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Subject: **Response to Portion of NRC RAI Letter No. 290 Related to ESBWR Design Certification Application - DCD Tier 2 Section 3.7 – Seismic Design; RAI Number 3.7-63 S02 Revision 1**

The purpose of this letter is to submit the GE Hitachi Nuclear Energy (GEH) revised response to the U.S. Nuclear Regulatory Commission (NRC) Request for Additional Information (RAI) letter number 290 sent by NRC letter dated January 6th, 2009 (Reference 1). Reference 2 transmitrted GEH's original response to Reference 1 which has been revised for clarification as a result of interactions with the staff. RAI Number 3.7-63 S02 Revision 1 is addressed in Enclosure 1.

Enclosure 1 deletes the materials related to DCD Tier 2, Appendix 3G changes as requested by the NRC. This RAI now deals with DCD Tier 2 Appendix 3A changes only.

The RAI response in Reference 2 included DCD Tier 2 Appendix 3G changes, which were specific to the Fire Water Storage Complex (FWSC). A revised stress analysis of the FWSC resulted in changes to DCD Tier 2 Subsection 3G.4.5.4, Tables 3G.4-10 through 3G.4-21 and Figure 3G.4-1. These DCD changes were necessary to correct for inadvertent omission of the hydrodynamic wall pressures induced by the vertical earthquake component in the original stress calculation for the firewater storage tank. The updated FWSC stress analysis resulted in additional reinforcement. These DCD Tier 2 Appendix 3G changes have been incorporated in the preliminary DCD Revision 6 that has been submitted to the NRC.

If you have any questions or require additional information, please contact me.

Sincerely,

Richard E. Kingston

Richard E. Kingston
Vice President, ESBWR Licensing

Reference:

1. MFN 09-009 Letter from U.S. Nuclear Regulatory Commission to Robert E. Brown, GEH, *Request For Additional Information Letter No. 290 Related to ESBWR Design Certification Application*, dated January 6, 2009
2. MFN 09-210 Letter from R. E. Kingston to U.S. Nuclear Regulatory Commission*, Response to Portion of NRC RAI Letter No. 290 Related to ESBWR Design Certification Application - DCD Tier 2 Section 3.7 – Seismic Design; RAI Number 3.7-63 S02* dated March 31, 2009

Enclosures:

1. Response to Portion of NRC RAI Letter No. 290 Related to ESBWR Design Certification Application - DCD Tier 2 Section 3.7 – Seismic Design; RAI Number 3.7-63 S02 Revision 1
2. Response to Portion of NRC RAI Letter No. 290 Related to ESBWR Design Certification Application - DCD Tier 2 Section 3.7 – Seismic Design; RAI Number 3.7-63 S02 Revision 1 – DCD Markups

cc:	AE Cubbage	USNRC (with enclosures)
	RE Brown	GEH/Wilmington (with enclosures)
	DH Hinds	GEH/Wilmington (with enclosures)
	EDRF Section	0000-0095-6241 R1(RAI 3.7-63 S02 R1)

ENCLOSURE 1

MFN 09-201 Revision 1

Response to NRC RAI Letter No. 290
Related to ESBWR Design Certification Application[1]

DCD Tier 2 Section 3.7 – Seismic Design

RAI Number 3.7-63 S02 (Revision 1)

[1] Original Response and Supplement 1 previously submitted under MFNs 08-232 and 08-232, Supplement 2 without DCD updates are included to provide historical continuity during review.

NRC RAI 3.7-63

DCD Revision 4 Section 3A.4.1 states:

> *"....For the generic sites defined in Subsection 3A.3.1, the design response spectra are conservatively applied at the level of foundation in the free field. The input motion for North Anna ESP site is also defined at the foundation level.*
>
> *For the layered site cases, the input ground motion is defined as an outcrop motion at the RBFB foundation level for the RBFB and CB. The corresponding surface motion is generated for use as input to the SASSI2000 calculation for each site.*
>
> *For the FWSC, which is essentially a ground surface founded structure, the input ground motion is taken to be 1.35 times the RBFB/CB foundation input motion and is applied directly at the foundation level."*

The staff requires the following clarification and additional information related to the above statements:

(a) Based on the first two sentences above, it appears to the staff that the ground motion for the CB was applied at two different elevations: at the CB foundation level for the generic sites defined in Subsection 3A.3.1, and at the RBFB foundation level for the layered site cases. Please confirm this, or clarify what was actually done. If this is the case, please describe what differences in CB response would be expected for the layered site cases if the input ground motion had been defined as an outcrop motion at the CB foundation level.

(b) The third sentence above defines the input ground motion used for the FWSC SSI analyses as "1.35 times the RBFB/CB foundation input motion…applied directly at the foundation level." Please provide a detailed technical basis for the selection of the 1.35 factor, including pertinent quantitative information upon which this determination is based.

GEH Response

(a) GEH confirms that the ground motion for the CB was applied at the CB foundation level for the generic site cases and at the RBFB foundation level for the layered site cases.

Applying the outcrop motion at the RBFB foundation level for the layered site cases is a more conservative approach than applying the outcrop motion directly at the CB foundation level. This is demonstrated in Figure 3.7-63(1) by comparing the response spectra of the surface motion when the ground motion is applied at the RBFB foundation level and at the CB foundation level for the typical layered site Case 2 described in DCD Tier 2 Table 3A.3-3. The response spectrum of the surface motion is larger in the case when the ground motion is applied at the RBFB foundation level than in the case when the ground motion is applied at the CB foundation level. Therefore, it is expected that the CB response would be smaller for the layered site cases if the input ground motion had been defined as an outcrop motion at the CB foundation level instead at the RBFB foundation level.

(b) The technical basis for scaling the RBFB/CB foundation input motion for ground motions at other depths is to maintain a broad-band spectrum shape that is rich in all frequencies, regardless of site conditions, for the purpose of standard plant design. Broad-band design spectrum at any foundation depth is compatible with smooth site-specific ground motion response spectrum (GMRS) and associated foundation input response spectrum (FIRS) generated in accordance with RG 1.208 requirements for new units. The 1.35 scale factor was determined such that the resulting spectrum at the FWSC foundation level envelops the FIRS at the North Anna 3 site as shown in Figure 3.7-63(2) for the horizontal motion and Figure 3.7-63(3) for the vertical motion.

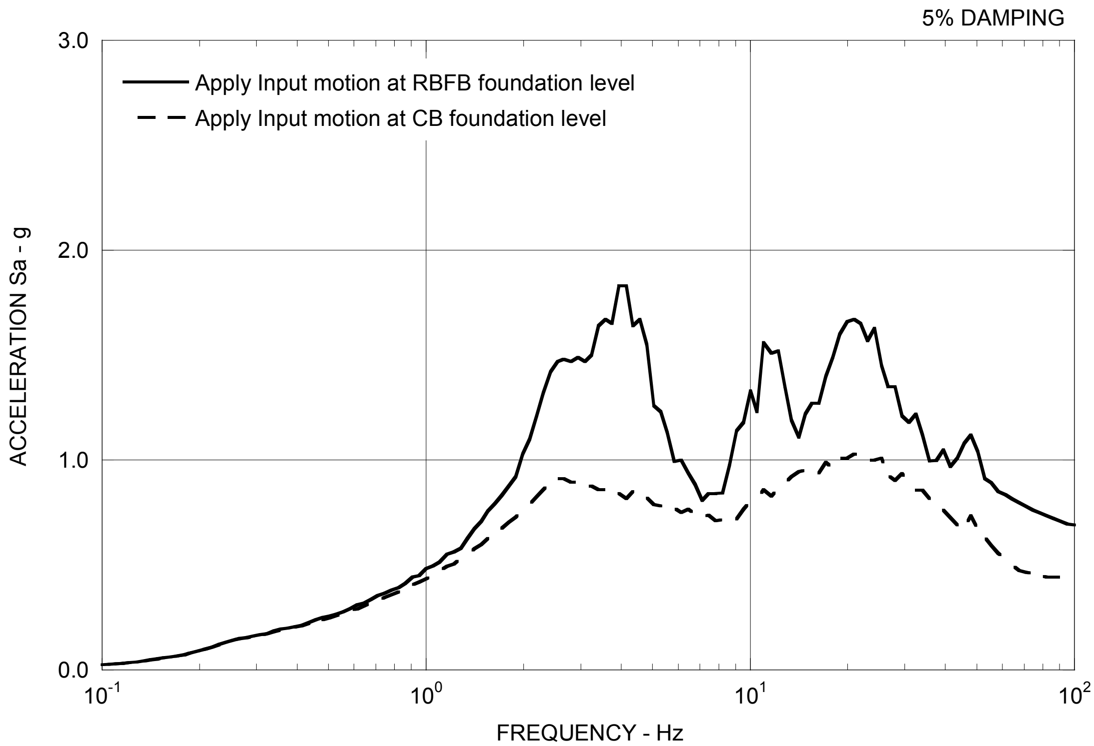


Figure 3.7-63(1) Comparison of Surface Response Spectra for Layered Case 2 when the Input Motion is applied at Different Levels

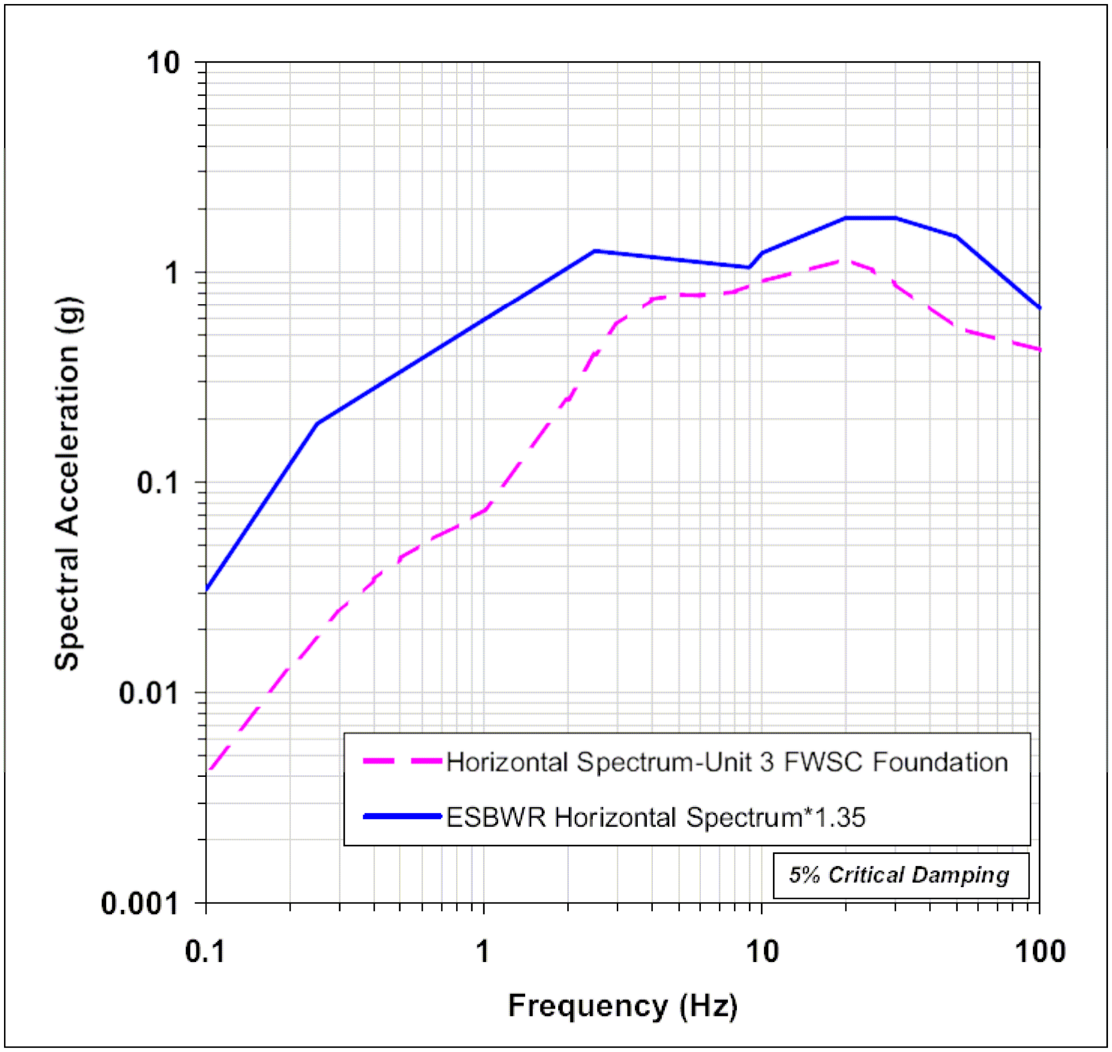


Figure 3.7-63(2) Comparison of Horizontal SSE Design Response Spectrum with NA3 Site-Specific Spectra at FWSC Foundation Level (Reproduced from North Anna 3 COLA FSAR Figure 2.0-203)

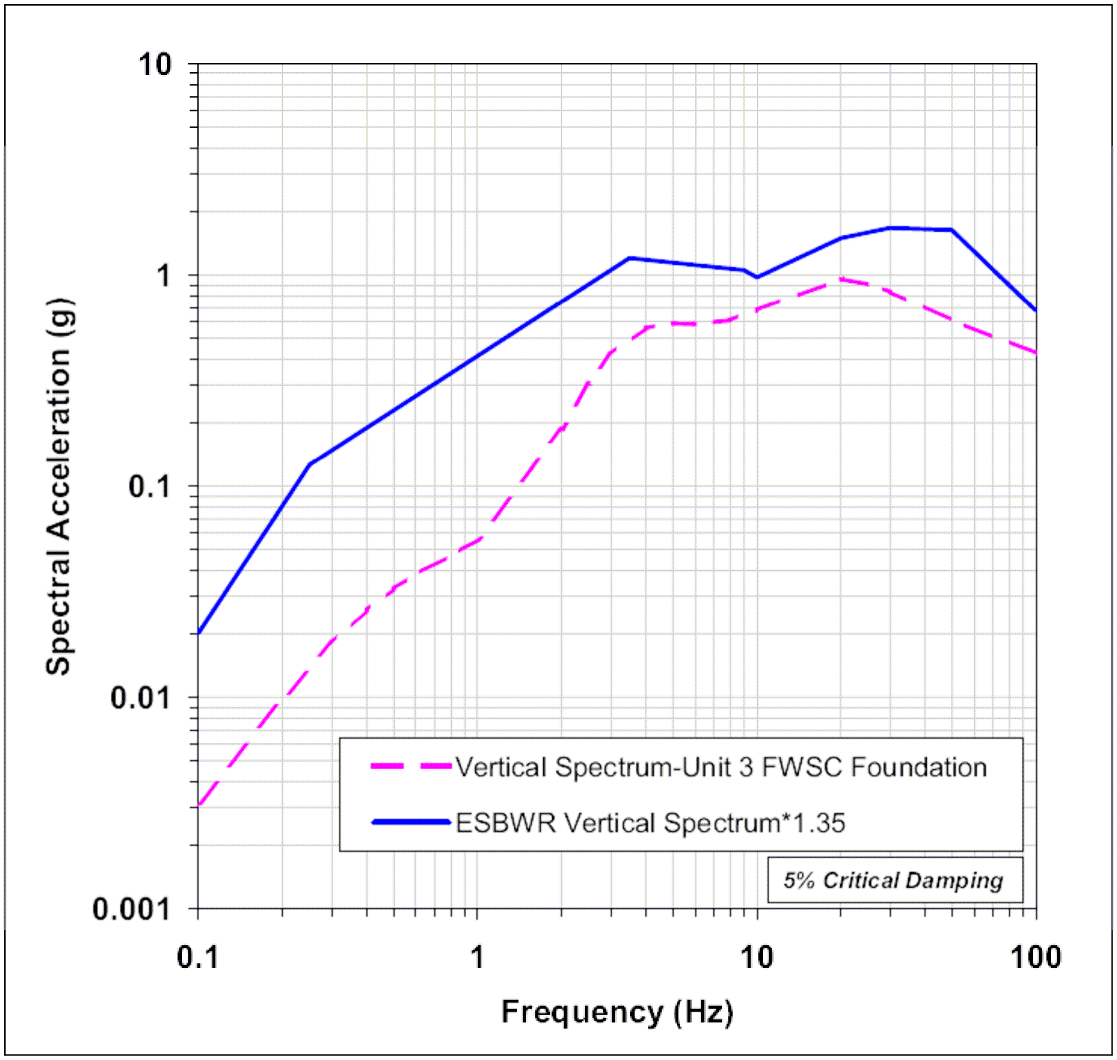


Figure 3.7-63(3) Comparison of Vertical SSE Design Response Spectrum with NA3 Site-Specific Spectra at FWSC Foundation Level (Reproduced from North Anna 3 COLA FSAR Figure 2.0-204)

DCD Impact

No DCD change was made in response to this RAI.

NRC RAI 3.7-63, Supplement 1

The staff reviewed GEH's response to RAI 3.7-63, and concluded that additional information is needed before it can complete its assessment of the two technical issues covered by this RAI.

Part (1) - GEH needs to submit a comparison of the surface spectra derived by placing the input motion at the bottom of the RB/FB foundation to the surface spectra derived by placing the input motion at the bottom of the CB foundation, for each of the 4 SASSI layered soil cases. In deriving the surface spectra from the foundation motions, the method identified as the NRC method in GEH's response to RAI 3.7-16 must be used. Submit four (4) figures, similar to Figure 3.7-63(1).

In reviewing Figure 3.7-63(1), the staff noted that the surface spectra corresponding to placing the input motion at the bottom of the CB foundation (dashed line) does not appear to be correct. It resembles the spectrum of the input motion, at the foundation level. The dashed line would be expected to exhibit the same pattern of peaks and valleys as the solid line. GEH needs to confirm that the dashed line is correct, and provide an explanation for the unexpected shape.

Part (2) – The staff notes that GEH can define any surface spectrum it chooses to for design certification of the fire water service complex (FWSC). COL applicants will need to demonstrate that the site-specific surface spectrum is enveloped by the spectrum GEH has used for design certification of the FWSC. If this is not the case, then a site-specific analysis of the FWSC will be required at the COL stage. This will be in addition to the required comparisons at the RB/FB and CB foundation levels. SRP 3.7.1 specifies a check at the foundation level for each structure.

The staff believes that the surface spectra used for seismic analysis of the FWSC should envelope the 8 surface spectral plots that the staff has asked GEH to derive under Part (1) above. This would ensure consistency between the input at the RB/FB and CB foundation levels and the input at the surface for the FWSC. GEH's proposed 1.35 factor on the input motion at the bottom of the RB/FB foundation may or may not produce a suitable envelope. Based on comparing Figure 3.7-63(1) to Figure 3.7-63(2), it appears to the staff that a 1.35 factor may not be sufficient over the entire frequency range.

The staff requests GEH to re-assess its methodology for selecting the surface spectra for seismic design of the FWSC; provide the technical basis for its selection; and identify the necessary COL applicant action items to ensure the seismic adequacy of the FWSC at each site.

GEH Response

Part (1) - Figures 3.7-63(4) through (7) show comparisons of the surface spectra derived by placing the input motion at the bottom of the RB/FB foundation to the surface spectra derived by placing the input motion at the bottom of the CB foundation for each of the 4 SASSI layered soil cases by using the method identified as the NRC Method in GEH's response to NRC RAI 3.7-16, Supplement 2 transmitted to the NRC via MFN 06-274, Supplement 2.

Since the fundamental frequencies of the CB in the horizontal directions are around 3 Hz, as shown in DCD Tier 2 Table 3A.7-8, the CB responses would be smaller for all layered site cases if the input ground motion had been applied at the CB foundation level instead at the RB/FB foundation level.

GEH confirms that both the solid and dashed lines in Figure 3.7-63(1) have been correctly calculated by using the method identified as the DCD Method in GEH's response to NRC RAI 3.7-16, Supplement 2 transmitted to the NRC via MFN 06-274, Supplement 2, which includes the entire soil column up to the ground surface in a single SHAKE run with outcrop motion input at the foundation level.

The reason for the dashed line resembling the foundation input spectrum is because the CB (14.9 m embedment) is shallower than the top layer (20m thick) of the layered sites (see DCD Tier 2 Table 3A.3-3). In other words, the soil properties above the foundation are the same as those below the foundation in the region of the top layer and, as a result, the surface motion resembles the foundation input motion. This can be further explained by the one-dimensional wave propagation theory below:

a. Soil displacement at layer *m* is expressed as:

$$u_m(x,t) = E_m e^{i(kx+\omega t)} + F_m e^{-i(kx-\omega t)} \qquad \text{Equation 3.7-63(1)}$$

where $k = \sqrt{\frac{\rho\ \omega^2}{G^*}}$, *G** is a complex soil stiffness considering damping

b. For the multi-soil layer system, the upward component, E, and the downward component, F, for each soil layer are calculated by Equation 3.7-63(2) considering the continuity of displacement and shear stress at each layer boundary.

$$E_{m+1} = \frac{1}{2} E_m (1+\alpha_m) e^{ik_m h_m} + \frac{1}{2} F_m (1-\alpha_m) e^{-ik_m h_m}$$
$$F_{m+1} = \frac{1}{2} E_m (1-\alpha_m) e^{ik_m h_m} + \frac{1}{2} F_m (1+\alpha_m) e^{-ik_m h_m} \qquad \text{Equation 3.7-63(2)}$$

where $$\alpha_m = \frac{k_m \cdot G_m^*}{k_{m+1} \cdot G_{m+1}^*}$$

c. Since the full reflection occurs at the ground surface, the E and F components are equal at the top surface layer.

$$E_1 = F_1 \quad \text{Equation 3.7-63(3)}$$

d. From Equations 3.7-63(2) and 3.7-63(3), the motion components at the second layer are derived to be:

$$E_2 = \frac{E_1}{2}\left\{(1+\alpha_1)e^{ik_1h_1} + (1-\alpha_1)e^{-ik_1h_1}\right\}$$
$$F_2 = \frac{E_1}{2}\left\{(1-\alpha_1)e^{ik_1h_1} + (1+\alpha_1)e^{-ik_1h_1}\right\}$$

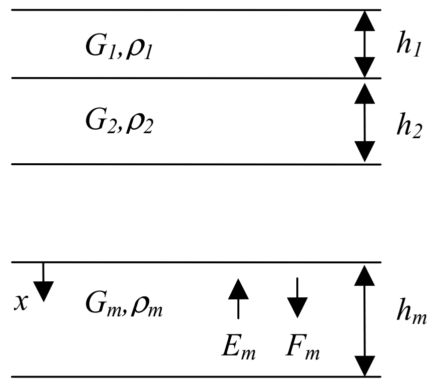
Equation 3.7-63(4)

e. The transfer function of the ground surface displacement relative to the outcrop displacement ($2E_2$) at the top of the second layer becomes:

$$H(\omega) = \frac{E_1 + F_1}{2E_2} = \frac{E_1}{E_2}$$
$$= \frac{E_1}{\frac{E_1}{2}\left\{(1+\alpha_1)e^{ik_1h_1} + (1-\alpha_1)e^{-ik_1h_1}\right\}}$$
$$= \frac{2}{(1+\alpha_1)e^{ik_1h_1} + (1-\alpha_1)e^{-ik_1h_1}}$$

Equation 3.7-63(5)

f. According to the above transfer function, the response at the ground surface approaches the input motion when the soil properties of the 1st layer is the same as those of the 2nd layer, since α_1 becomes 1.0 and $H(\omega)$ approaches 1.0.



Part (2) - The surface spectra computed from the input spectra defined at the RB/FB and CB foundations, as shown in Figures 3.7-63(4) through 3.7-63(7), exhibit distinct peaks and valleys. Using these surface spectra directly as input motion could under-predict or over-predict the FWSC response depending on the SSI frequencies. The more balanced approach for the standard plant design is to maintain the broad-band characteristics in the foundation input spectra that is rich in all frequencies, regardless of site conditions. This is the technical basis for the selection of FSWC input spectra to be 1.35 times the broad-band Certified Seismic Design Response Spectra (CSDRS) for the RB/FB and CB. As stated in the original response to this RAI, the 1.35 scale factor was chosen to envelop the FWSC Foundation Input Response Spectra (FIRS) at the North Anna 3 site. To ensure the seismic adequacy of the FWSC at each site, the COL applicant is required to compare the site-specific FIRS for the FWSC with the FWSC CSDRS, which is 1.35 times the values shown in DCD Tier 2 Figures 2.0-1 and 2.0-2 as stipulated in footnote 9 to DCD Tier 2 Table 2.0-1.

DCD Tier 1 Table 5.1-1, DCD Tier 2 Table 2.0-1, DCD Tier 2 Subsection 3.7.1.1 and DCD Tier 2 Subsection 3A.4.1 will be revised in Revision 6 to clarify that the input ground motion for the Firewater Service Complex is applied directly at the foundation level, specifically at the bottom of the base slab.

DCD Tier 2 Table 1.9-3, DCD Tier 2 Table 1.9-20, DCD Tier 2 Subsection 2.0.2 and DCD Tier 2 Table 2.0-2 will be revised in Revision 6 to clarify that the COL applicant confirm that the site-specific Foundation Input Response Spectra is enveloped by the ESBWR design response spectra referenced at the foundation level.

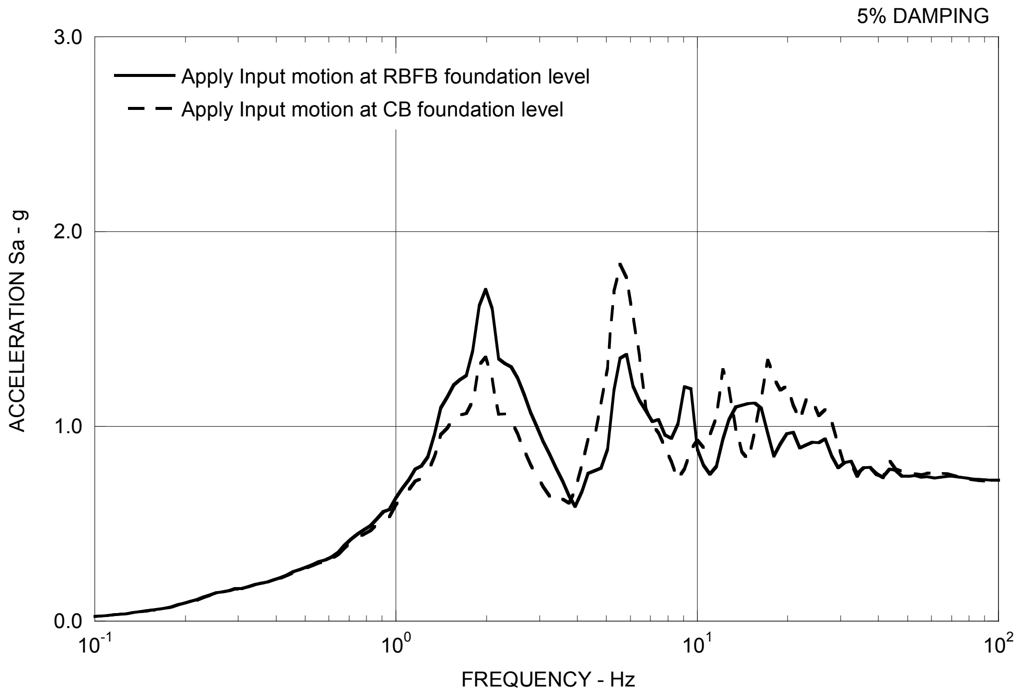


Figure 3.7-63(4) Comparison of Surface Response Spectra for Layered Case 1

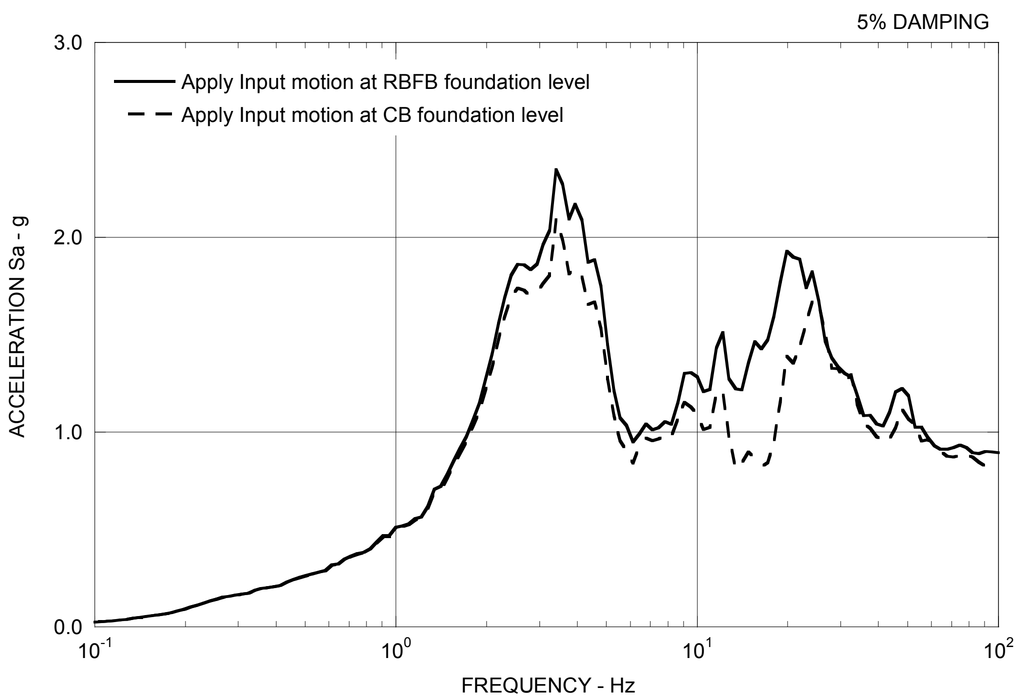


Figure 3.7-63(5) Comparison of Surface Response Spectra for Layered Case 2

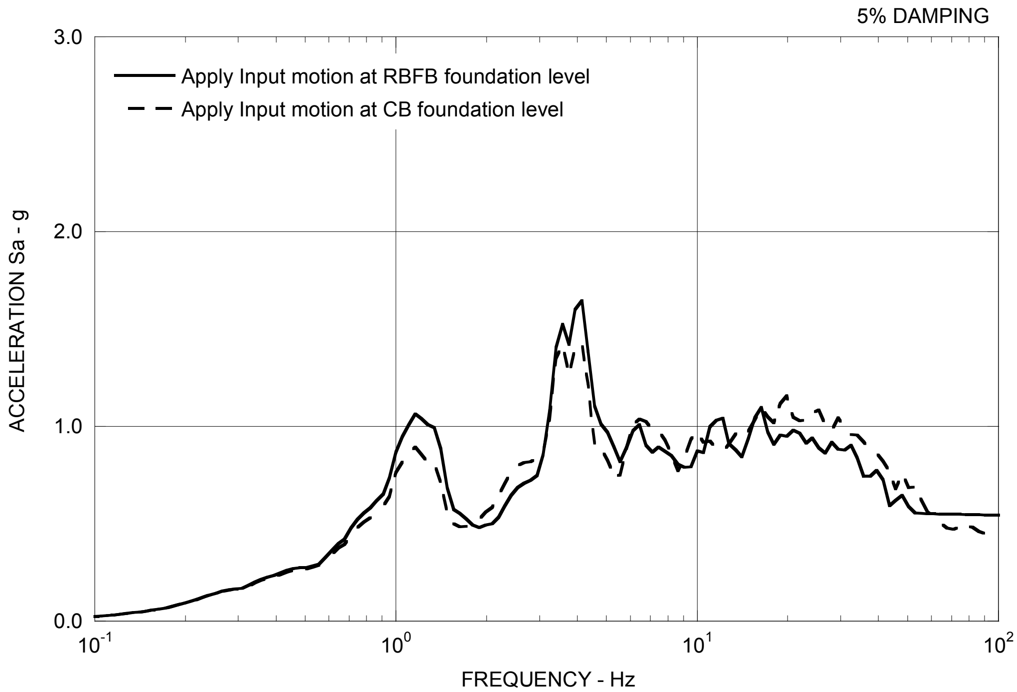


Figure 3.7-63(6) Comparison of Surface Response Spectra for Layered Case 3

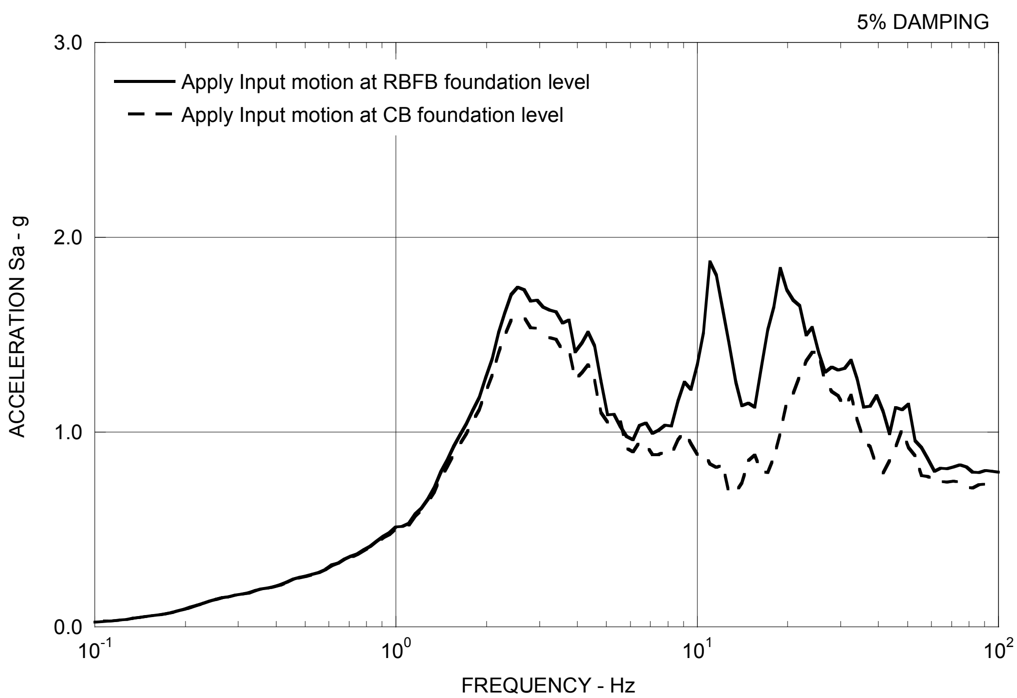


Figure 3.7-63(7) Comparison of Surface Response Spectra for Layered Case 4

DCD Impact

Markups of DCD Tier 1 Table 5.1-1, DCD Tier 2 Table 1.9-3, DCD Tier 2 Table 1.9-20, DCD Tier 2 Subsection 2.0.2, DCD Tier 2 Table 2.0-1, DCD Tier 2 Table 2.0-2, DCD Tier 2 Subsection 3.7.1.1 and DCD Tier 2 Subsection 3A.4.1 were provided to the NRC in MFN 08-232, Supplement 2, dated February 11, 2009.

NRC RAI 3.7-63, Supplement 2

During a teleconference on 12/10/2008 related to RAI 3.7-63 S01, the staff discussed with GEH how the potential for structure-soil-structure interaction was addressed in its evaluation of the FWSC. GEH indicated that it had not conducted any specific analysis due to the appreciable distance between the closest building (CB) and the FWSC. The staff considers that a quantitative evaluation of this potential effect is needed to address this issue. The following two approaches may be considered:

(1) GEH conducts a generic structure-soil-structure analysis for the FWSC.

(2) The COL applicant develops its site-specific FIRS for the FWSC foundation by an analysis that considers structure-soil-structure interaction effects. As long as the site-specific FIRS for the FWSC, including any interaction effects, falls below 1.35 x CSDRS, then the FWSC is seismically qualified by reference to the ESBWR DCD.

GEH may propose an alternative for staff consideration.

Revised GEH Response

GEH has conducted a generic structure-soil-structure interaction analysis for the FWSC with the CB.

The analysis model is composed of these two independent structures coupled through soil, as shown in Figure 3.7-63(8), using the SASSI2000 computer code. The same layered site Case 2 considered for the interaction between the RB/FB and CB is also used in the interaction between the CB and FWSC (CL-2 for CB and FL-2 for FWSC). The input motion for the coupled CB-FWSC SSI model is the Certified Seismic Design Response Spectra (CSDRS) applied at the CB foundation level. This analysis case is named Case FL-5.

The analysis results of the structural response in terms of maximum vertical accelerations and maximum member forces are presented in Tables 3.7-63(1) and 3.7-63(2) for the FWSC and Tables 3.7-63(3) and 3.7-63(4) for the CB together with their percentage differences from the DCD Tier 2 Revision 5 design envelope loads. The design envelope loads bound all structural response results of the structure-soil-structure interaction analysis.

Figures 3.7-63(9) through 3.7-63(26) show comparisons of floor response spectra (FRS) with the design envelope spectra at selected locations in the two structures. The FRS for the corresponding analysis Cases CL-2 and FL-2 without the structure-soil-structure interaction effect are also shown in the figures for comparison. It is confirmed from the results that the FRS with the structure-soil-structure interaction effect are bounded by the DCD Revision 5 design envelope spectra in all frequency ranges. Consequently, it can be concluded that 1.35 times CSDRS is a conservative design input motion to the FWSC and can be compared with the site-specific FIRS directly without considering structure-soil-structure interaction effects in COL applications. DCD

Tier 2 Appendix 3A will be updated in Revision 6 to include the analysis performed and results obtained for structure-soil-structure interaction between the FWSC and CB.

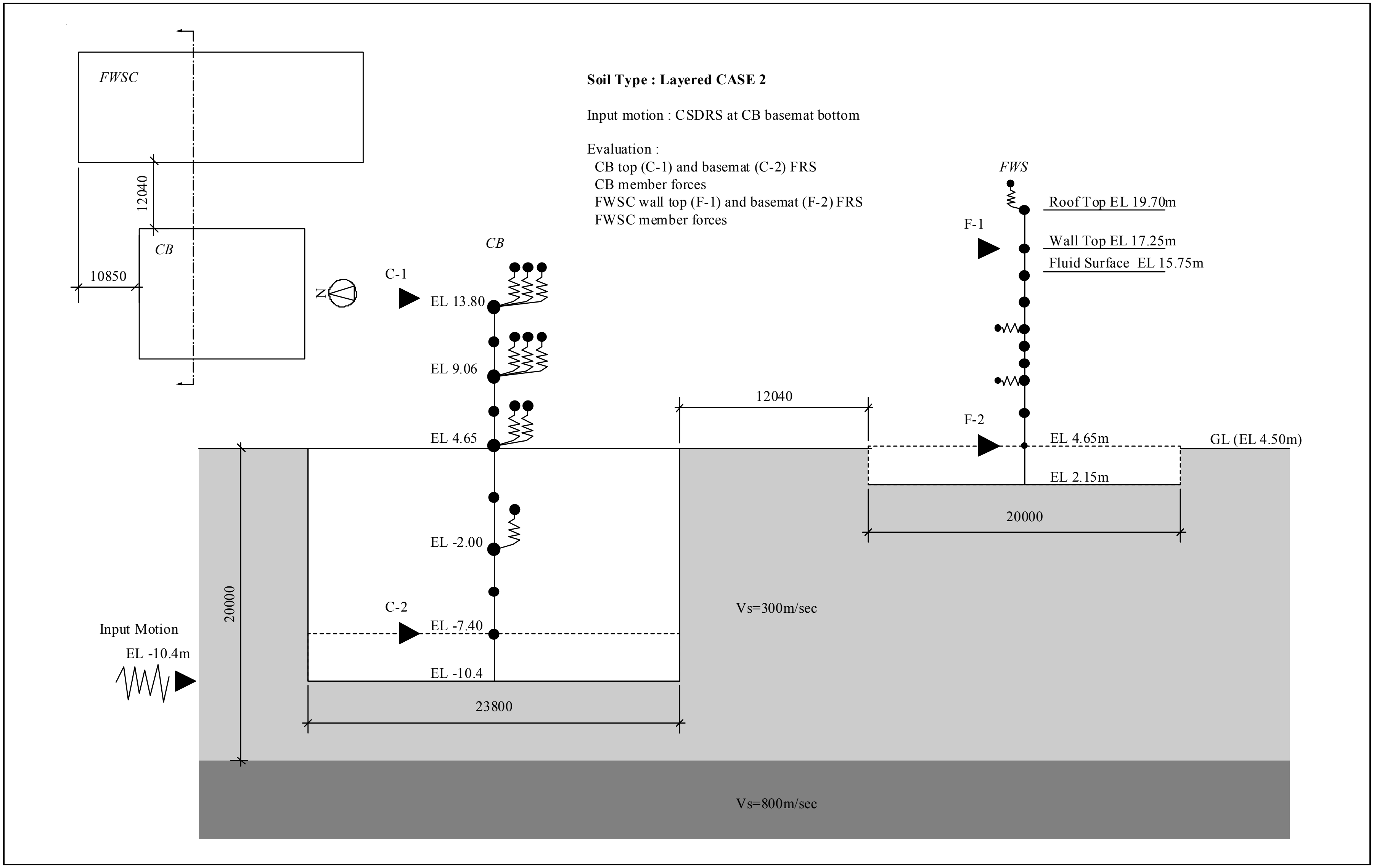


Figure 3.7-63(8) Structure-Structure Interaction Analysis Model

Table 3.7-63(1) FWSC Vertical Acceleration

(a) Structure-Structure Analysis

Elev. (m)	Node No.	Stick Model	Max. Vertical Acceleration (g)
19.70	10	FWS	0.48
17.25	9	FWS	0.48
15.53	8	FWS	0.48
13.81	7	FWS	0.48
12.10	6	FWS	0.48
11.00	5	FWS	0.48
9.90	4	FWS	0.48
8.81	3	FWS	0.48
6.73	2	FWS	0.47
4.65	8002	FWSC	0.47
2.15	8001	FWSC	0.46
19.70	11	Oscillator	1.35

Elev. (m)	Node No.	Stick Model	Max. Vertical Acceleration (g)
8.25	405	FPE	0.46
6.45	402	FPE	0.46

(b) DCD Rev.5

Elevation (m)	Node No.	Stick Model	Max. Vertical Acceleration (g)
19.70	10	FWS	1.69
17.25	9	FWS	1.64
15.53	8	FWS	1.58
13.81	7	FWS	1.58
12.10	6	FWS	1.43
11.00	5	FWS	1.23
9.90	4	FWS	1.13
8.81	3	FWS	1.05
6.73	2	FWS	1.00
4.65	8002	FWSC	0.78
2.15	8001	FWSC	0.78
19.70	11	Oscillator	3.26

Elevation (m)	Node No.	Stick Model	Max. Vertical Acceleration (g)
8.25	405	FPE	1.12
6.45	402	FPE	1.09

(c) Ratio with DCD Rev.5 ((a)/(b))

Elevation (m)	Node No.	Stick Model	Ratio with DCD Rev.5
19.70	10	FWS	29%
17.25	9	FWS	29%
15.53	8	FWS	31%
13.81	7	FWS	31%
12.10	6	FWS	34%
11.00	5	FWS	39%
9.90	4	FWS	43%
8.81	3	FWS	46%
6.73	2	FWS	47%
4.65	8002	FWSC	61%
2.15	8001	FWSC	59%
19.70	11	Oscillator	41%

Elevation (m)	Node No.	Stick Model	Ratio with DCD Rev.5
8.25	405	FPE	41%
6.45	402	FPE	42%

Table 3.7-63(2) FWSC Seismic Forces

(a) Structure-Structure Analysis

FWS

Elev. (m)	Node No.	Elem No.	Shear		Moment		Torsion (MN-m)
			X-dir. (MN)	Y-dir. (MN)	X-dir. (MN-m)	Y-dir. (MN-m)	
19.70	10				0.7	0.8	
		9	1.0	1.0	2.7	3.0	0.5
17.25	9				3.6	4.3	
		8	2.6	2.6	7.6	8.3	1.6
15.53	8				8.4	9.6	
		7	3.7	3.6	14.3	15.4	2.7
13.81	7				14.8	16.5	
		6	4.7	4.6	22.7	24.6	3.6
12.10	6				23.1	24.9	
		5	5.6	5.5	29.2	31.6	4.3
11.00	5				29.5	31.8	
		4	6.2	6.0	36.1	39.3	4.9
9.90	4				36.5	39.6	
		3	6.9	6.6	43.8	45.4	5.3
8.81	3				44.1	47.3	
		2	13.7	13.0	71.9	70.8	5.8
6.73	2				72.3	71.5	
4.65	1	1	14.9	14.0	103.2	97.6	6.3

FPE

Elev. (m)	Node No.	Elem No.	Shear		Moment		Torsion (MN-m)
			X-dir. (MN)	Y-dir. (MN)	X-dir. (MN-m)	Y-dir. (MN-m)	
8.25	405	402,			1.1	3.1	
4.65	404	401	2.1	2.1	6.6	7.4	2.7

(b) DCD Rev.5

FWS

Elev. (m)	Node No.	Elem No.	Shear		Moment		Torsion (MN-m)
			X-dir. (MN)	Y-dir. (MN)	X-dir. (MN-m)	Y-dir. (MN-m)	
19.70	10				4.3	7.0	
		9	4.6	5.1	14.2	19.3	0.7
17.25	9				22.1	26.7	
		8	11.1	12.1	39.0	46.9	2.2
15.53	8				45.4	57.2	
		7	15.5	16.5	70.7	84.4	3.6
13.81	7				76.1	92.3	
		6	19.3	20.1	107.5	124.5	4.9
12.10	6				111.3	128.4	
		5	22.8	23.8	133.8	152.9	5.8
11.00	5				136.4	157.0	
		4	24.6	25.3	163.4	184.2	6.4
9.90	4				165.6	187.5	
		3	26.1	26.6	194.2	216.5	6.9
8.81	3				197.0	220.6	
		2	43.3	45.5	278.9	295.0	7.5
6.73	2				280.9	298.7	
4.65	1	1	45.3	48.0	366.2	375.3	8.1

FPE

Elev. (m)	Node No.	Elem No.	Shear		Moment		Torsion (MN-m)
			X-dir. (MN)	Y-dir. (MN)	X-dir. (MN-m)	Y-dir. (MN-m)	
8.25	405	402,			2.2	9.7	
4.65	404	401	8.1	7.4	27.7	27.0	15.1

(c) Ratio with DCD Rev.5 ((a)/(b))

FWS

Elev. (m)	Node No.	Elem No.	Shear		Moment		Torsion (MN-m)
			X-dir.	Y-dir.	X-dir.	Y-dir.	
19.70	10				16%	12%	
		9	22%	20%	19%	15%	74%
17.25	9				16%	16%	
		8	23%	21%	19%	18%	74%
15.53	8				18%	17%	
		7	24%	22%	20%	18%	74%
13.81	7				19%	18%	
		6	25%	23%	21%	20%	75%
12.10	6				21%	19%	
		5	24%	23%	22%	21%	75%
11.00	5				22%	20%	
		4	25%	24%	22%	21%	76%
9.90	4				22%	21%	
		3	26%	25%	23%	21%	77%
8.81	3				22%	21%	
		2	32%	29%	26%	24%	78%
6.73	2				26%	24%	
4.65	1	1	33%	29%	28%	26%	78%

FPE

Elev. (m)	Node No.	Elem No.	Shear		Moment		Torsion (MN-m)
			X-dir.	Y-dir.	X-dir.	Y-dir.	
8.25	405	402,			52%	33%	
4.65	404	401	26%	28%	24%	27%	18%

Table 3.7-63(3) CB Vertical Acceleration

(a) Structure-Structure Analysis

Elevation (m)	Node No.	Stick Model	Max. Vertical Acceleration (g)
13.80	6	CB	0.43
9.06	5	CB	0.41
4.65	4	CB	0.40
-2.00	3	CB	0.37
-7.40	2	CB	0.36
-10.40	1	CB	0.36
13.50	9001	Oscillator	0.89
	9002	Oscillator	0.55
	9003	Oscillator	0.58
9.06	9101	Oscillator	0.81
	9102	Oscillator	0.48
	9103	Oscillator	0.53
4.65	9201	Oscillator	0.45
	9202	Oscillator	0.49
-2.00	9301	Oscillator	0.41

(b) DCD Rev.5

Elevation (m)	Node No.	Stick Model	Max. Vertical Acceleration (g)
13.80	6	CB	1.00
9.06	5	CB	0.86
4.65	4	CB	0.74
-2.00	3	CB	0.56
-7.40	2	CB	0.51
-10.40	1	CB	0.51
13.50	9001	Oscillator	2.19
	9002	Oscillator	1.34
	9003	Oscillator	1.43
9.06	9101	Oscillator	2.00
	9102	Oscillator	1.26
	9103	Oscillator	1.43
4.65	9201	Oscillator	1.30
	9202	Oscillator	1.43
-2.00	9301	Oscillator	1.39

(c) Ratio with DCD Rev.5 ((a)/(b))

Elevation (m)	Node No.	Stick Model	Max. Vertical Acceleration (g)
13.80	6	CB	43%
9.06	5	CB	48%
4.65	4	CB	54%
-2.00	3	CB	66%
-7.40	2	CB	71%
-10.40	1	CB	71%
13.50	9001	Oscillator	41%
	9002	Oscillator	41%
	9003	Oscillator	41%
9.06	9101	Oscillator	41%
	9102	Oscillator	38%
	9103	Oscillator	37%
4.65	9201	Oscillator	35%
	9202	Oscillator	34%
-2.00	9301	Oscillator	30%

Table 3.7-63(4) CB Seismic Forces

(a) Structure-Structure Analysis

Elev. (m)	Node No.	Elem No.	Shear X-Dir. (MN)	Shear Y-Dir. (MN)	Moment X-Dir. (MN-m)	Moment Y-Dir. (MN-m)	Torsion (MN-m)
13.80	6				29	26	
		6	10.6	12.7	59	59	8.8
9.06	5				73	81	
		5	20.7	24.0	158	175	20.3
4.65	4				71	96	
		4	40.4	45.8	311	274	25.2
-2.00	3				112	145	
-7.40	2	3	74.5	84.9	466	514	40.8

(b) DCD Rev.5

Elev. (m)	Node No.	Elem No.	Shear X-Dir. (MN)	Shear Y-Dir. (MN)	Moment X-Dir. (MN-m)	Moment Y-Dir. (MN-m)	Torsion (MN-m)
13.80	6				160	124	
		6	33.1	29.1	250	197	73.2
9.06	5				360	275	
		5	53.3	54.8	573	443	127.8
4.65	4				723	540	
		4	75.6	80.1	1136	988	178.2
-2.00	3				1232	1036	
-7.40	2	3	124.4	99.4	1570	1525	248.2

(c) Ratio with DCD Rev.5 ((a)/(b))

Elev. (m)	Node No.	Elem No.	Shear X-Dir. (MN)	Shear Y-Dir. (MN)	Moment X-Dir. (MN-m)	Moment Y-Dir. (MN-m)	Torsion
13.80	6				18%	21%	
		6	32%	44%	24%	30%	12%
9.06	5				20%	29%	
		5	39%	44%	28%	40%	16%
4.65	4				10%	18%	
		4	53%	57%	27%	28%	14%
-2.00	3				9%	14%	
-7.40	2	3	60%	85%	30%	34%	16%

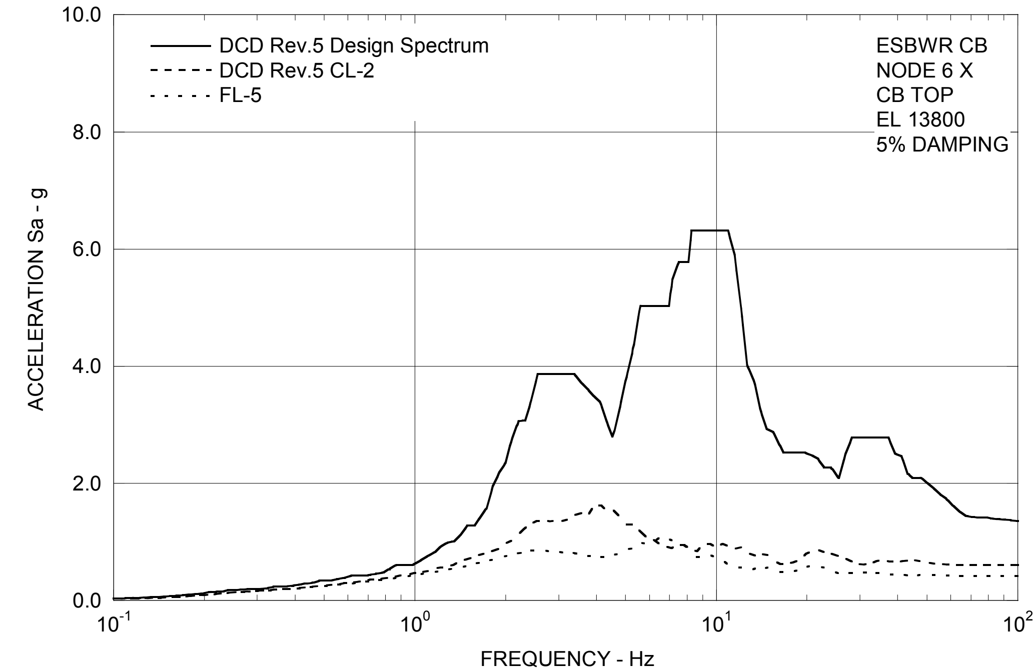


Figure 3.7-63(9) FRS (Effect of Structure-Structure Interaction) – CB Top X

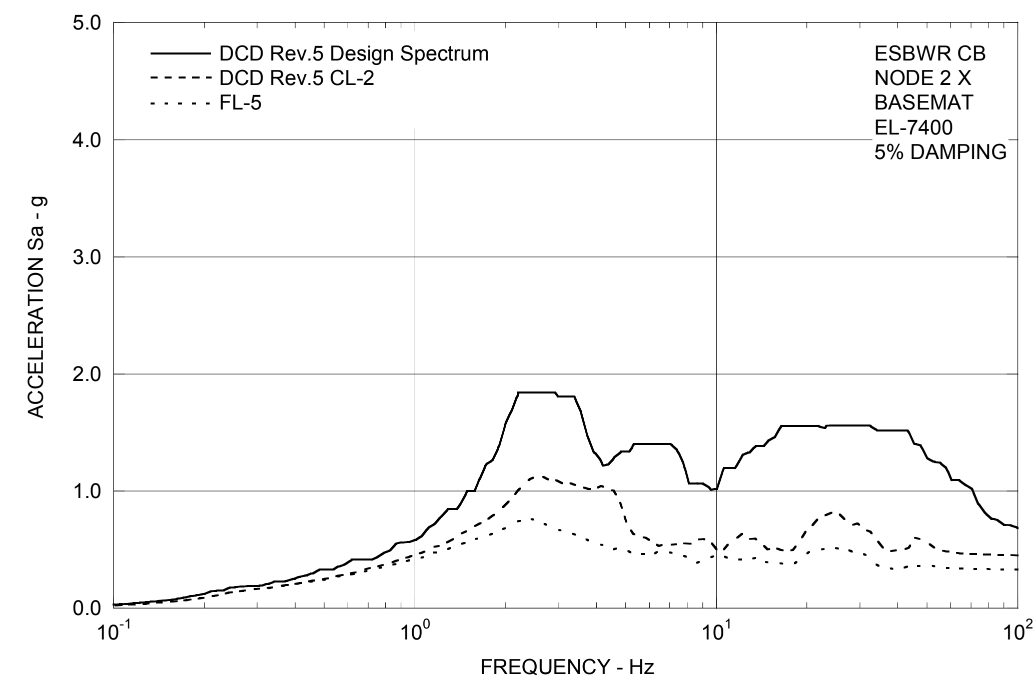


Figure 3.7-63(10) FRS (Effect of Structure-Structure Interaction) – CB Basemat X

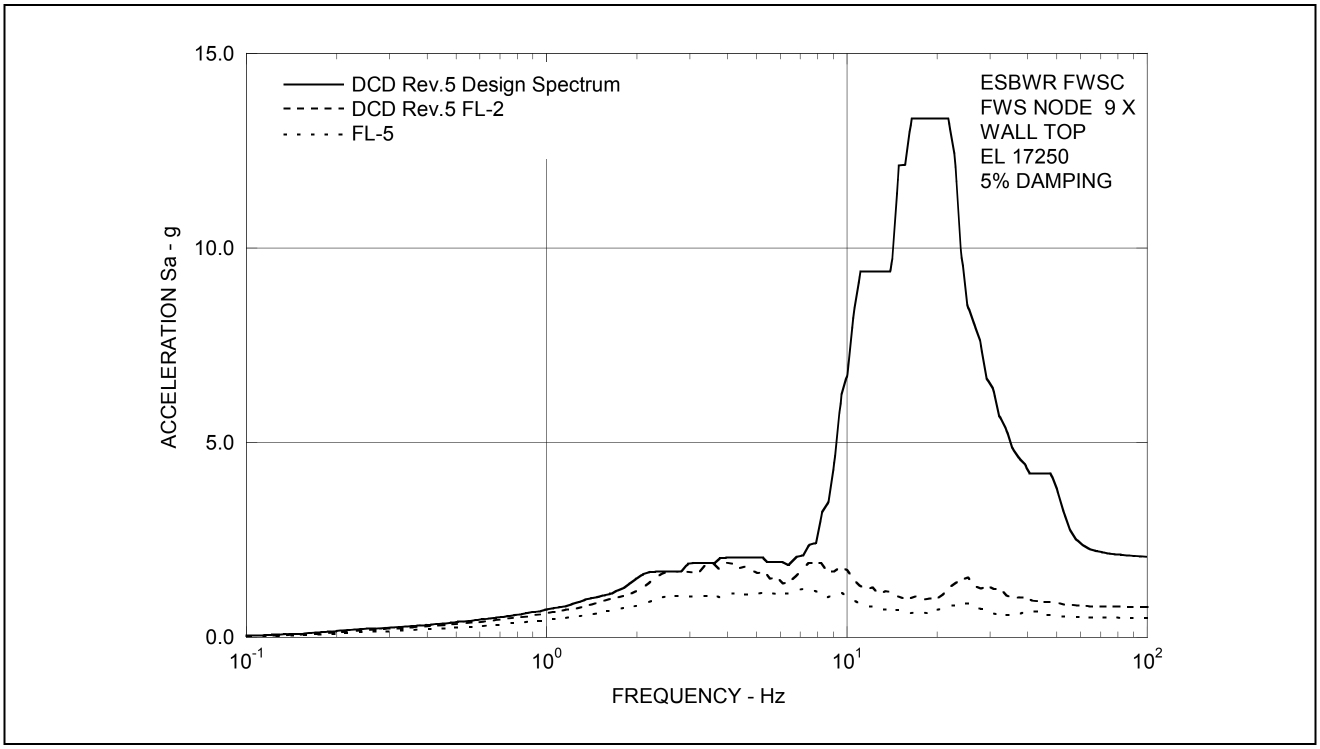


Figure 3.7-63(11) FRS (Effect of Structure-Structure Interaction) – FWS Wall Top X

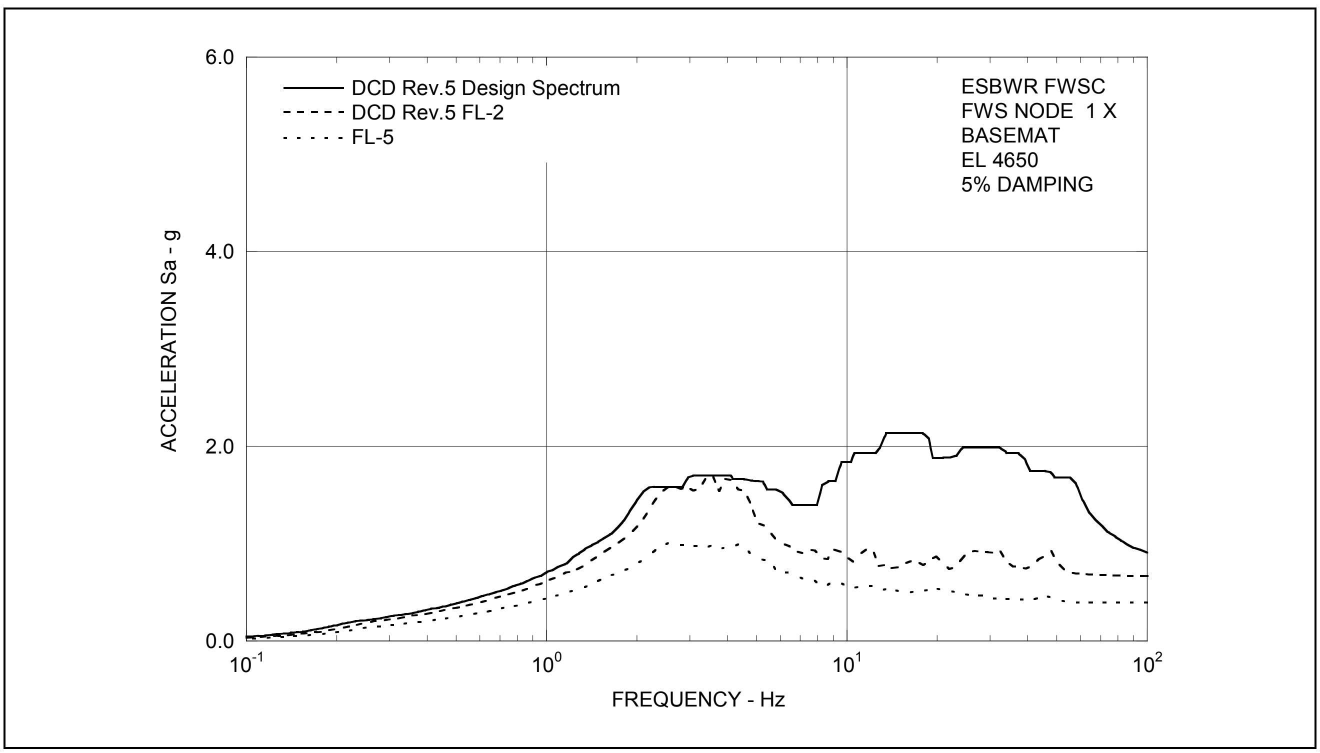


Figure 3.7-63(12) FRS (Effect of Structure-Structure Interaction) – FWS Basemat X

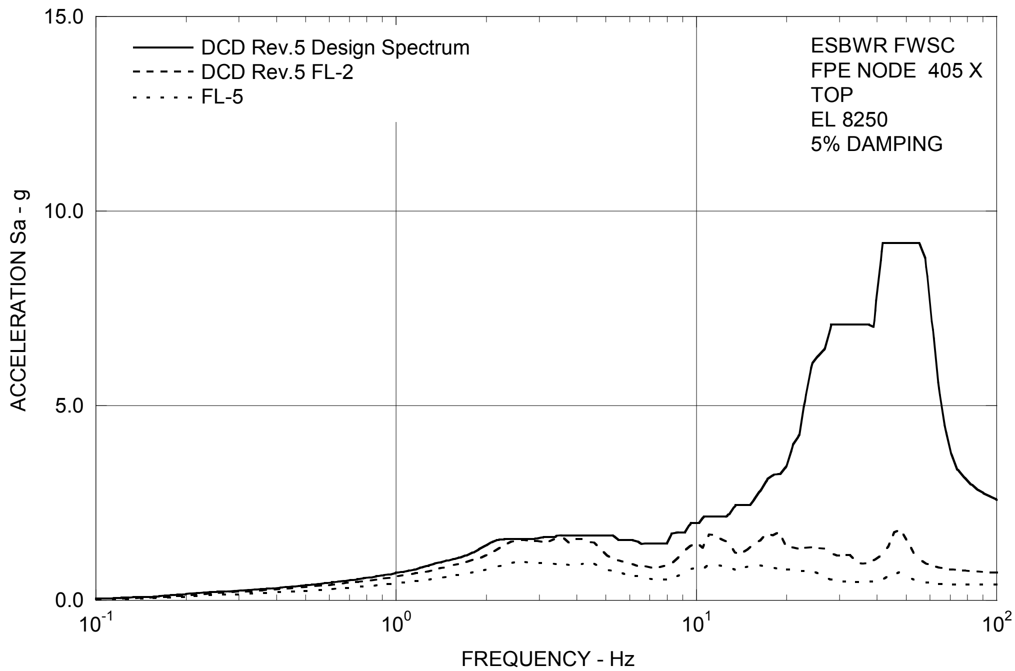


Figure 3.7-63(13) FRS (Effect of Structure-Structure Interaction) – FPE Top X

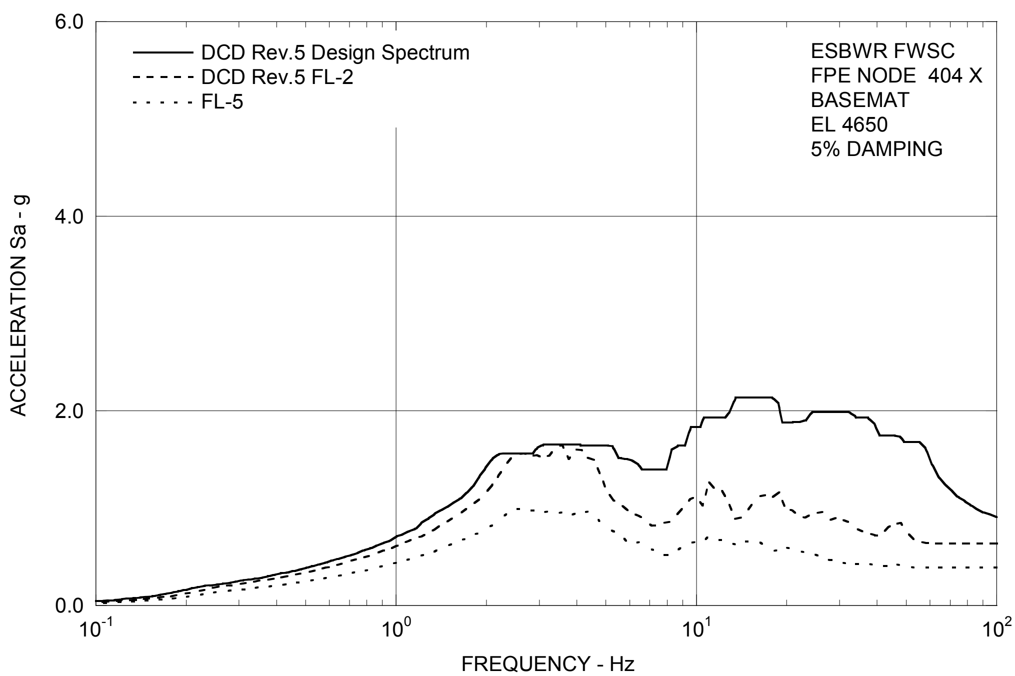


Figure 3.7-63(14) FRS (Effect of Structure-Structure Interaction) – FPE Basemat X

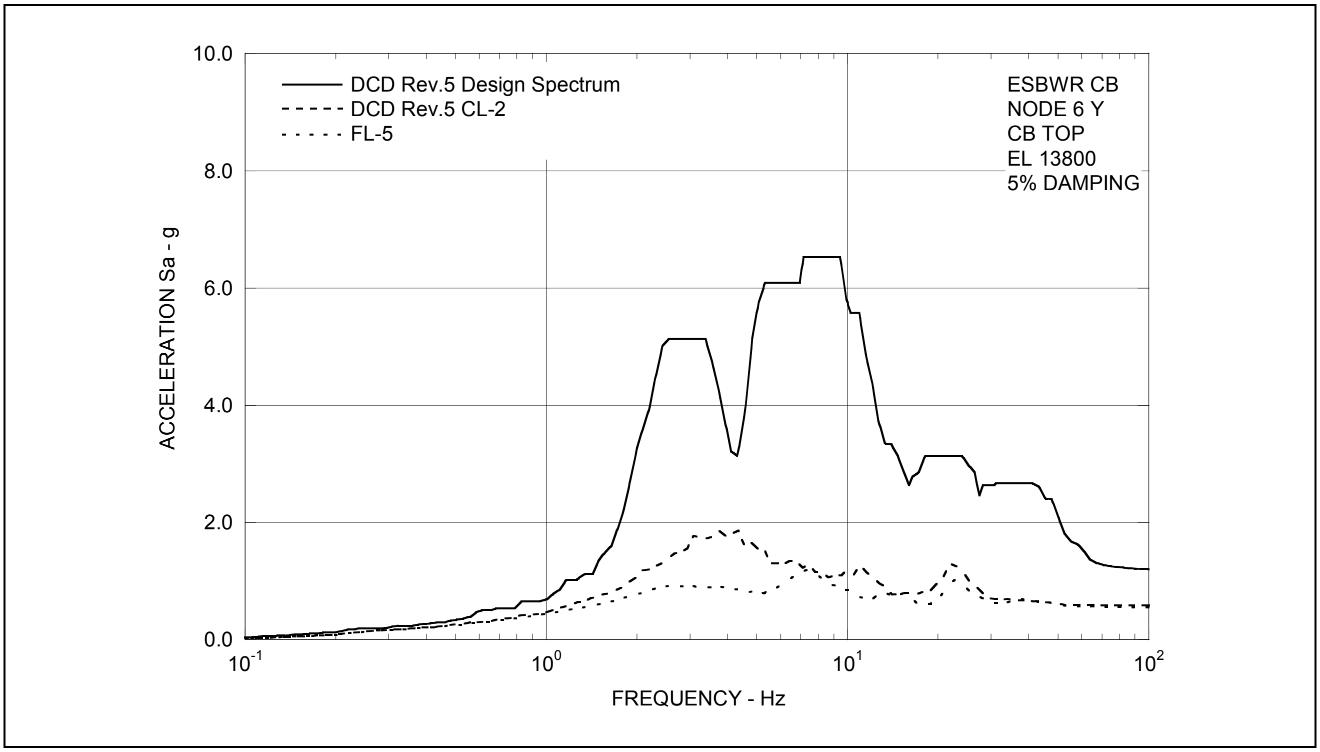


Figure 3.7-63(15) FRS (Effect of Structure-Structure Interaction) – CB Top Y

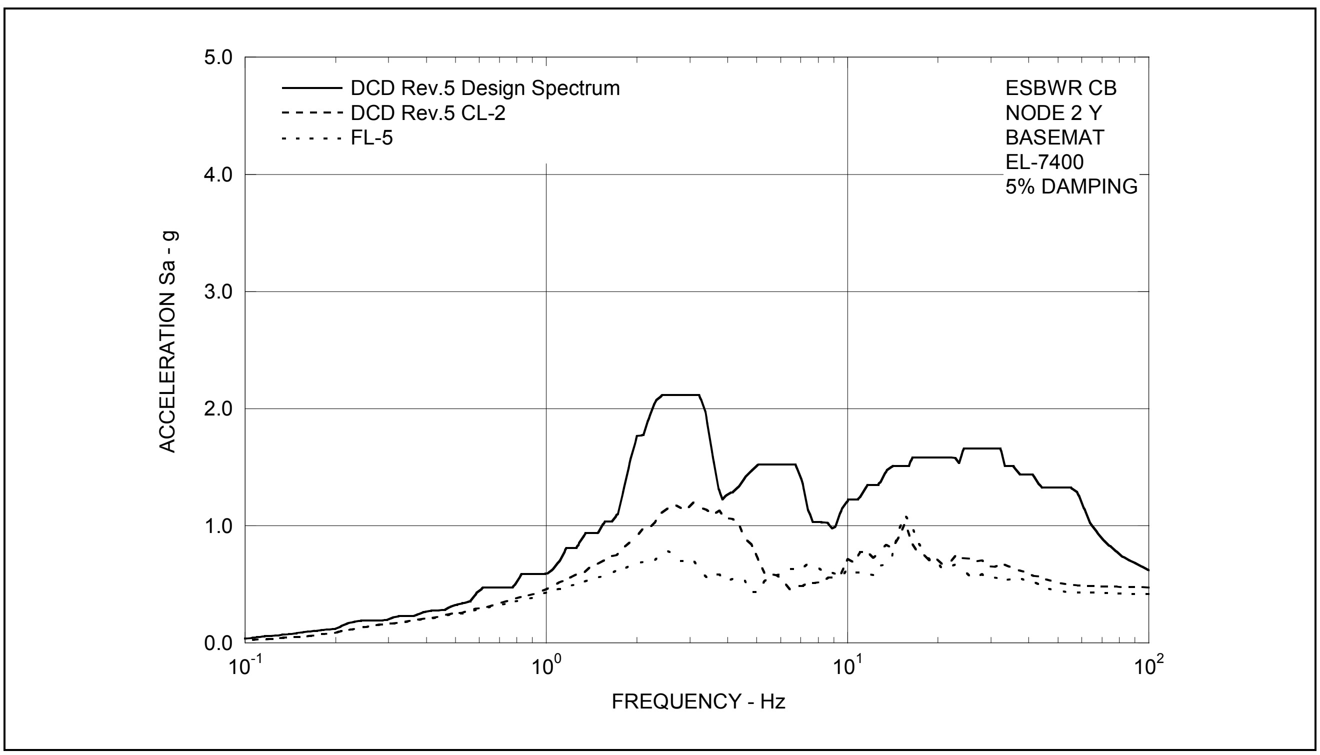


Figure 3.7-63(16) FRS (Effect of Structure-Structure Interaction) – CB Basemat Y

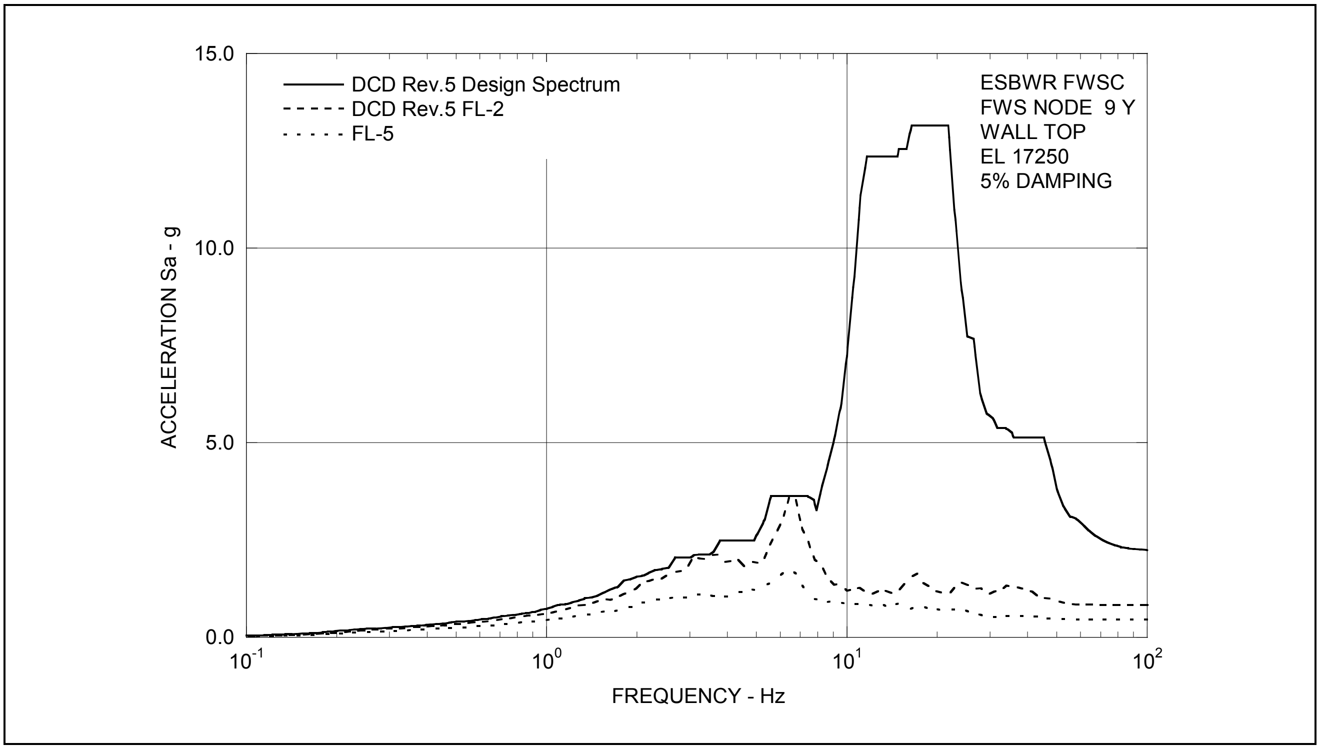


Figure 3.7-63(17) FRS (Effect of Structure-Structure Interaction) – FWS Wall Top Y

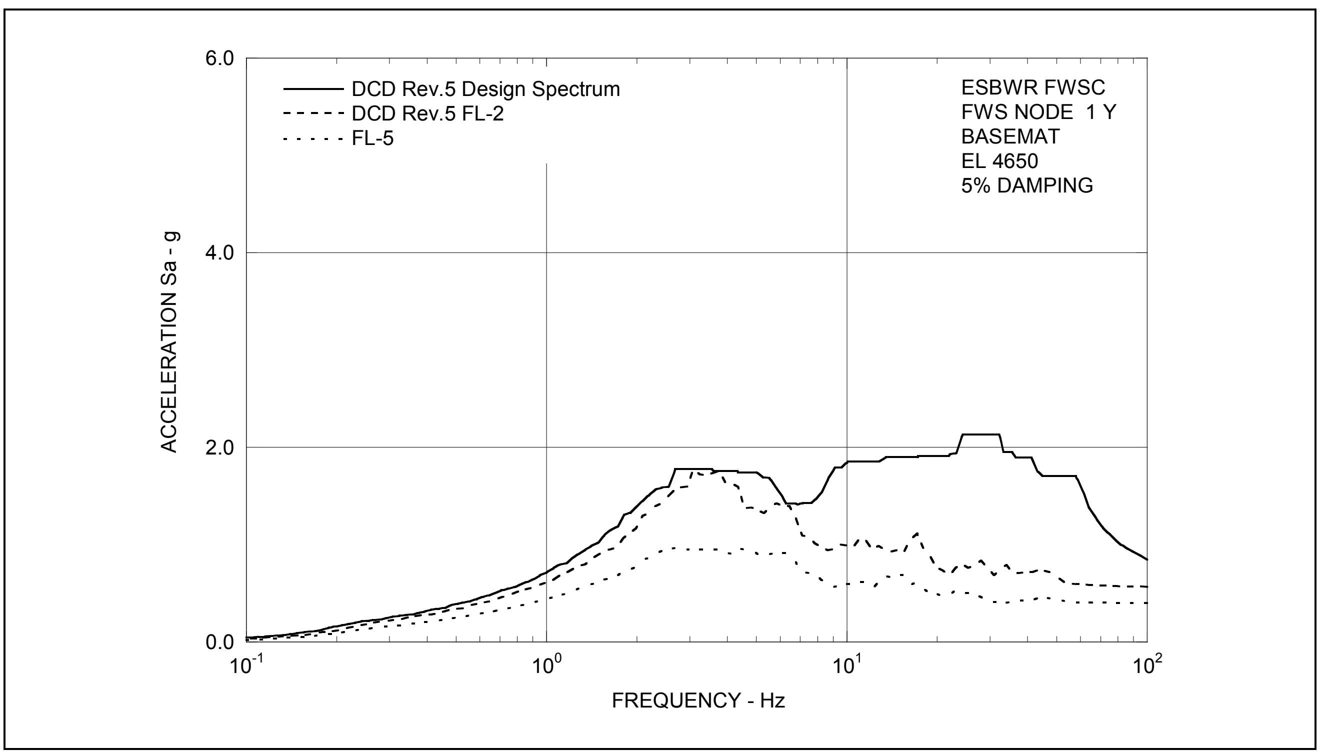


Figure 3.7-63(18) FRS (Effect of Structure-Structure Interaction) – FWS Basemat Y

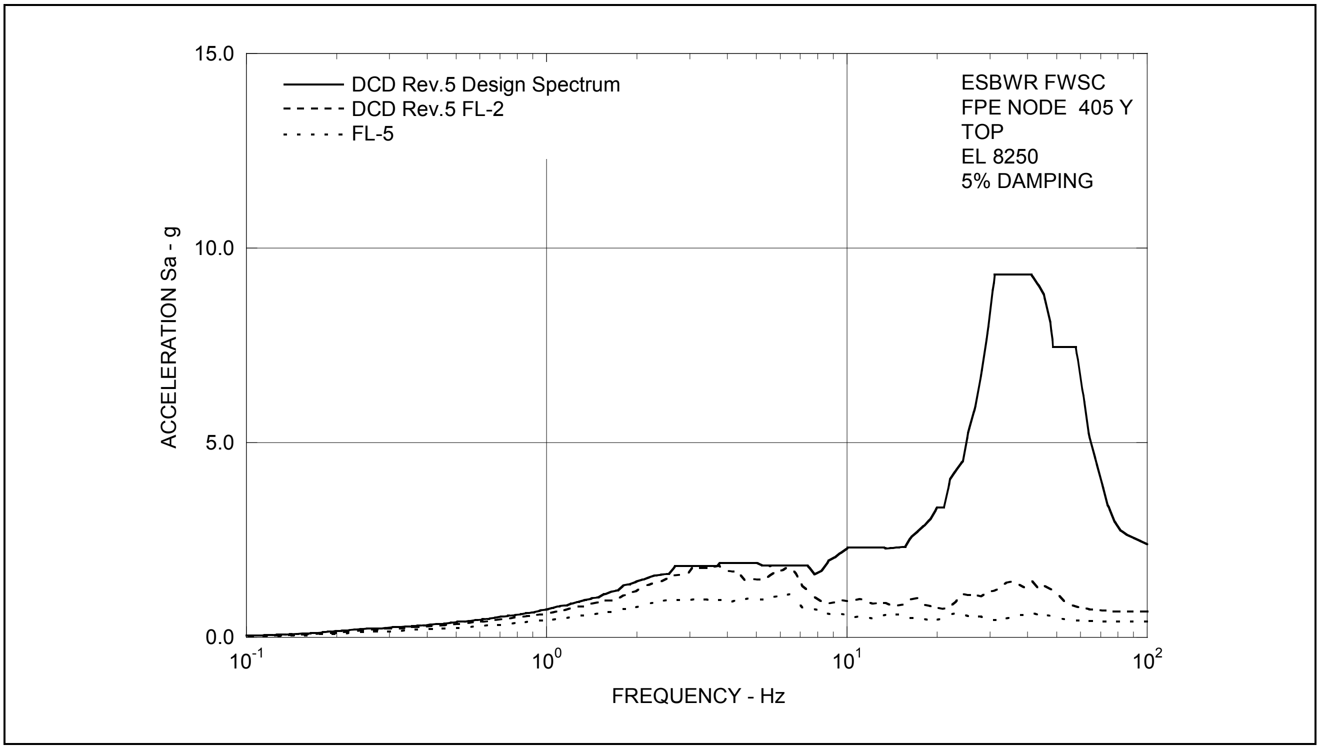


Figure 3.7-63(19) FRS (Effect of Structure-Structure Interaction) – FPE Top Y

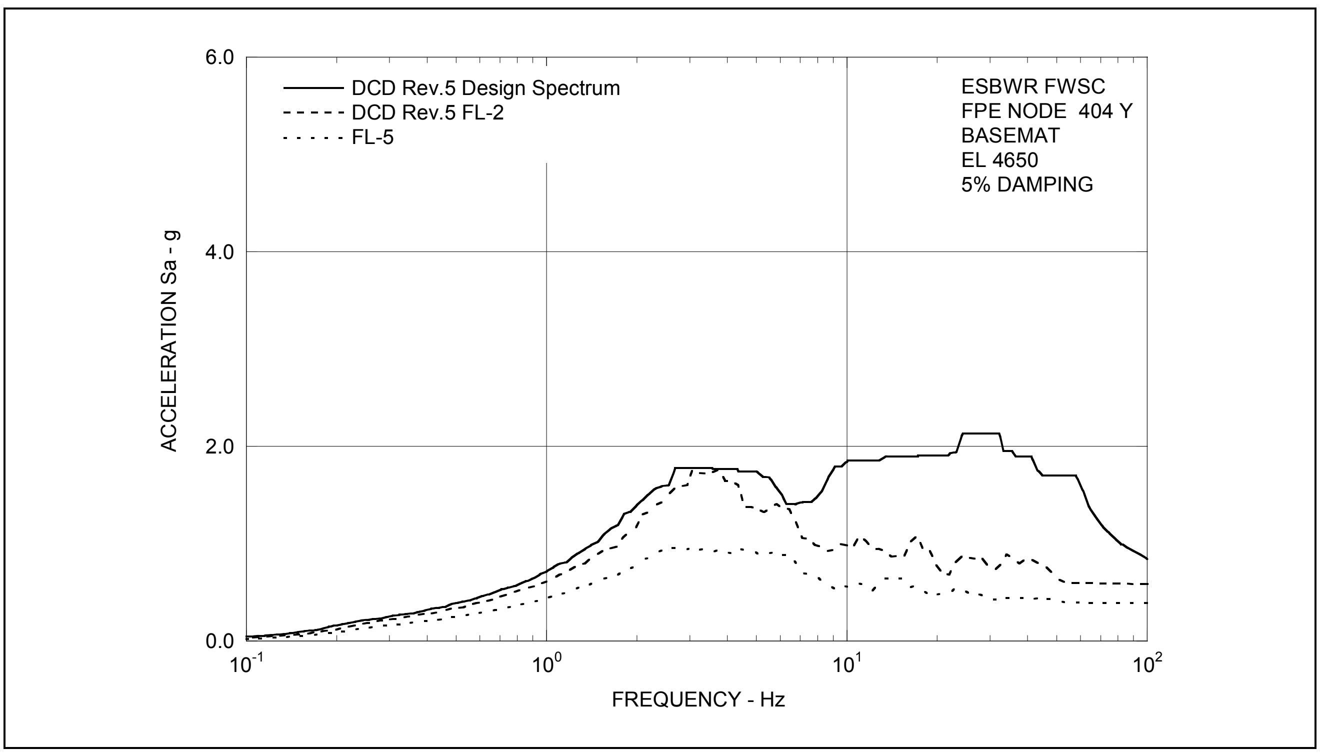


Figure 3.7-63(20) FRS (Effect of Structure-Structure Interaction) – FPE Basemat Y

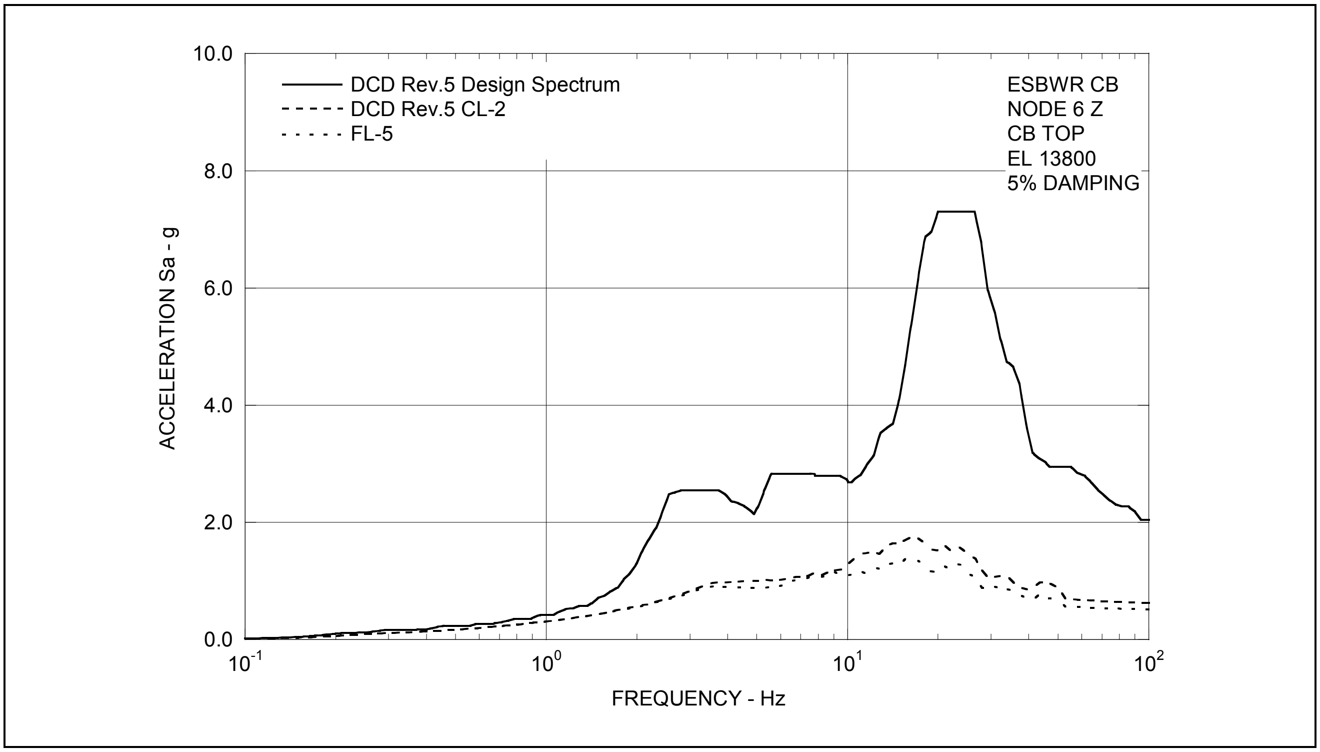


Figure 3.7-63(21) FRS (Effect of Structure-Structure Interaction) – CB Top Z

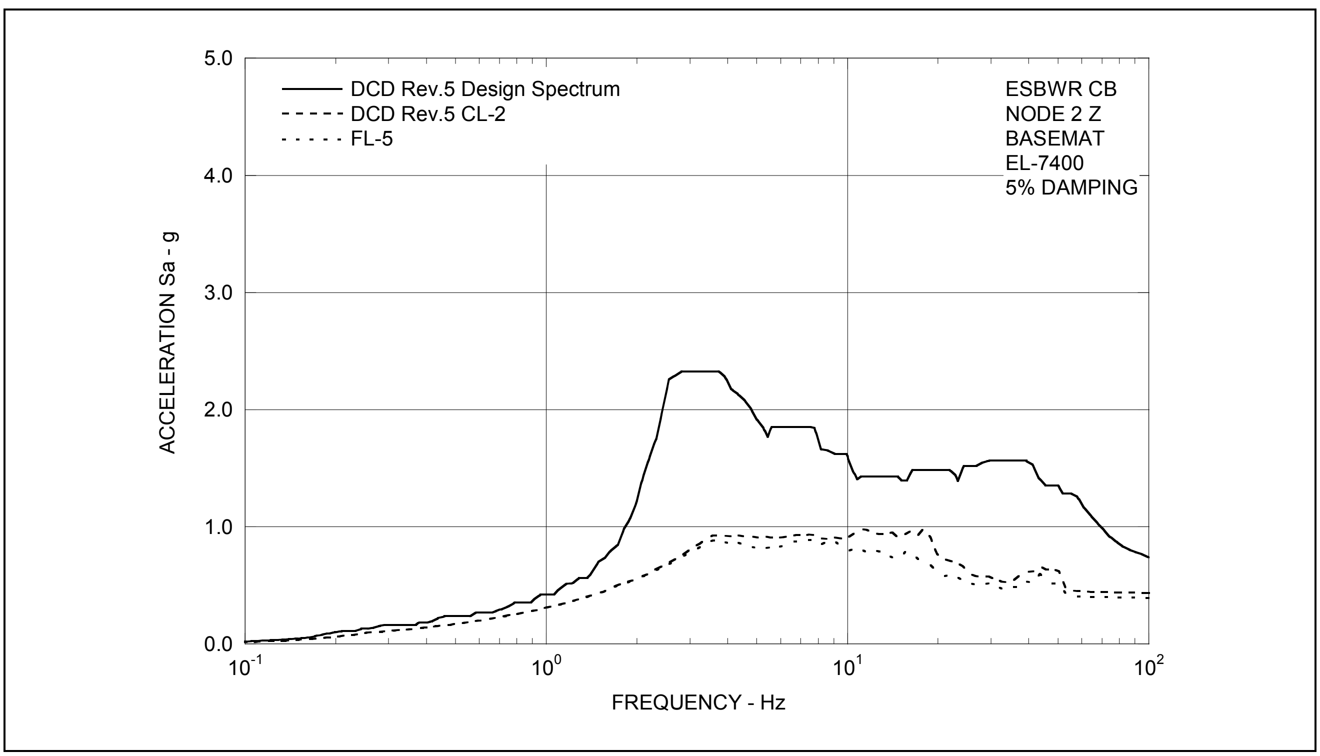


Figure 3.7-63(22) FRS (Effect of Structure-Structure Interaction) – CB Basemat Z

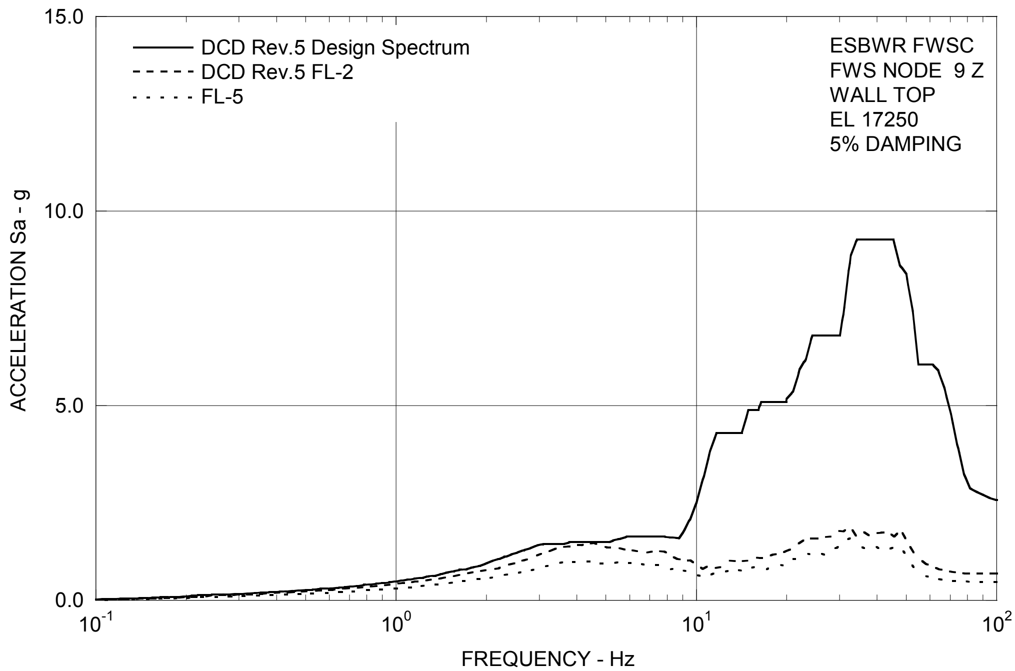


Figure 3.7-63(23) FRS (Effect of Structure-Structure Interaction) – FWS Wall Top Z

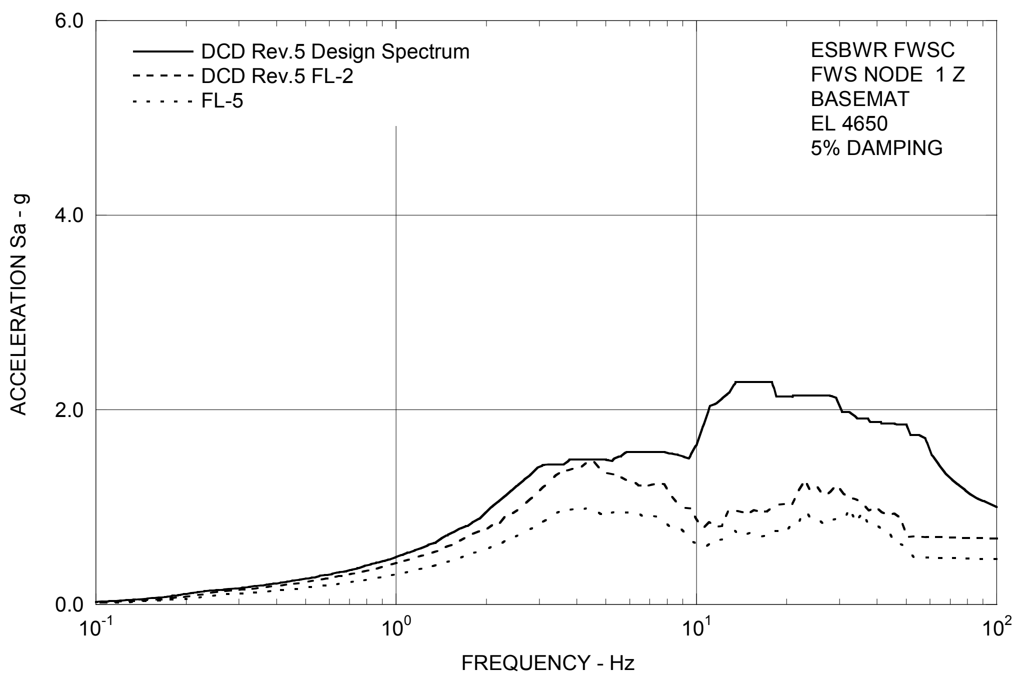


Figure 3.7-63(24) FRS (Effect of Structure-Structure Interaction) – FWS Basemat Z

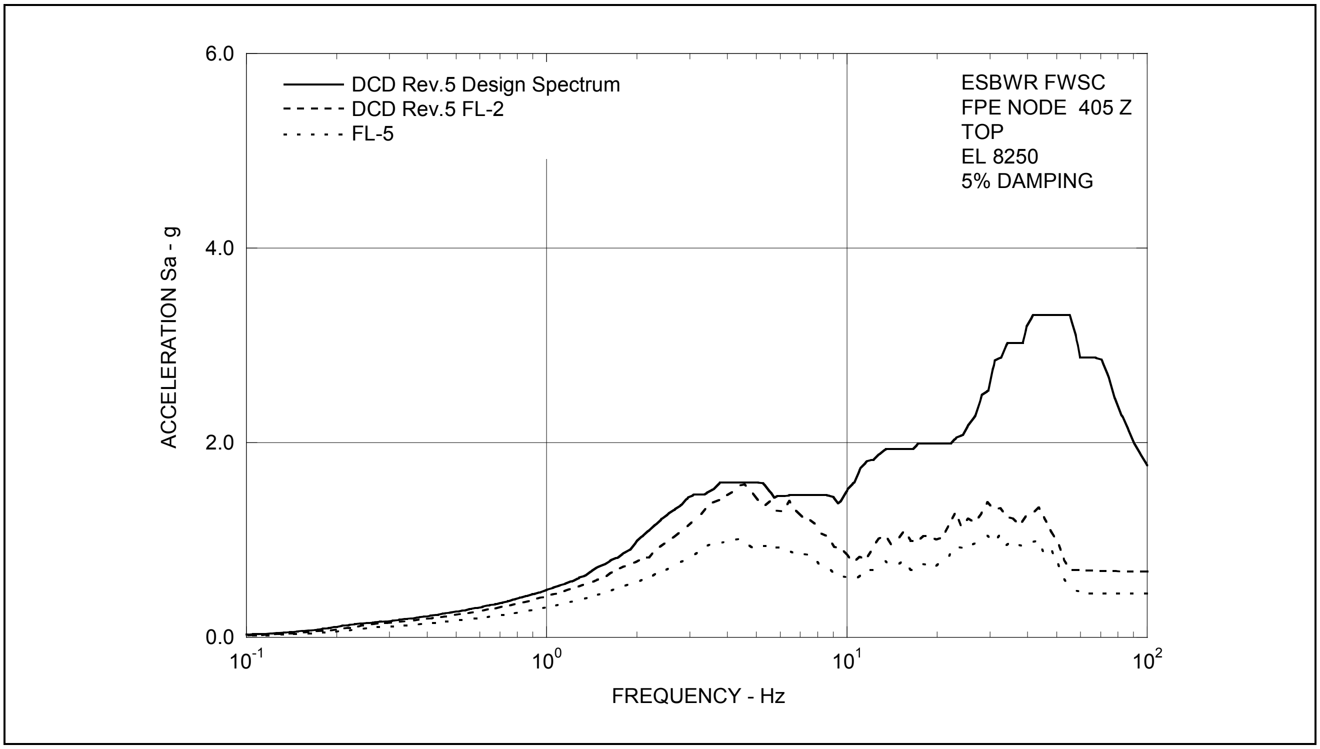


Figure 3.7-63(25) FRS (Effect of Structure-Structure Interaction) – FPE Top Z

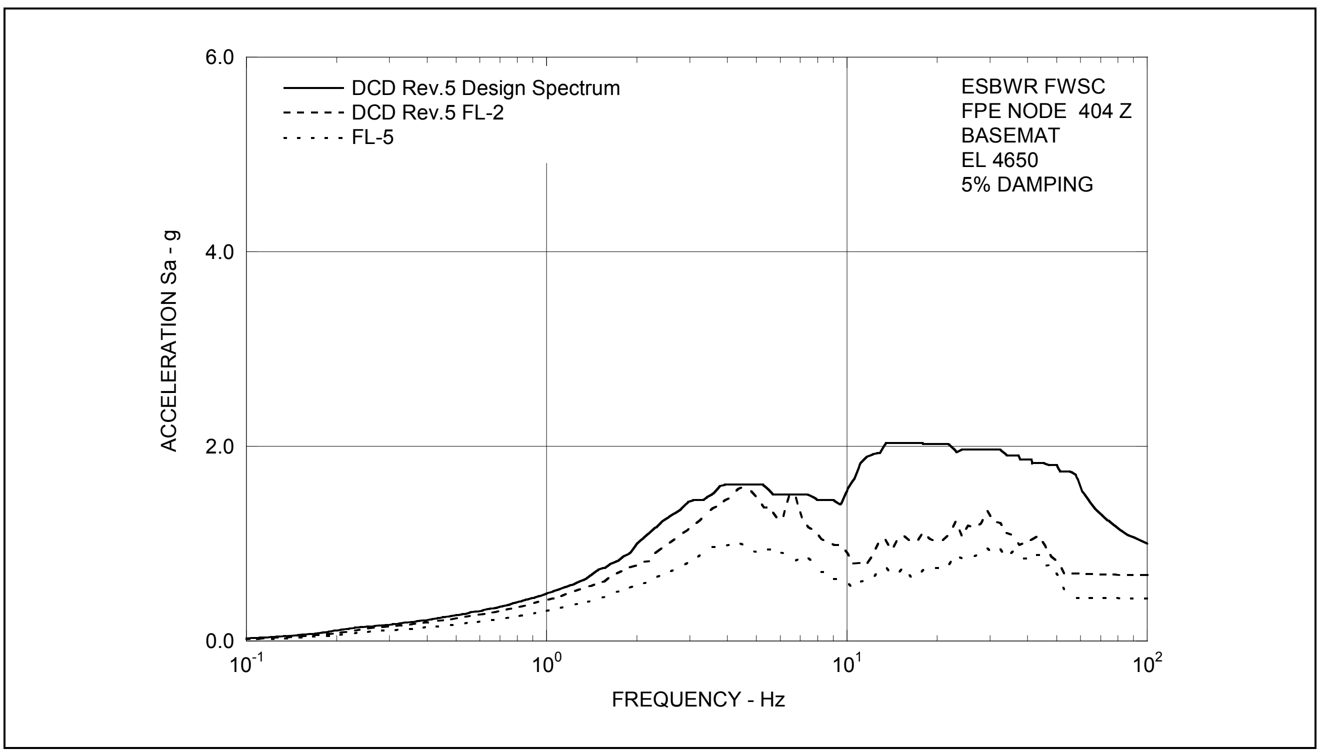


Figure 3.7-63(26) FRS (Effect of Structure-Structure Interaction) – FPE Basemat Z

DCD Impact

DCD Tier 2 Subsections 3A.1, 3A.6, 3A.8.11 and DCD Tier 2 Table 3A.6-1 will be revised in Revision 6 as noted in the attached markups.

DCD Tier 2 Figures 3A.8.11-7 through 3A.8.11-24 will be added in Revision 6 as noted in the attached markups.

3A. SEISMIC SOIL-STRUCTURE INTERACTION ANALYSIS

3A.1 INTRODUCTION

This appendix presents Soil-Structure Interaction (SSI) analysis performed for two site conditions, generic site and North Anna Early Site Permit (ESP) site-specific, adopted to establish seismic design loads for the Reactor Building (RB), Fuel Building (FB), Control Building (CB) and Firewater Service Complex (FWSC) of the ESBWR Standard Plant under safe shutdown earthquake (SSE) excitation. The RB and FB are integrated and founded on a common basemat. They are termed RB/FB hereafter. The FWSC is composed of two Firewater Storage Tanks (FWS) and a Fire Pump Enclosure (FPE), which are founded on a common basemat. The SSE design ground motion at the foundation level for both site conditions is described in Subsection 3.7.1. The SSI analysis results are presented here in the form of site-enveloped seismic responses at key locations in the RB/FB, CB and FWSC. The structural adequacy calculations for the RB, FB, CB and FWSC are shown in Appendix 3G.

For a standard plant design, the analysis must be performed over a range of site parameters. The site parameters considered and their ranges together form the generic site conditions. The generic site conditions are selected to provide an adequate seismic design margin for the standard plant located at any site with site parameters within the range of parameters considered in this study. In addition, the North Anna ESP site-specific condition is also considered in this study. When actual sites for these facilities are selected, site-specific geotechnical data is developed and submitted to the Nuclear Regulatory Commission (NRC) demonstrating compatibility with the site enveloping parameters considered in the standard design.

This appendix details the basis for selecting the site conditions and analysis cases, and the method of the seismic SSI analysis. Descriptions of the input motion and damping values, the structural model, and the soil model are included. The parametric study SSI results as well as the enveloping seismic responses are also presented.

To demonstrate the seismic adequacy of the standard ESBWR design, 34~~1~~ RB/FB cases, 14~~1~~ CB cases and 74 FWSC cases are analyzed for the uniform site cases using the sway-rocking stick model for the SSE condition. In addition, 6 RB/FB cases, 6 CB cases and 54 FWSC cases are analyzed for the layered site cases using the SASSI2000 SSI model. The enveloped results reported in this appendix form the design SSE loads.

3A.6 SOIL-STRUCTURE INTERACTION ANALYSIS CASES

To establish design envelopes of seismic responses of the RB/FB complex, SSI analyses are performed for 3134 cases of uniform sites and 6 cases of layered sites, as summarized in Table 3A.6-1. Similarly for the CB, SSI analyses are performed for 11 14 cases of uniform sites and 6 cases of layered sites. SSI analyses for the FWSC are performed for 4 7 cases of uniform sites and 54 cases of layered sites.

The enveloping results are obtained from the responses of all SSI cases to cover a wide range of conditions.

Table 3A.6-1

Seismic SSI Analysis Cases (Continued)

Building	No.	Model	Input Motion	Layered Soil Conditions			
				case1	case2	case3	case4
RBFB	RL-1	Base	Single envelope spectra	*			
	RL-2	Base	Single envelope spectra		*		
	RL-3	Base	Single envelope spectra			*	
	RL-4	Base	Single envelope spectra				*
	RL-5	Cracked (1)	Single envelope spectra	(critical case from RL-1 to RL-4)			
	RL-6	Cracked wall out-of-plane (2)	Single envelope spectra	(critical case from RL-1 to RL-4)			
CB	CL-1	Base	Single envelope spectra	*			
	CL-2	Base	Single envelope spectra		*		
	CL-3	Base	Single envelope spectra			*	
	CL-4	Base	Single envelope spectra				*
	CL-5	Cracked (1)	Single envelope spectra	(critical case from CL-1 to CL-4)			
	CL-6	Structure-structure interaction effect (3)	Single envelope spectra	(critical case from CL-1 to CL-4)			
FWSC	FL-1	Base	Single envelope spectra	*			
	FL-2	Base	Single envelope spectra		*		
	FL-3	Base	Single envelope spectra			*	
	FL-4	Base	Single envelope spectra				*
	FL-5	Structure-structure interaction effect (4)	Single envelope spectra	(critical case from CL-1 to CL-4)			
FWSC	FC-1	Cracked (1)	Single envelope spectra	(critical case from FU-1 and FL-1 to FL-4)			

Building	No.	Model	Input Motion	Layered Soil Conditions			
				case1	case2	case3	case4
RB/FB	RL-1	Base	Single envelope spectra	*			
	RL-2	Base	Single envelope spectra		*		
	RL-3	Base	Single envelope spectra			*	
	RL-4	Base	Single envelope spectra				*
	RL-5	Cracked (1)	Single envelope spectra	(critical case from RL-1 to RL-4)			
	RL-6	Cracked wall out-of-plane (2)	Single envelope spectra	(critical case from RL-1 to RL-4)			
CB	CL-1	Base	Single envelope spectra	*			
	~~CL-2~~	~~Base~~	~~Single envelope spectra~~		~~*~~		
	CL-3	Base	Single envelope spectra			*	
	CL-4	Base	Single envelope spectra				*
	CL-5	Cracked (1)	Single envelope spectra	(critical case from CL-1 to CL-4)			
	CL-6	Structure-structure interaction effect (3)	Single envelope spectra	(critical case from CL-1 to CL-4)			
FWSC	FL-1	Base	Single envelope spectra	*			
	FL-2	Base	Single envelope spectra		*		
	FL-3	Base	Single envelope spectra			*	
	FL-4	Base	Single envelope spectra				*
FWSC	FC-1	Cracked (1)	Single envelope spectra	(critical case from FU-1 and FL-1 to FL-4)			

(1) Concrete stiffness 50% reduced model considering crack effect

(2) Wall out-of-plane oscillator model considering crack effect

(3) Soil response obtained from the RB/FB analysis is used as input motion for the CB model

(4) The input motion for the coupled CB-FWSC interaction analysis is the CSDRS applied at the CB foundation level.

(2) Perform the CB SASSI2000 analysis using the input motion obtained in Step 1.

For the comparison of without and with structure-structure interaction effect, Case CL-2 layered site is selected, because the CB shows the largest responses at Case CL-2 site among various layered sites. The corresponding RB/FB case is Case RL-2. The CB case considering structure-structure interaction effect is called Case CL-6.

Comparisons of FRS at the top and basemat of the CB are shown in Figures 3A.8.11-1 through 3A.8.11-6. The broadened envelope results of Case CU-3 (uniform site, single envelope input motion case) are also shown in the figures for comparison.

It is found from the results that the effect of structure-structure interaction is the largest in the Y direction (East-West) FRS, however, both FRS without and with structure-structure interaction effect are bounded by the broadened envelope responses of uniform site cases in the whole frequency range. Thus the effect of structure-structure interaction between the RB/FB and CB is included in the enveloping design loads (Section 3A.9).

~~The FWSC is located about 12 m (39.4 ft) away from the CB and much farther away from the RB/FB. The FWSC is also less massive than the CB and RB/FB. Based on the effect on CB response due to the interaction with the RB/FB described above, the structure-to-structure interaction influence on the FWSC response is deemed insignificant.~~ In addition to the through-soil interaction between the RB/FB and CB described above, the structure-structure interaction analysis is also performed for the FWSC with CB for the same layered site Case 2 (CL-2 for CB and FL-2 for FWSC). The analysis model is composed of these two independent structures coupled through soil using the SASSI2000 computer code. The input motion for the coupled SSI model is the Certified Seismic Design Response Spectra (CSDRS) applied at the CB foundation level. This analysis case is named Case FL-5.

Figures 3A.8.11-7 through 3A.8.11-24 show comparisons of FRS with the design envelope spectra at the top of the structure and basemat for the CB and FWSC. The FRS for the corresponding analysis Cases CL-2 and FL-2 without the structure-structure interaction effect are also shown in the figures for comparison. It is confirmed from the results that the FRS with the structure-structure interaction effect are bounded by the design envelope spectra in all frequency ranges. Thus the effect of structure-structure interaction between the CB and FWSC is included in the enveloping design loads (Section 3A.9).

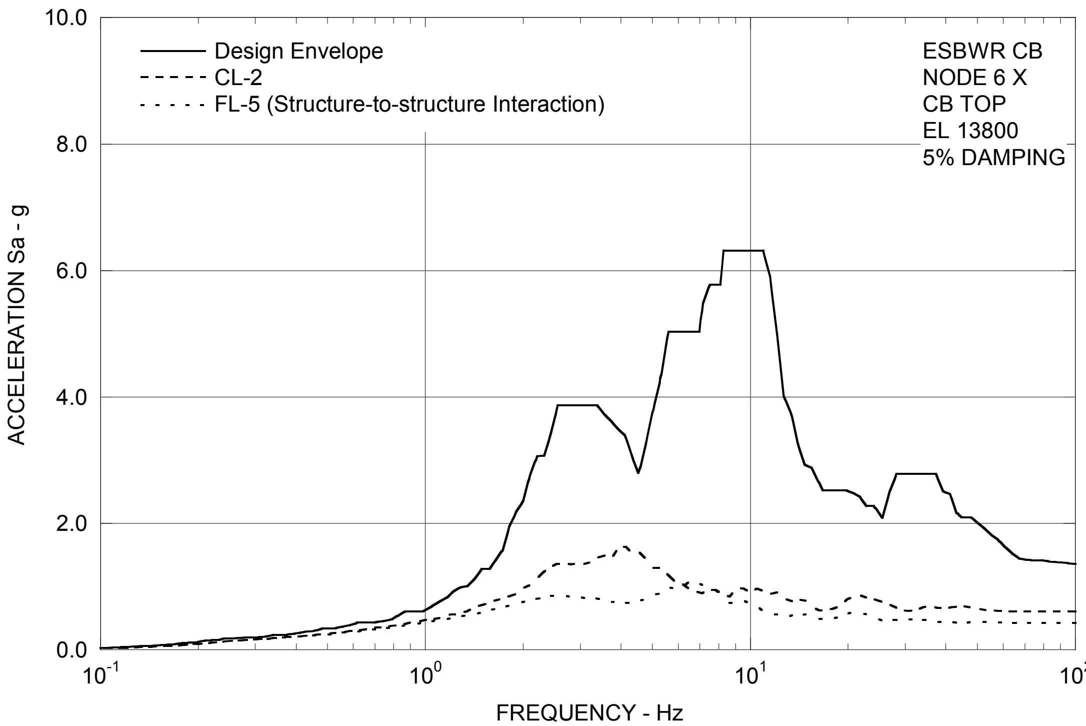


Figure 3A.8.11-7. FRS (Effect of Structure-Structure Interaction) – CB Top X

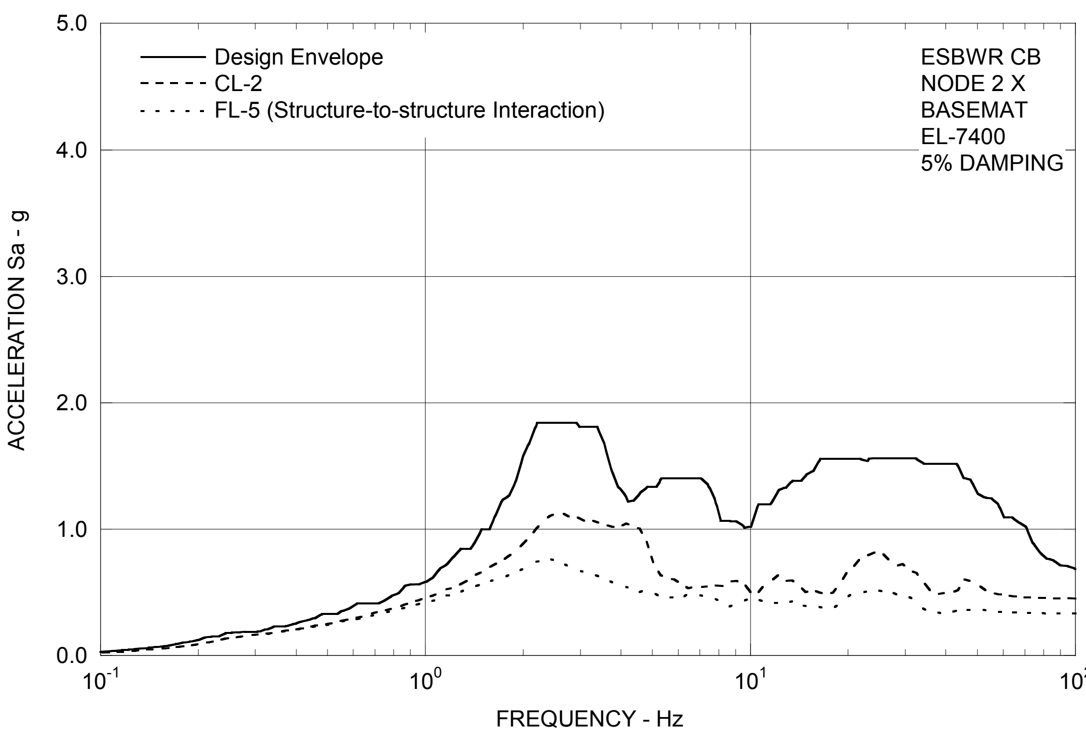


Figure 3A.8.11-8. FRS (Effect of Structure-Structure Interaction) – CB Basemat X

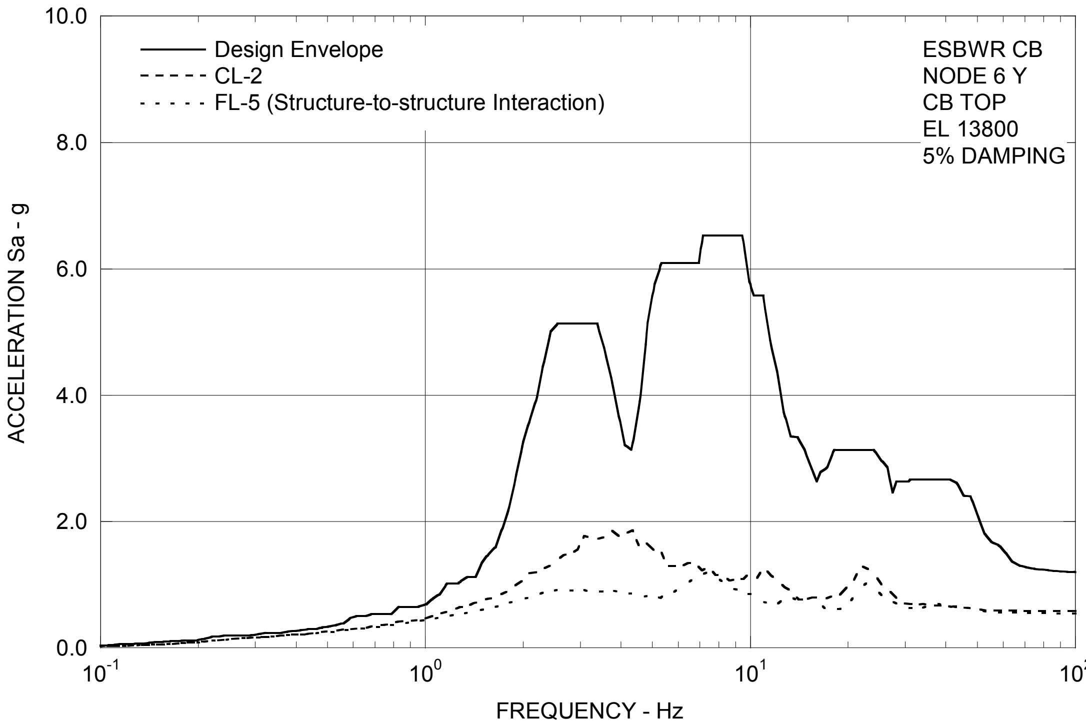


Figure 3A.8.11-9. FRS (Effect of Structure-Structure Interaction) – CB Top Y

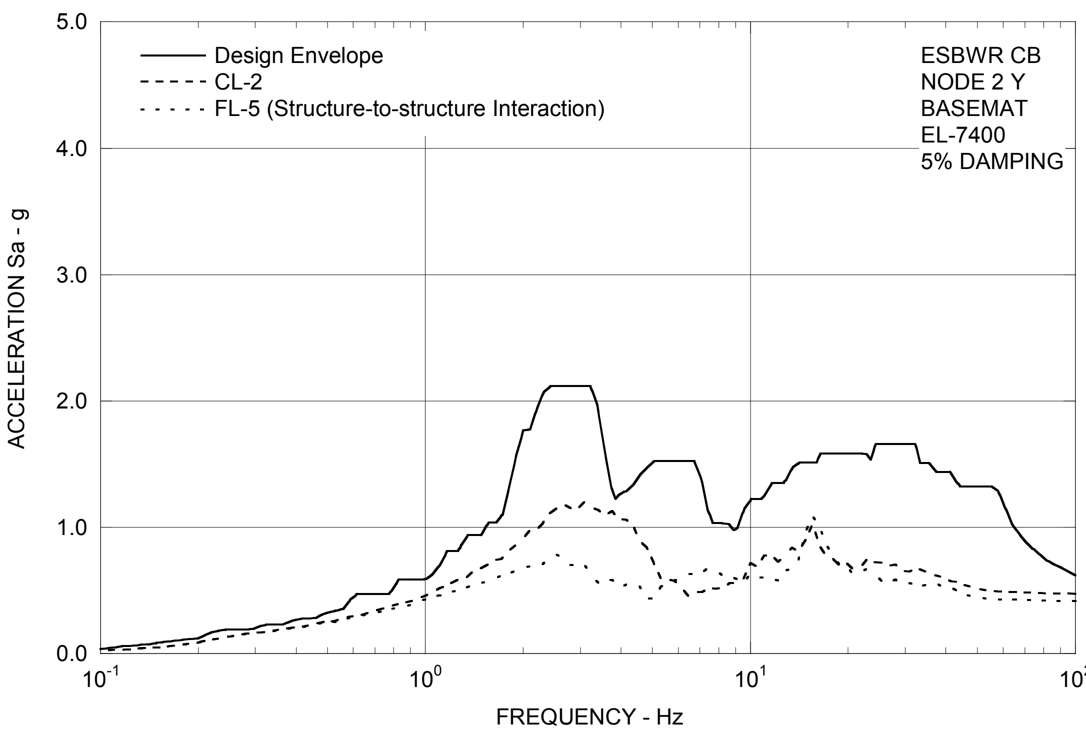


Figure 3A.8.11-10. FRS (Effect of Structure-Structure Interaction) – CB Basemat Y

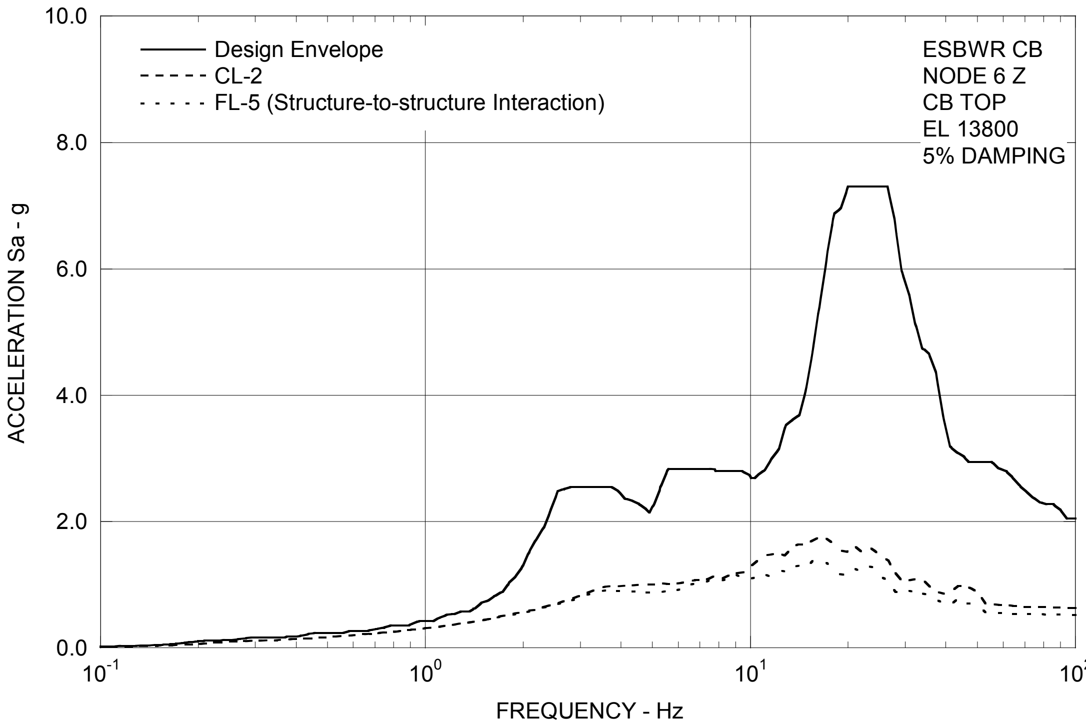


Figure 3A.8.11-11. FRS (Effect of Structure-Structure Interaction) – CB Top Z

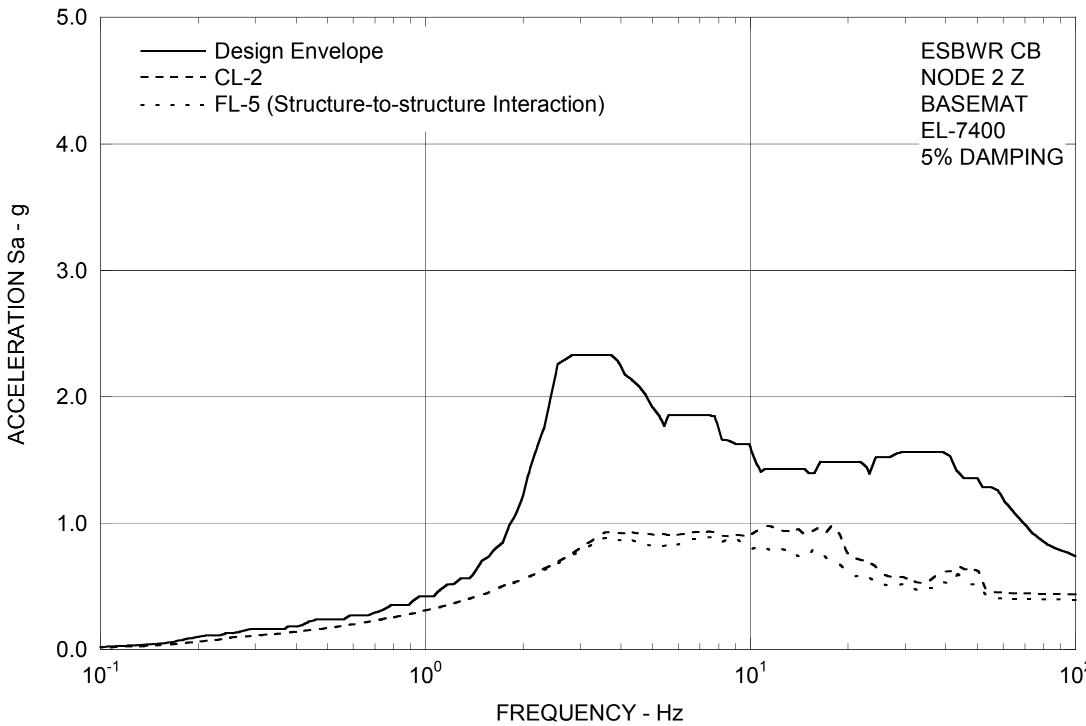


Figure 3A.8.11-12. FRS (Effect of Structure-Structure Interaction) – CB Basemat Z

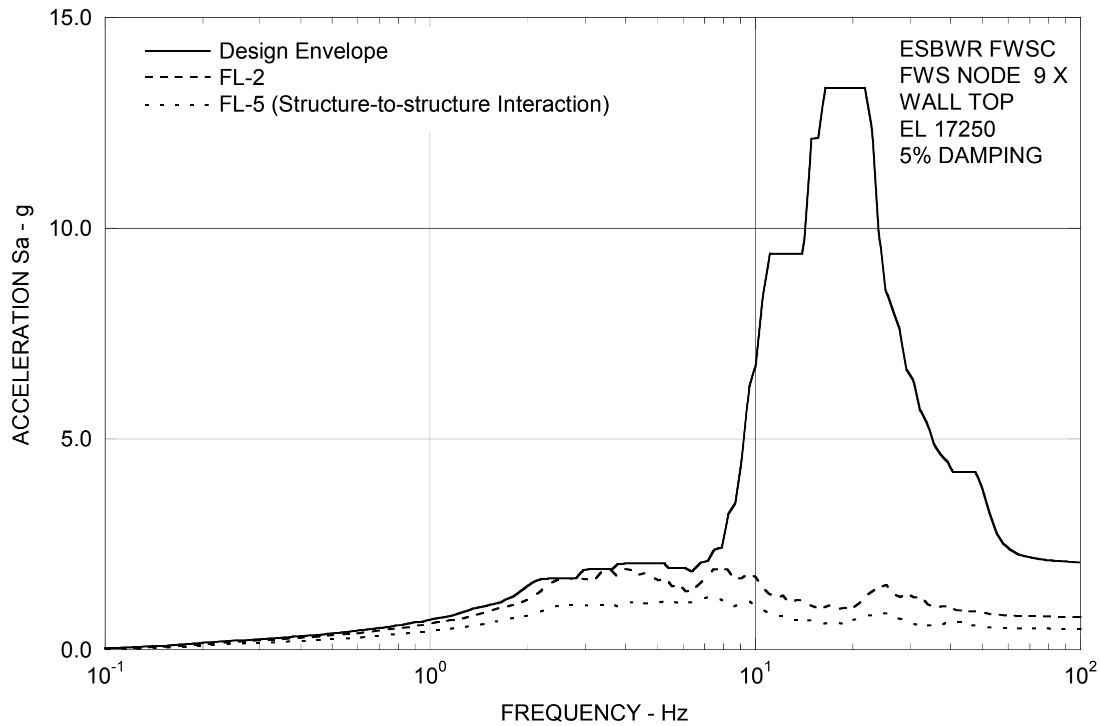


Figure 3A.8.11-13. FRS (Effect of Structure-Structure Interaction) – FWS Wall Top X

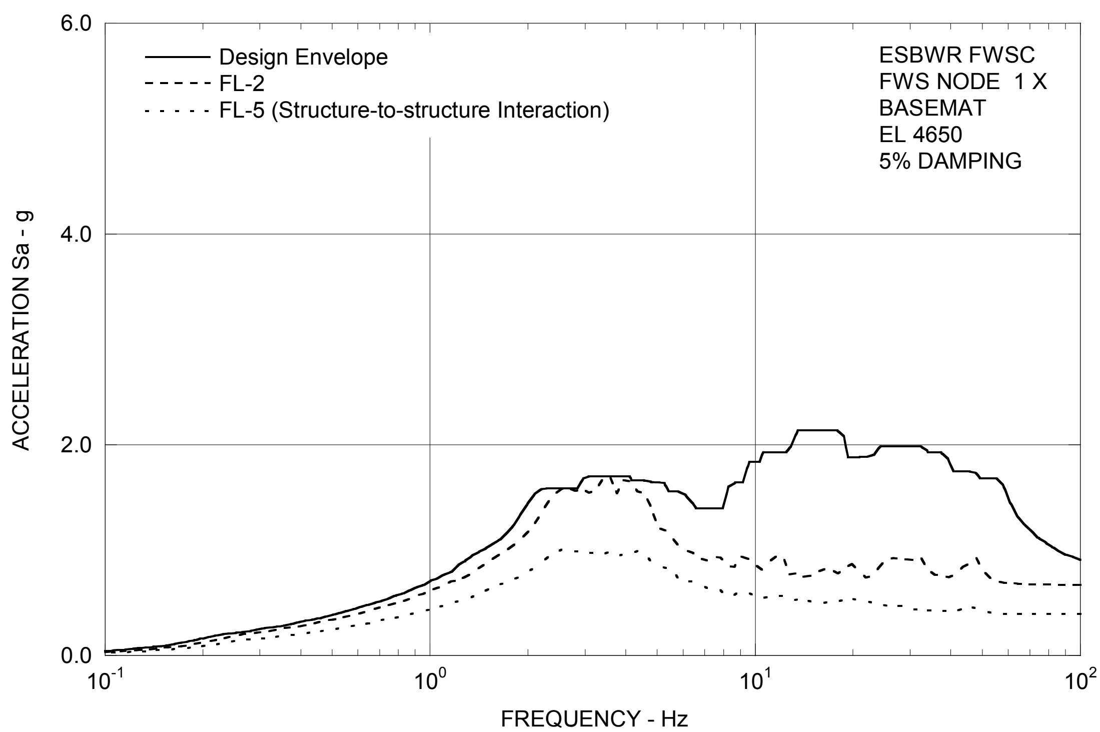


Figure 3A.8.11-14. FRS (Effect of Structure-Structure Interaction) – FWS Basemat X

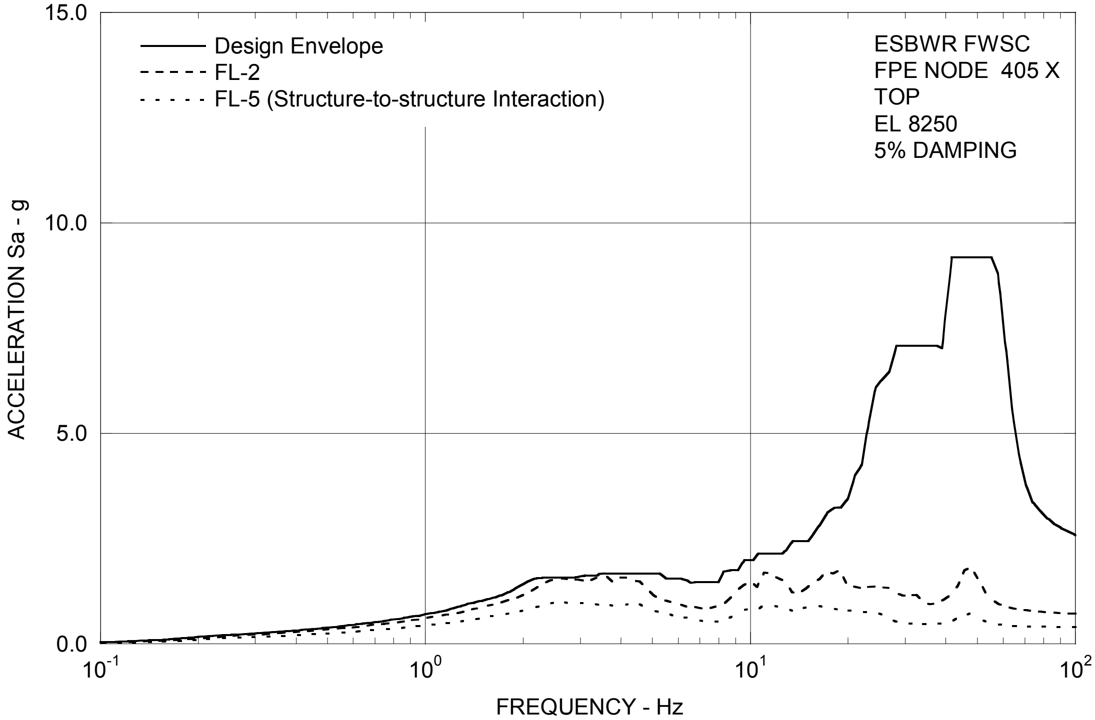


Figure 3A.8.11-15. FRS (Effect of Structure-Structure Interaction) – FPE Top X

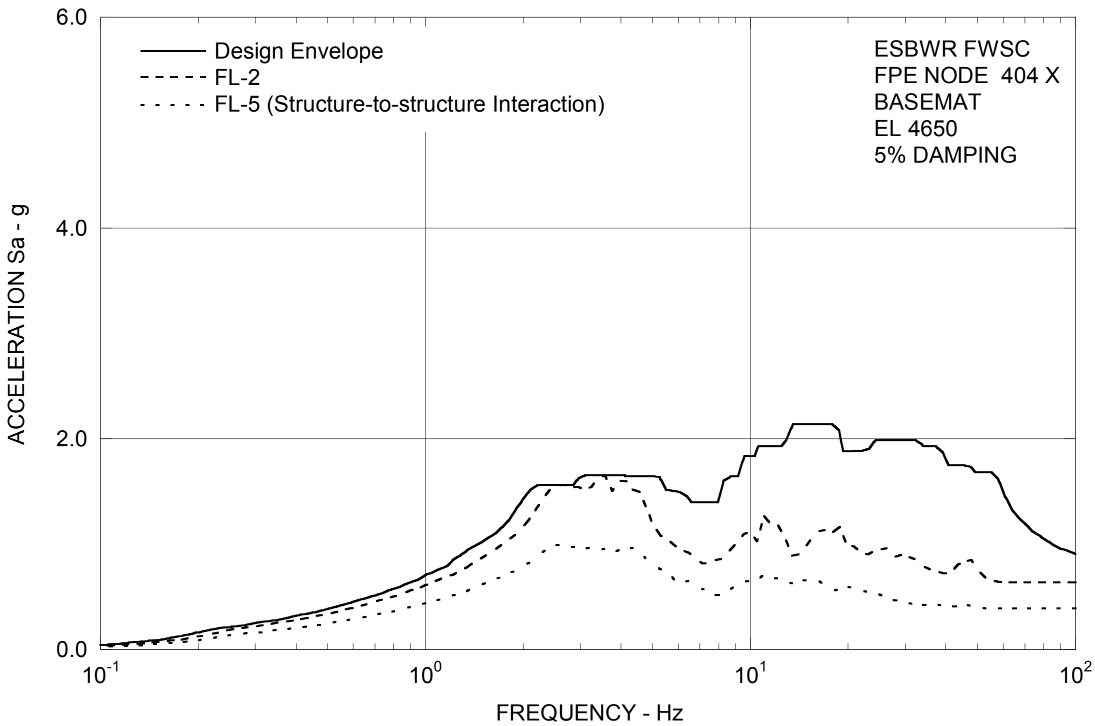


Figure 3A.8.11-16. FRS (Effect of Structure-Structure Interaction) – FPE Basemat X

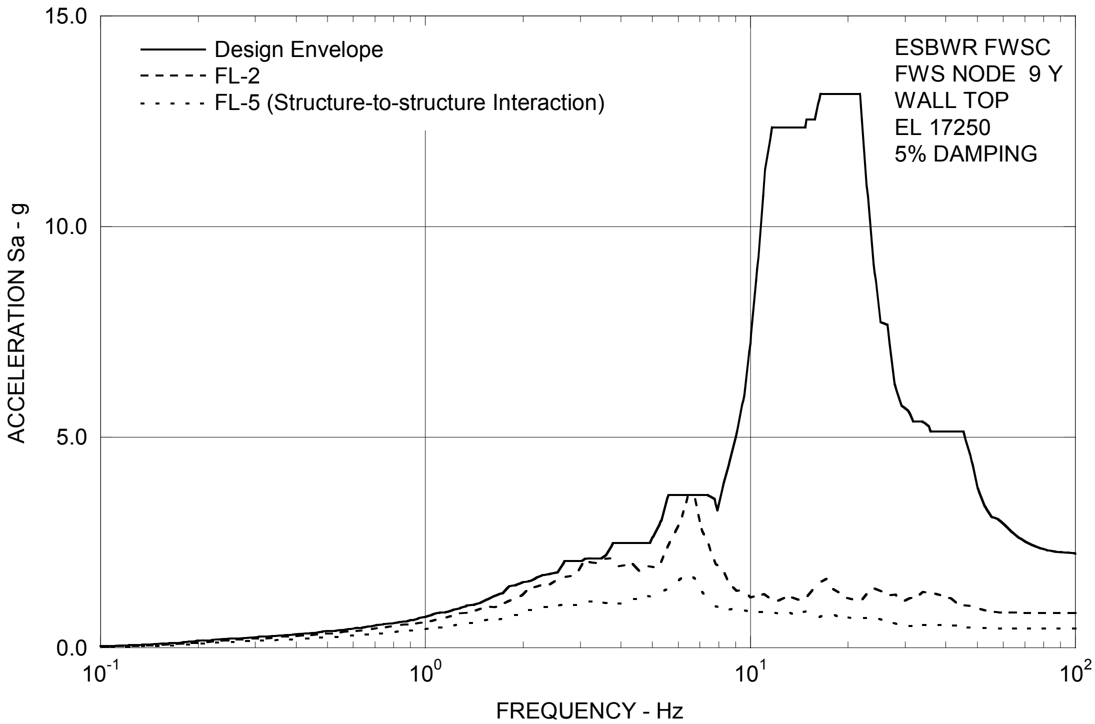


Figure 3A.8.11-17. FRS (Effect of Structure-Structure Interaction) – FWS Wall Top Y

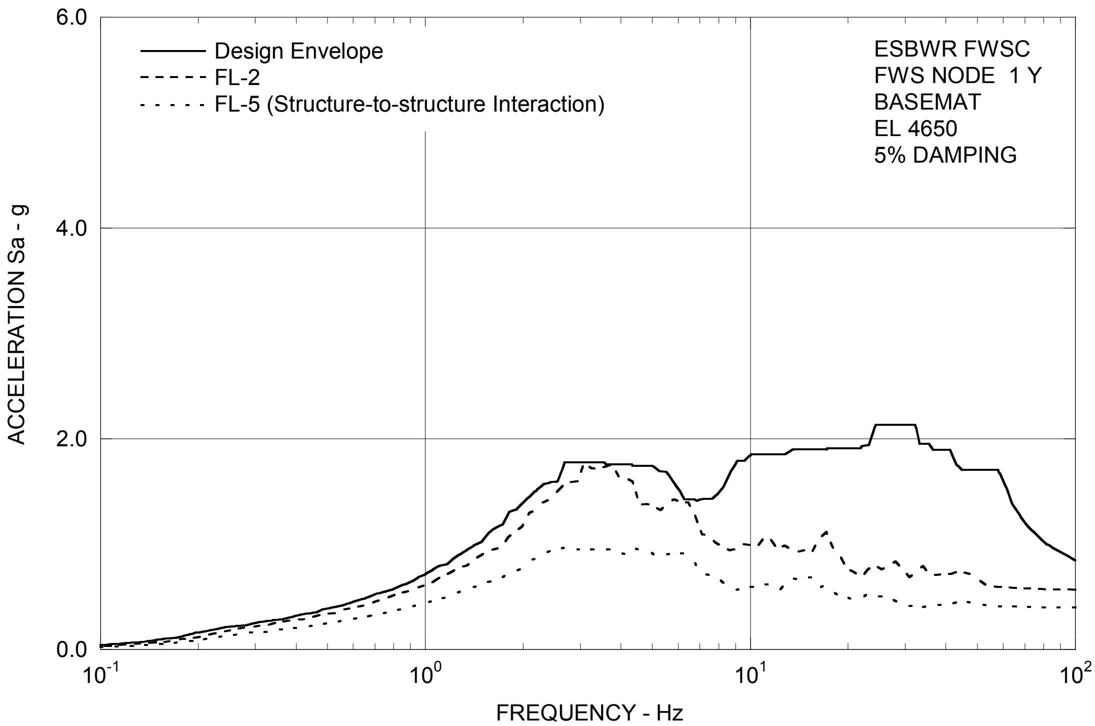


Figure 3A.8.11-18. FRS (Effect of Structure-Structure Interaction) – FWS Basemat Y

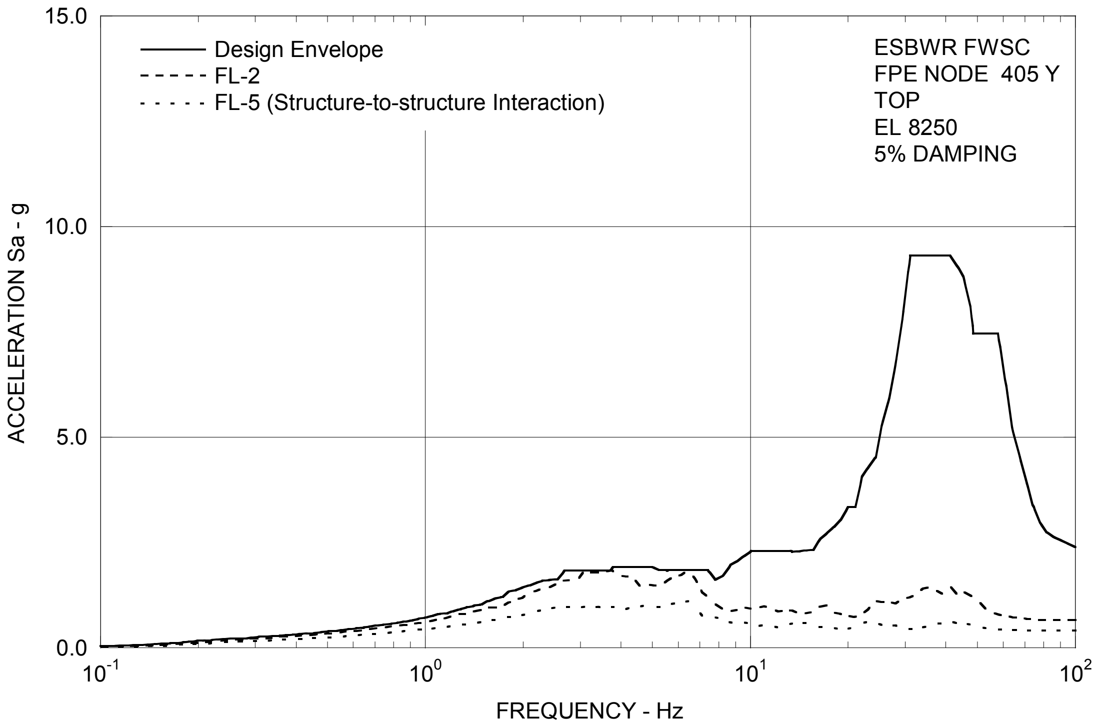


Figure 3A.8.11-19. FRS (Effect of Structure-Structure Interaction) – FPE Top Y

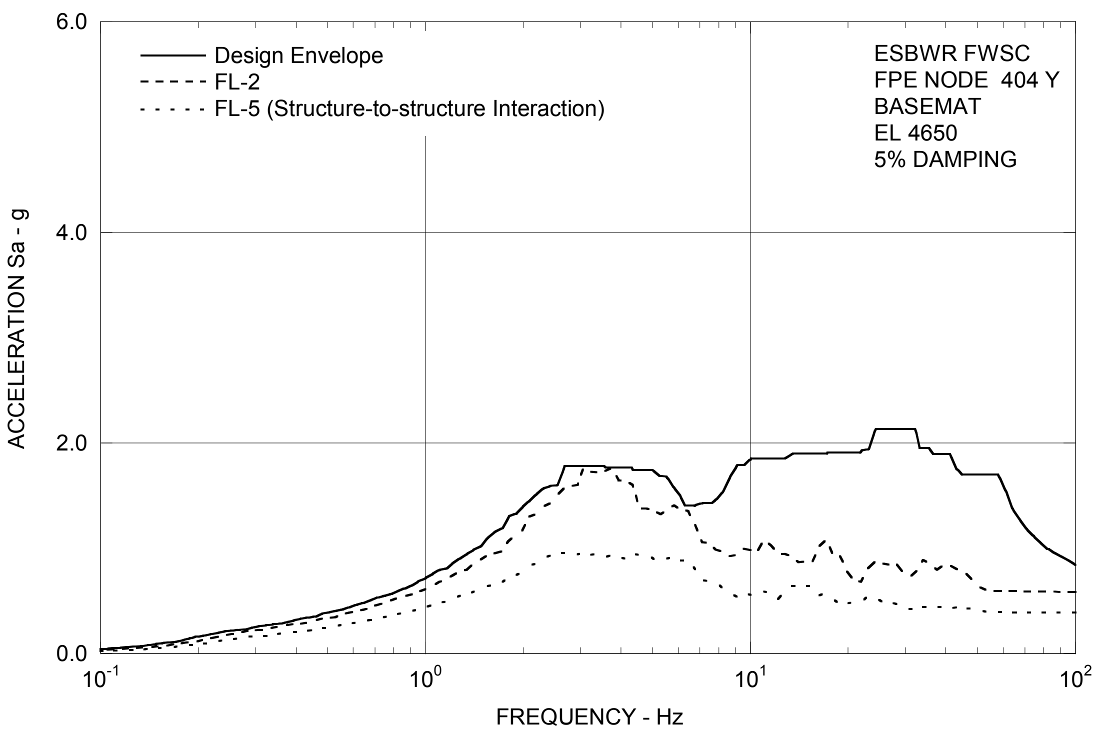


Figure 3A.8.11-20. FRS (Effect of Structure-Structure Interaction) – FPE Basemat Y

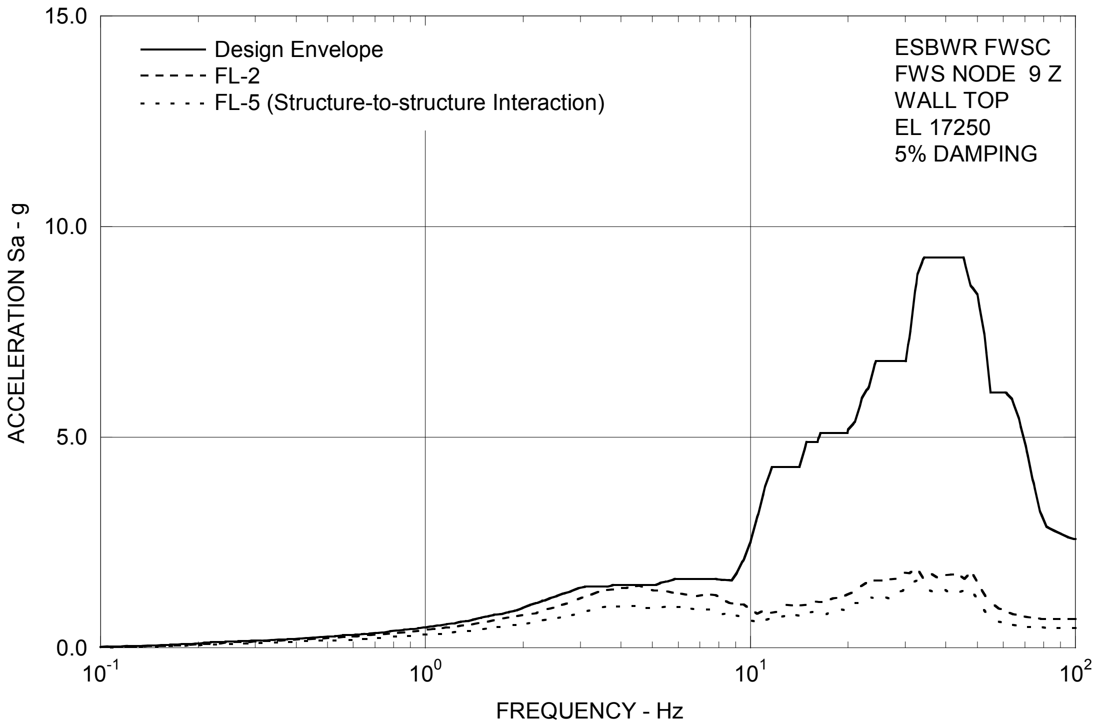


Figure 3A.8.11-21. FRS (Effect of Structure-Structure Interaction) – FWS Wall Top Z

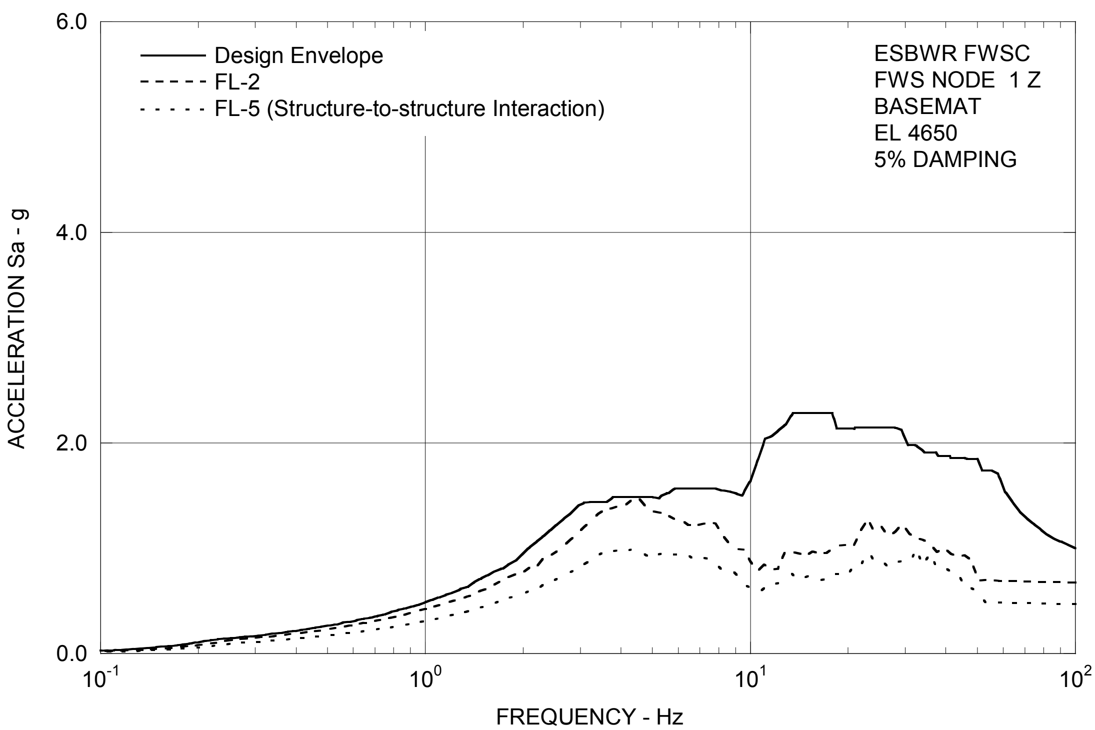


Figure 3A.8.11-22. FRS (Effect of Structure-Structure Interaction) – FWS Basemat Z

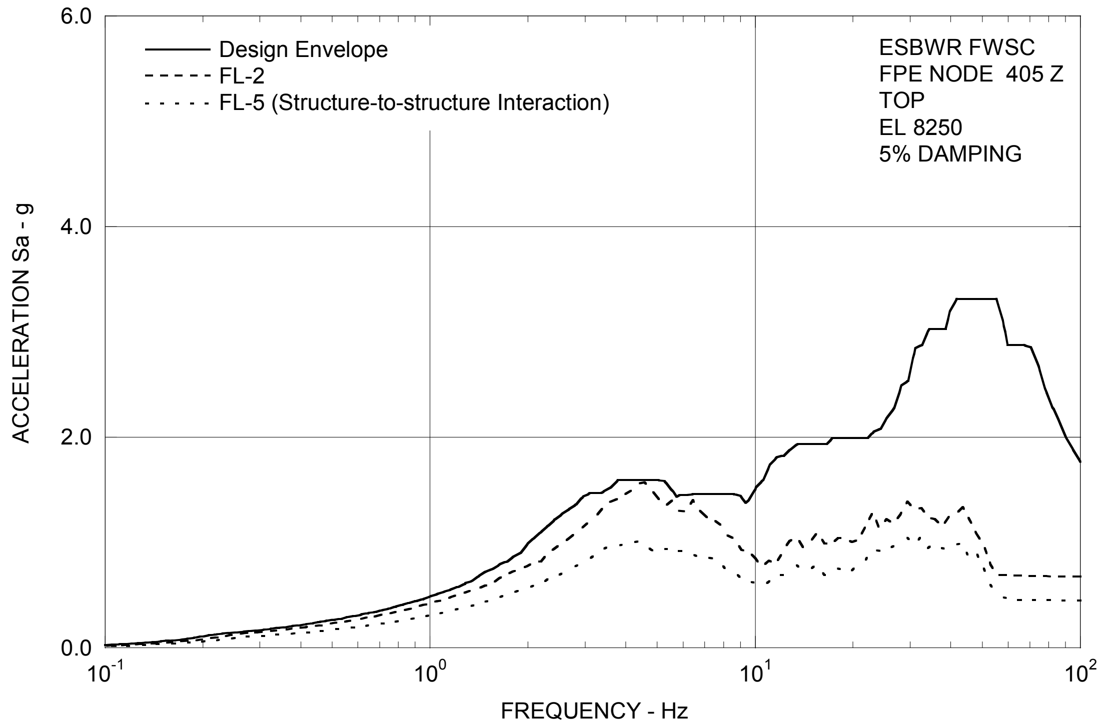


Figure 3A.8.11-23. FRS (Effect of Structure-Structure Interaction) – FPE Top Z

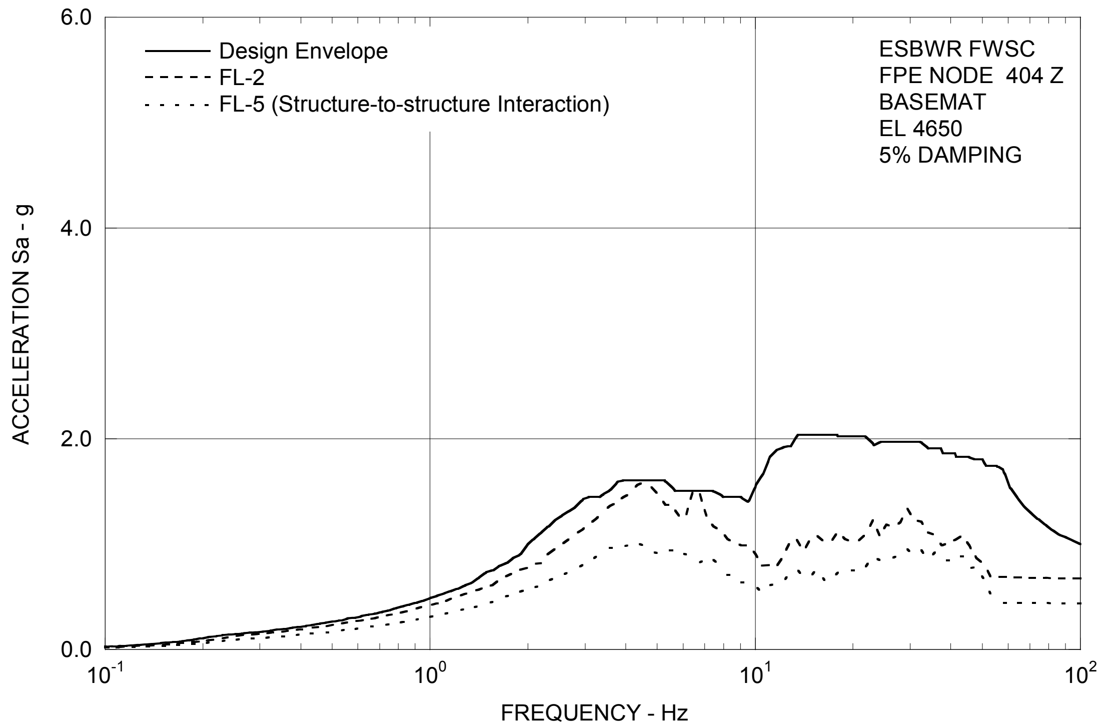


Figure 3A.8.11-24. FRS (Effect of Structure-Structure Interaction) – FPE Basemat Z