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The Effect on Seismic Capacity of Equipment Considering Incoherency Analysis

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1. Introduction

Seismic analysis of nuclear power plants(NPPs) assumes that the ground motion is the same regardless of the size of the foundation of the structure. But at any instant in time, the input motion at every point under the structure foundation is not the same. For massive rigid foundations common for nuclear structures the overall high-frequency motion is reduced as waves cancel each other across the foundation/soil interface. The reductions referred to here as ground motion incoherence(GMI) effects are due to non-vertically propagating shear waves and reflections and refractions causing incoherence as the earthquake waves pass through the underlying heterogeneous geologic media.

Among the seismic fragility variables, the GMI coefficient is determined by the size of the foundation of the structure and controlled by frequency of the equipment(components) as a factor to account for the difference in ground motion. In this study, the effect on the High Confidence of Low Probability of Failure(HCLPF) according to the GMI effect is estimated. The GMI effect can be calculated by performing in coherence analysis or by the EPRI methodology after coherence analysis. The GMI effect between Incoherence based on Soil-Structure Interaction(SSI) analysis and EPRI methodology is presented briefly.

2. SSI Analysis Procedure

Linear finite element computer program ACS SASSI [1] which is a SASSI family of code is used to obtain the seismic response. Fig. 1 shows the Computer Program SASSI/ACS SASSI and Fig. 2 shows the finite element(FE) model of sample structure. Coherency and Incoherency analysis was performed on the sample structure according to the following procedure.

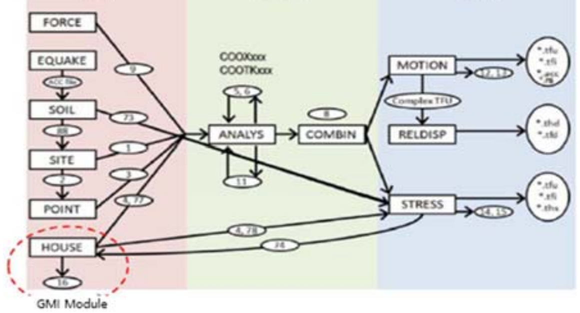


Fig. 1. Layout of Computer Program SASSI/ACS SASSI

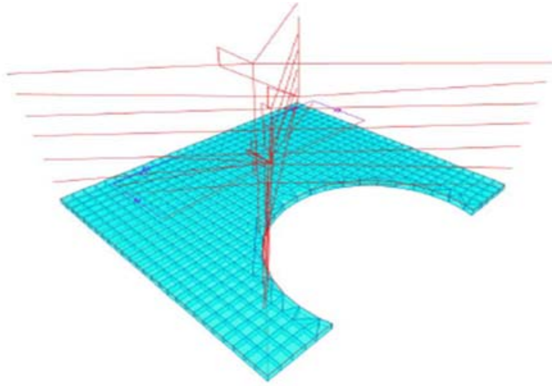
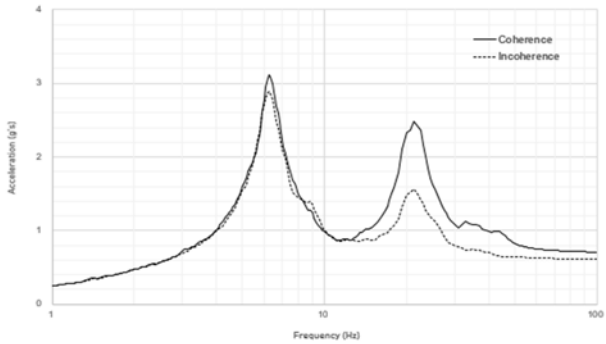


Fig. 2. Modeling of Sample Structure

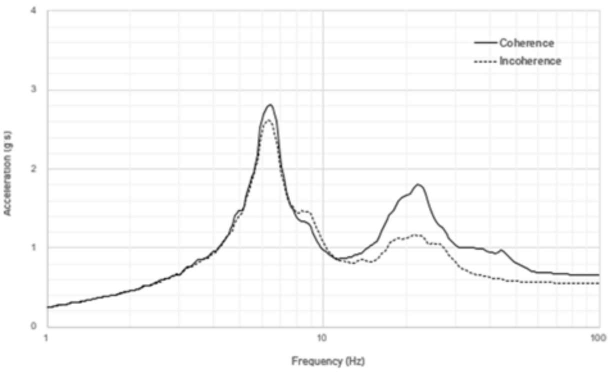
3. GMI Effect

3.1 Incoherence SSI Analysis Results

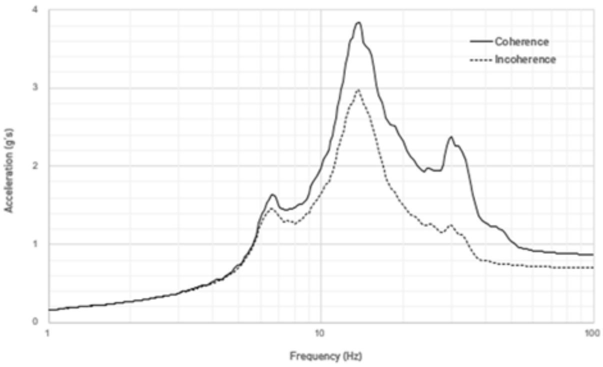
Based on the result of SSI analysis [2], the results of coherence and incoherence analysis in the representative level 2 of sample structure are shown in Fig. 3.



(a) Horizontal 1



(b) Horizontal 2



(c) Vertical(Slab)

Fig. 3. GMI-reduced ISRS (SSI analysis) at Level 2, 5% Damping

Table 1 presents the GMI reduction factor for each level, directions(two horizontal and one vertical), and important frequencies. The reduction factor is the ratio of the response (Coherency vs Incoherency analysis)

Table I: GMI Reduction Factor for SSI Analysis Results

Level	freq. (Hz)	Coherence (CO) (SSI)			Incoherence (INC) (SSI)			Reduction Factor (CO/INC)		
		H1 (g)	H2 (g)	V (g)	H1 (g)	H2 (g)	V (g)	H1	H2	V
1	5	1.15	1.10	0.68	1.12	1.06	0.66	1.03	1.04	1.03
	10	0.79	0.79	1.68	0.75	0.76	1.41	1.05	1.04	1.19
	15	0.98	0.93	2.43	0.76	0.74	1.86	1.29	1.25	1.31
	20	1.90	1.33	2.21	1.20	0.93	1.43	1.59	1.43	1.55
	25	1.07	1.01	2.69	0.79	0.81	1.58	1.35	1.24	1.71
2	5	1.60	1.47	0.73	1.54	1.41	0.71	1.03	1.04	1.04
	10	0.99	0.98	1.97	1.00	1.07	1.65	0.98	0.91	1.19
	15	1.05	1.04	3.49	0.86	0.83	2.66	1.21	1.25	1.31
	20	2.33	1.67	2.32	1.48	1.13	1.50	1.57	1.47	1.54
	25	1.62	1.41	1.97	1.16	1.06	1.26	1.39	1.32	1.56
3	5	1.97	1.85	0.81	1.90	1.77	0.77	1.03	1.04	1.04
	10	1.38	1.37	2.20	1.44	1.52	1.84	0.96	0.90	1.20
	15	1.01	1.00	4.18	0.92	0.92	3.17	1.11	1.09	1.32
	20	1.50	1.35	3.05	1.09	0.99	2.00	1.38	1.36	1.52
	25	1.50	1.34	2.42	1.08	0.98	1.58	1.39	1.38	1.53
4	5	2.21	2.12	0.85	2.14	2.03	0.81	1.03	1.05	1.05
	10	1.69	1.72	2.39	1.75	1.84	1.99	0.97	0.93	1.20
	15	1.17	1.09	4.82	1.02	1.05	3.65	1.15	1.05	1.32
	20	1.04	1.07	3.91	0.92	0.94	2.54	1.13	1.14	1.54
	25	1.01	1.02	3.53	0.89	0.89	2.10	1.13	1.15	1.69
5	5	2.41	2.36	0.88	2.32	2.25	0.83	1.04	1.05	1.05
	10	2.01	2.08	2.54	2.02	2.15	2.10	0.99	0.96	1.21
	15	1.51	1.42	5.33	1.23	1.29	4.01	1.24	1.11	1.33
	20	1.84	1.70	4.66	1.31	1.30	2.99	1.40	1.31	1.56
	25	1.38	1.47	4.45	1.19	1.21	2.59	1.16	1.22	1.72

3.2 Scaling Approach for GMI Effect

If incoherence analysis is not performed, EPRI 1002988[3] provides simplified guidance for incorporating GMI into a response spectrum scaling approach. The report [3] provides frequency-dependent GMI reduction factors for a foundation with 150 ft characteristic dimension and an equation for extrapolating the table to other foundation sizes.

Table II (Table B-1 of EPRI 1002988 [3]) presents the reduction factors at important frequency points.

Table II: Reduction Factor for 150 ft Foundation

Frequency(Hz)	Reduction Factor, R150
0.2	1.0
1	1.0
5	1.0
10	0.9
20*	0.8232
≥25	0.8

*Reduction factor determined by linear log-log interpolation

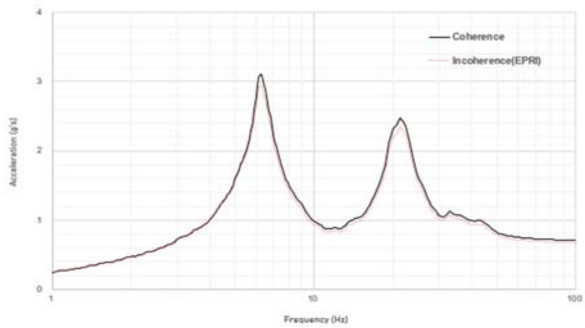
The equivalent plan dimension d_e of the sample structure basemat is computed to be 226.5 ft by taking a geometric mean of the two side dimensions.

$$d_e = \sqrt{(213.75\text{ft} \times 240\text{ ft})} = 226.5\text{ ft}$$

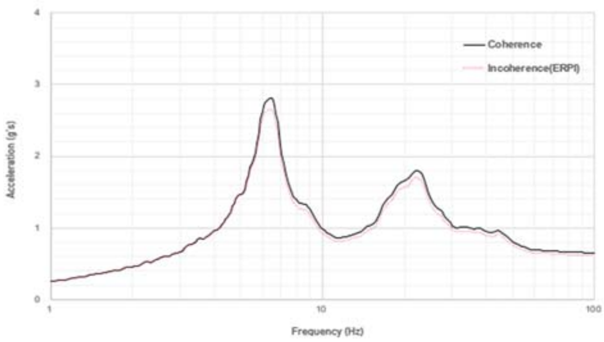
With this equivalent plan dimension, reduction factors are computed at various frequency points using the following equation.

$$RF_k = 1 - \frac{d_e}{150\text{ ft}} \times (1 - R_{150})$$

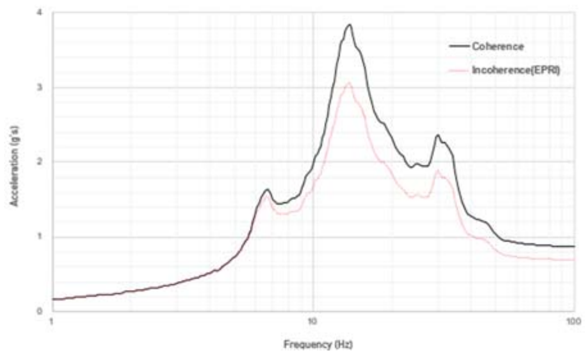
Multiplying the reduction factors to the in-structure response spectra (coherence analysis) results in GMI-reduced ISRS(Incoherence). Figure 4 shows the results considering GMI effect at each direction.



(a) Horizontal 1



(b) Horizontal 2



(c) Vertical(Slab)

Fig. 4. GMI-reduced ISRS (EPRI) at Level 2, 5% Damping

Table III: GMI Reduction Factor for Analysis Results

Level	freq. (Hz)	Coherence (CO) (SSI)			Incoherence (INC) (ERPI)			Reduction Factor (CO/INC)		
		H1 (g)	H2 (g)	V (g)	H1 (g)	H2 (g)	V (g)	H1	H2	V
1	5	1.15	1.10	0.68	1.15	1.10	0.68	1.00	1.00	1.00
	10	0.79	0.79	1.68	0.75	0.75	1.42	1.05	1.05	1.18
	15	0.98	0.93	2.43	0.93	0.88	1.93	1.05	1.05	1.26
	20	1.90	1.33	2.21	1.80	1.26	1.75	1.05	1.05	1.26
	25	1.07	1.01	2.69	1.01	0.96	2.14	1.05	1.05	1.26
2	5	1.60	1.47	0.73	1.60	1.47	0.73	1.00	1.00	1.00
	10	0.99	0.98	1.97	0.94	0.92	1.67	1.05	1.06	1.18
	15	1.05	1.04	3.49	0.99	0.98	2.77	1.05	1.06	1.26
	20	2.33	1.67	2.32	2.21	1.57	1.84	1.05	1.06	1.26
	25	1.62	1.41	1.97	1.54	1.33	1.57	1.05	1.06	1.26
3	5	1.97	1.85	0.81	1.97	1.85	0.81	1.00	1.00	1.00
	10	1.38	1.37	2.20	1.31	1.28	1.87	1.05	1.06	1.18
	15	1.01	1.00	4.18	0.96	0.94	3.31	1.05	1.06	1.26
	20	1.50	1.35	3.05	1.43	1.27	2.41	1.05	1.06	1.26
	25	1.50	1.34	2.42	1.43	1.26	1.91	1.05	1.06	1.26
4	5	2.21	2.12	0.85	2.21	2.12	0.85	1.00	1.00	1.00
	10	1.69	1.72	2.39	1.60	1.61	2.03	1.05	1.06	1.18
	15	1.17	1.09	4.82	1.11	1.03	3.82	1.05	1.06	1.26
	20	1.04	1.07	3.91	0.98	1.01	3.10	1.05	1.06	1.26
	25	1.01	1.02	3.53	0.96	0.95	2.80	1.05	1.06	1.26
5	5	2.41	2.36	0.88	2.41	2.36	0.88	1.00	1.00	1.00
	10	2.01	2.08	2.54	1.90	1.95	2.15	1.06	1.07	1.18
	15	1.51	1.42	5.33	1.43	1.33	4.22	1.06	1.07	1.26
	20	1.84	1.70	4.66	1.74	1.60	3.69	1.06	1.07	1.26
	25	1.38	1.47	4.45	1.31	1.38	3.53	1.06	1.07	1.26

4. Conclusion

This study demonstrates reduction of high-frequency response for large rigid foundation mats due to incoherency effect. Incoherent (both analysis and scaling approach) to coherent spectral ratios are computed as a general indicator of the effect of incoherency. It is judged that a reduction effect can be expected more if incoherency analysis is performed than scaling approach presented by EPRI 1002988[3].

Based on the results, the ground motion incoherency leads to reductions in the in-structure response spectra(ISRS) at frequencies higher than structure fundamental natural frequency range from 6 Hz to 7Hz. The natural frequencies of the slabs in the vertical direction is about 15 Hz, where significant high frequency content exist. The GMI effect for vertical direction is larger than that for horizontal direction. Based on the incoherency results, seismic fragility for equipment is governed by vertical ISRS is more effective than horizontal ISRS in terms of HCLPF.

References

[1] Computer Program ACS SASSI (KEPCO E&C Program Registration No.: E-W-CE-1309-3.0) User's Manual

[2] KEPCO E&C, 보조건물 상관성 및 비상관성 SSI 해석보고서, 2020. 7.

[3] Electric Power Research Institute, Seismic Fragility Application Guide, EPRI 1002988, Final Report, Palo Alto, CA, Dec. 2002.

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