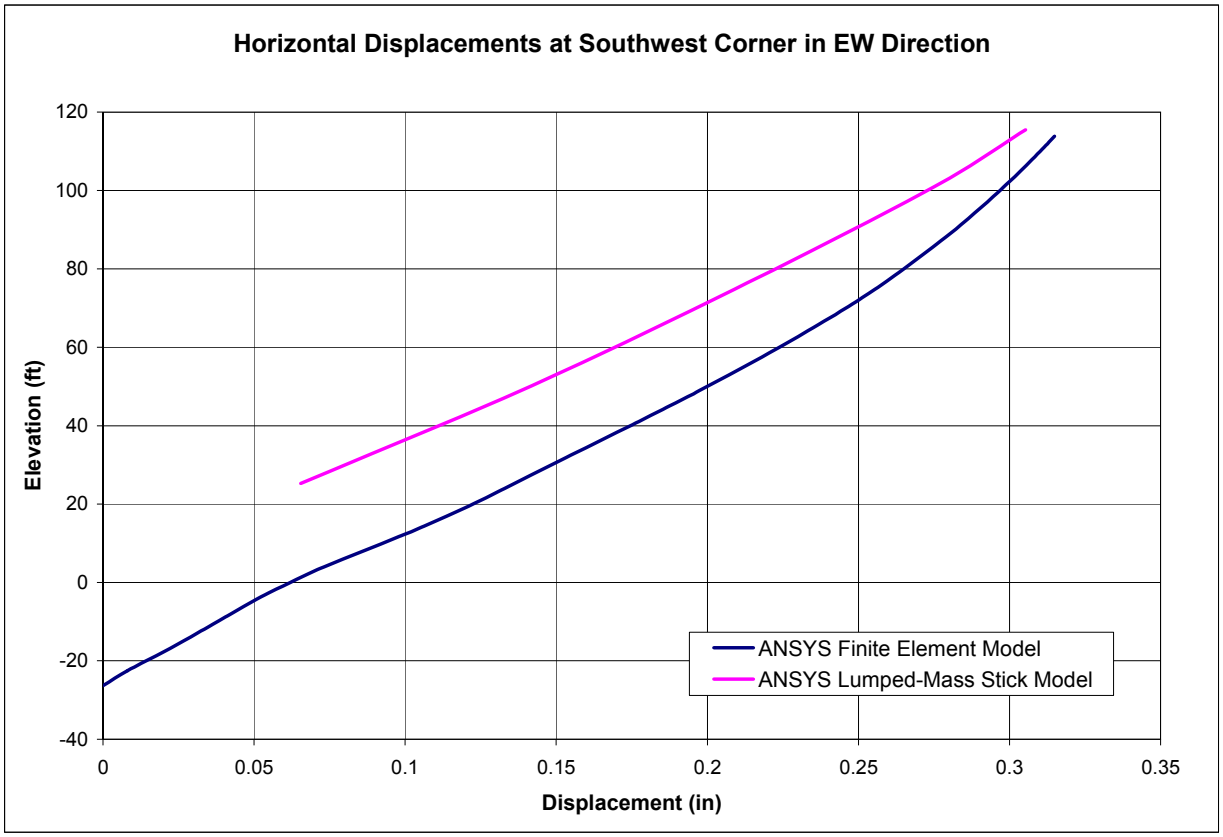

Figure 5.3.4.1-6 Horizontal Displacement Results At Southwest Corner of Reactor Building Under 1g Load in Horizontal Direction (Y)

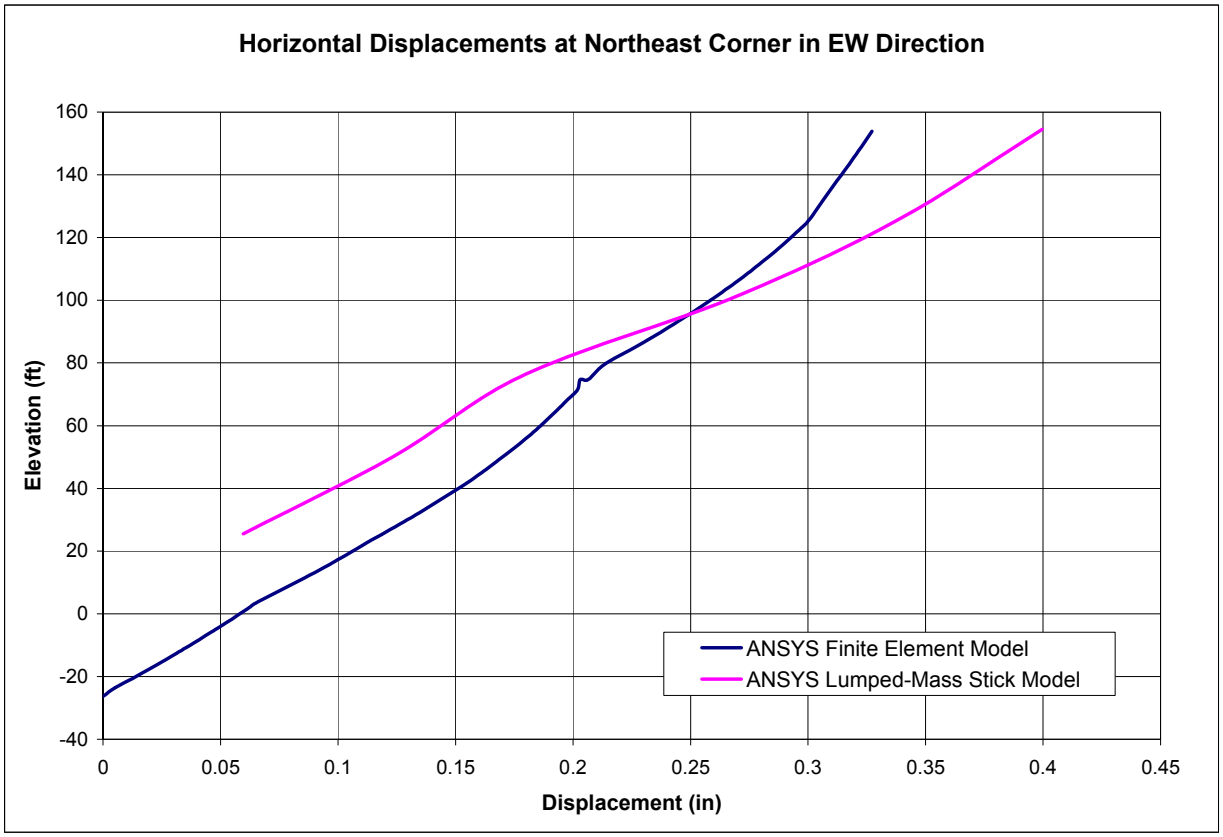

Figure 5.3.4.1-7 Horizontal Displacement Results At Northeast Corner of Reactor Building Under 1g Load in Horizontal Direction (Y)

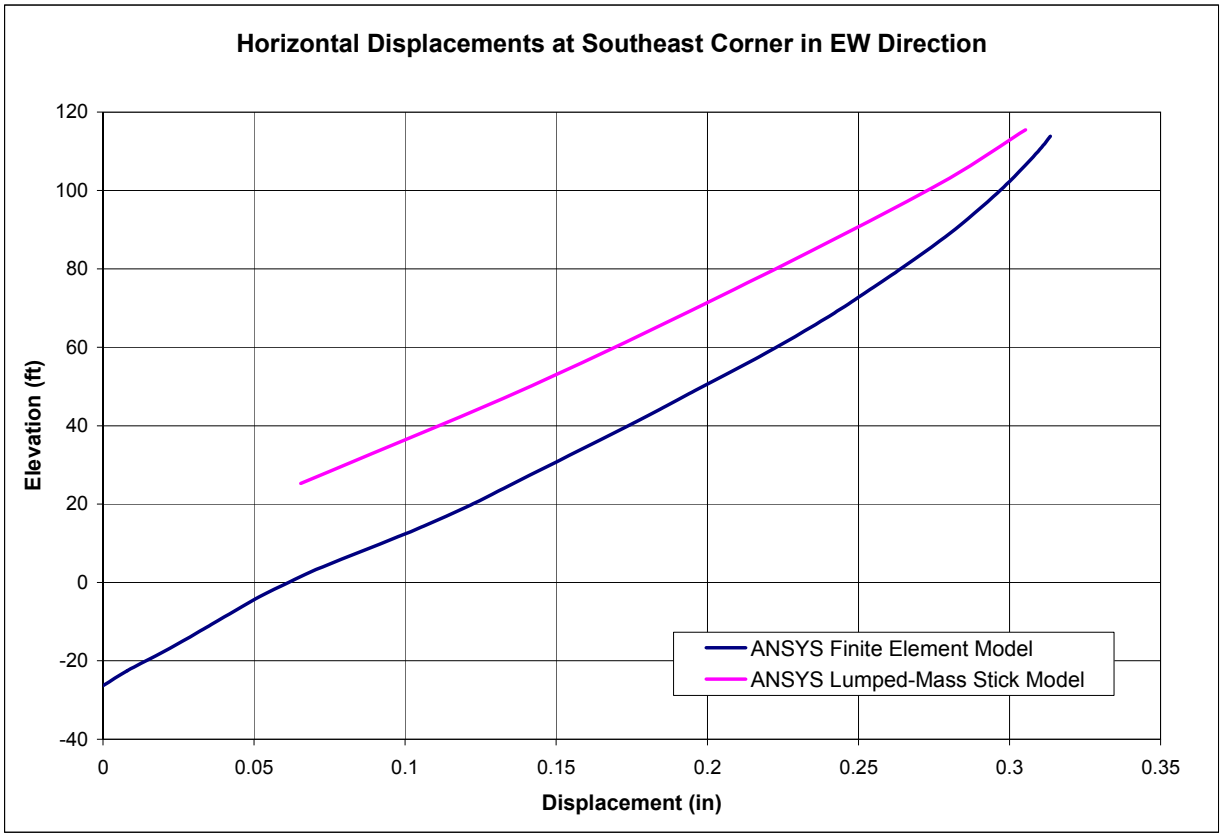

Figure 5.3.4.1-8 Horizontal Displacement Results At Southeast Corner of Reactor Building Under 1g Load in Horizontal Direction (Y)

5.3.4.2 Modal Analysis

A modal analysis using ANSYS is performed on the 3-D FE model. The dominant natural frequencies and effective masses obtained from these analyses are shown in the following tables.

Table 5.3.4.2-1 Modal Properties of First 3 Modes, X-Direction (NS)

MODE	FREQUENCY (HZ)	PERIOD (sec)	PARTIC.FACTOR	EFFECTIVE MASS (lbs*sec^2/ft)
1	5.631	0.178	513.13	263298
12	10.737	0.0931	-171.03	29252.8
133	21.614	0.0463	25.112	630.589

Table 5.3.4.2-2 Modal Properties of First 3 Modes, Y-Direction (EW)

MODE	FREQUENCY (HZ)	PERIOD (sec)	PARTIC.FACTOR	EFFECTIVE MASS (lbs*sec^2/ft)
3	6.218	0.161	606.09	367351
26	13.128	0.0762	193.02	37257.7
225	26.051	0.0384	42.234	178.0

Table 5.3.4.2-3 Modal Properties of First 3 Modes, Z-Direction (Vertical)

MODE	FREQUENCY (HZ)	PERIOD (sec)	PARTIC.FACTOR	EFFECTIVE MASS (lbs*sec^2/ft)
22	12.630	0.0792	305.83	93530.7
56	16.446	0.0608	163.41	26700
455	34.319	0.0291	-23.573	555.691

An SSI analysis is performed on the SASSI model with the model resting on the surface of a half-space with hard-rock properties. This is to simulate the response of the structure under a fixed base condition. Transfer Functions at selected nodes are obtained from the SSI analysis and are presented in Figures 5.3.4.2-1 through 5.3.4.2-3. These figures indicate amplification spikes at or close to the dominant frequency points shown in Tables 5.3.4.2-1 through 5.3.4.2-3. This indicates that the stick model captures the structure response to dynamic load in all directions properly.

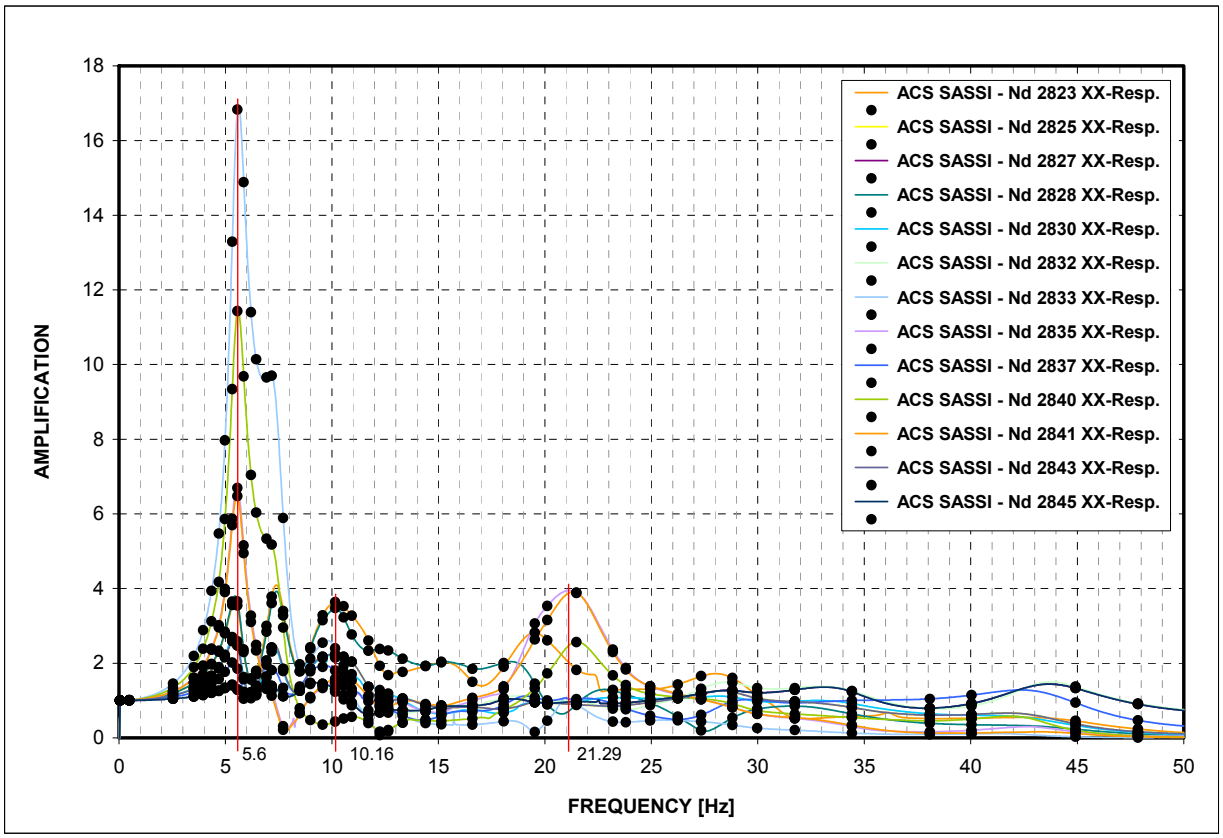

Figure 5.3.4.2-1 R/B Lumped Mass Stick Model Transfer Functions, X-Direction

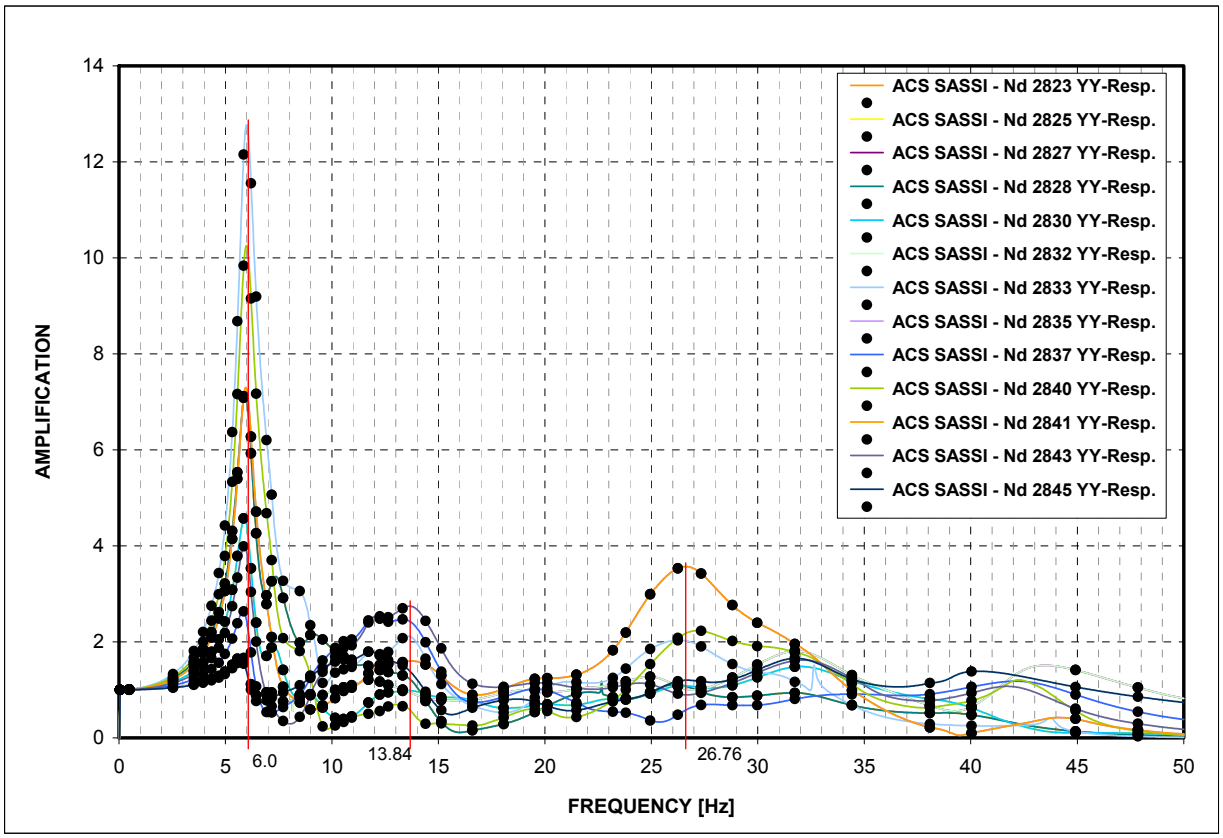

Figure 5.3.4.2-2 R/B Lumped Mass Stick Model Transfer Functions, Y-Direction

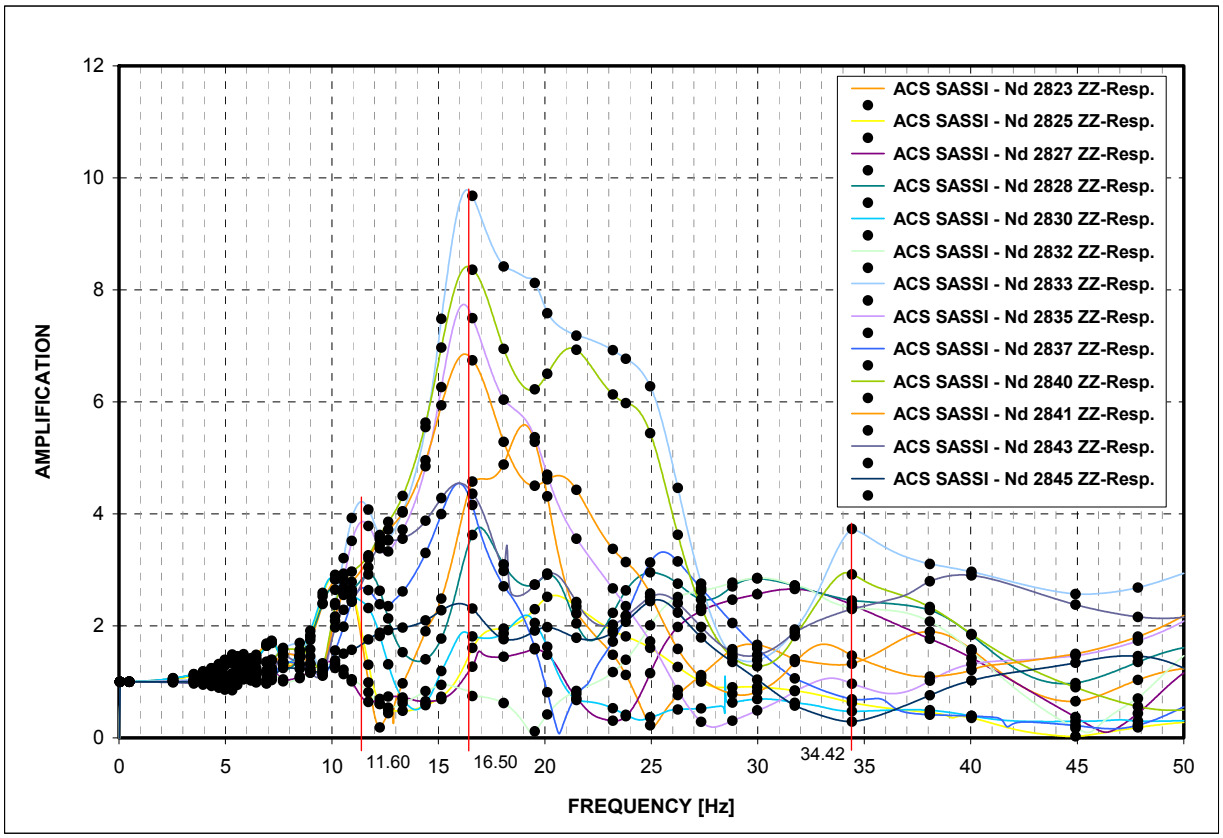

Figure 5.3.4.2-3 R/B Lumped Mass Stick Model Transfer Functions, Z-Direction

5.3.4.3 Mode-Superposition Transient Dynamic Analysis

A dynamic Time-History response analysis using modal superposition is performed on the R/B models using ANSYS, and the calculated response is compared with the results of the SASSI analyses of model resting on the surface of a rigid half-space. Acceleration response spectra (ARS) with 5 % damping are generated for each model at lumped mass locations. These acceleration response spectra indicate that the stick model captures the structure response to dynamic loads in all directions properly.

As can be seen in the following ARS (Figure 5.3.4.3-1 through Figure 5.3.4.3-25) generated for representative nodes, the stick model captures the main structure response to dynamic loads. The comparison of the ARS results from the detailed FE model and the R/B lumped-mass stick model do not demonstrate the ability of the lumped mass stick model to accurately capture the local responses at all locations within the R/B. The methodology used for development of design ISRS, presented in MUAP 10006, where the responses at lumped mass locations and outrigger locations are enveloped together with the SDOF model responses, are intended to compensate for these modeling shortcomings of the lumped mass stick model. A study will be performed on a 3-D FE SASSI model of the R/B complex structures that will capture the local high frequency effects more effectively than the lumped-mass stick models enhanced with SDOF models.

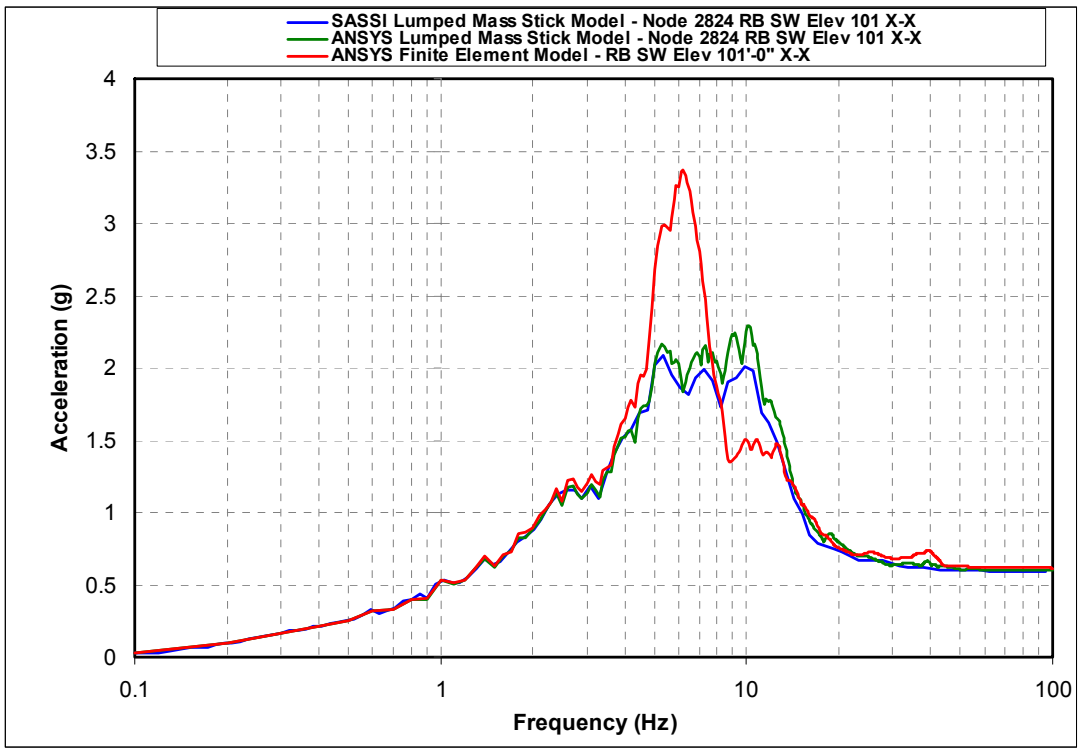

Figure 5.3.4.3-1 Acceleration Response Spectrum Southwest Corner Elev. 101'-0" Node 2824, NS Direction

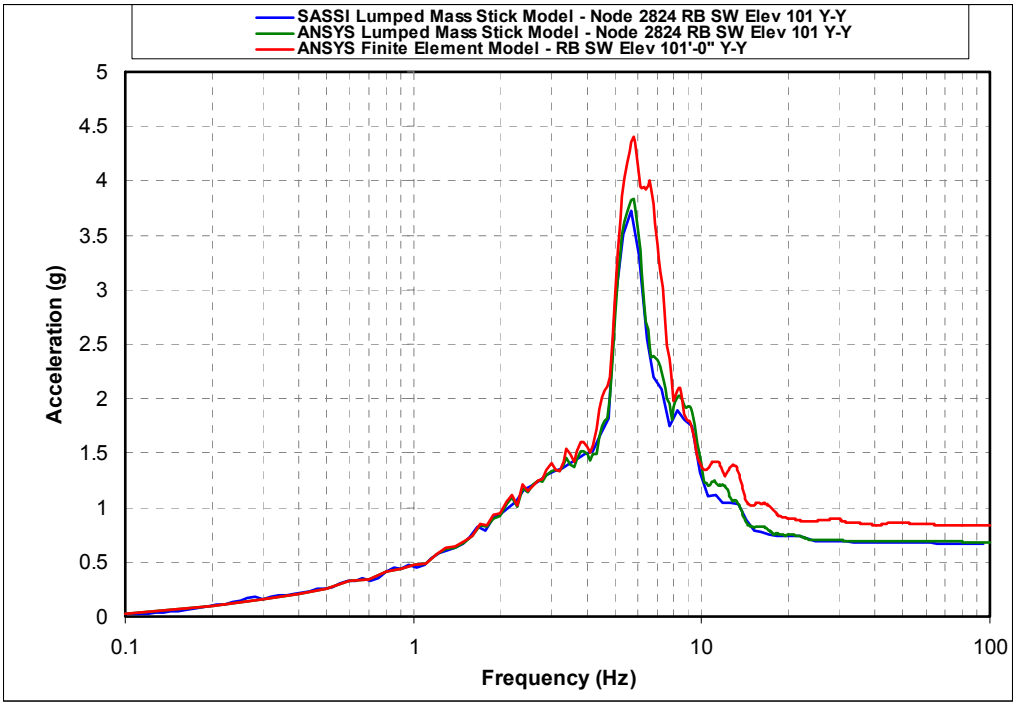

Figure 5.3.4.3-2 Acceleration Response Spectrum Southwest Corner Elev. 101'-0" Node 2824, EW Direction

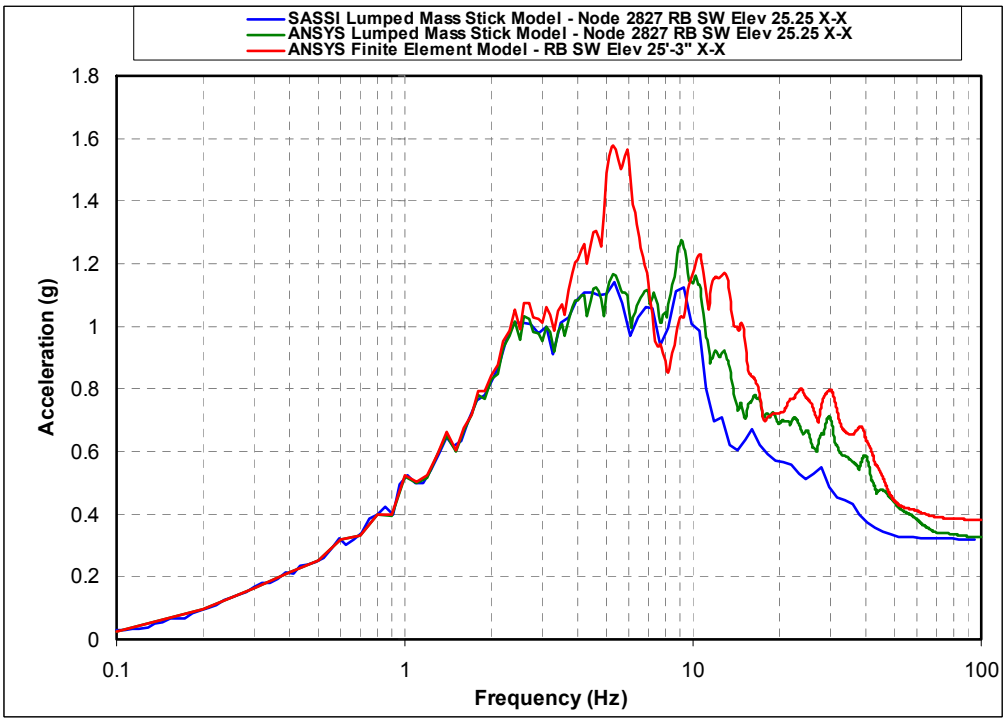

Figure 5.3.4.3-3 Acceleration Response Spectrum Southwest Corner Elev. 25'-3" Node 2827, NS Direction

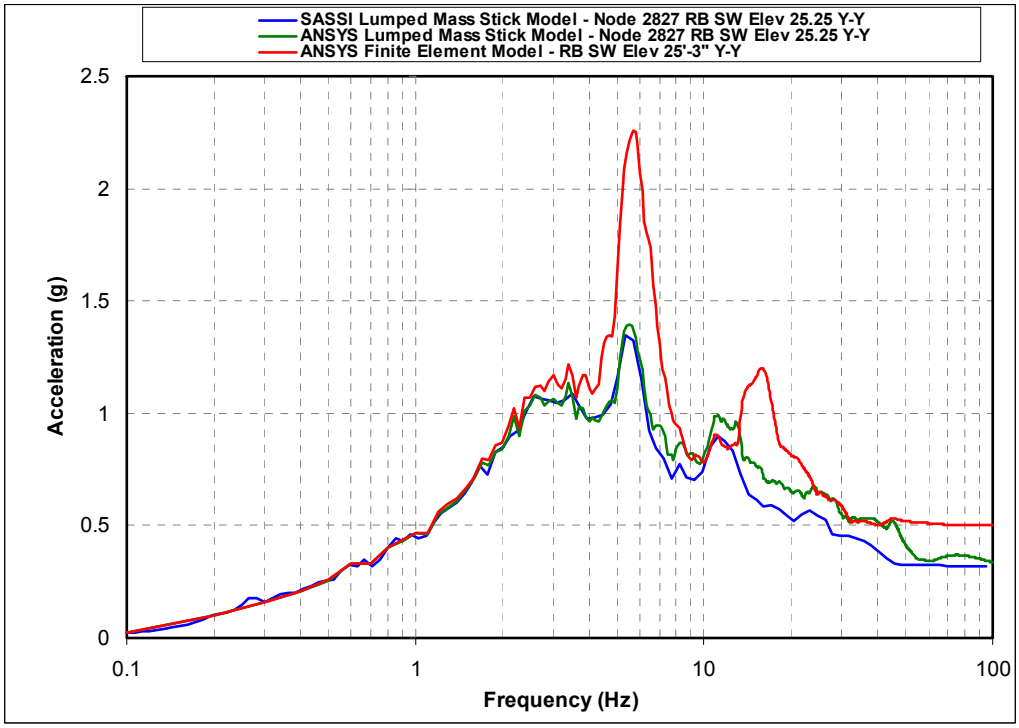

Figure 5.3.4.3-4 Acceleration Response Spectrum Southwest Corner Elev. 25'-3" Node 2827, EW Direction

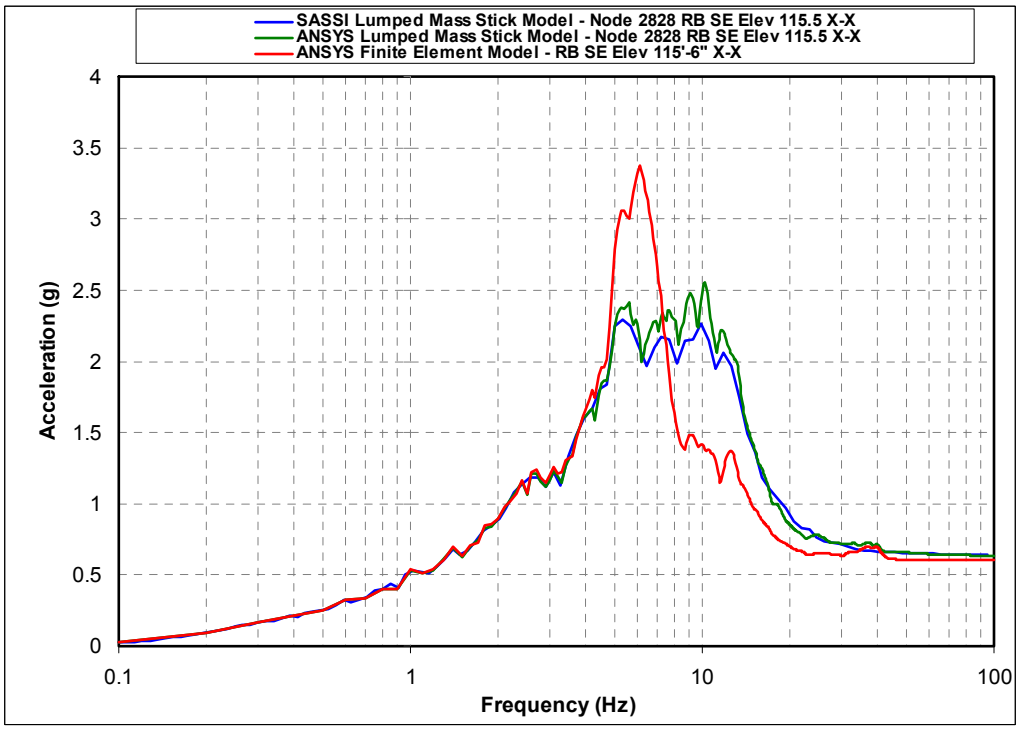

Figure 5.3.4.3-5 Acceleration Response Spectrum Southeast Corner Elev. 115'-6" Node 2828, NS Direction

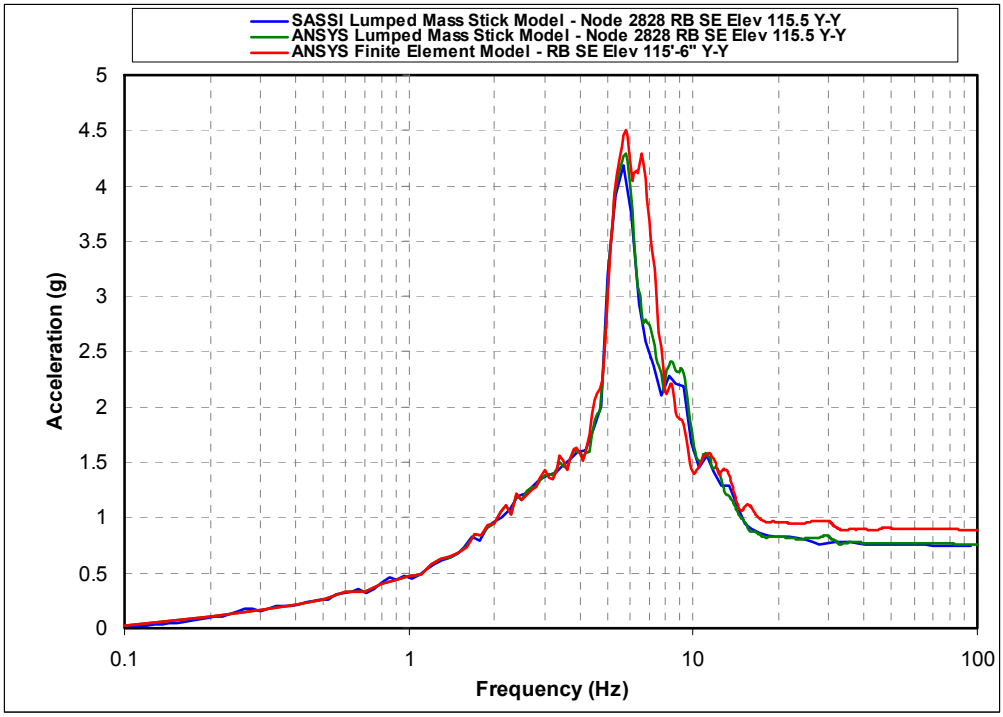

Figure 5.3.4.3-6 Acceleration Response Spectrum Southeast Corner Elev. 115'-6" Node 2828, EW Direction

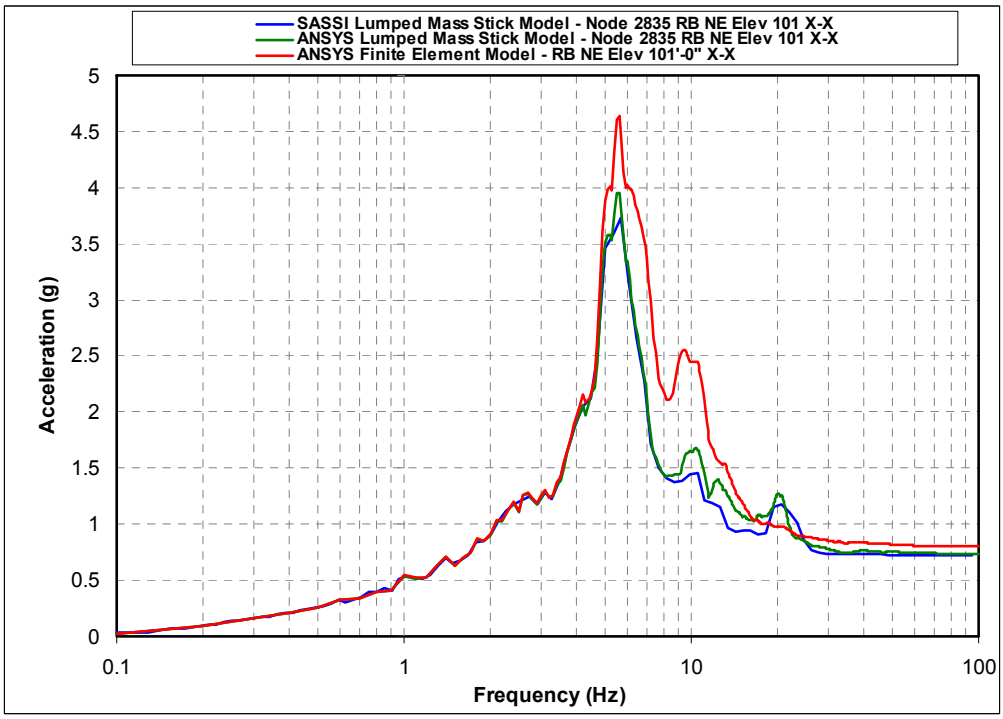

Figure 5.3.4.3-7 Acceleration Response Spectrum Northeast Corner Elev. 101'-0" Node 2835, NS Direction

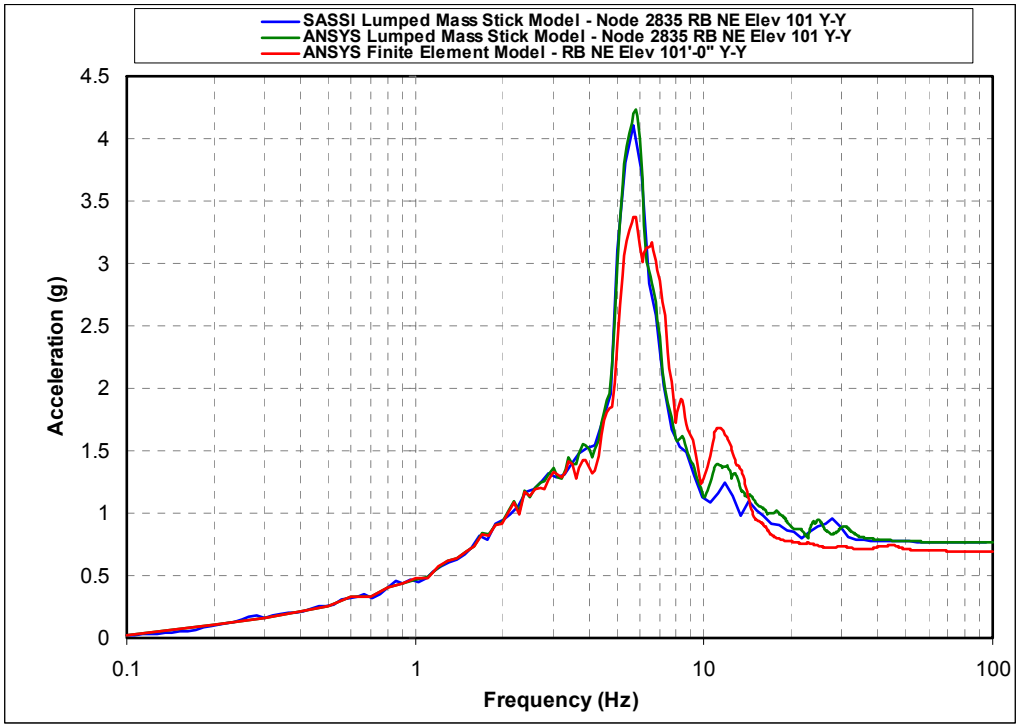

Figure 5.3.4.3-8 Acceleration Response Spectrum Northeast Corner Elev. 101'-0" Node 2835, EW Direction

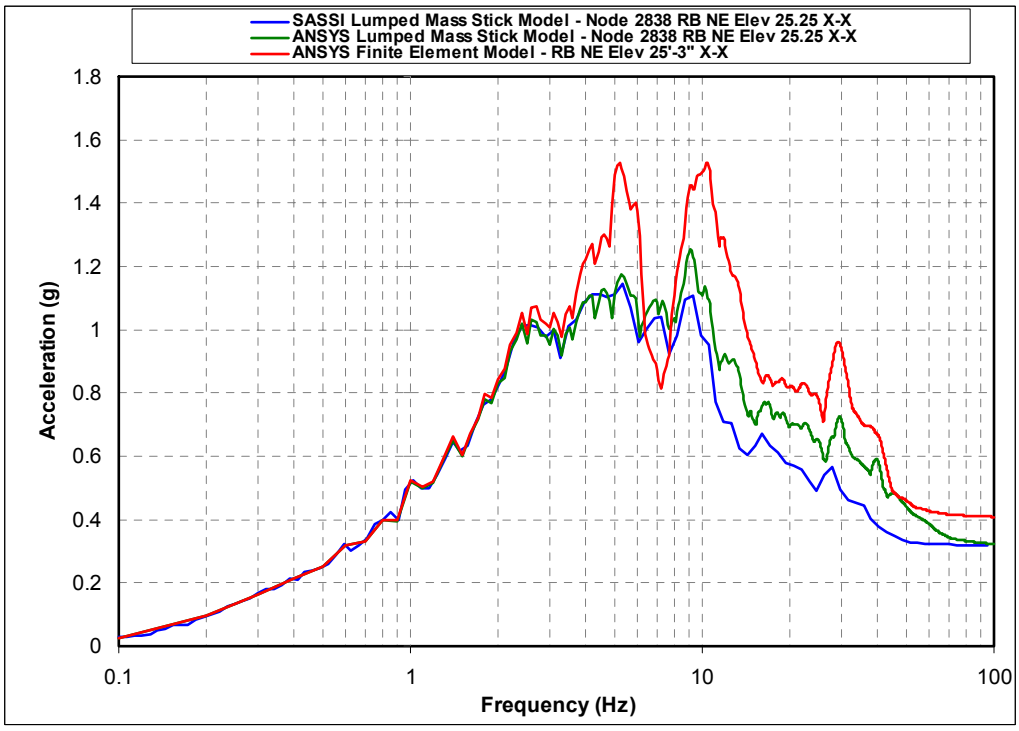

Figure 5.3.4.3-9 Acceleration Response Spectrum Northeast Corner Elev. 25'-3" Node 2838, NS Direction

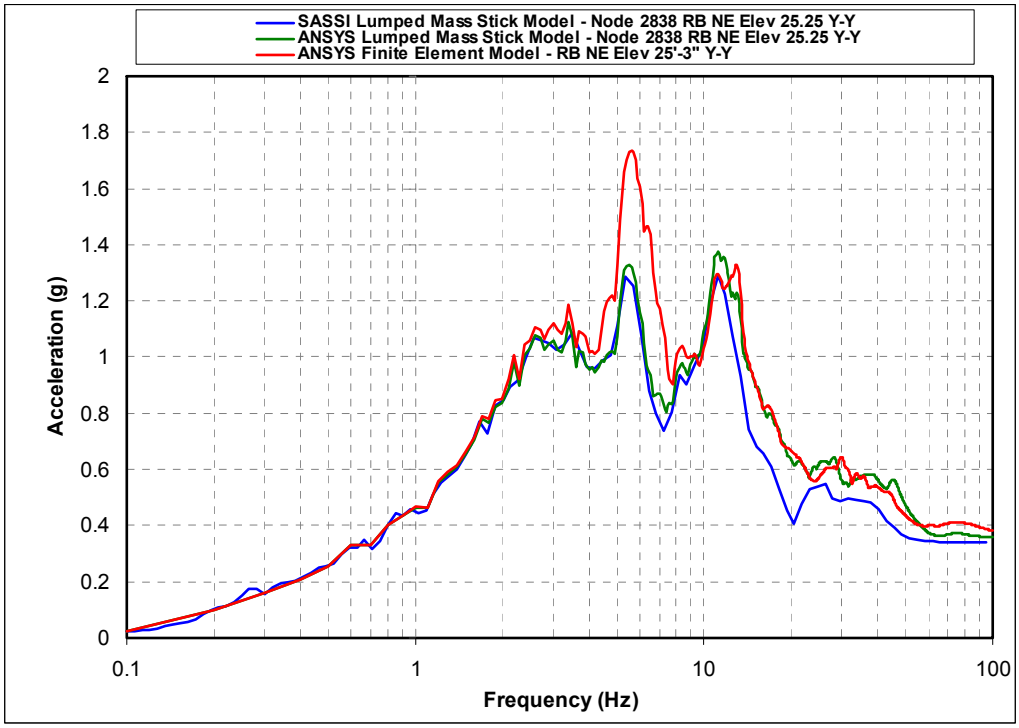

Figure 5.3.4.3-10 Acceleration Response Spectrum Northeast Corner Elev. 25'-3" Node 2838, EW Direction

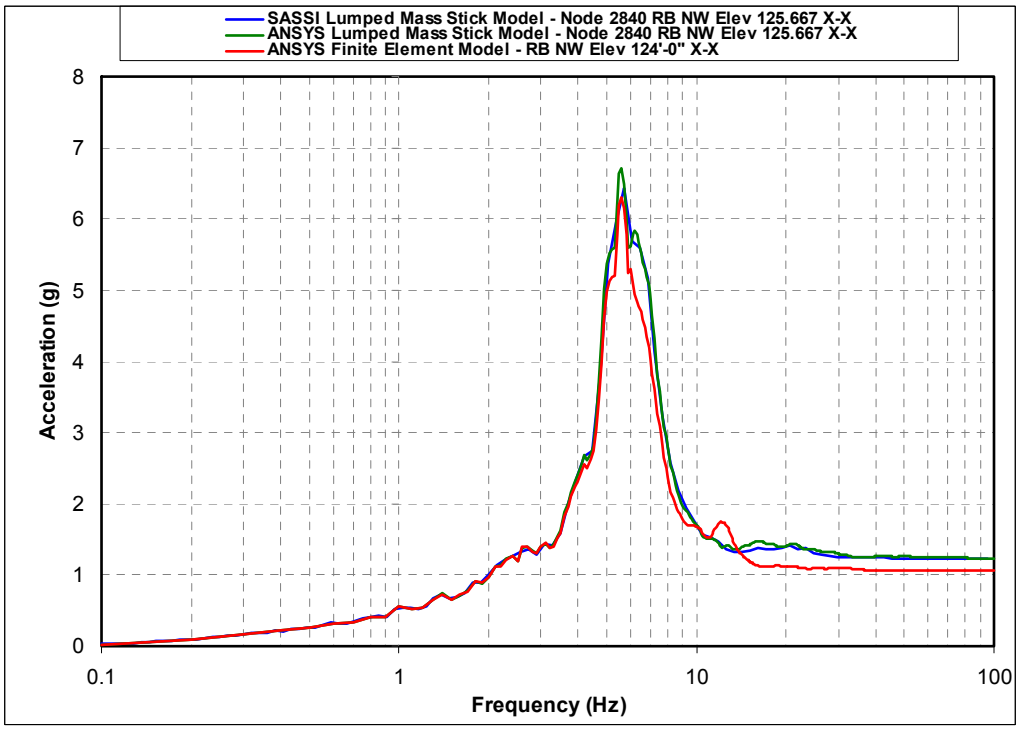

Figure 5.3.4.3-11 Acceleration Response Spectrum Northeast Corner Elev. 124'-0" Node 2840, NS Direction

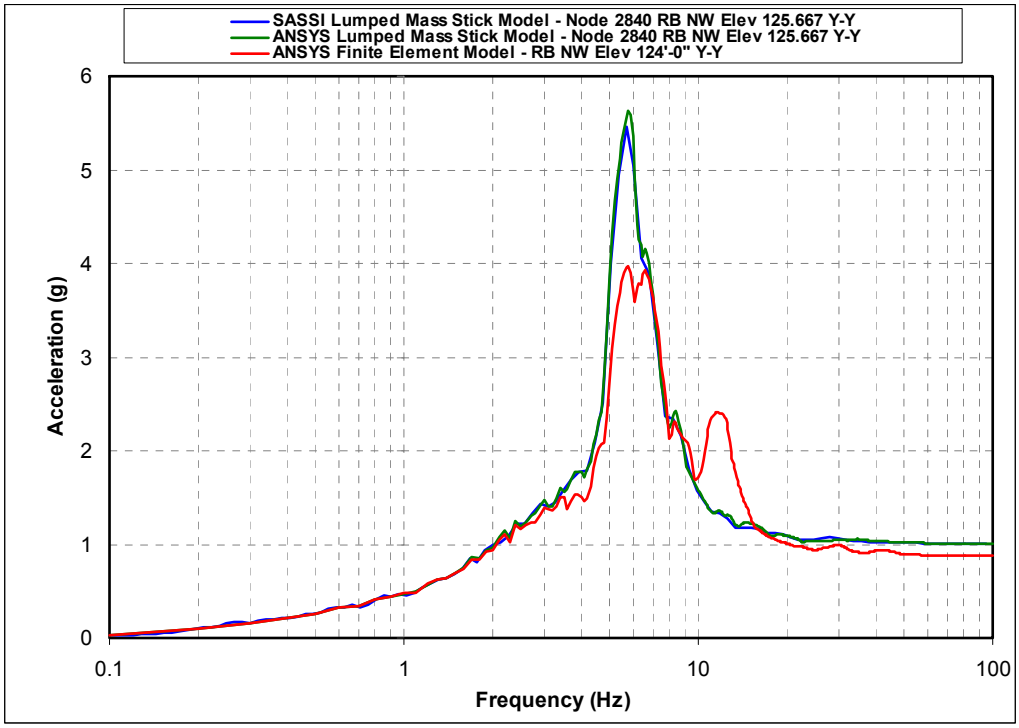

Figure 5.3.4.3-12 Acceleration Response Spectrum Northeast Corner Elev. 124'-0" Node 2840, EW Direction

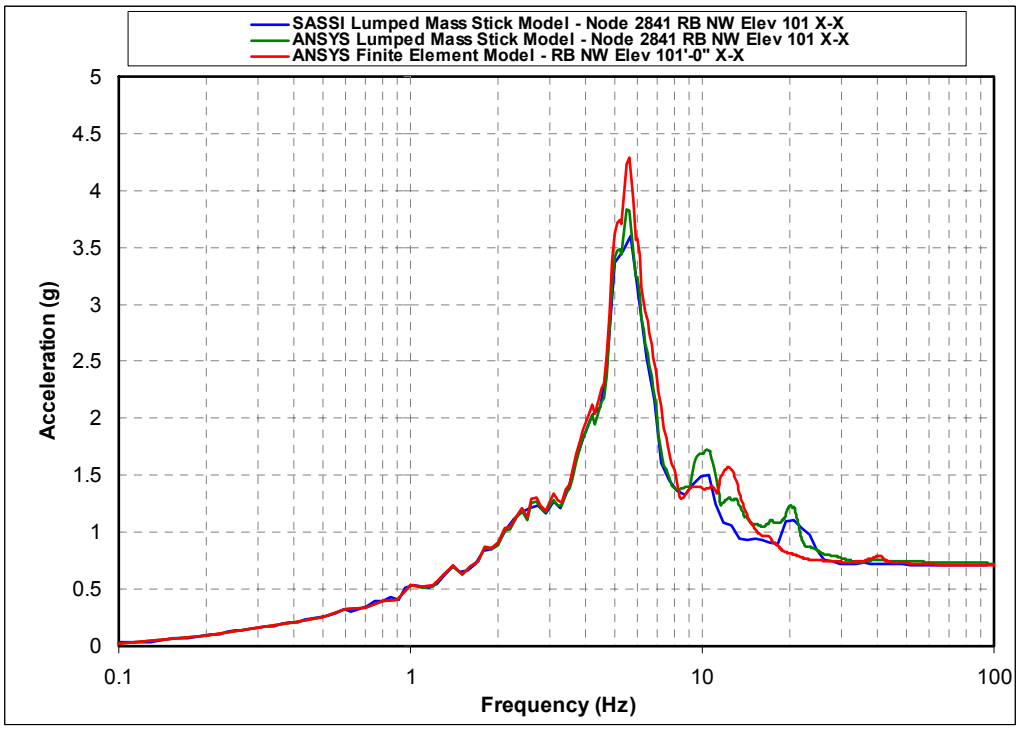

Figure 5.3.4.3-13 Acceleration Response Spectrum Northeast Corner Elev. 101'-0" Node 2841, NS Direction

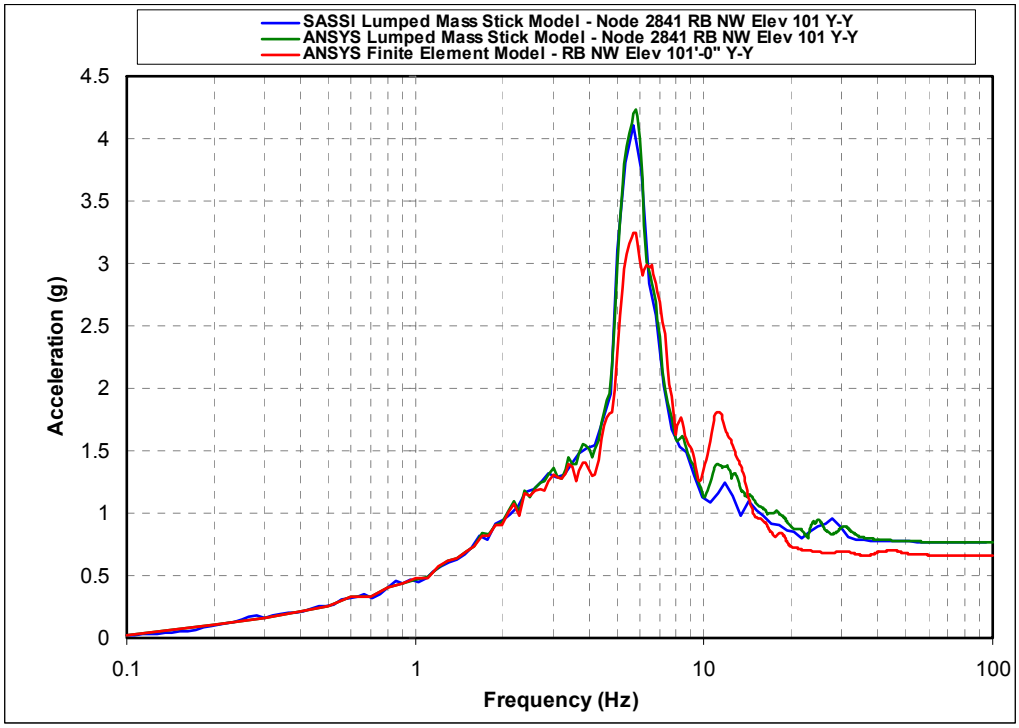

Figure 5.3.4.3-14 Acceleration Response Spectrum Northeast Corner Elev. 101'-0" Node 2841, EW Direction

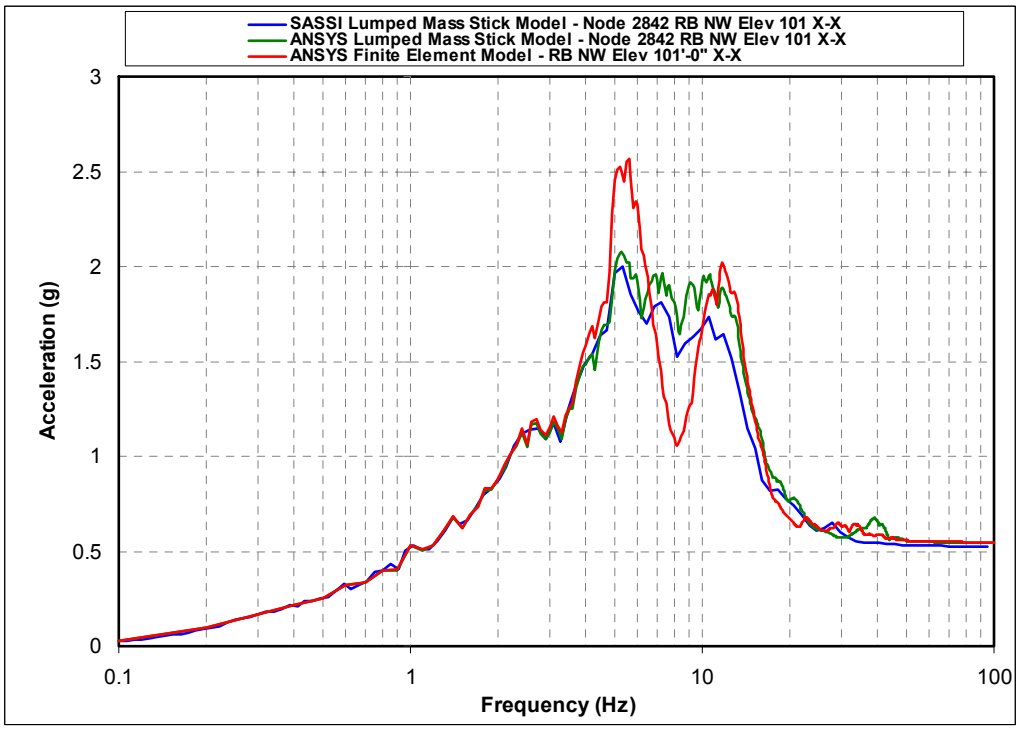

Figure 5.3.4.3-15 Acceleration Response Spectrum Northeast Corner Elev. 101'-0" Node 2842, NS Direction

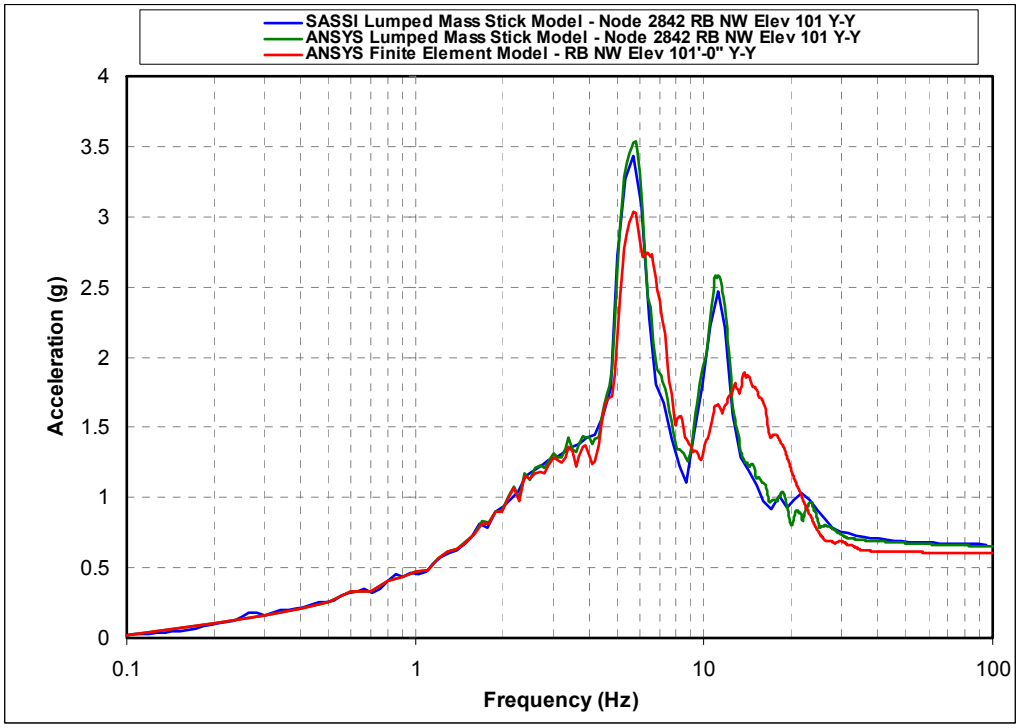

Figure 5.3.4.3-16 Acceleration Response Spectrum Northeast Corner Elev. 101'-0" Node 2842, EW Direction

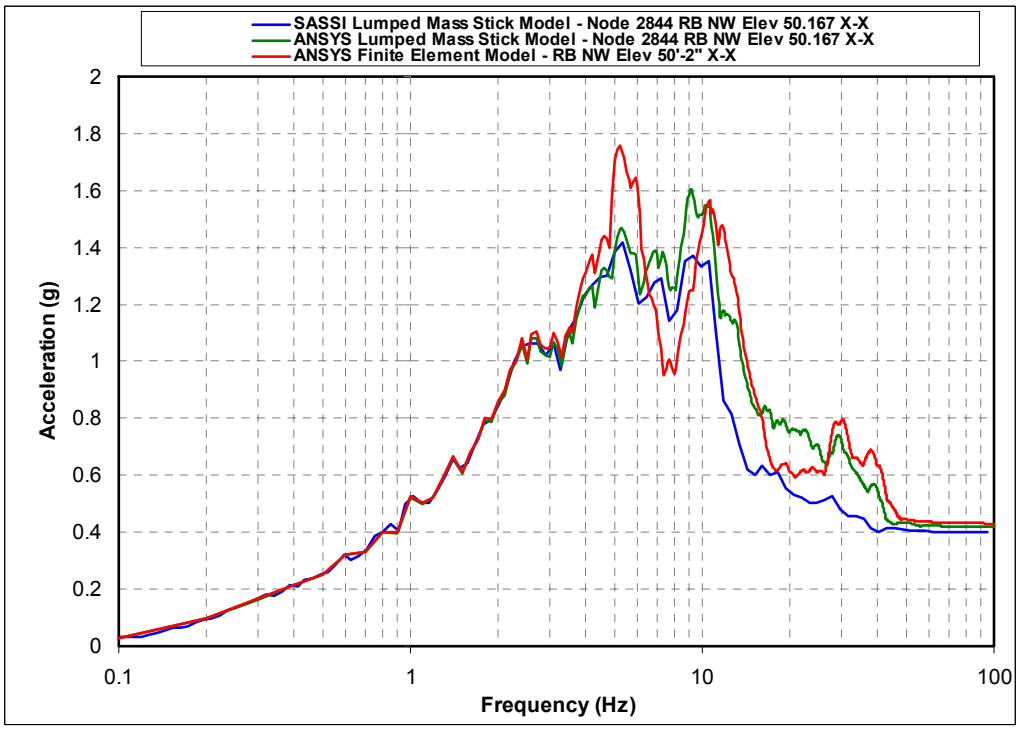

Figure 5.3.4.3-17 Acceleration Response Spectrum Northeast Corner Elev. 50'-2" Node 2844, NS Direction

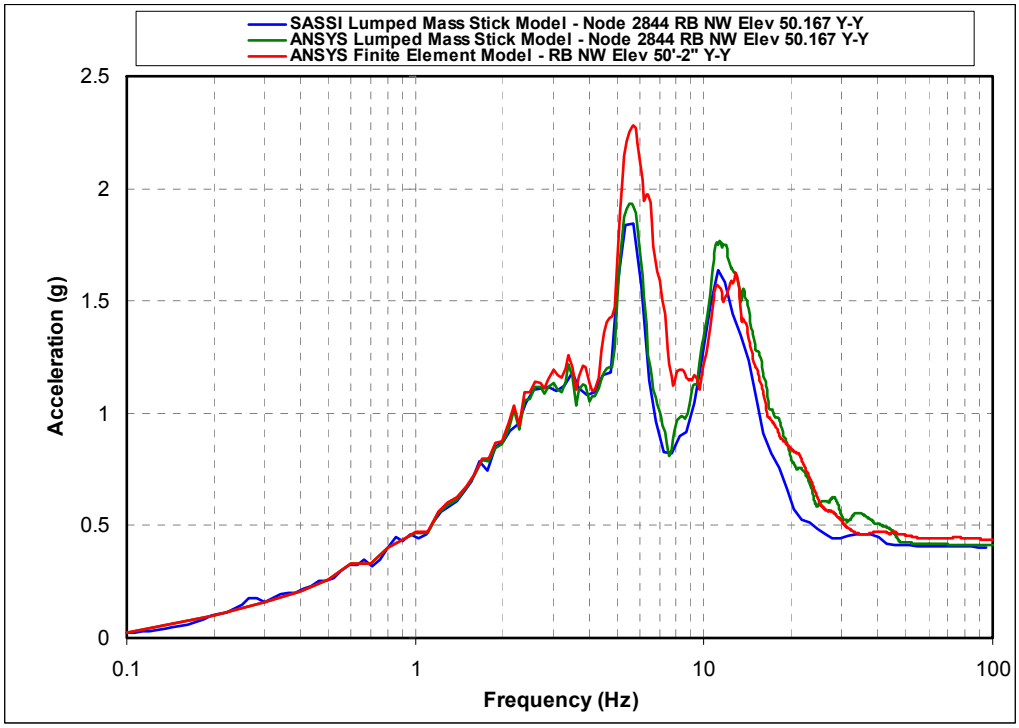

Figure 5.3.4.3-18 Acceleration Response Spectrum Northeast Corner Elev. 50'-2" Node 2844, EW Direction

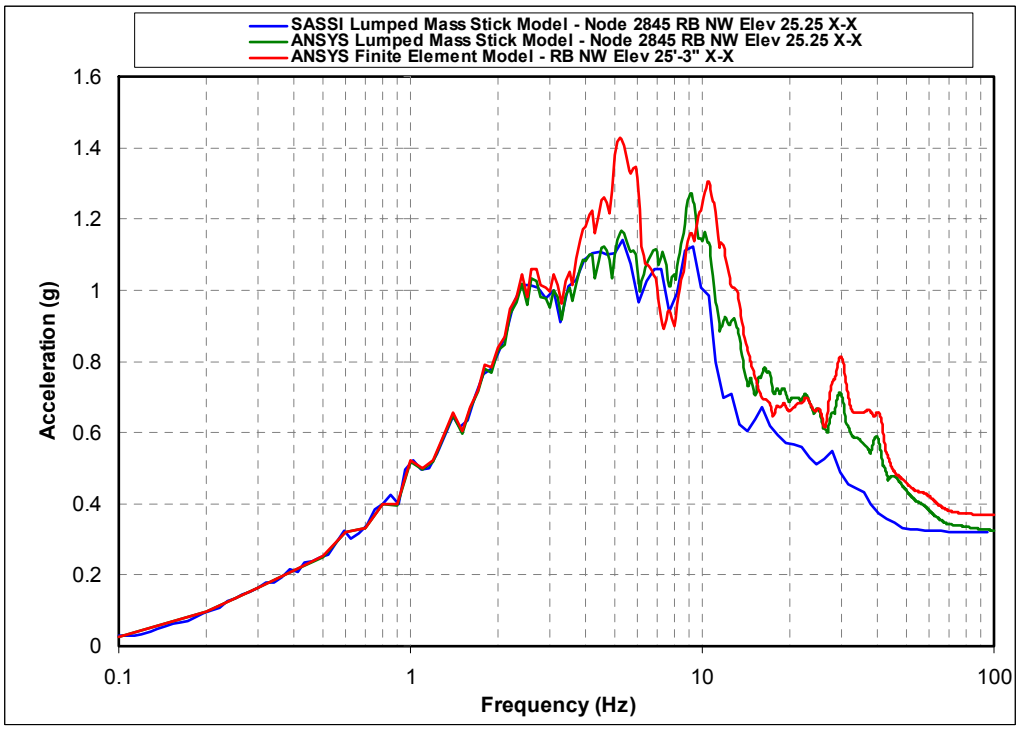

Figure 5.3.4.3-19 Acceleration Response Spectrum Northeast Corner Elev. 25'-3" Node 2845, NS Direction

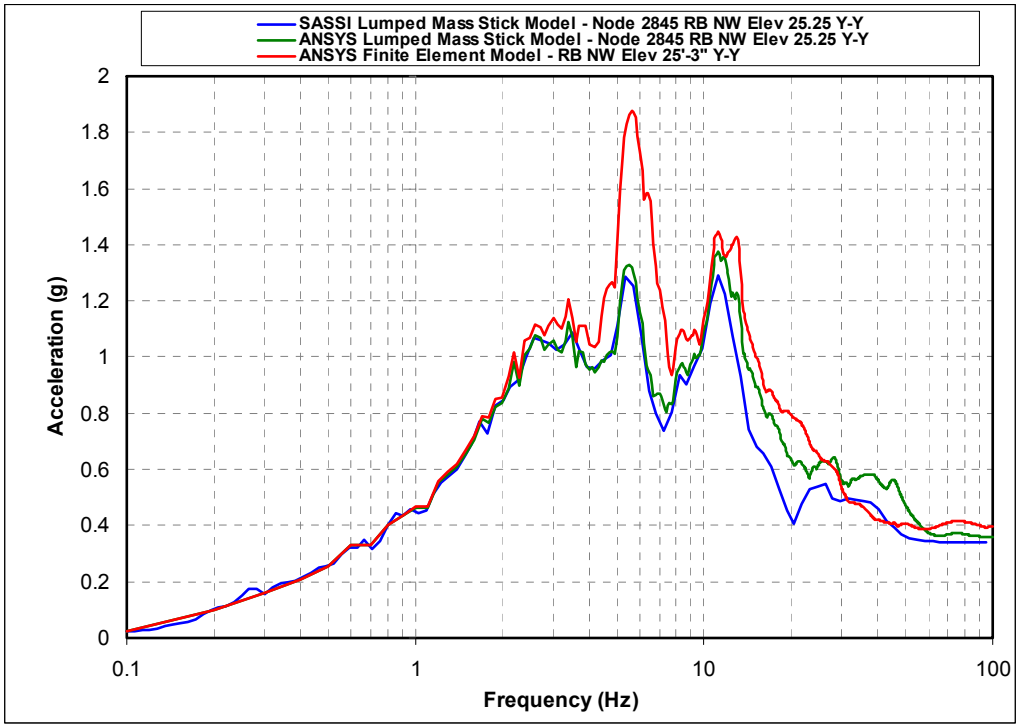

Figure 5.3.4.3-20 Acceleration Response Spectrum Northeast Corner Elev. 25'-3" Node 2845, EW Direction

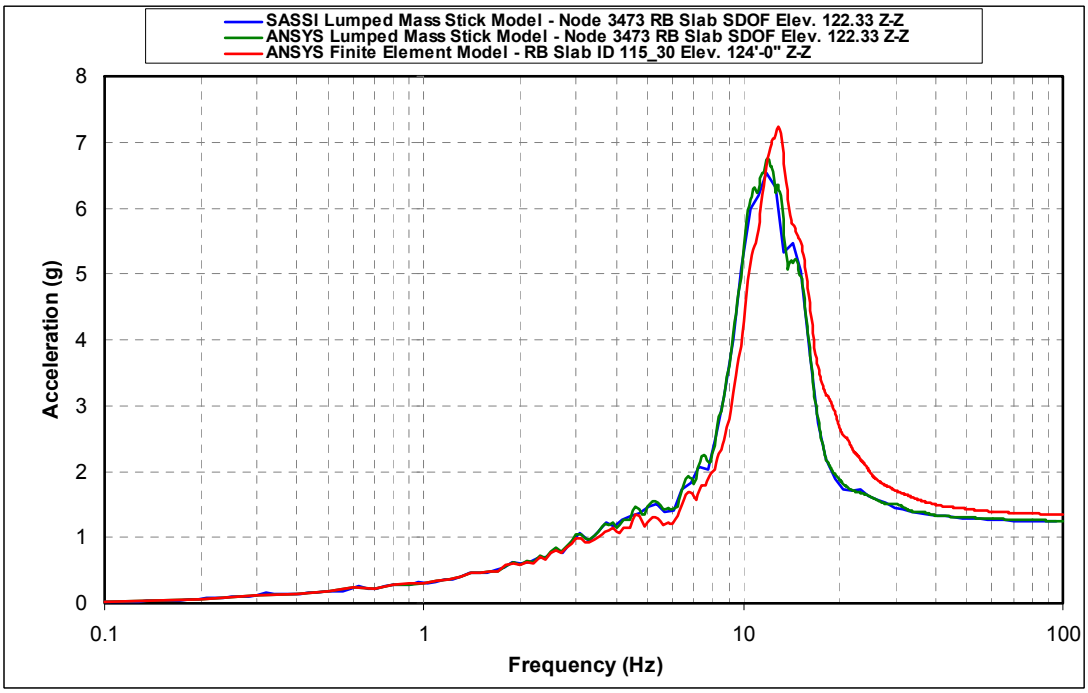

Figure 5.3.4.3-21 Acceleration Response Spectrum R/B Slab ID 115_30 Elev. 124'-0" Node 3473, Vertical Direction

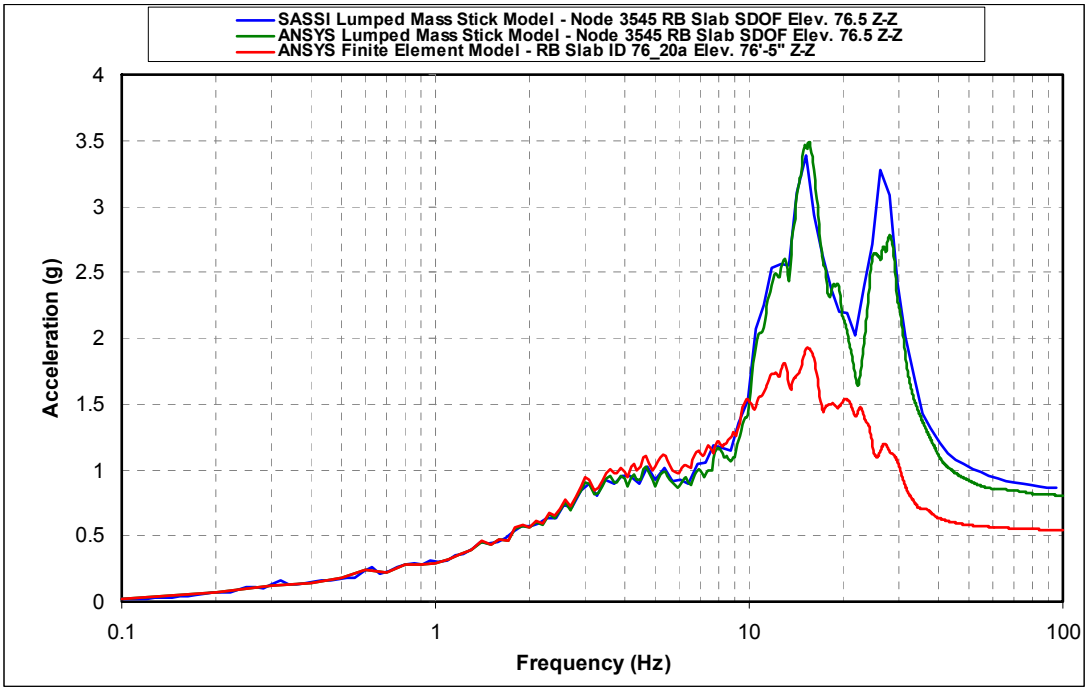

Figure 5.3.4.3-22 Acceleration Response Spectrum R/B Slab ID 76_20a Elev. 76'-5" Node 3545, Vertical Direction

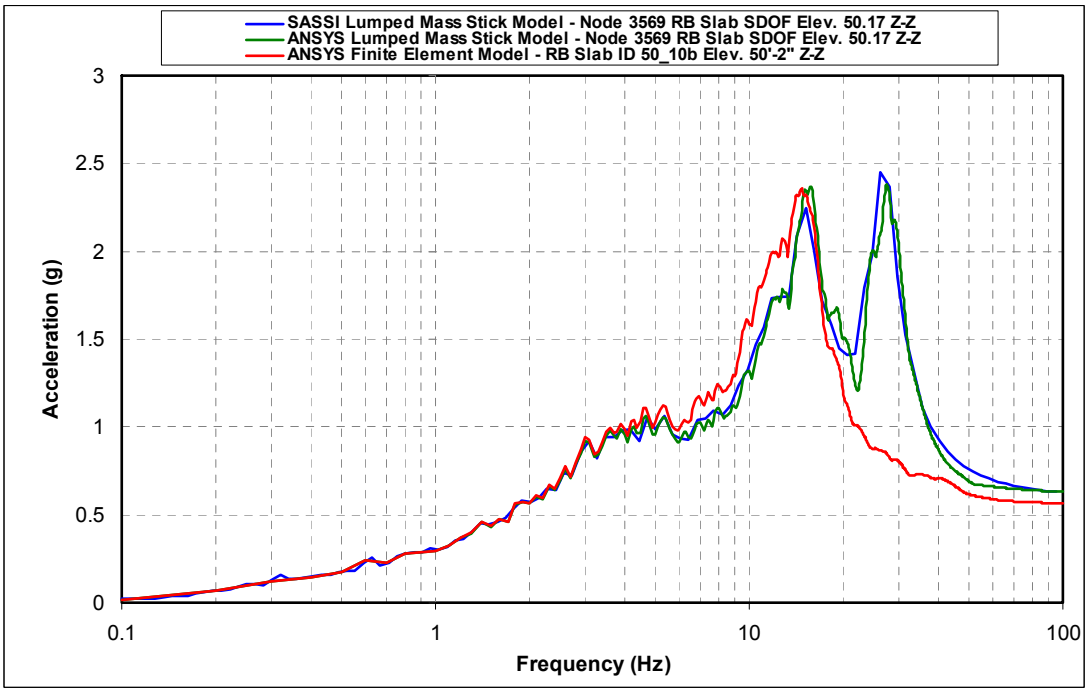

Figure 5.3.4.3-23 Acceleration Response Spectrum R/B Slab ID 50_10b Elev. 50'-2" Node 3569, Vertical Direction

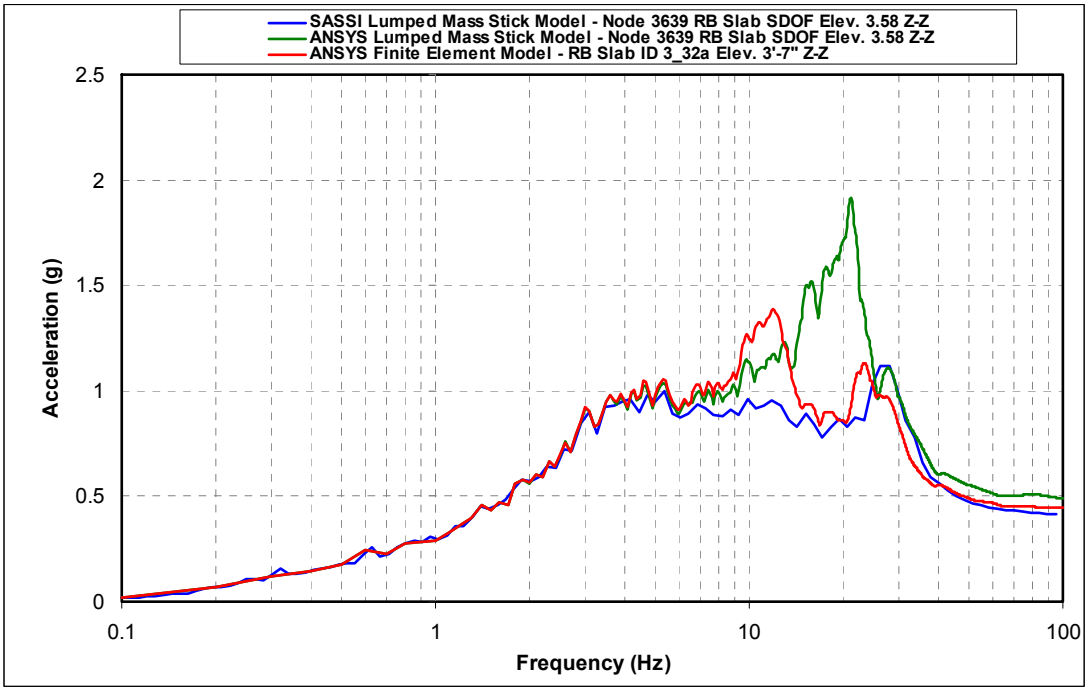

Figure 5.3.4.3-24 Acceleration Response Spectrum R/B Slab ID 3_32a Elev. 3'-7" Node 3639, Vertical Direction

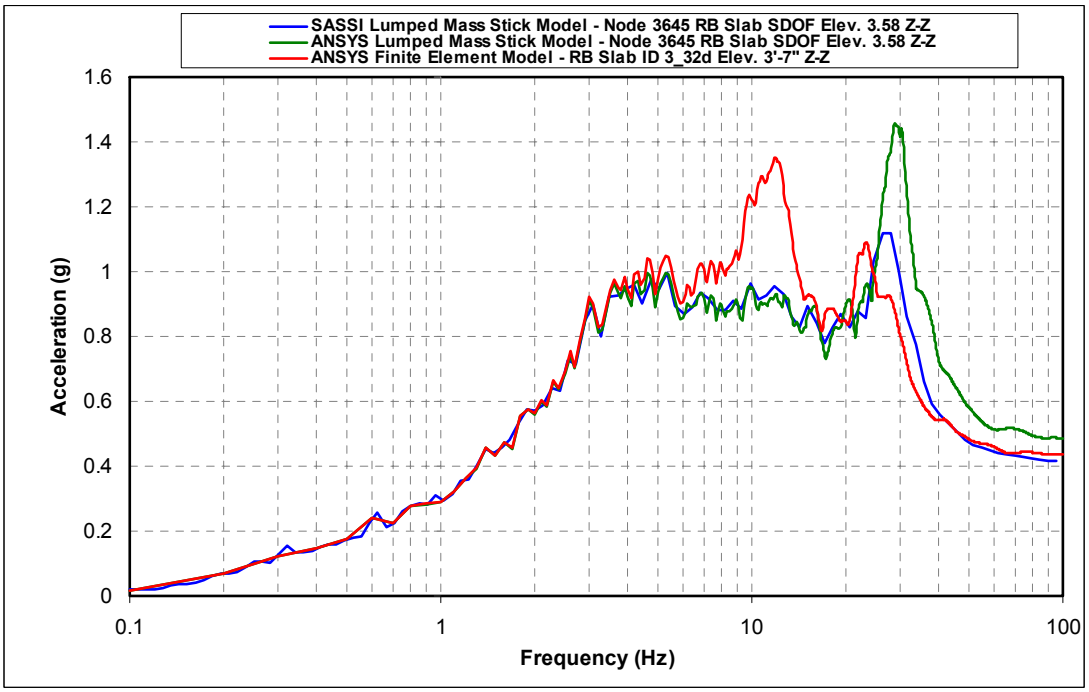

Figure 5.3.4.3-25 Acceleration Response Spectrum R/B Slab ID 3_32d Elev. 3'-7" Node 3645, Vertical Direction

5.3.5 CIS Verification Results

5.3.5.1 1g Static Analysis

A 1g static analysis in the vertical (Z) direction with full constraints at the bottom of the Containment structure is performed on both CIS models (Stick and 3-D FE) to verify their overall static weight.

The total weight of the Stick Model is 95,370 kips.

The total weight of the 3-D FE Model is 94,856 kips.

This represents a difference of 1.01% between the total weights of both models.

A 1g static analysis in the horizontal (X and Y) directions with full constraints at the bottom of the CIS is also performed on both models. The displacement results from both static analyses are used to compare the structure stiffness of the two models in all directions. The displacement distributions along the height of the PCCV are plotted in Figures 5.3.5.1-1 through 5.3.5.1-4 below, and indicate that the stick model stiffness is comparable to that of the 3-D FE Model.

Discrepancies in the lateral displacements of IC00-IC61 branch at elevations below elevation 25 ft. corresponding to the elevation of the lumped mass node IC02 are due to local stiffness effects. The detailed FE model of the containment internal structure (CIS) uses two types of elements to represent the stiffness of the bottom 25 ft of the structure, shell elements representing the steel/structure walls at the CIS periphery and solid elements representing the CIS central portion. The CIS lumped-mass stick model uses only one stick element between two floor elevations to represent the overall stiffness of the structure. The variation in the results obtained from the analysis of the detailed FE model for the displacements at the periphery of the model are due to variation of the local stiffness of the CIS part of the structure modeled with shell elements.

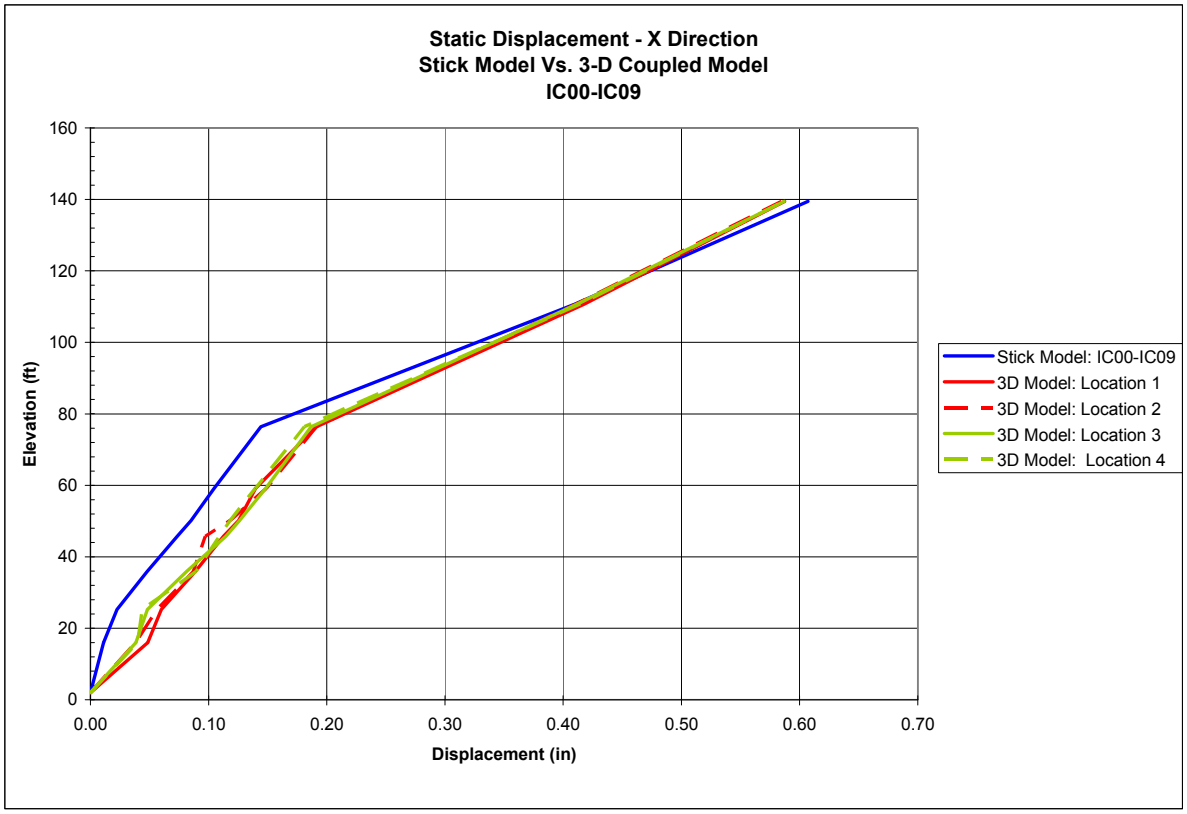

Figure 5.3.5.1-1 Horizontal Displacement Results IC00 – IC09 Under 1g Load in Horizontal Direction (X)

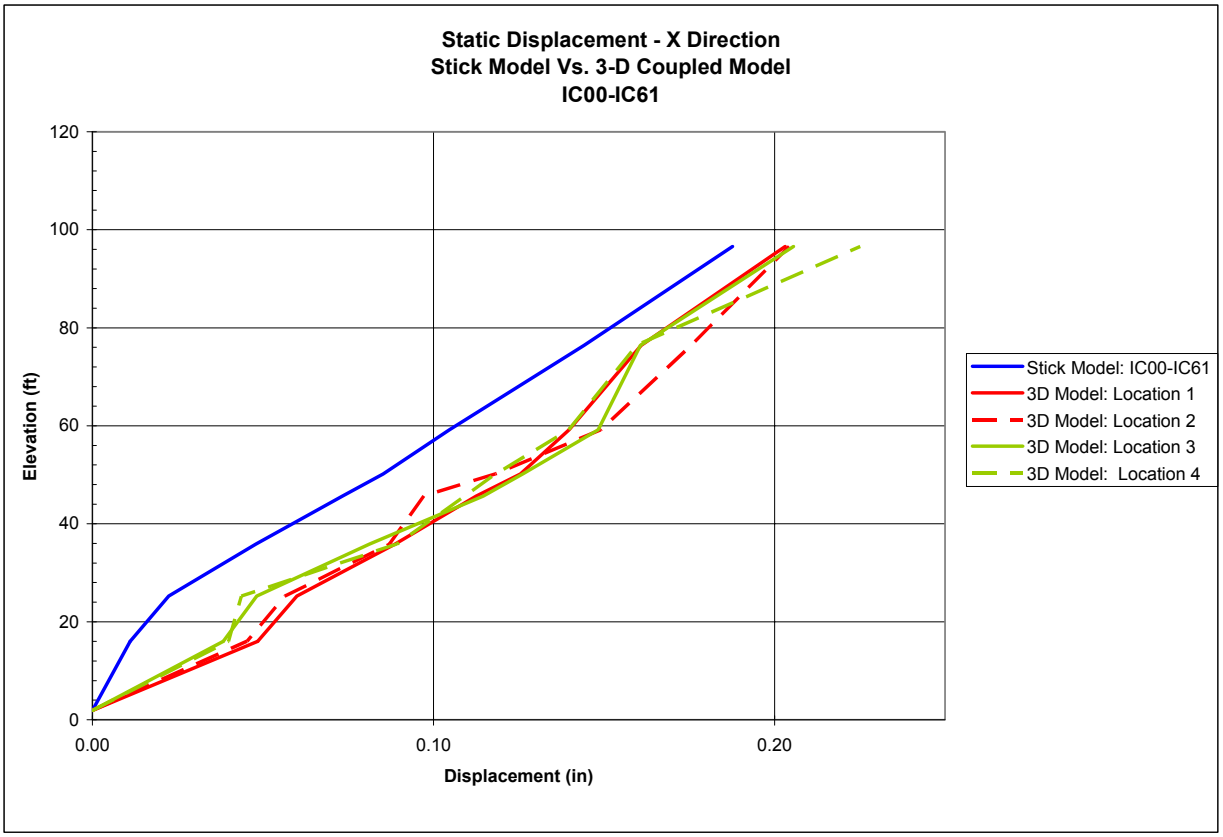

Figure 5.3.5.1-2 Horizontal Displacement Results IC00 – IC61 Under 1g Load in Horizontal Direction (X)

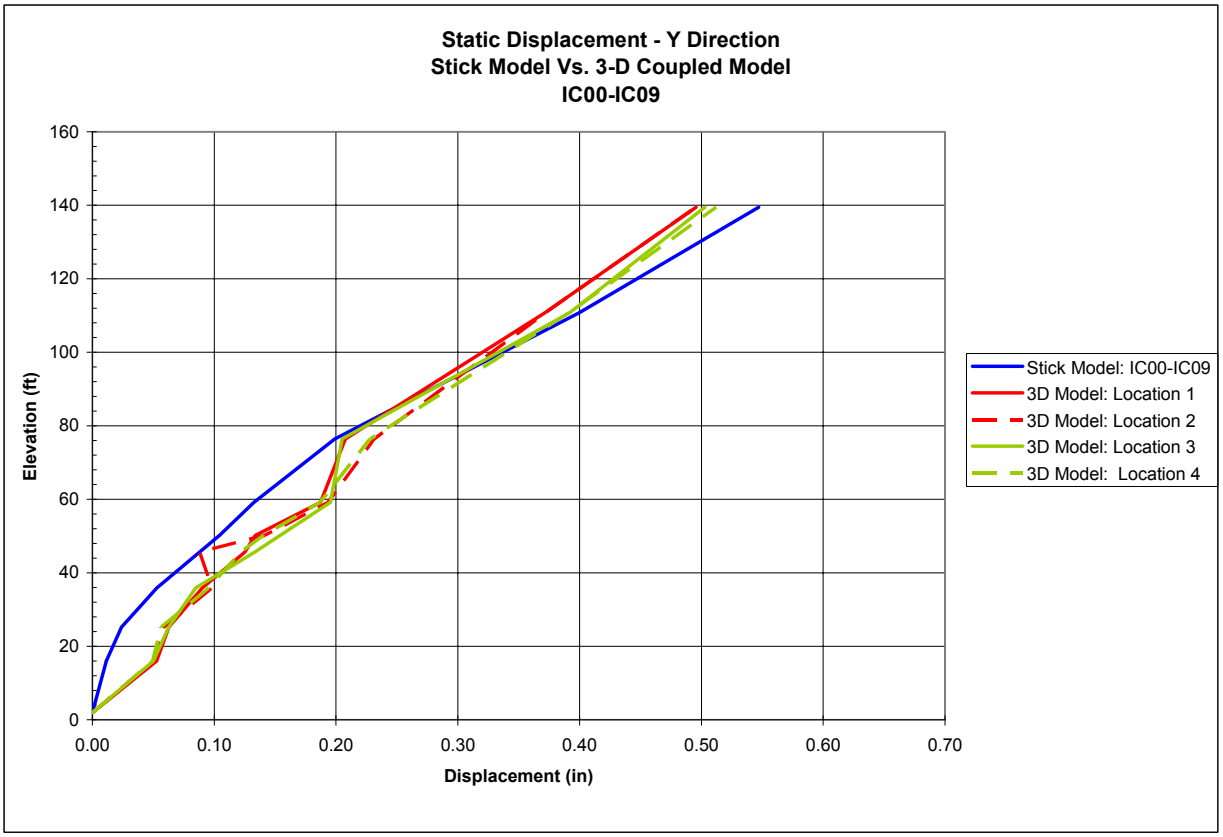

Figure 5.3.5.1-3 Horizontal Displacement Results IC00 – IC09 Under 1g Load in Horizontal Direction (Y)

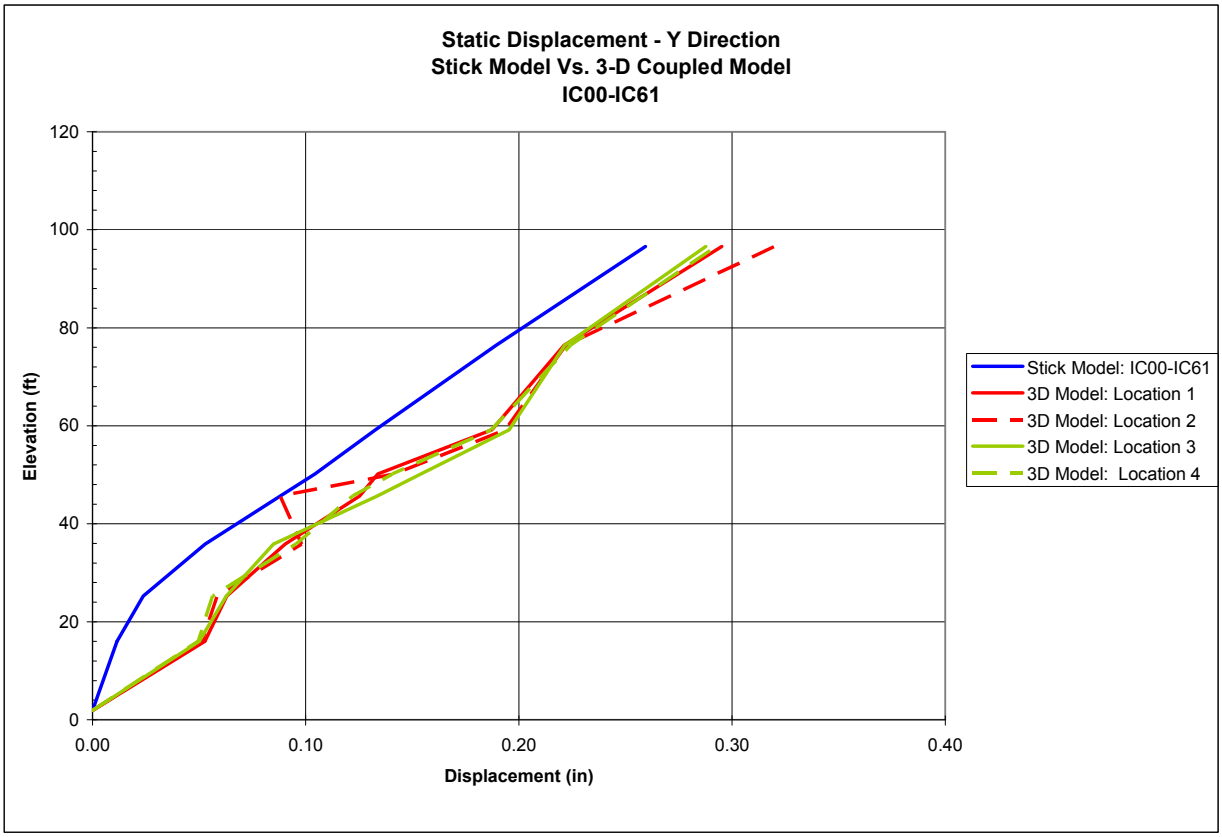

Figure 5.3.5.1-4 Horizontal Displacement Results IC00 – IC61 Under 1g Load in Horizontal Direction (Y)

5.3.5.2 Modal Analysis

A modal analysis using ANSYS is performed on the 3-D detailed FE model. The dominant natural frequencies and effective masses obtained from these analyses are shown in the following tables (Table 5.3.5.2-1 through Table 5.3.5.2-3):

Table 5.3.5.2-1 Modal Properties of First 3 Modes, X-Direction (NS)

MODE	FREQUENCY (HZ)	PERIOD (sec)	PARTIC.FACTOR	EFFECTIVE MASS (lbs*sec^2/ft)
1	5.90	0.169	199.81	39926.0
5	7.91	0.126	226.04	51094.7
20	11.14	0.0898	-174.96	30611.3

Table 5.3.5.2-2 Modal Properties of First 3 Modes, Y-Direction (EW)

MODE	FREQUENCY (HZ)	PERIOD (sec)	PARTIC.FACTOR	EFFECTIVE MASS (lbs*sec^2/ft)
1	5.90	0.169	199.81	39926.0
5	7.91	0.126	226.04	51094.7
20	11.14	0.0898	-174.96	30611.3

Table 5.3.5.2-3 Modal Properties of First 3 Modes, Z-Direction (Vertical)

MODE	FREQUENCY (HZ)	PERIOD (sec)	PARTIC.FACTOR	EFFECTIVE MASS (lbs*sec2/ft)
29	13.51	0.0740	143.21	20508.4
42	17.00	0.0588	169.96	28887.0
49	18.67	0.0536	110.06	12112.4

A SSI analysis is performed on the R/B complex SASSI model with the model resting on the surface of a half-space with hard-rock properties. This is to simulate the response of the structure under a fixed base condition. Transfer functions at selected nodes are obtained from the SSI analysis and are presented in Figures 5.3.5.2-1 through 5.3.5.2-3. These figures indicate amplification spikes at or close to the dominant frequency points shown in Tables 5.3.5.2-1 through 5.3.5.2-3. This indicates that the stick model captures the structure response to dynamic loads in all directions properly.

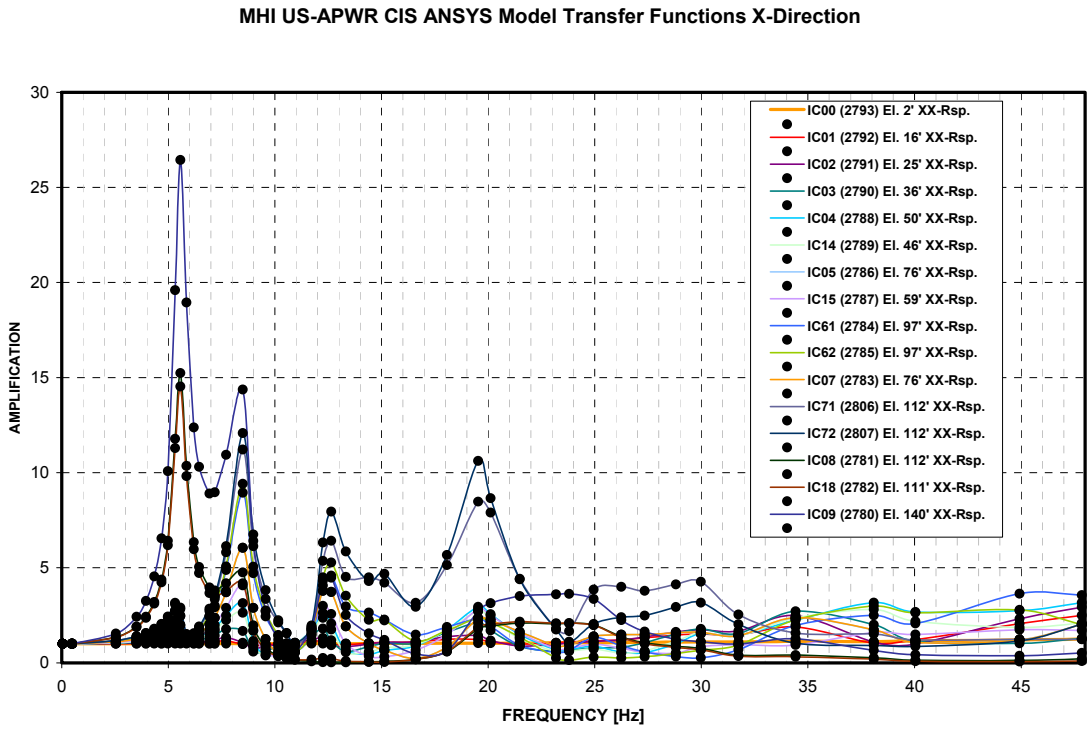

Figure 5.3.5.2-1 CIS Lumped Mass Stick Model Transfer Functions, X-Direction

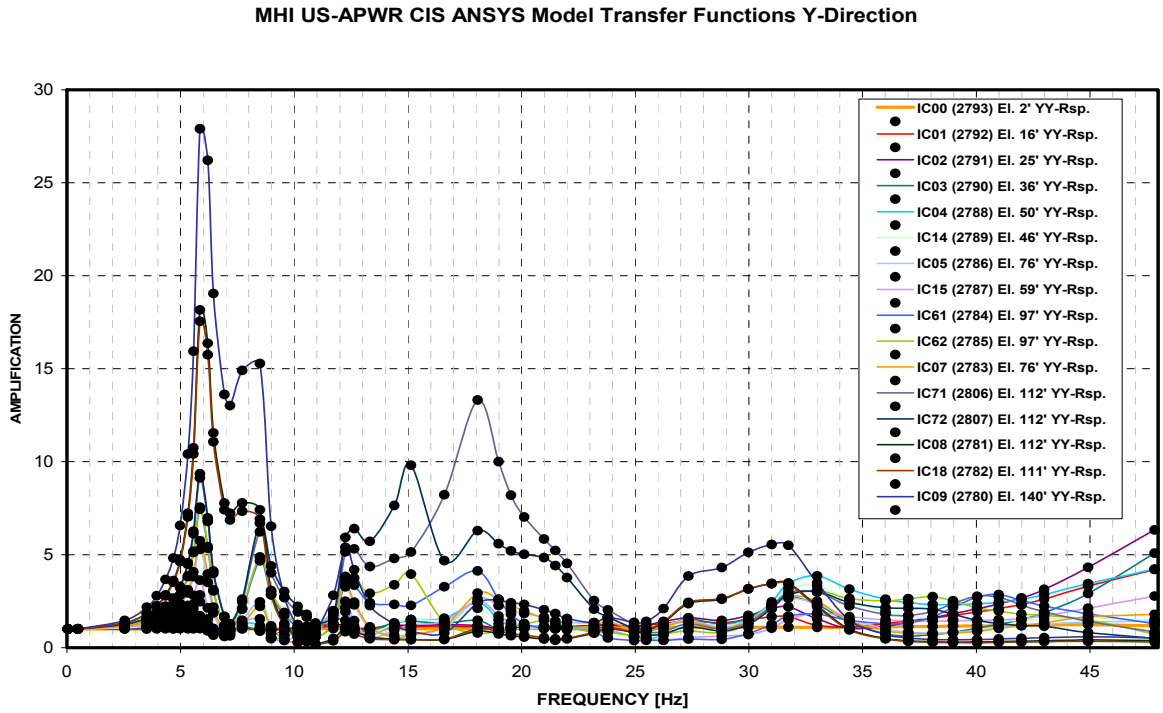

Figure 5.3.5.2-2 CIS Lumped Mass Stick Model Transfer Functions, Y-Direction

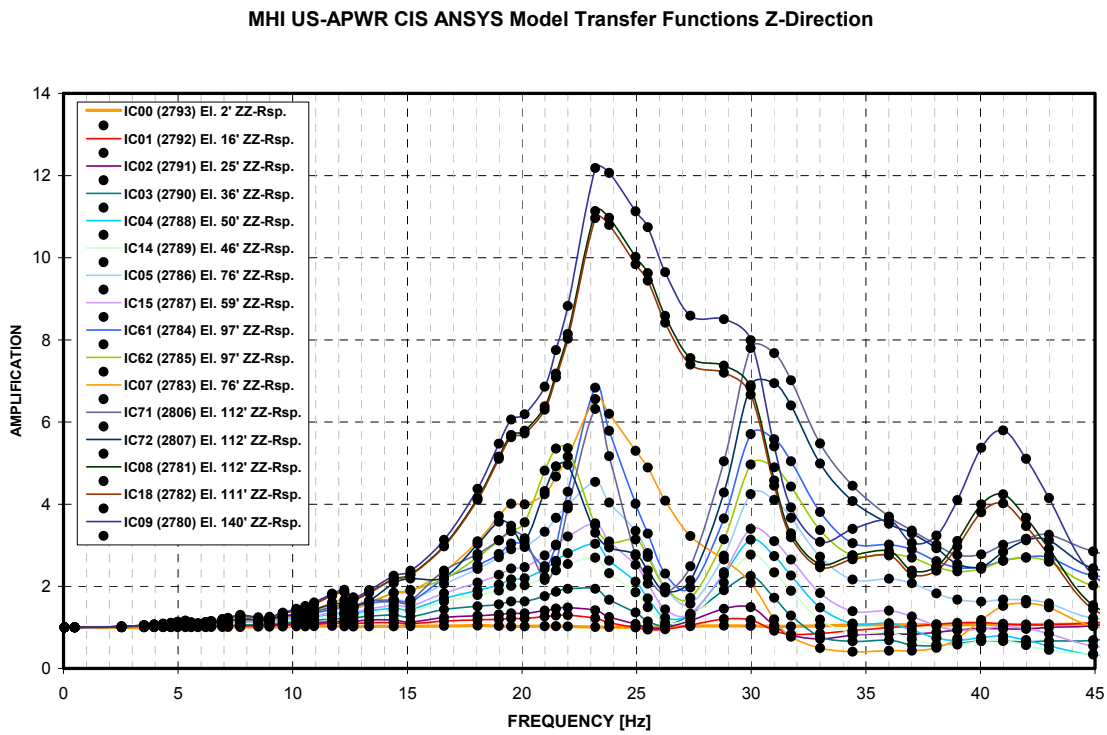

Figure 5.3.5.2-3 CIS Lumped Mass Stick Model Transfer Functions, Z-Direction

5.3.5.3 Mode-Superposition Transient Dynamic Analysis

A dynamic Time-History response analysis using modal superposition is performed on the CIS models using ANSYS, and the calculated response is compared with the results of the SASSI analyses of model resting on the surface of a rigid half-space. Acceleration response spectra (ARS) with 5 % damping are generated for each model at lumped mass locations. These acceleration response spectra indicate that the stick model captures the structure response to dynamic loads in all directions properly.

As can be seen in the following ARS generated for representative nodes IC03, IC05, IC61, and IC62, the stick model captures the main structure response to dynamic loads in all directions (Figure 5.3.5.3-1 through 5.3.5.3-12). Note that several node points in the FE model, which represent the stick model lumped mass, are selected to compare against the respective stick model's lumped mass. The figures show that the lumped-mass stick model has a limited ability to capture higher frequency local responses at all locations of the CIS. SSI analyses will be performed on a 3-D FE SASSI model of the R/B complex structures to validate that the ISRS generated from the lumped-mass-stick model envelope all of the local vibration responses.

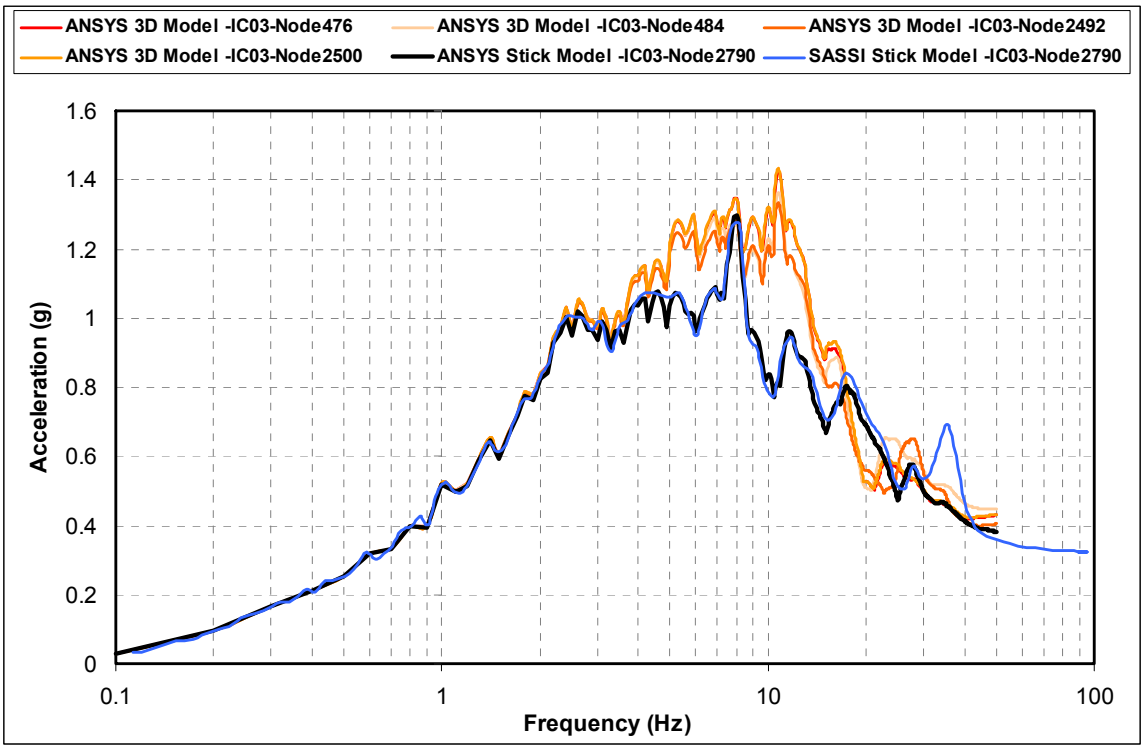

Figure 5.3.5.3-1 Acceleration Response Spectrum Node IC03, NS Direction

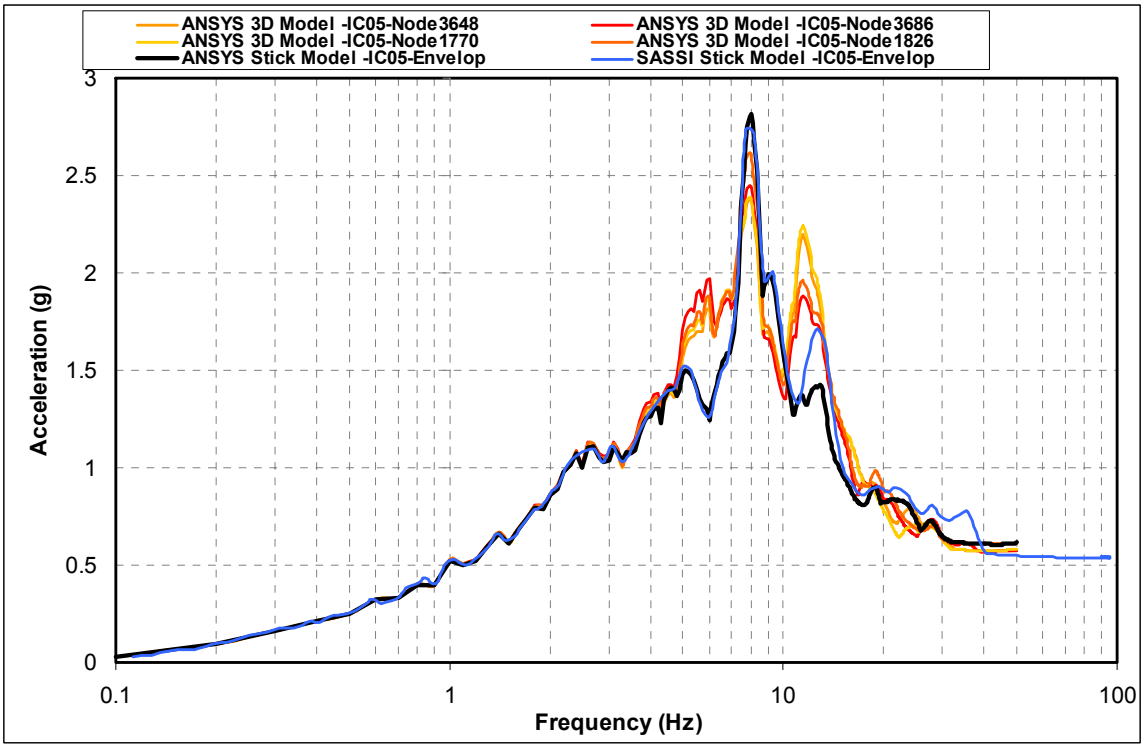

Figure 5.3.5.3-2 Acceleration Response Spectrum Node IC03, EW Direction

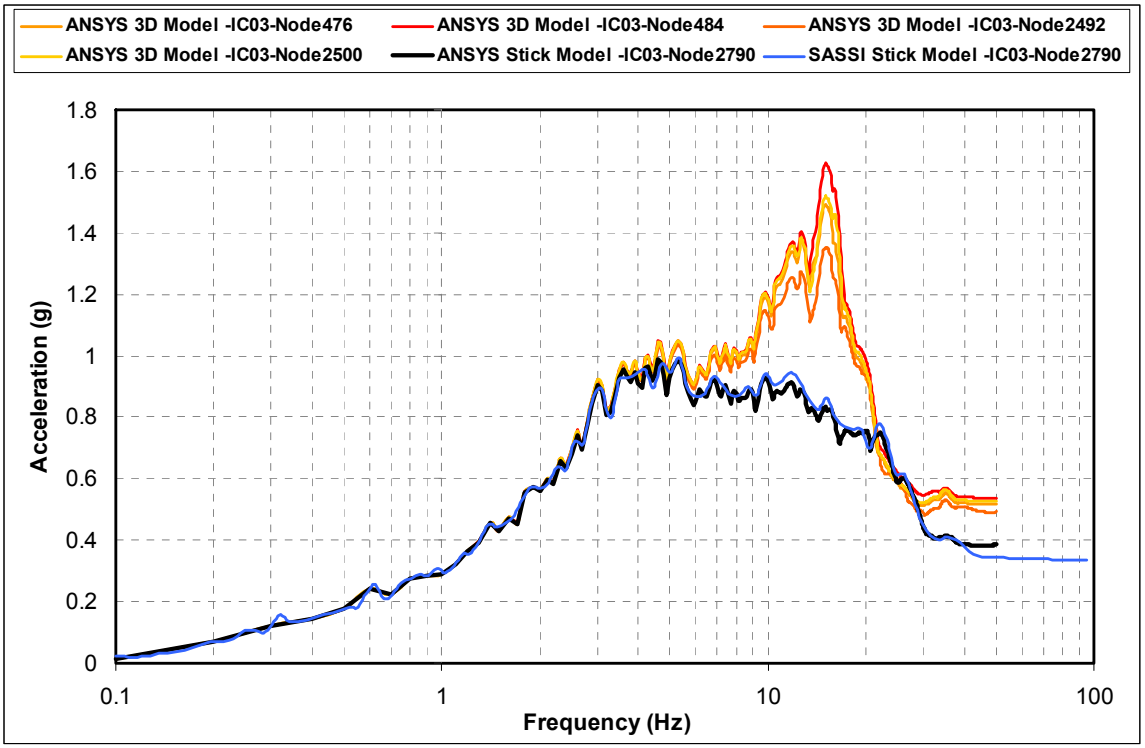

Figure 5.3.5.3-3 Acceleration Response Spectrum Node IC03, Vertical Direction

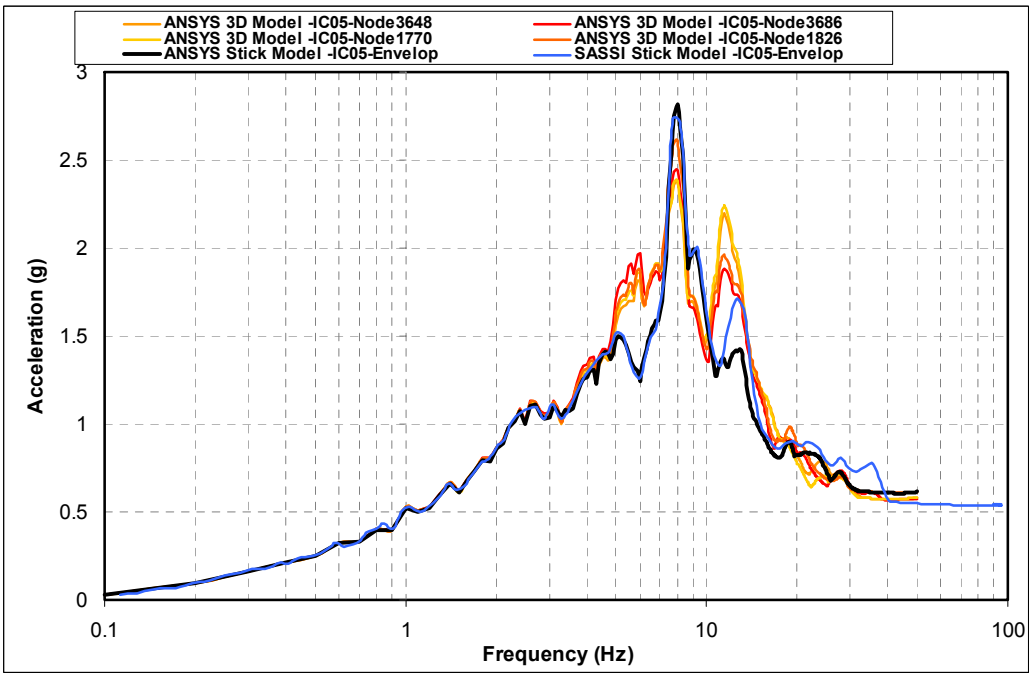

Figure 5.3.5.3-4 Acceleration Response Spectrum Node IC05, NS Direction

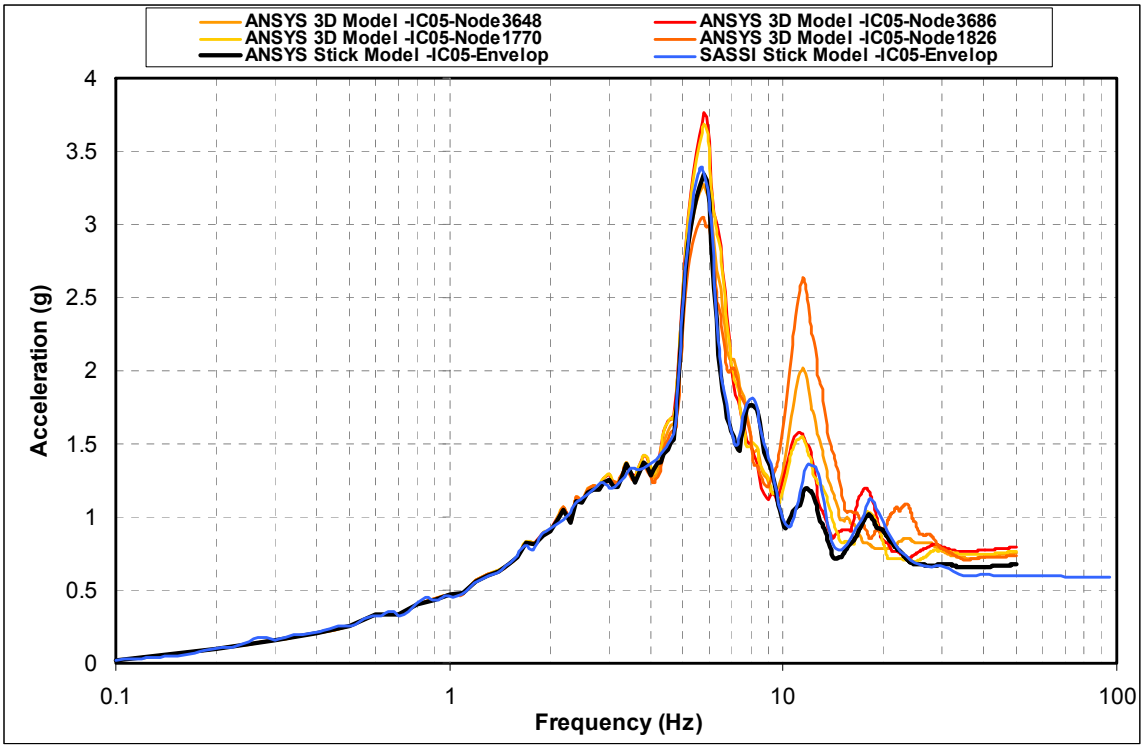

Figure 5.3.5.3-5 Acceleration Response Spectrum Node IC05, EW Direction

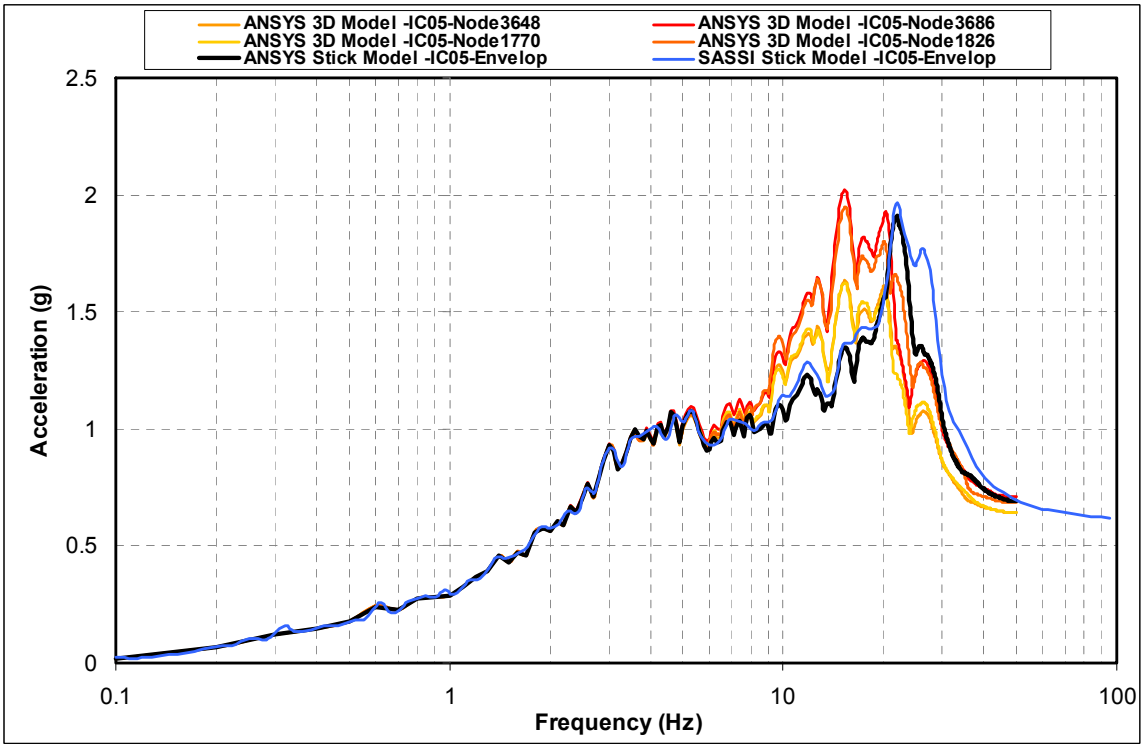

Figure 5.3.5.3-6 Acceleration Response Spectrum Node IC05, Vertical Direction

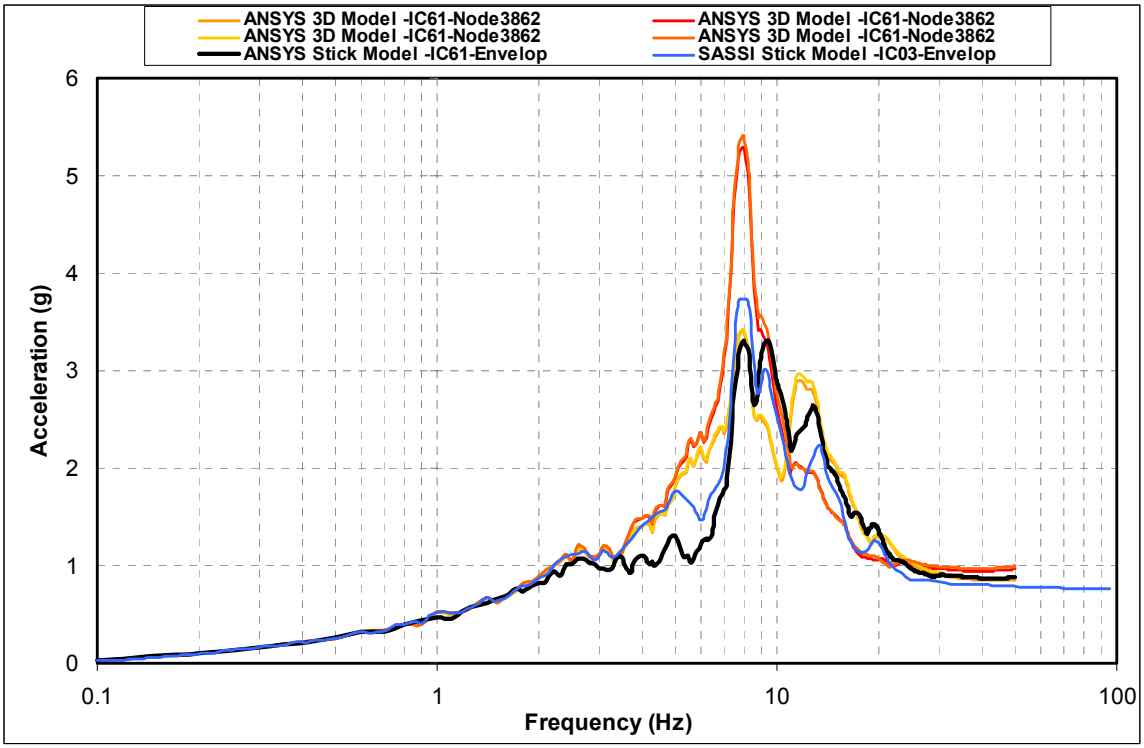

Figure 5.3.5.3-7 Acceleration Response Spectrum Node IC61, NS Direction

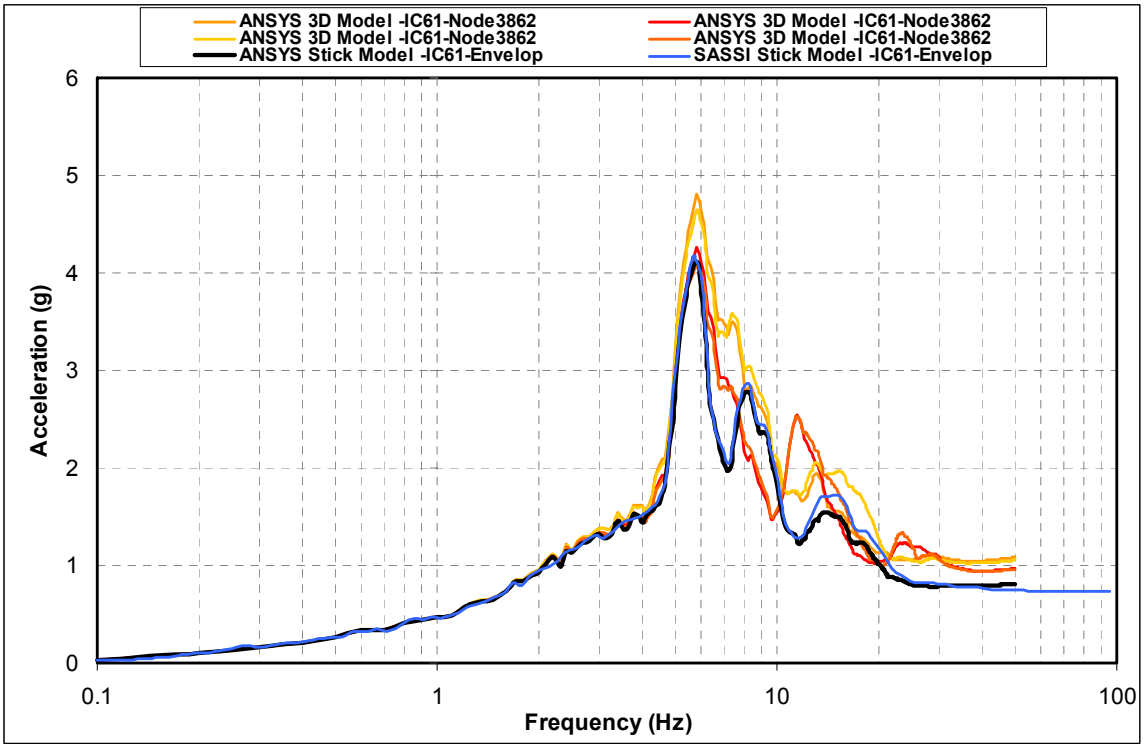

Figure 5.3.5.3-8 Acceleration Response Spectrum Node IC61, EW Direction

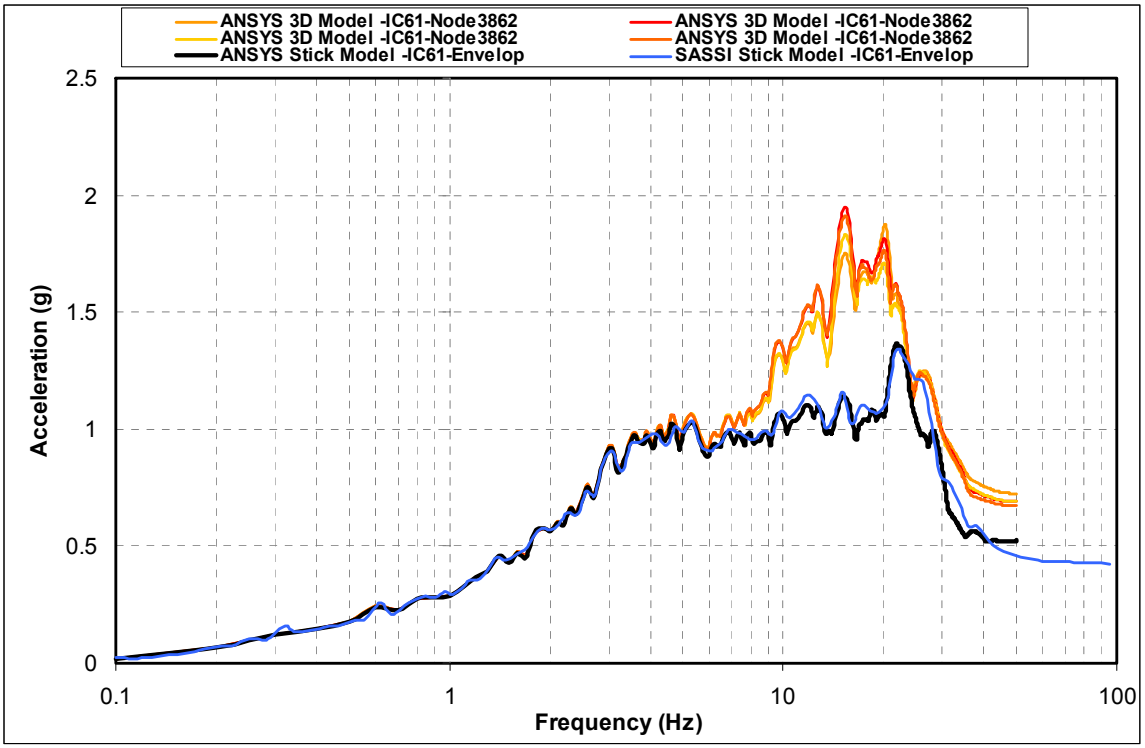

Figure 5.3.5.3-9 Acceleration Response Spectrum Node IC61, Vertical Direction

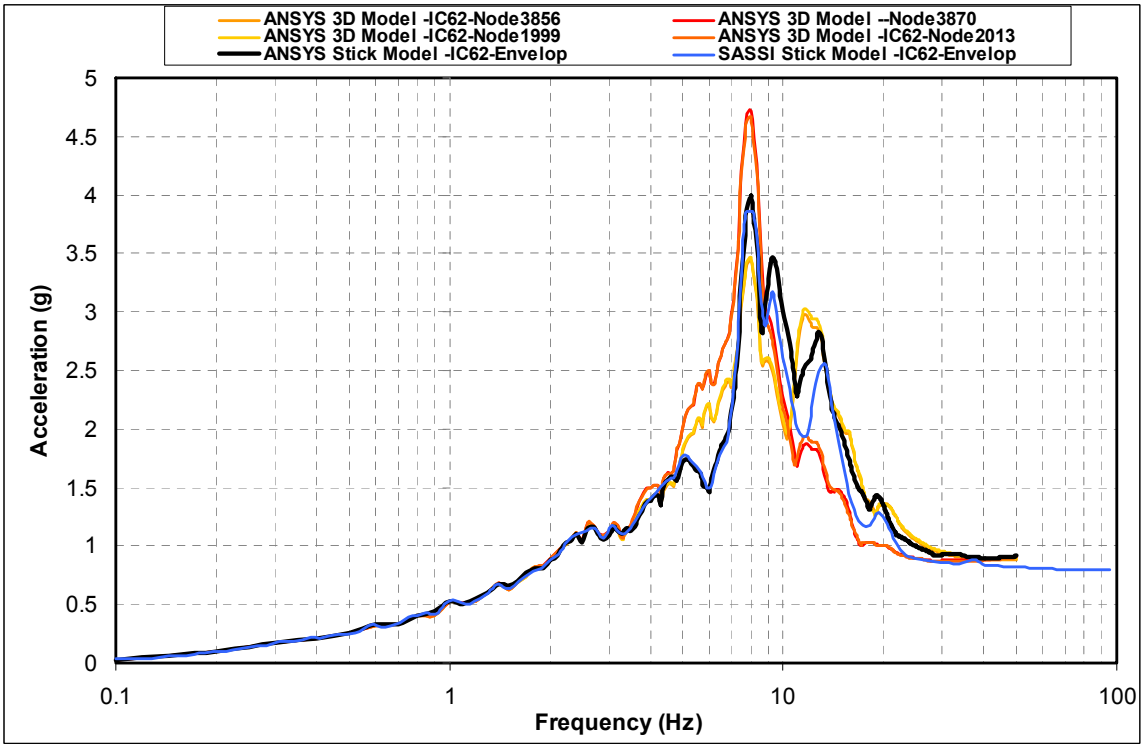

Figure 5.3.5.3-10 Acceleration Response Spectrum Node IC62, NS Direction

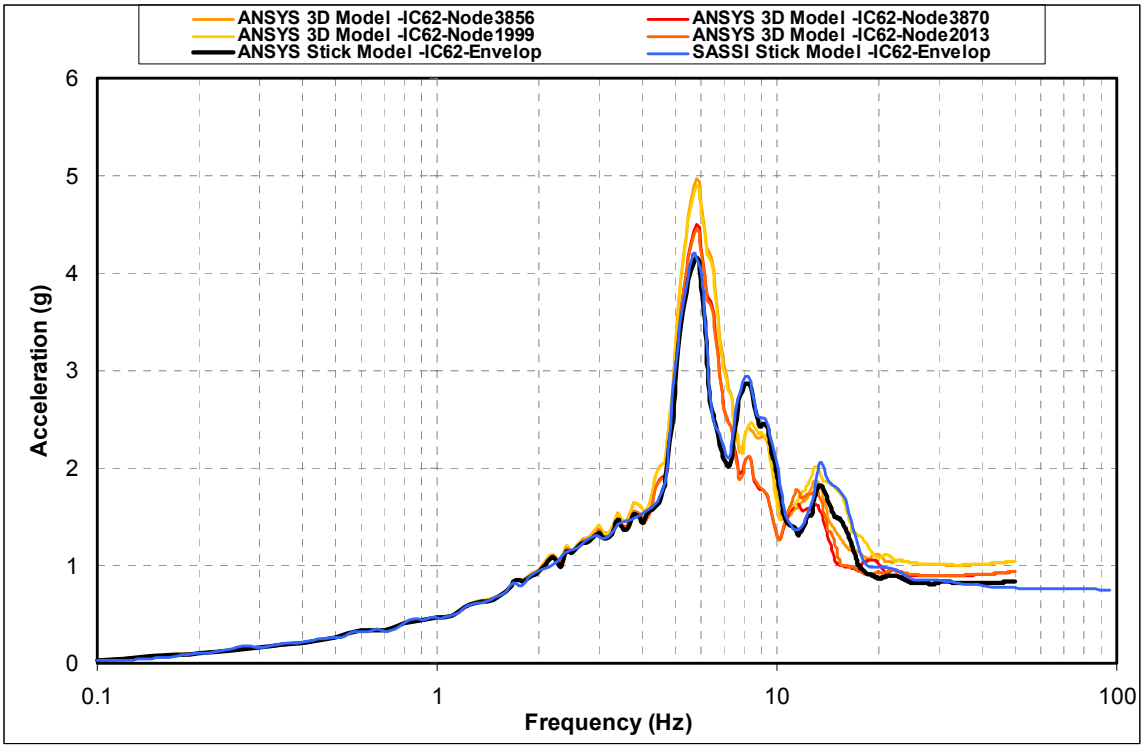

Figure 5.3.5.3-11 Acceleration Response Spectrum Node IC62, EW Direction

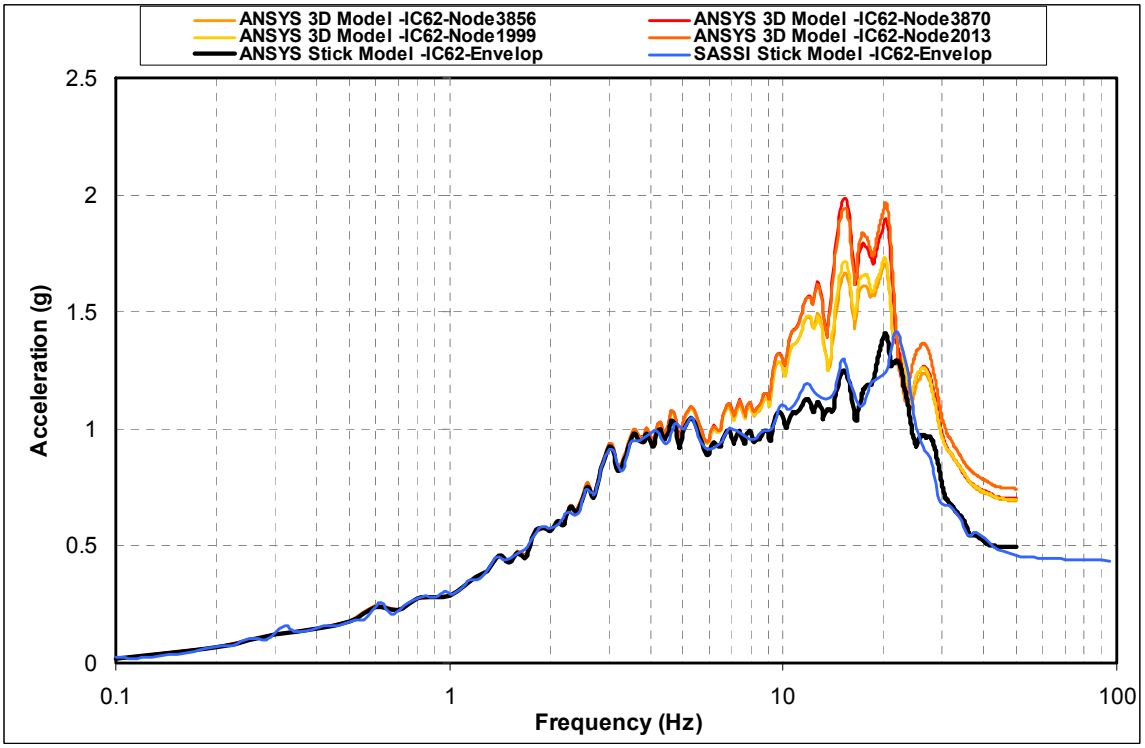

Figure 5.3.5.3-12 Acceleration Response Spectrum Node IC62, Vertical Direction