EPRI AP1000 NI Model Studies on Seismic Structure-Soil-Structure-Interaction (SSSI) Effects for Hypothetical Site Condition That Includes 40 ft Backfill Soil Over A Hard Rock Foundation

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Disclaimer: The SSI models used herein are not the actual AP1000 SSI models used for seismic design. The NI model is a modified AP1000 stick model by EPRI that has significantly larger mass excentricities than actual AP1000 model, and the Annex Building model is a generic AB structure model and not the actual AB structure of the AP1000 NPP layout.

ABSTRACT

The paper presents the results of a research study on seismic structure-soil-structure interaction (SSSI) including the effects of motion incoherency. Specifically, the seismic SSSI between the AP1000 NI complex (EPRI AP1000 stick model [1]) and a generic adjacent Annex Building (AB) structure are investigated. The AB structure is assumed to be a light and stiff structure with a mass of only fraction of the mass of the AP1000 NI structures (basemat mats not included). To investigate the SSSI effects three computational SSI models were employed: 1) NI stick model, 2) Isolated AB stick model and 3) Coupled NI-AB stick model. Each of these SSI models was run separately and the SSI results were compared. It should be noted that the EPRI AP1000 stick foundation size was modified from 150ft x 150ft to 160ft x 255ft to better reflect the actual foundation size of the AP1000 NI complex. The seismic input is defined by a site specific UHRS input that is the same as that used in the EPRI studies [1] anchored to a ZPGA of 0.30g. The site-specific UHRS input was defined at the top of the rock foundation. The NI is assumed to be founded on a rock foundation and the AB is at grade level with 40 ft of uniform backfill soil that sits on the rock foundation. Coherent vs. incoherent SSI analyses are performed for the isolated and coupled structures. Comparative results show the effects of motion incoherency on i) in-structure response spectra (ISRS), and ii) structural forces and moments in sticks.

CASE STUDIES

The paper investigates the effects of the seismic structure-soil-structure interaction (SSSI) for the EPRI AP1000 NI complex and Annex Building (AB). The AB structure is assumed to be a light and stiff structure with a mass of only fraction of the mass of the AP1000 NI structures (basemat mats not included).

To investigate the SSSI effects three computational SSI models were employed: 1) NI stick model, 2) Isolated AB stick model and 3) Coupled NI-AB stick model. Each of these SSI models was run separately and the SSSI results were compared. It should be noted that the EPRI AP1000 stick foundation size was modified from 150ft x 150ft to 160ft x 255ft to better reflect the actual foundation size of the AP1000 NI complex.

The soil site condition was considered to be a two layer soil deposit, namely, a uniform top soil layer on a hard-rock foundation. The uniform top soil layer is a 40 ft backfill soil layer that has a shear wave velocity Vs = 1,000 fps. The hard-rock foundation below 40ft depth has a shear wave velocity Vs = 8,000 fps. The AP1000 NI complex is fully embedded in the backfill layer and sits on the hard-rock foundation (at Elevation 60 ft). The AB structure has no embedment and sits on the backfill layer at the ground surface level nearby the NI complex (at Elevation 100 ft). Figure 1 shows the NI model and the coupled NI-AB model.

The seismic input is defined by a site specific high-frequency UHRS input that is the same as that used in the EPRI studies [1] anchored to a ZPA of 0.30g. The site-specific UHS input was defined at the top of the rock foundation.

INCOHERENT SSI ANALYSIS METHODOLOGY

Coherent and incoherent SSI analyses were performed using the ACS SASSI Version 2.3.0 software [2]. The incoherent SSI analyses are performed using Stochastic Simulation approach that was validated by EPRI [1]. The Stochastic Simulation approach (called SASSI-Simulation in the EPRI studies) is similar to the Monte Carlo simulation used for probabilistic analyses. The theoretical basis of the Stochastic Simulation approach is described in References 1 and 3. The (mean) incoherent SSI response is computed as the average of the results computed from a set of statistical SSI analyses using random field realizations of the incoherent free-field motion input. Besides the mean incoherent SSI responses, the SSI Stochastic Simulation approach could provide insightful information on the scatter of the SSI responses that can be useful for both design and probabilistic risk assessment studies. The Stochastic Simulation approach is applicable to both simple stick models with rigid mat foundations and complex FE models with flexible mat foundations.

It should be noted that by default the Stochastic Simulation approach includes all the extracted coherency matrix eigenvectors (also called incoherent spatial modes) for computing incoherent SSI response. This is very important for the high frequency range that the participation of higher-order incoherent spatial modes is large, especially in vertical direction and flexible foundation mats. The inclusion of all incoherent spatial also produces an “exact” recovery of the free-field coherency matrix at the SSI interaction nodes that is a key input quantity for the incoherent SSI analysis. The accuracy of coherency function recovery can be checked for each SSI frequency.

The site-specific incoherent SSI analyses were performed using the 2007 Abrahamson hard-rock plane-wave coherency functions provided by EPRI [4]. For this research investigation we used only 8 stochastic simulations to compute the mean incoherent ISRS and structural forces. As shown in the EPRI validation studies [1], a reduced number of simulations as low as 5 simulations are sufficient to get reasonably accurate mean incoherent ISRS and structural force estimates. Thus, it was considered that the use of a set of 8 simulations provides a reasonable accuracy for the purpose of the research study.

RESULTS

The results include both coherent and incoherent analysis results for the three SSI models.

Figures 2 and 3 show results based on the isolated AB SSI model. The two figures show plots of the computed and interpolated acceleration transfer functions (ATF) and the 5% damping ISRS in Y (transverse) direction at the AB basemat center (Elevation 100 ft) and at a higher elevation (Elevation 154 ft). Two site condition cases were considered for AB for comparison puposes: i) AB founded on the soil layer and ii) AB founded directly on the hard-rock foundation considered going up to the ground surface (no soil layer). The result comparisons indicate significant SSI effects. These SSI effects also include the soil motion amplification from the baserock input motion to the ground surface.

From Figure 2, it should be noted that for the hard-rock foundation, the coherent ATF have the value of unity at the basemat center location since there is no motion amplification through the hard-rock foundation. The motion incoherency effect reduces the ATF amplitudes above 8-10 Hz. As expected, for the backfill soil layer case, Figure 2 shows a significant amplification of the soil motion at the ground surface.

Figure 3 shows ISRS results at the AB basemat corner computed for the two site condition cases. Since the UHS input is a high-frequency input, the high-frequency range ISRS amplitudes are signficantly higher than the mid frequency range ISRS amplitudes. The higher-order vibration modes of the backfill soil are excited by the UHS input, as shown in Figure 3, which is especially visible for the basemat center location.

Figures 4 through 7 show the acceleration transfer function (ATF) and the ISRS results for the three SSI models, isolated AB, NI and coupled NI-AB. Figures 4 shows computed and interpolated ATF for the isolated AB model and the coupled NI-AB model at the AB basemat structure. Figures 4 shows the SSSI effects are significant for the AB structure. The AB structure behaves differently due to the presence of the NI complex (stiff and founded on the hard-rock foundation) that constraints its vibration on the soil foundation and also changes the shear wave propagation pattern around the AB foundation.

Figure 5 shows the main ISRS spectral peak at 5.0 Hz that corresponds to the global SSI mode of AB structure on the soil foundation is “vanished” due to the dynamic coupling with the NI complex. Instead, there are new ISRS peaks at higher frequencies. These peaks are produced by the dynamic coupling with the NI complex that excites higher frequency modes of the AB structure. At the higher elevations in the AB structure, the ISRS computed using couple NI-AB model could be larger due to the higher-order modes that are excited due to the nearby presence of the NI complex. It should be noted that the global SSI vibration mode of AB structure on the foundation soil that is dominant at 5.0 Hz for the isolated AB model is apparently not excited or only very minimally in the coupled NI-AB model.

Figure 6 and 7 shows the computed 5% damping ISRS for the NI model and the coupled NI-AB model at the top of the SCV (steel containment vessel) stick at Elevation 282 ft and the ASB stick at Elevation 333 ft. The ISRS computed in the X and Y directions are shown. It should be noted that the isolated NI model provides typically slightly larger ISRS than the coupled NI-AB model.

Figure 8 shows the coherent and incoherent shear forces in the AB structure computed using the isolated AB model and the coupled NI-AB model. It should be noted that effects of the dynamic coupling between NI and AB are to reduce significantly the base shear forces in the AB structure. The shape of the AB structure shear force diagram indicates that the global translational SSI mode is practically not excited in the coupled NI-AB model.

Figure 9 shows the shear forces in the three NI structures, ASB, CIS and SCV. It should be noted that the effects of dynamic coupling combined with incoherency effects slightly reduces the shear forces in the three structures. Both the effects of SSSI and incoherency are very modest for the shear forces in the NI structures.

CONCLUSIONS

For the investigated case study, the effects of SSSI are relatively minor for the NI complex structures, but significant for the AB structure. Specifically, for both coherent and incoherent inputs, the SSSI effects reduce largely the shear forces in the AB structure and almost negligibly in the NI complex structures. The current seismic structural design approach that assumes isolated SSI models used for the NI complex and the AB structure appears to be a conservative approach.

REFERENCES

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4. Abrahamson, N. 2007. "Effects of Seismic Motion Incoherency Effects" Palo Alto, CA, EPRI TR-1015111

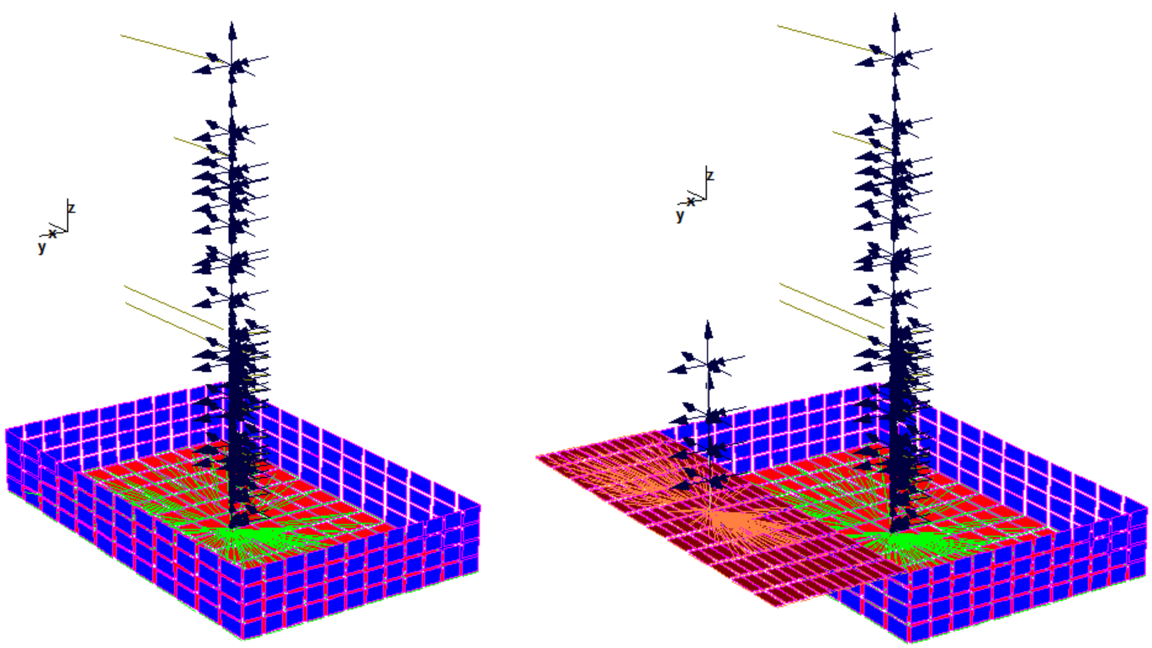

Figure 1 The NI Model (left) and Coupled NI-AB Model (right)

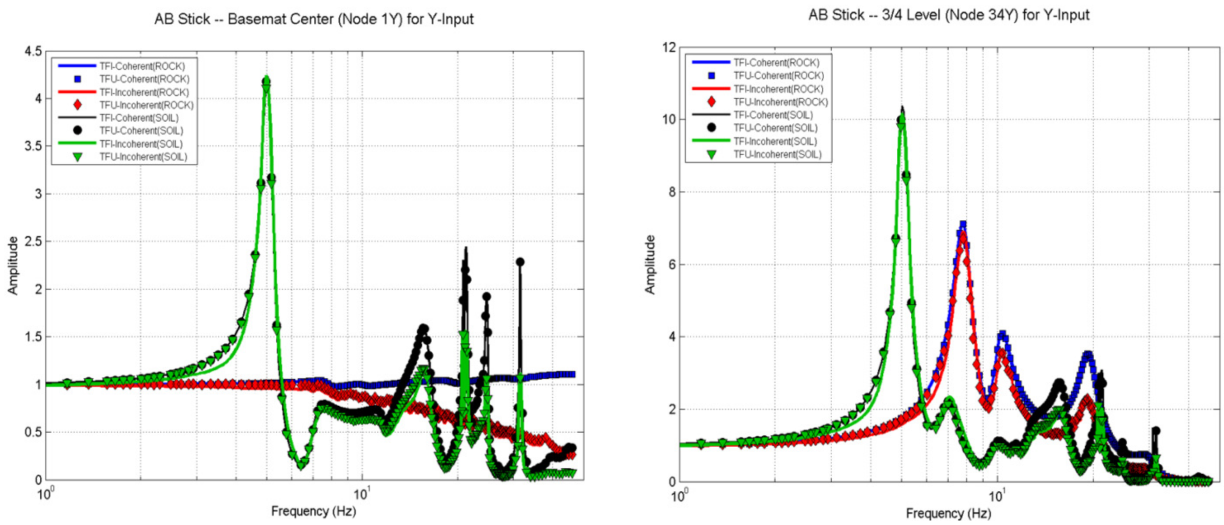

Figure 2 Comparative ATF for Isolated AB Model in Y-Direction Assuming AB Founded on Backfill Soil and Hard-Rock; Basemat Center (left), Elevation 100 ft and Higher Level, Elevation 154 ft (right)

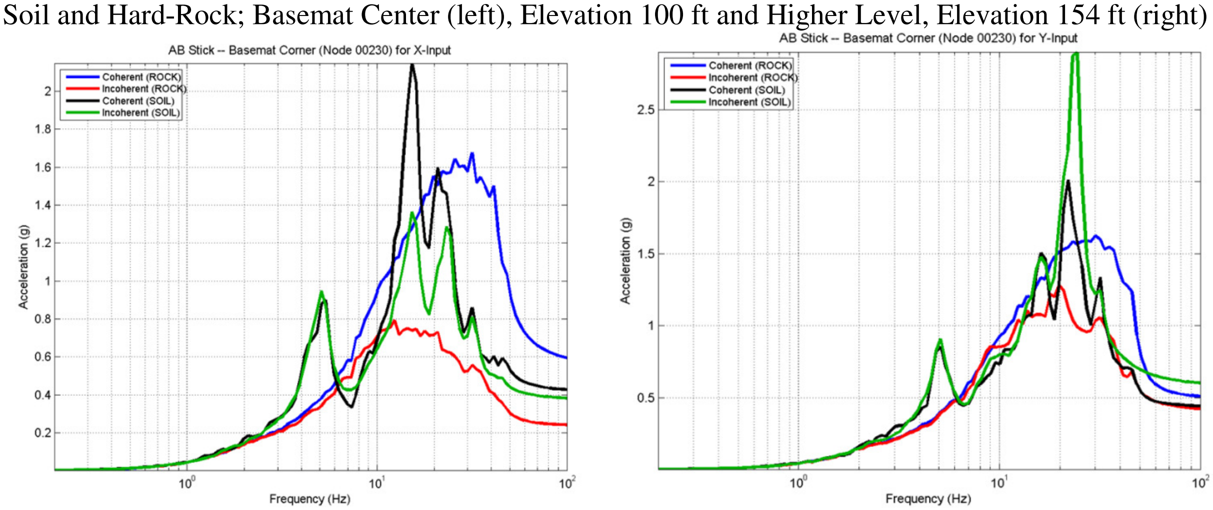

Figure 3 Comparative 5% Damping ISRS for Isolated AB Model in X (left) and Y (right) Directions at AB Basemat Corner (Elevation 100 ft), Assuming AB Founded on Backfill Soil and Hard-Rock

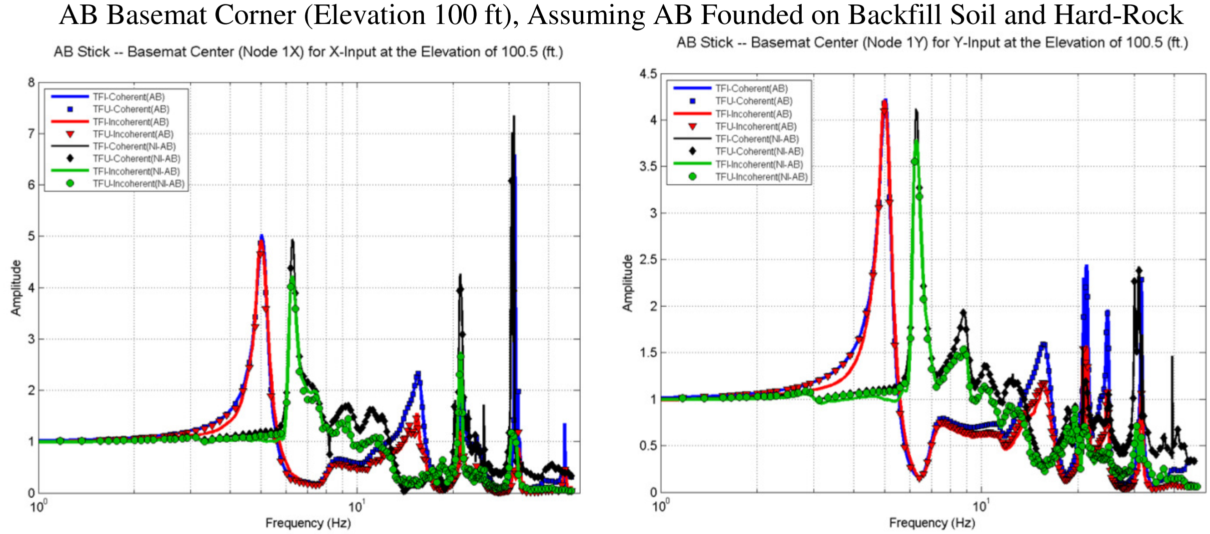

Figure 4 Comparative ATF for Isolated AB Model and Coupled NI-AB Model in X (left) and Y (right) Direction at AB Basemat Center, Elevation 100 ft

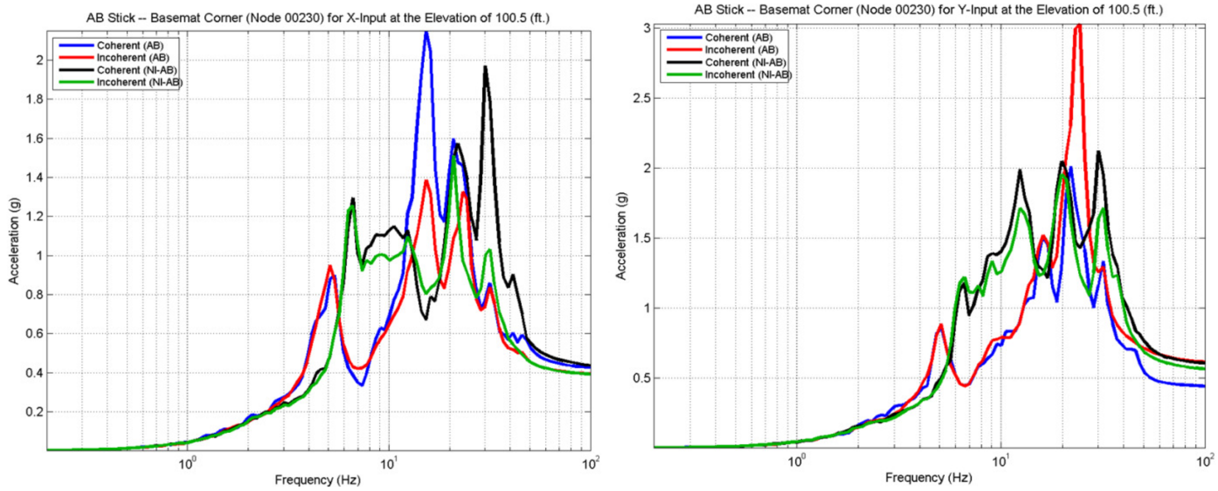

Figure 5 Comparative 5% Damping ISRS for Isolated AB Model and NI-AB Coupled Model in X (left) and Y (right) Directions at Basemat Corner, Elevation 100 ft

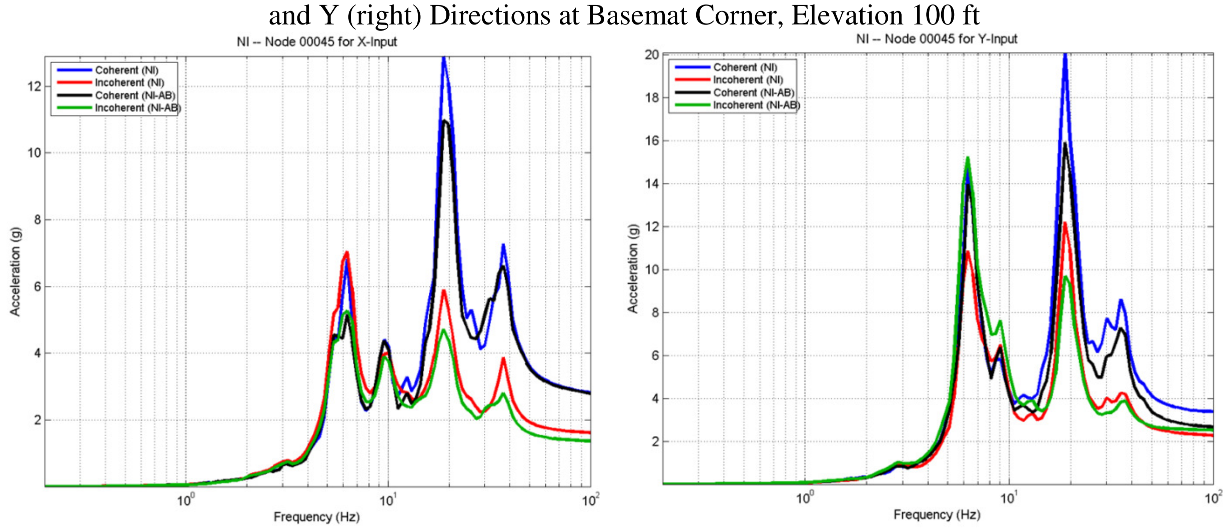

Figure 6 Comparative 5% Damping ISRS for NI Model and Coupled NI-AB Model in X (left) and Y (right) Directions at Top of SCV Stick at Elevation 282 ft

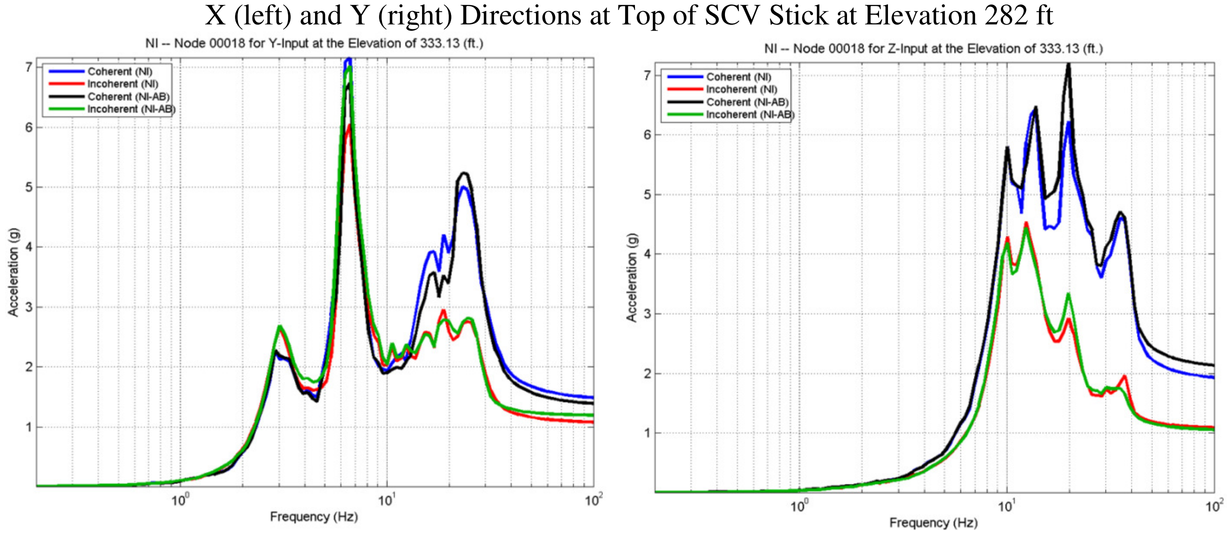

Figure 7 Comparative 5% Damping ISRS for NI Model and Coupled NI-AB Model in X (left) and Y (right) Directions at Top of ASB Stick at Elevation 333 ft

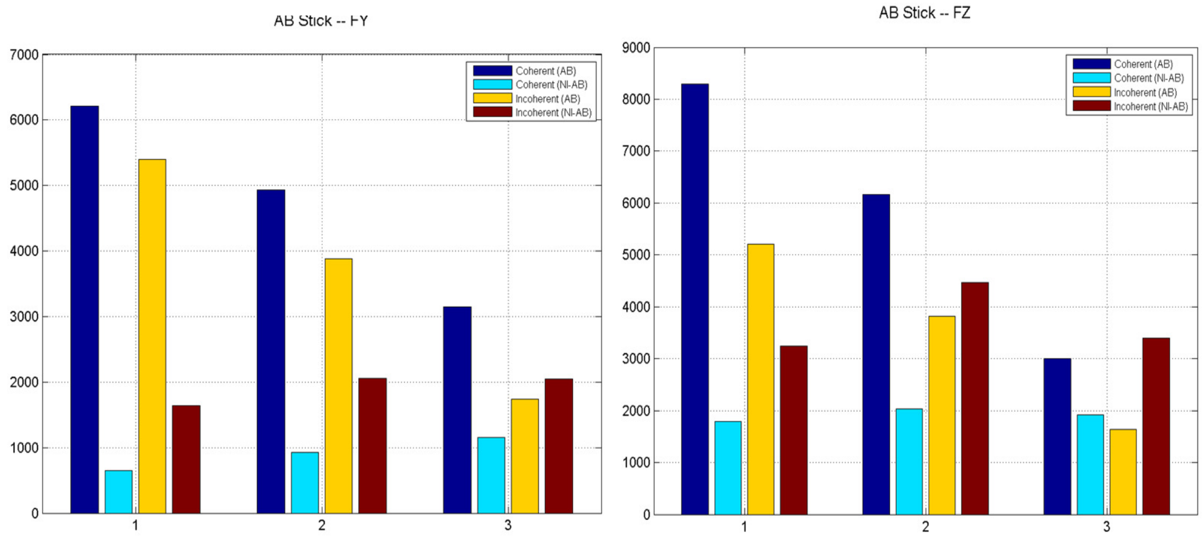

Figure 8 Shear Forces (kips) in AB Structure for the X-direction (right) and Y-direction for the Isolated AB Model and the Coupled NI-AB Model (Element #1 is at Base, Element #3 is close to Top)

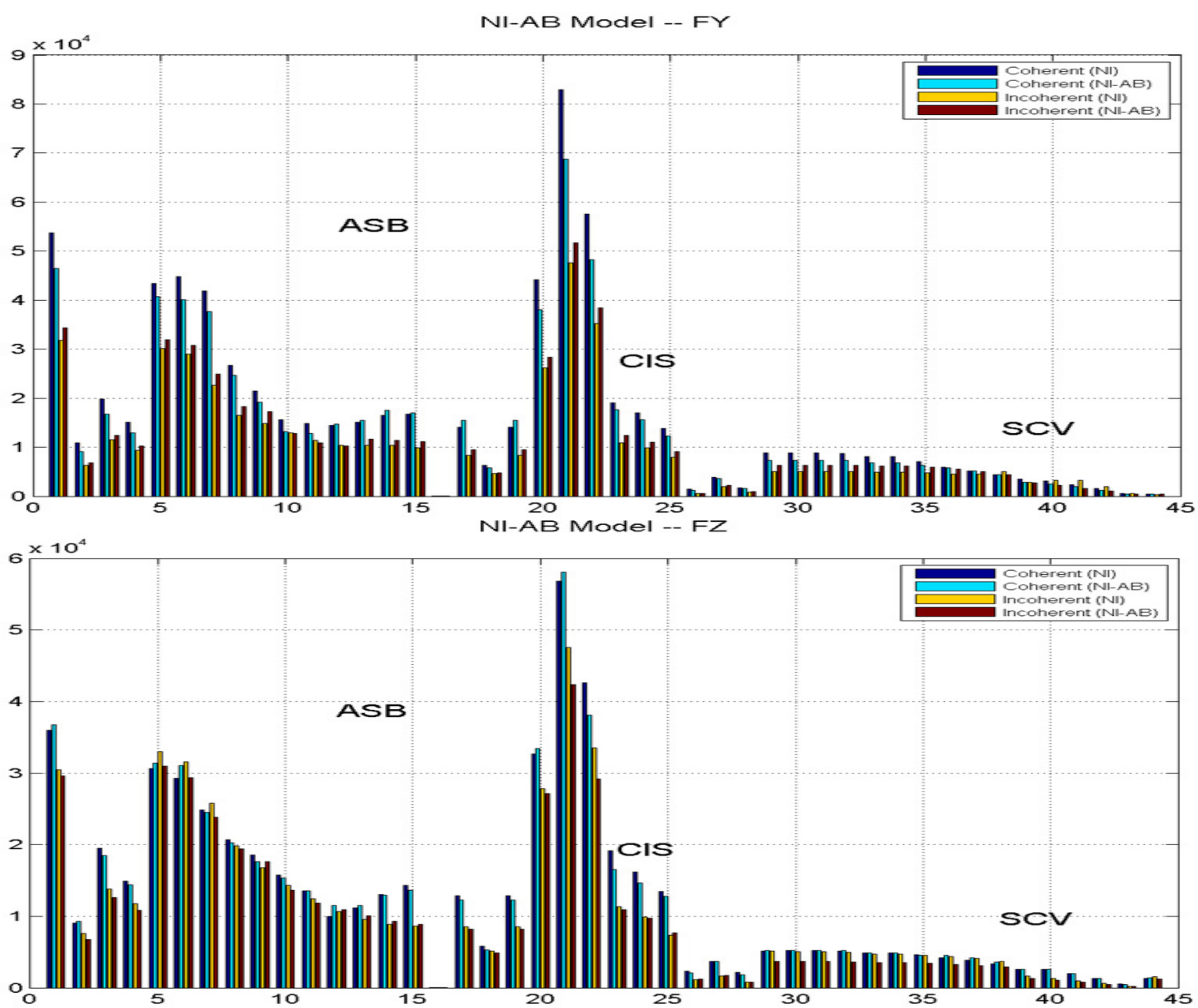

Figure 9 Shear Forces (kips) in NI Structures (ASB, CIS, SCV) for X-direction (upper) and Y-direction (lower) for NI Model and Coupled NI-AB Model