Transactions, **SMiRT-25**
Charlotte, NC, USA, August 4-9, 2019
Division V

REDUCTION IN SEISMIC DEMAND BY USING EQUIPMENT-STRUCTURE INTERACTION

Ankit R. Dubey[1], Saran Bodda[1], Abhinav Gupta[2], Joe Vasquez[3], Divakar Bhargava[3]

[1] Doctoral Student, North Carolina State University, Raleigh, NC, USA (adubey@ncsu.edu)
[2] Director, CNEFS, North Carolina State University, Raleigh, NC, USA (agupta1@ncsu.edu)
[3] Dominion Energy, Richmond, VA, USA (joe.vasquez@dominionenergy.com)

ABSTRACT

The In-Structure Response Spectra (ISRS) are commonly generated by neglecting the interaction between structure (primary system) and the equipment (secondary system) mounted on the floors due to significant differences in their structural characteristics that can often lead to numerical instability in the analysis of combined coupled primary-secondary systems. However, studies have shown that this simplification may lead to conservative results when equipment is tuned to one of the modes of the structure (EPRI, 2017; Gupta & Gupta, 1995). A significant reduction in the peak values of ISRS can be achieved when considering the interaction between the primary system and secondary system. In this paper, we present the results from a coupled equipment structure interaction (ESI) study of an Auxiliary Building in a nuclear power plant.

INTRODUCTION

In response to the accident at the Fukushima Daiichi nuclear power plants following the 2011 Great Tohoku Earthquake and subsequent tsunami, the Nuclear Regulatory Commission (NRC) established a Near Term Task Force (NTTF). Acting on the recommendations of the NTTF, NRC requested the licensees and holders of construction permit under 10 CFR 50 (Code of Federal Regulations, Title 10, Part 50), to reevaluate the seismic hazard at their sites.

The calculation of the site specific ground motion response spectra (GMRS) for the nuclear plants in the central and eastern United States showed that the site GMRS exceeded the existing plant's safe shutdown earthquake in some cases. The plants have used GMRS to conduct seismic probabilistic risk assessments (SPRA) for demonstrating acceptable level of risk.

As a part of these SPRA studies, complete soil-structure models are typically used in conjunction with detailed structural models of the building to conduct seismic analyses with the foundation input response spectrum (FIRS) as the input motion. These analyses help generate the in-structure response spectra (ISRS) at various elevations and provide the seismic demands on the structure and equipment. The ISRS are commonly generated by neglecting the interaction between structure (primary system) and the mounted equipment (secondary system) on the floors. However, studies have shown that this simplification may lead to conservative results when equipment is tuned to one of the modes of the structure (EPRI, 2017; Gupta & Gupta, 1995).

This paper presents the details of the Auxiliary Building model in a nuclear power plant, its dynamic characteristics, as well as the results from the equipment-structure interaction (ESI) study. It is

shown that a noticeable reduction in the ISRS amplitude is attained while considering the interaction between the structure and the equipment. First, we present the details of the Auxiliary Building model and its dynamic characteristics.

AUXILIARY BUILDING

The Auxiliary Building (AB) at a nuclear power plant is frequently located adjacent to the reactor containment structure and houses most of the auxiliary and safety systems associated with the reactor such as radioactive waste systems, chemical and volume control systems, and emergency cooling water systems The FE model of Auxiliary Building model created using SAP2000 (CSI, 2016) is used in this study. The model comprises of AREA (ASEC), Frame (FSEC), and SOLID (Solid) sections. The AREA (ASEC) elements have been used to model walls & slabs, frame elements have been used to model beams, columns, & braces, and the SOLID elements have been used to model the soil. A three-dimensional (3D) view of the structural AB model is provided in Figure 1.

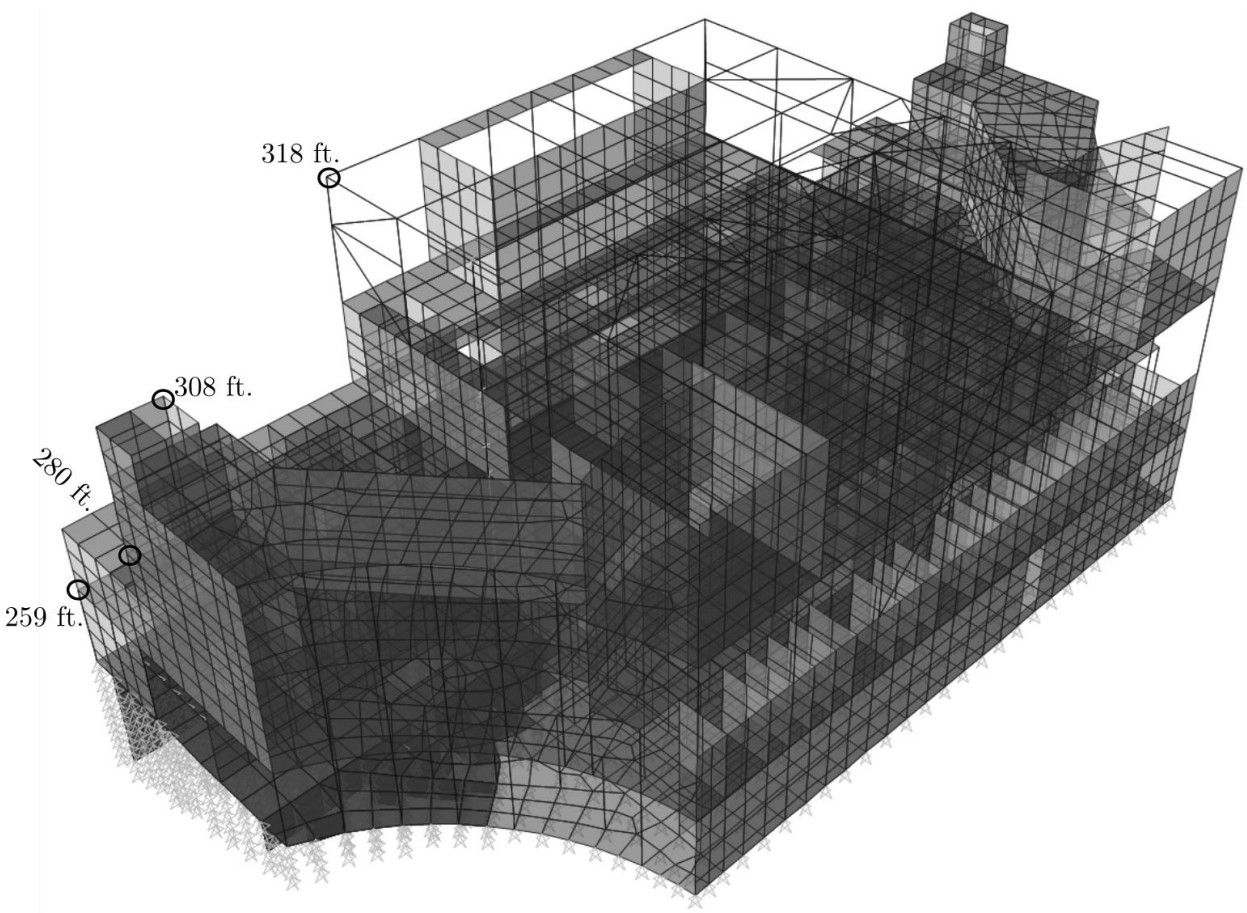

Figure 1. 3D View of the Structural AB Model

Modal Analysis of Auxiliary Building

Modal analysis of the FE model is performed to determine the dynamic characteristics of the Auxiliary Building. Table 1 represents the modal frequencies of the Auxiliary Building.

Table 1: Modal Frequencies of Auxiliary Building

Mode	1	10	20	50	100	150	200	250	300
Frequency (Hz)	2.71	8.44	11.31	17.03	25.29	30.93	35.52	41.45	45.75

In order to conduct a coupled analysis to assess the ESI effects on the ISRS, it is essential to model the equipment located in the Auxiliary Building. In the next section, we present the details used to model the equipment for the purposes of this study.

EQUIPMENT DETAILS

In this study, we consider equipment such as electrical cabinet and control panels. These equipment have relays mounted on them. The anchorage of the cabinet are qualified by using the peak values of ISRS and the relays are qualified using the in-cabinet response spectra (ICRS) which are evaluated by further amplifying the ISRS to account for the amplification due to the vibration of electrical cabinets/control panels. Many SPRA studies have shown that the excessively high peaks of ISRS due to updated hazards have rendered the cabinet anchorages or relays as non-compliant.

The effect of equipment-structure interaction in such cases has the potential to reduce the peaks of ISRS and thereby leading to a more realistic representation of seismic demand for qualification of cabinet anchorage and relays. The equipment-structure interaction depends on the weight of equipment (Gupta & Gupta, 1997; Burdisso & Singh, 1987). As described in detail in Gupta & Gupta (1997), the ratio of modal mass participation in the secondary system mode to that of the primary system mode constitutes what is termed as modal mass ratio. Relatively small values of modal mass ratios can provide significant equipment-structure interaction when the modes of the primary and secondary systems are tuned or nearly tuned. Table 2 indicates the location and weight of the equipment that are considered in this study. These are located at 259 ft floor elevation in the Auxiliary Building. Figure 2 shows the location of the equipment on this floor. Table 3 gives the location and weight of the equipment located on a different floor at elevation 280 ft. Figure 3 shows the location of the equipment at this floor.

Table 2. Location and weight of equipment located at 259 ft.

Equipment Location (Node)	**Equipment Wt. (lb)**
1230	15200
988	19200
159	16000
2965	22400

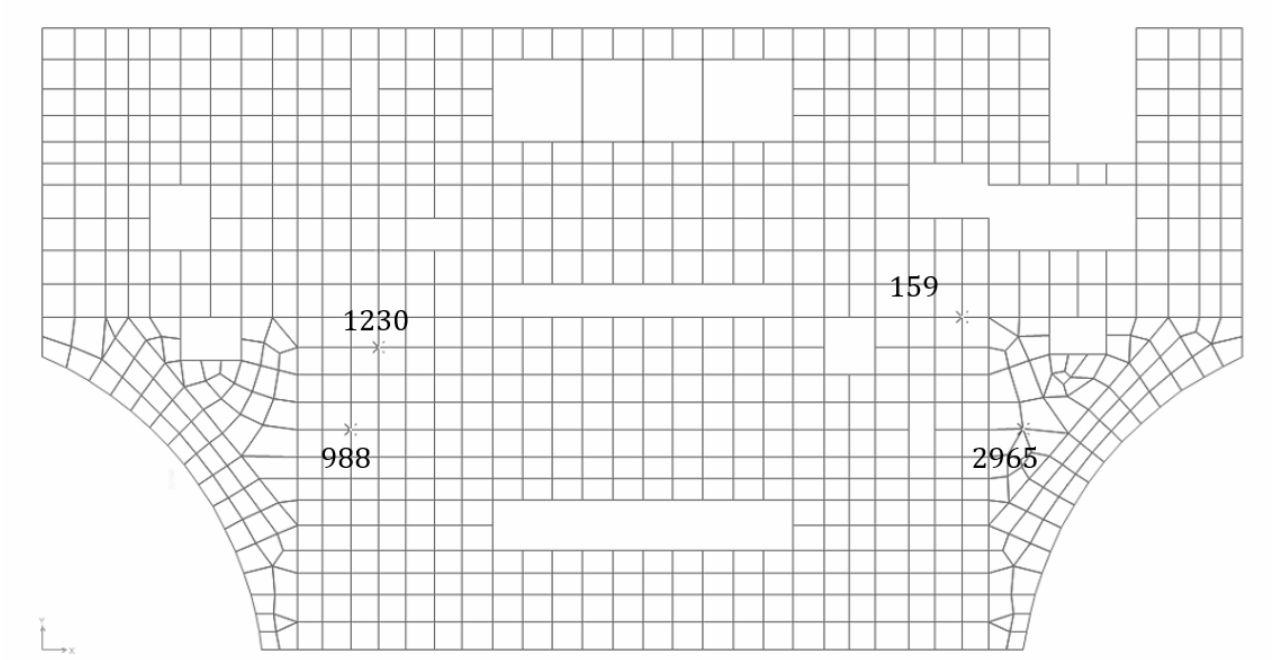

Figure 2. Equipment Locations at 259 ft.

Table 3. Location and weight of equipment located at 280 ft.

Equipment Location (Node)	Equipment Weight (lb)
3353	10182
5930	10182
5982	10182
3616	10182

Figure 3. Equipment Locations at 280 ft.

COUPLED ANALYSIS TO ASSESSS THE REDUCTION IN SEISMIC DEMAND

In order to assess the reduction in seismic demand due to ESI, the uncoupled ISRS is first obtained for all the nodes where the equipment are placed. The uncoupled (excluding the effect of equipment mass) ISRS at a particular direction for a specific damping ratio is obtained by combining the acceleration response spectra due to input in all the three orthogonal directions, using the square root of sum of squares (SRSS).

For a coupled analysis, the equipment are modeled as single degree of freedom oscillators on their respective node locations and the complete equipment mass is placed on a single node for the coupled analysis. Figures 4 - 7 shows the ESI effect for various locations on the Auxiliary Building.

The reductions in spectral ordinates indicates the importance of considering the interaction between structure (primary system) and the floor mounted equipment (secondary system). Table 4 shows the percentage reductions in spectral ordinates due to ESI effects at the various locations. Overall, reductions of up to 55% are observed. At an elevation of 259 ft., the reduction due to ESI effect is 55.66% for Node 159 and 18.22% for Node 1230. At an elevation of 280 ft., the reduction due to ESI effect is 33.98% for Node 3553 and 28.39% for Node 5982. For some analyses, we did not observe significant reduction in the spectral response as the reduction in response depends on the frequency of the input motion as well as the frequency at which the equipment is tuned.

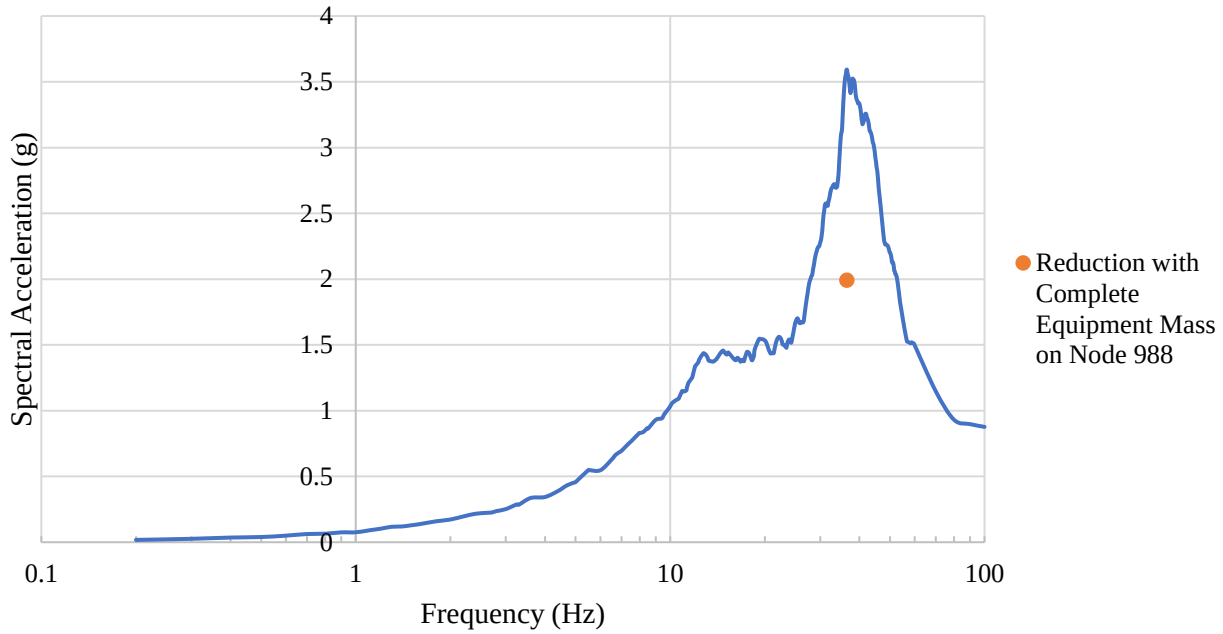

Figure 4. ESI effect, Node 988

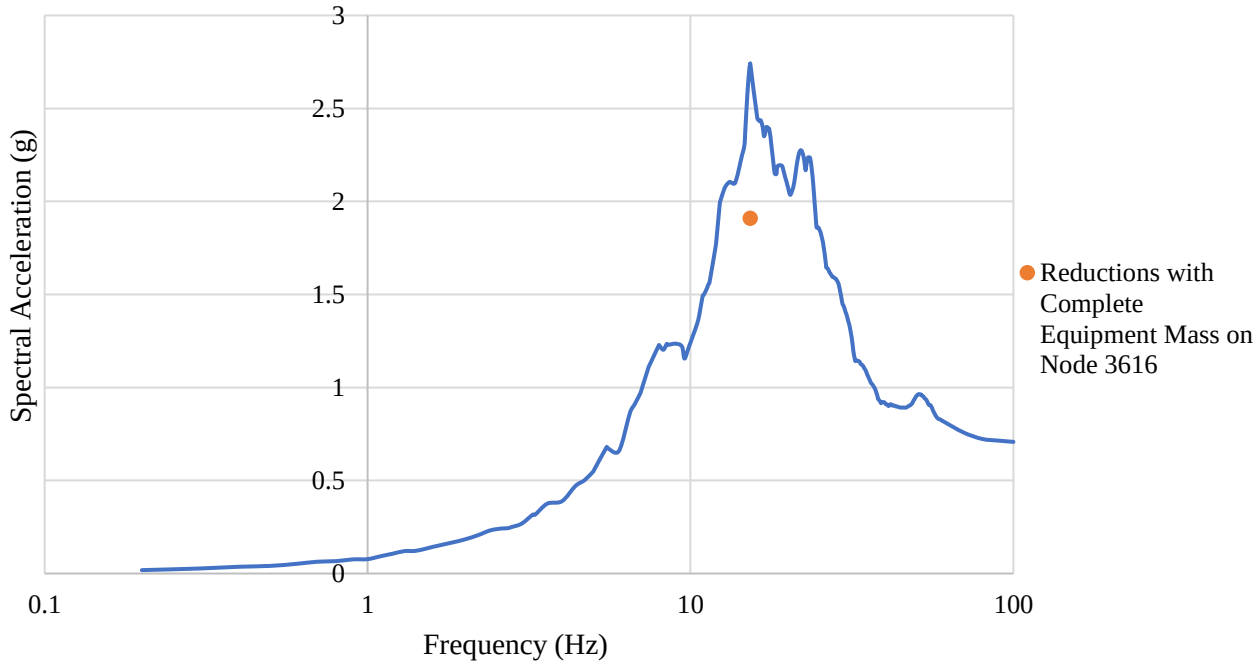

Figure 5. ESI effect, Node 3616

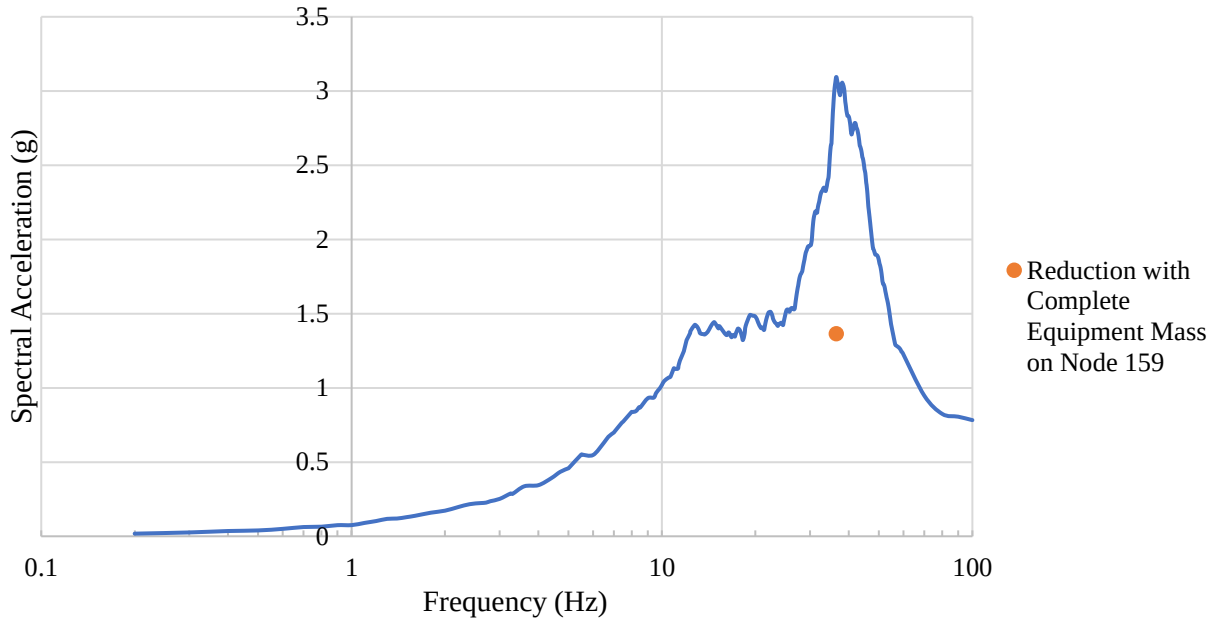

Figure 6. ESI effect, Node 159

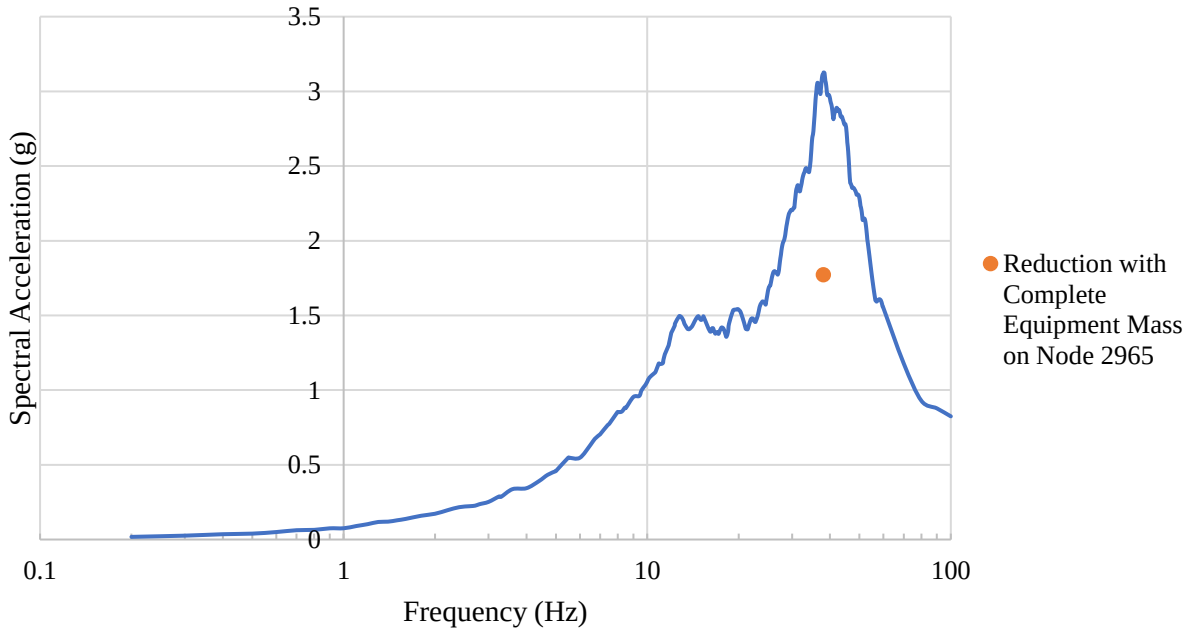

Figure 7. ESI effect, Node 2965

Table 4: Percentage reductions in spectral ordinates due to ESI effects

Elevation	Node	ISRS Peak Freq. (Hz)	ISRS Peak Amp (g)	Equipment Weight (lb)	Reductions after coupled analysis
259	1230	37.89	2.14	15200	18.22 %
259	988	36.50	3.59	19200	44.57 %
259	159	36.41	3.09	16000	55.66 %
259	2965	38.10	3.13	22400	43.45 %
280	3353	15.31	2.59	10182	33.98 %
280	5930	34.52	2.62	10182	33.21 %
280	5982	15.31	2.36	10182	28.39 %
280	3616	15.31	2.74	10182	30.29 %

CONCLUSIONS

The conventional practice of generating In-Structure Response Spectra (ISRS) by neglecting the interaction between structure (primary system) and the mounted equipment (secondary system) on the floors can lead to excessively conservative results. The results from these conservative analyses then serve as input in the seismic probabilistic risk assessment (SPRA) of the nuclear facility. Therefore, ignoring the effects of coupling may lead to excessively high-risk estimates. The results of the coupled analyses presented in this paper indicate that a significant reduction in the spectral ordinates can be achieved while considering the interaction between the structure and the equipment.

REFERENCES

CSI (2016), "SAP2000 Integrated Software for Structural Analysis and Design," *Computers and Structures Inc*., Berkeley, California.

Burdisso, R.A., and Singh, M.P. (1987). "Seismic Analysis of Multiply Supported Secondary Systems with Dynamic Interaction Effects." *Earthquake Engineering Structural Dynamics*, Volume 15, Pages 1005- 1022.

Electric Power Research Institute (EPRI) *"*Coupled Analysis of Primary-Secondary System to Generate Floor Response Spectra: Quantifying Reduction Factors for Coupled In-Structure Response Spectra Amplitudes*"*, 3002010666, Final Report, November 2017.

Gupta, A., and Gupta, A. K. (1997). "Seismic response of tuned single degree of freedom secondary systems." *Nuclear Engineering and Design*, Volume 172, Pages 17–25.

Gupta, A., and Gupta, A. K. (1997). CREST-IRS: A computer program for generating in-structure response spectra (Version 1.0). Center for Nuclear Power Plant Structures, Equipment and Piping in the Department of Civil Engineering.

Gupta, A., and Gupta, A.K. (1995). "New developments in coupled seismic analysis of equipment and piping." *Transactions of the 13th International Conference on Structural Mechanics in Technology* (SMiRT 13), Porto Alegre, Brazil, August 13-18, 1995.

Gupta, A., and Gupta, A.K. (1995). "Application of New developments in Coupled Seismic Analysis of Equipment and Piping." *Transactions of the 13th International Conference on Structural Mechanics in Technology* (SMiRT 13), Porto Alegre, Brazil, August 13-18, 1995.

Lysmer, J., Mansour T., Freddie T., Shahriar V., and Ostadan F. (1981). "SASSI: a system for analysis of soil-structure interaction."