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MFN 06-274

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Subject: **Response to RAI Letter Number 20 Related to ESBWR Design Certification Application – Seismic Design – RAI Numbers 3.7-16, 3.7-24, 3.7-27, 3.7-30, 3.7-32, 3.7-33, 3.7-35, 3.7-37, 3.7-38, 3.7-39, 3.7-50, 3.7-54 and 3.7-57**

Enclosures 1 and 2 contain GE's response to the subject NRC RAIs transmitted via the Reference 1 letter. This completes GE's response to RAI Letter No. 20

If you have any questions about the information provided here, please let me know.

Sincerely,

Kathy Sedney for

David H. Hinds
Manager, ESBWR

D068

Enclosures:

1. MFN 06-274 - Response to RAI Letter Number 20 Related to ESBWR Design Certification Application – Seismic Design – RAI Numbers 3.7-16, 3.7-24, 3.7-27, 3.7-30, 3.7-32, 3.7-33, 3.7-35, 3.7-37, 3.7-38, 3.7-39, 3.7-50, 3.7-54 and 3.7-57
2. MFN 06-274 – SER-ESB-033, Parametric Evaluation of Effects on SSI Response, Rev. 0, RAIs 3.7-30, 3.7-33, 35, 39 & 50

Reference:

1. MFN 06-115, Letter from U. S. Nuclear Regulatory Commission to Mr. David H. Hinds, *Request for Additional Information Letter No. 20 Related to ESBWR Design Certification Application,* April 24, 2006

| | | |
|---|---|---|
| cc: | WD Beckner | USNRC (w/o enclosures) |
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| | LA Dudes | USNRC (w/o enclosures) |
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| | eDRF | 0000-0056-2781 |

# ENCLOSURE 1

**MFN 06-274**

**Response to NRC RAI Letter No. 20 Related to ESBWR Design Certification Application**

**Seismic Design**

**RAI Numbers 3.7-16, 3.7-24, 3.7-27, 3.7-30, 3.7-32, 3.7-33,**

**3.7-35, 3.7-37, 3.7-38, 3.7-39, 3.7-50, 3.7-54, and 3.7-57**

NRC RAI 3.7-16

*In DCD Section 3.7.2.1.1, the applicant presents the formulation of the equations of motion in terms of undamped eigenvalues and mode shapes, with solutions obtained by integration in the time domain. The applicant is requested to address the limitations of this formulation, particularly for the case of frequency-dependent SSI stiffness and damping coefficients.*

GE Response

As stated in DCD Section 3A.5, the base spring is evaluated from vibration admittance theory, based on three dimensional wave propagation theory for uniform half space soil. Though the spring values consist of frequency dependent real and imaginary parts, they are simplified and replaced with frequency-independent soil spring Kc, and damping coefficient Cc, respectively, for the time history analysis solved in the time domain.

The sites considered in the seismic analysis of the ESBWR standard plant cover a wide range of uniform soil/rock sites. For uniform sites the use of frequency-independent soil properties in the formulation is an acceptable approach in accordance with guidance of ASCE 4-98, Section 3.3.4.2.2.

The effects of frequency-dependent SSI stiffness and damping coefficients are evaluated for additional layered sites. See response to RAI 3.7-30 for details.

No DCD changes will be made in response to this RAI.

NRC RAI 3.7-24

*The last two sentences in the second paragraph on page 3.7-10 (DCD Section 3.7.2.3) state that the number of masses or dynamic degrees of freedom is considered adequate when additional degrees of freedom do not result in more than a 10% increase in response. Alternatively, the number of dynamic degrees of freedom is no less than twice the number of modes below the cutoff frequency. The staff generally agrees with this criteria, but it is not clear how the criteria has been implemented in the development of the seismic structural models. The applicant is requested to include in the DCD specific information on how these criteria were satisfied for each seismic structural model.*

GE Response

Since the SSI analyses were performed by the direct integration method in the time domain, the cutoff frequency was not applied. However, as mentioned in the response to RAI 3.7-17, the highest structural frequency of interest is 33 Hz for generic site and 50 Hz for North Anna site. Therefore, the number of dynamic degrees of freedom was checked if it is no less than twice the number of modes below 50Hz. According to the check results, the original RB/FB model in DCD has enough dynamic degrees of freedom. However, it was found that the original CB model in DCD does not have enough dynamic degrees of freedom.

Therefore, the CB model was modified to increase the number of masses. It is confirmed that for the revised model the number of dynamic degrees of freedom is no less than twice the number of modes below 50 Hz. Details can be found in SER-ESB-024, *Revised Control Building Stick Model, Rev.1*, provided to the NRC by MFN 06-251.

The original RB/FB model in DCD was also revised to add vertical shear springs to consider the vertical coupling of walls through the floor slabs/pool girders in response to NRC's Audit comment on RAI 3.7-36. It is confirmed that the number of dynamic degrees of freedom is no less than twice the number of modes below 50 Hz. Details can be found in SER-ESB-023, *Revised Reactor and Fuel Building Stick Model, Rev.1*, provided to the NRC by MFN 06-278.

DCD Section 3.7.2.3 (Page 3.7-11) will be revised in the next update as noted in the attached markup confirming that the number of degrees of freedom is no less than the number of modes below 50Hz.

NRC RAI 3.7-27

*In DCD Tier 1 Figures 2.17.5-1 through 2.17.5-11 and Tier 2 figure 1.2-1, the applicant did not provide the foundation dimensions for the RB/FB and the CB, nor the distance from the center of the reactor vessel to the edge of the RB/FB foundation. Because this information is important for the structural modeling and the seismic response of seismic Category I structures, the staff requests the applicant to include these dimensions in the above figures and to consider them as DCD Tier 1 information.*

GE Response

The foundation dimensions of the RB/FB were provided in DCD Rev. 1 Figures 3G.1-1, 3G.1-6, and 3G.1-7. The distance from the RPV center to the edge of the RB/FB foundation is also available in these figures. The CB foundation dimensions were provided in DCD Rev. 1 Figures 3G.2-1 and 3G.2-3.

DCD Tier 1 Figures 2.17.5-1 through 2.17.5-11 and Tier 2 Figure 1.2-1 will be updated to provide the critical building foundation dimensions in the next DCD revision.

NRC RAI 3.7-30

*The last part of the second paragraph on page 3A-4 of DCD Section 3A.3.1 states that three subsurface conditions (soft, medium, rock and hard rock sites) are considered to be uniform half-space, as provided in Table 3A.3-1 for SSI analyses. According to the staff's review experience, there are a number of sites composed of layered materials that should be considered for siting of nuclear plants. Such sites may have significant variation of shear wave velocity with depth, leading to potentially significant impedance mismatches between layers. Such profiles can have effective impedance functions that are significantly different from those associated with a uniform half-space. (See for example, "Handbook of Impedance Functions" by Sieffert and Cevaer). These sites are typically characterized by impedance functions that are highly frequency-dependent, particularly those associated with radiation damping. The approach of using a frequency-independent assumption for both stiffness and damping in SSI may lead to significantly different computed responses. The behavior (or response) of a massive structure (such as RB/FB or CB) may be significantly influenced by these variations due to site conditions. For the design of a standard plant such as ESBWR, the DCD should address the limitations on site layering that will be required, to ensure the applicability of the ESBWR design, which is based on the assumption of uniformity. The staff requests the applicant to include this information in the DCD, and also identify it as a COL interface item.*

GE Response

In order to enhance the applicability of the ESBWR design, four cases of layered sites shown in Table 3.7-30 (1) were evaluated for seismic analyses of the RB/FB and the CB using SASSI computer code. These cases cover a wide range of variation of shear wave velocity with depth so that the effect of impedance mismatches between layers can be captured. Details are contained in Enclosure 2, SER-ESB-033, *Parametric Evaluation of Effects on SSI Response, Rev.0.* Since the results of layered sites are considered in the site-envelope design loads, there is no limitation on site layering for COL application of the ESBWR standard plant design.

It should be noted that the input ground motion used in the layer site analysis, also in other additional analyses performed to address other related RAIs, corresponds to the single envelope ground spectrum described in response to RAI 3.7-5.

DCD Section 3.7.1 will be revised to clarify the definition of design ground motion, as shown in the attached markup.

DCD Section 3A.3.1 will be revised and Table 3A.3-3 will be added in the next update as shown in the attached markups.

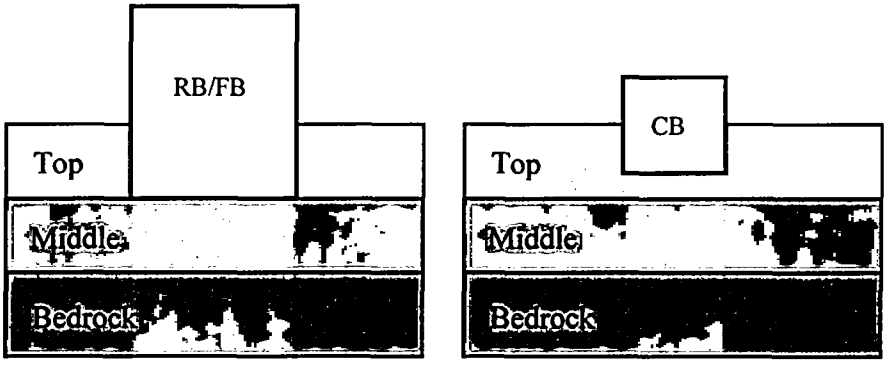
DCD Section 3A will also be revised in the next update to include the results of site layering evaluation.

**Table 3.7-30 (1) Layered Site Cases**

| Layer | Shear Wave Velocity (m/s) / Depth (m) | | | |
|---|---|---|---|---|
| | CASE 1 | CASE 2 | CASE 3 | CASE 4 |
| Top | 300/20 | 300/20 | 300/20 | 300/20 |
| Middle | 300/20 | 800/20 | 300/40 | 800/40 |
| Bedrock | 1700 | 1700 | 1700 | 1700 |

Note: 1) The 20 m depth of the middle layer corresponds to the embedded depth of the RB/FB and the 40 m depth corresponds to about one-half the largest plan dimension of the RB/FB foundation.

2) Properties of the three layers of soils are the same as the generic site properties for soft, medium, and hard soils in DCD Table 3A.3-1.



NRC RAI 3.7-32

*DCD Appendix 3A, Tables 3A.3-1 and 3A.3-2 indicate material (hysteretic) damping values assumed for foundation soils for the various uniform site cases. However, no mention is made in the SSI description of how these damping parameters are combined with the SSI radiation damping values listed in Tables 3A.5-1 and 3A.5-2. The staff requests the applicant clarify in the DCD how these properties (material damping and radiation damping) were considered in the SSI calculations and how significant they are to facilitate responses.*

GE Responses

The SSI radiation damping values listed in DCD Tables 3A.5-1 and 3A.5-2 are the only damping of soil considered in the SSI calculations. Soil material damping values listed in DCD Tables 3A.3-1 and 3A.3-2 are conservatively neglected.

The SSI analytical formulation is described in detail in the response to RAI 3.7-49. When the SSI radiation damping is calculated by the formulation, the soil material damping values are input as zero.

DCD Section 3A.5 will be revised in the next update as noted in the attached markup to clarify how these properties were considered in the SSI calculations.

NRC RAI 3.7-33

*DCD Section 3A.5 indicates that the use of lateral pressures computed from the equivalent static pressure analysis listed in ASCE 4-98 is conservative. Based on reviews of a number of facilities, it is known that actual pressures computed from detailed SSI evaluations of embedded foundations are directly influenced by the characteristics of the foundation response spectrum used to define the ground motions as well as the relative stiffness (shear wave velocity) of the soils above the basemat level. The staff requests the applicant clearly indicate in the DCD either (1) the technical basis for the statement that these static pressures are conservative for any site, or (2) any limitations that need to be incorporated into the acceptable site profile characteristics to limit the actual dynamic pressures anticipated.*

GE Response

In order to confirm that the ASCE 4-98 approach is conservative, an additional evaluation was performed for the layered sites with deep embedment using SASSI computer code, as described in the response to RAI 3.7-30. This evaluation shows that the lateral pressures calculated by the ASCE 4-98 approach is generally bounding. An envelope of these two sets of values will be used for exterior wall design. Details are contained in Enclosure 2, SER-ESB-033, *Parametric Evaluation of Effects on SSI Response, Rev.0.*

DCD Section 3A will be revised in the next update to include this information.

NRC RAI 3.7-35

*As stated in DCD Appendix 3A, Section 3A.7, the elastic half-space theory was used for modeling the soil foundation for both the generic site condition and the North Anna site condition. The staff identified the following issues in need of clarification: (1) what soil damping (material damping and energy loss due to wave propagation) was assigned for the SSI analyses, and (2) how the embedment effects (especially at relatively soft soil sites) were considered in the analysis. The applicant is requested to address these clarifications, and also describe how the elastic half-space theory was applied to the North Anna site, in the DCD.*

GE Response

(1) Please see the responses to RAIs 3.7-16 and 3.7-32.

(2) In order to evaluate the embedment effects, additional evaluation is performed for the layered sites with deep embedment using SASSI computer code, as described in the response to RAI 3.7-30. This evaluation shows that the effect of embedment works to reduce basemat reaction shear forces. Details are contained in Enclosure 2, SER-ESB-033, *Parametric Evaluation of Effects on SSI Response, Rev.0.*

The foundation properties considered in the SSI analysis for North Anna site shown in DCD Table 3A.3-2 are applied as uniform half-space soil. As stated in DCD Section 3A.3.2, they are determined based on the North Anna ESP site-specific conditions. See response to RAI 3.7-7 for further details.

DCD Section 3A will be revised in the next update to provide the requested clarifications.

NRC RAI 3.7-37

*In the third paragraph of DCD Appendix 3A, Section 3A.5, the applicant discussed how to use the frequency-independent soil-spring $K_c$, and damping coefficient $C_c$ to represent the soil foundation in the SSI analysis of the RB/FB and CB. DCD Tables 3A.5-1 and 3A.2 provide tabulated numerical values of $K_c$ and $C_c$ for the RB/FB and CB. However, the applicant did not describe in the DCD how the frequency-dependent soil-springs (real and imaginary parts of the soil stiffness) were calculated, and how these frequency-dependent soil-springs were converted to frequency-independent soil-springs and damping ratios. The staff requests the applicant provide a detailed description in the DCD.*

GE Response

The detailed description for the calculation of the frequency-dependent soil-springs (real and imaginary parts of the soil impedance) was provided in the response to RAI 3.7-49, in which the procedure used to convert these frequency-dependent soil impedance to frequency-independent soil stiffness and damping ratio was also described. An illustrative example for comparison of the calculated frequency-dependent impedance with the equivalent frequency-independent soil stiffness and damping is shown in Figure 3.7-37 (1) for the soft site.

DCD Section 3A.5 will be revised in the next update as noted in the attached mark-up to provide a detailed description.

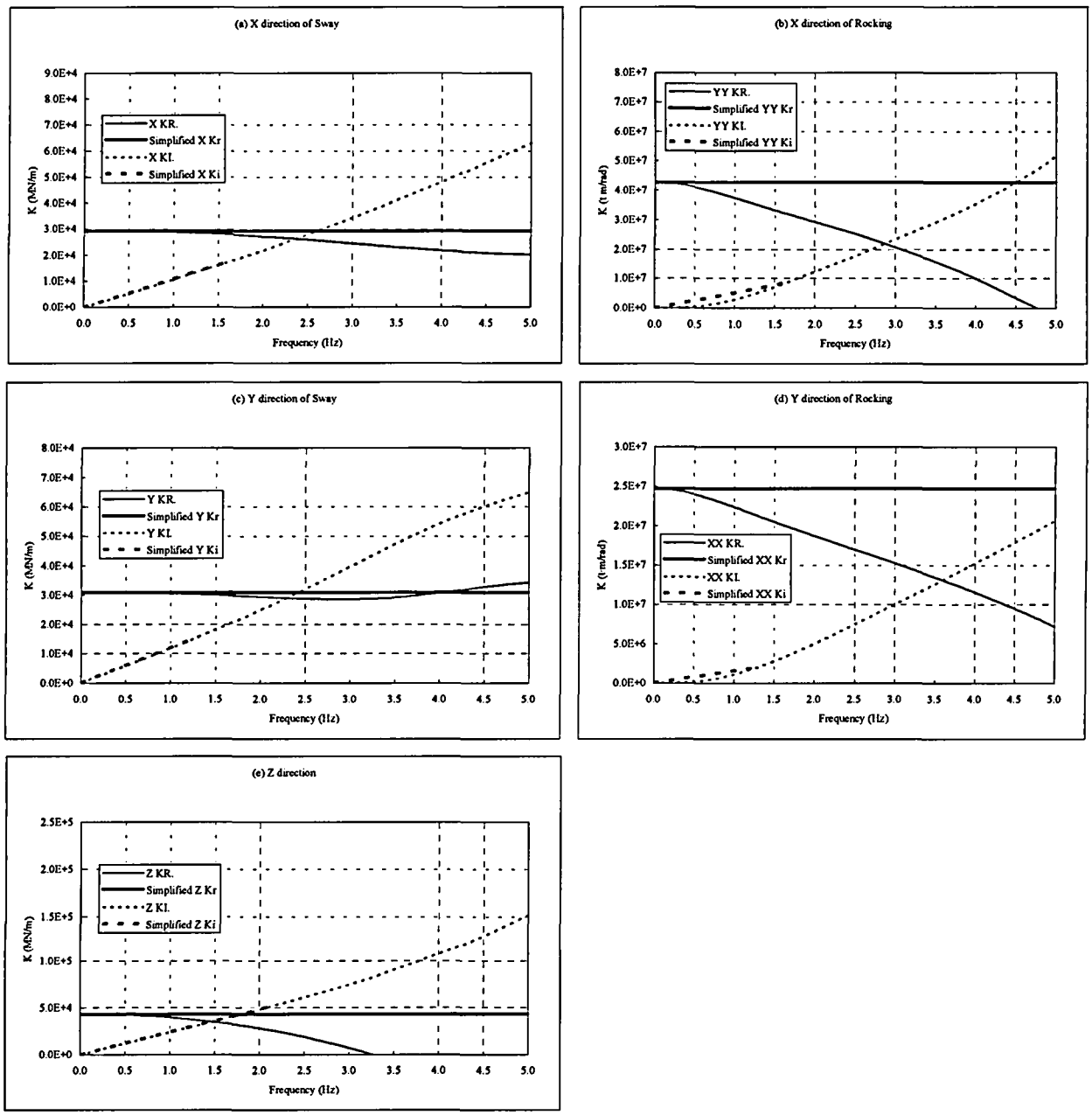



**Figure 3.7-37 (1) Frequency-Dependent vs. Frequency-Independent Soil Spring for RB/FB at Soft Site**

NRC RAI 3.7-38

*It is stated in DCD Appendix 3A that the shear wave velocities and material damping ratios are strain compatible. The staff requests the applicant provide the following information in the DCD: (1) the theory (methods or formula) for calculating all soil springs, (2) the method (or formula) for calculating damping ratios, and (3) a clear description how the strain dependency of these values is accounted for in the soil-springs used in the SSI analyses.*

GE Response

(1) and (2): See the response to RAI 3.7-37.

(3): As stated in DCD Section 3A.3, the shear wave velocities and the material damping ratios shown in DCD Tables 3A.3-1 and 3A.3-2 are considered to be compatible with the strain level expected during SSE. These strain compatible values were used directly in computing soil spring and damper properties.

DCD Section 3A.3 will be revised in the next update as noted in the attached markup.

NRC RAI 3.7-39

*For the SSI analyses that were performed, the staff requests the applicant to describe in detail in the DCD how it considered the effect of structure-to-structure interaction through the soil between the RB/FB and CB. The staff considers this a potentially significant effect, especially for the response of the CB.*

GE Response

In order to address the effect of structure-to-structure interaction through the soil between the RB/FB and CB, an additional evaluation is performed for the layered sites using SASSI computer code.

This evaluation shows that the effect of structure-to-structure interaction is the largest in the Y-direction (East-West) response of the CB. However, the Floor Response Spectra (FRS) with and without structure-to-structure interaction effect are bounded by the broadened envelope responses of uniform site cases in the whole frequency range. Details are contained in Enclosure 2, SER-ESB-033, *Parametric Evaluation of Effects on SSI Response, Rev.0.*

DCD Section 3A will be revised in the next update to include this information.

NRC RAI 3.7-50

*DCD Section 3.7.2.3, "Procedures Used for Analytical Modeling," does not address the method used to develop stiffness values (uncracked concrete sections versus cracked concrete sections) for concrete structural elements for the seismic analysis models. The staff requests the applicant include in the DCD a detailed description of the method applied to determine the stiffness values for both cracked concrete sections and uncracked concrete sections in the seismic analysis models.*

GE Response

In order to address the effect of the cracked concrete stiffness, an additional evaluation is performed using SASSI computer code, assuming that the cracked concrete stiffness is 50% of the uncracked value in accordance with ASCE 43-05, Section 3.4.1.

This evaluation shows that the Floor Response Spectra (FRS) peaks move to lower frequencies when concrete cracking is considered. However, both FRSs of uncracked and cracked cases are bounded by the broadened envelope response of uniform site cases in the whole frequency range. Details are contained in Enclosure 2 SER-ESB-033, *Parametric Evaluation of Effects on SSI Response, Rev.0.*

DCD Section 3A will be revised in the next update to include this information.

NRC RAI 3.7-54

*In DCD Section 3.7.5, the applicant indicated that the COL applicant needs to confirm that the site-specific shear wave velocity is no less than 1,000 fps in order to confirm the design adequacy of the plant. However, in following the guidance of the SRP for an individual site evaluation, the COL applicant needs to perform site-specific response calculations, reducing the low-strain shear-wave velocity profile from the Best Estimate (BE) to a Lower Bound (LB) value, defined as the BE divided by the square root of 2. DCD Section 3.7.5 needs to indicate that 1,000 fps is a LB velocity and not a BE velocity, or, as an alternative, the minimum acceptable BE velocity can be specified. In addition, since all design analyses were performed for assumed uniform velocity profiles, the site acceptance criteria needs to include information on what degree of variation from the uniform velocity profile is acceptable for the design.*

GE Response

Please see response to RAI 3.7-31 for clarification of the minimum shear wave velocity definition. To enhance site suitability for ESBWR Standard Plant design, additional SSI analyses are performed for generic layered sites using the SASSI computer code. See response to RAI 3.7-16 for details.

NRC RAI 3.7-57

*DCD Tier 2, Section 3.7.2.3 indicates that the mathematical model of the structural system is constructed either as a stick model or a finite element model. These models are used in the soil-structure interaction (SSI) response analyses to determine seismic response of the soil structure system as indicated in DCD Section 3.7.2.4 and described in Appendix 3A to DCD Section 3.7. The free-field ground motions used as input to the plant analysis and design are described in DCD Section 3.7.1 and are ground motions that envelope either the RG 1.60 low frequency response spectrum or the high frequency ground motion developed for the North Anna early site permit site.*

*DCD Figure 3.7-30 presents a plot of the North Anna design ground response spectrum and indicates a response spectrum that possesses its primary spectral accelerations in the frequency ranges from about 10 Hz to 50 Hz with a peak spectral acceleration at a frequency of about 20 Hz for the horizontal response spectrum and about 30 to 50 Hz for the vertical response spectrum. Appendix 3A to DCD Section 3.7 presents descriptions of the stick models developed for use in SSI analyses for the primary structures and internals of the plant. DCD tables 3A.7-5 through 3A.7-14 present the results of eigenvalue analyses that are carried to frequencies as high as 27 Hz. These indicate participation factors of 0.28 at frequencies as high as about 25 Hz. The staff requests that the applicant demonstrate that the stick structural models developed based on the process described in the DCD can transmit frequencies up to 50 Hz and be able to capture the responses resulting from the high frequency components of North Anna input ground motions.*

GE Response

Please see the response to RAI 3.7-24.

classified as Category IV (Power Generating Stations) with an Occupancy Importance Factor of 1.5. Either of the methods permitted by IBC, simplified analysis or dynamic analysis, is acceptable for determination of seismic loads on NS structures and equipment.

The Operating Basis Earthquake (OBE) is a design requirement. For the ESBWR OBE ground motion is chosen to be one-third of the SSE ground motion. Therefore, no explicit response or design analysis is required to show that OBE design requirements are met. This is consistent with Appendix S to 10 CFR 50. The effects of low-level earthquakes (lesser magnitude than the SSE) on fatigue evaluation and plant shutdown criteria are addressed in Subsections 3.7.3.2 and 3.7.4.4, respectively.

## 3.7.1 Seismic Design Parameters

As discussed in Standard Review Plan (SRP) 3.7.1, structures that are important to safety and that must withstand the effects of earthquakes are designed to the relevant requirements of GDC 2 and comply with Appendix A to 10 CFR 100 concerning natural phenomena. Standardized plants envelop the most severe earthquakes that affected a great number of sites where a nuclear plant may be located, with sufficient margin considering limited accuracy, quantity and period of time in which historical data have been accumulated. Seismic design parameters considered for ESBWR comprise two site conditions, generic sites and early site permit (ESP) sites. Three sites, North Anna (Reference 3.7-2), Clinton (Reference 3.7-3) and Grand Gulf (Reference 3.7-4) are currently in the process of ESP application to the NRC. A review of the three site conditions reveals that Clinton and Grand Gulf are bounded by the envelope of generic site and North Anna conditions. North Anna ESP site is therefore selected for further consideration in conjunction with generic sites for site enveloping seismic design of the ESBWR Standard Plant. COL Applicant will confirm that site-specific seismic design parameters do not exceed the site envelope parameters discussed in Subsection 3.7.5.1.

### *3.7.1.1 Design Ground Motion*

The ESBWR standard plant SSE design ground motion is rich in both low and high frequencies. The low-frequency ground motion follows RG 1.60 ground spectra anchored to 0.3g. The high-frequency ground motion matches the North Anna ESP site-specific spectra as representative of most severe rock sites in the Eastern US. These two ground motions are considered separately in the basic design. To verify the basic design the two separate inputs are further enveloped to form a single ground motion as the design basis ground motion for ESBWR. The single envelope design ground response spectra are shown in Figures 2.5-1 and 2.5-2 for horizontal and vertical direction, respectively. They are defined as free-field outcrop spectra at the foundation level (bottom of the base slab). Application of design ground motion at the foundation level is a conservative approach for deeply embedded foundations as compared to the compatible free-field motion deconvoluted from the free ground surface motion at the finished grade. The ESBWR Reactor Building (RB) and Control Building (CB) foundations are embedded at depth of 20 m (66 ft) and 14.9 m (49 ft), respectively. The Fuel Building (FB) shares a common foundation mat with the RB. The development of design ground motion is delineated in the following subsections.

#### 3.7.1.1.1 Low-Frequency Ground Motion

The ground response spectra for low-frequency ground motion are developed in accordance with Regulatory Guide 1.60 anchored to 0.3g and specified at the foundation level in the free field for generic sites. The 0.3g SSE design response spectra for various damping ratios are shown in Figures 3.7-1 and 3.7-2 for the horizontal and vertical motions, respectively. The horizontal response spectra are equally applicable to two orthogonal horizontal directions.

Seismic input motions in the form of time histories are generated to envelop the design response spectra. The generic site 0.3g SSE acceleration time histories for two horizontal components (H1 and H2) and vertical (VT) component are shown in Figures 3.7-3 through 3.7-5, respectively, together with corresponding velocity and displacement time histories. Each time history has a total duration of 22 seconds.

These time histories satisfy the spectrum-enveloping requirement stipulated in the NRC Standard Review Plan (SRP) 3.7.1. The computed response spectra for 2%, 3%, 4%, 5% and 7% damping are compared with the corresponding design Regulatory Guide 1.60 spectra in Figures 3.7-6 through 3.7-10 for the H1 component, in Figures 3.7-11 through 3.7-15 for the H2 component, and in Figures 3.7-16 through Figure 3.7-20 for the VT component. The response spectra are computed at frequency intervals suggested in Table 3.7.1-1 of SRP 3.7.1 plus three additional frequencies at 40, 50, and 100 Hz.

The time histories of the two horizontal components also satisfy the Power Spectra Density (PSD) requirement stipulated in Appendix A to SRP 3.7.1. The computed PSD functions envelop the target PSD of a maximum 0.3g acceleration with a wide margin in the frequency range of 0.3 Hz to 24 Hz as shown in Figures 3.7-21 and 3.7-22 for the H1 and H2 components, respectively. In these figures, the curve labeled as 80% of the target PSD is the minimum PSD requirement.

The target PSD compatible with Regulatory Guide 1.60 vertical spectrum is not specified in Appendix A to SRP 3.7.1. Using the same methodology on which the minimum PSD requirement of Appendix A to SRP 3.7.1 for the Regulatory Guide 1.60 horizontal spectrum is based, the vertical target PSD compatible with the Regulatory Guide 1.60 vertical spectrum is derived using the following approach (Reference 3.7-15):

(1) Establish initial candidate PSD.

(2) Calculate several time histories using the PSD, each with a different phase function.

(3) Calculate 2% critically damped pseudovelocity response spectrum (PSV) of each time history.

(4) Compare the suite of PSVs from (3) to a target PSV.

(5) If the average of the suite of PSVs does not fit (this is a visual fit) the target PSV, adjust form of PSD and go to Step (2).

(6) Obtain the final PSD.

This vertical target PSD with the following input coefficients for 1.0g peak ground acceleration, is defined as $S_0(f)$ at frequency f:

$$S_0(f) = 2288.51 cm^2/s^3 (f/3.5)^{0.2}$$

$f \leq 3.5$ Hz

$= 2288.51 cm^2/s^3 (3.5/f)^{1.6}$

$3.5 < f \leq 9.0$ Hz

$= 504.98 cm^2/s^3 (9.0/f)^{3.0}$

$9.0 < f \leq 16.0$ Hz

$= 89.88 cm^2/s^3 (16.0/f)^{7.0}$

$f > 16.0$ Hz

The PSD function of vertical component of the design time history (SSE with 0.3g PGA) is computed and subsequently averaged and smoothed using SRP 3.7.1 criteria. Similarly, the target PSD is computed for 0.3g maximum acceleration. The PSD of the design time history is compared with the target and 80% of target PSD in Figure 3.7-23. As shown in this figure, PSD of the vertical time history envelops the target PSD with a wide margin. This comparison confirms the adequacy of energy content of the vertical time history.

The time histories of three spatial components are checked for statistical independency. The cross-correlation coefficient at zero time lag is 0.01351 between H1 and H2, 0.07037 between H1 and VT, and 0.07367 between H2 and VT. The cross-correlation coefficients are less than 0.16 as recommended in the reference of Regulatory Guide 1.92. Thus, H1, H2, and VT acceleration time histories are mutually statistically independent.

The 0.3g RG 1.60 input motion is considered in the basic design seismic analysis for generic uniform sites using the DAC3N computer code.

#### 3.7.1.1.2 High-Frequency Ground Motion

The high-frequency ground motion is North Anna site-specific developed in the ESP application. The ESBWR foundation elevations at North Anna ESP site are EL. 205 ft for RB/FB and EL. 222 ft for CB. Since the low frequency parts of North Anna SSE ground spectra are enveloped by the 0.3g Regulatory Guide 1.60 generic site spectra with large margins, only the high frequency part is explicitly taken into account. The high frequency SSE ground spectra and compatible time histories at elevations of CB and RB/FB foundation level are shown in Figures 3.7-24 to 3.7-35.

| Data | CB Base | RB/FB Base |
|---|---|---|
| Horizontal H1 target spectrum | Figure 3.7-24 | Figure 3.7-30 |
| Horizontal H1 time histories | Figure 3.7-25 | Figure 3.7-31 |
| Horizontal H2 target spectrum | Figure 3.7-26 | Figure 3.7-32 |
| Horizontal H2 time histories | Figure 3.7-27 | Figure 3.7-33 |
| Vertical target spectrum | Figure 3.7-28 | Figure 3.7-34 |
| Vertical time histories | Figure 3.7-29 | Figure 3.7-35 |

The spectrum figures are associated with 5% damping. The PGA values, corresponding to the spectral acceleration at 100 Hz of the target spectra, are 0.492g at the CB base and 0.469g at the RB/FB base in both horizontal and vertical directions. The time histories are generated under the spectral matching criteria given in NUREG/CR-6728 and the cross-correlations between the

three individual components are all less than the 0.16 requirement. Since a more stringent matching criteria of NUREG/CR-6728 is used, a separate Power Spectral Density (PSD) check per SRP 3.7.1.II.1 is not required.

The high-frequency input ground motion thus defined is considered in the basic design seismic analysis for North Anna ESP site condition using the DAC3N computer code.

#### 3.7.1.1.3 Single Envelope Ground Motion

The single envelope ground response spectra are constructed to envelope the low-frequency 0.3g RG 1.60 spectra (Subsection 3.7.1.1.1) and the high-frequency North Anna site-specific spectra (Subsection 3.7.1.1.2). The smoothed target spectra of 5% damping are shown in Table 3.7-2 and in Figures 2.5-1 and 2.5-2. The spectral values up to and including 9 Hz and 10 Hz in the horizontal and vertical directions, respectively, are based on 0.3g RG 1.60 spectra. At higher frequencies the spectral values closely match that of the envelope of North Anna ESP spectra at ESBWR RB/FB and CB foundations as a representative ground motion for Eastern US sites founded on rock. Note that there has never been recorded a seismic event containing simultaneously very high low-frequency excitations and very high high-frequency motions. Therefore, this envelope is very conservative in terms of energy content and is used to verify the basic design previously discussed.

A single set of three orthogonal, statistically independent time histories is generated to match the target spectra in accordance with NUREG/CR-6728 criteria. The computed response spectra are compared with the corresponding target spectra in Figures 3.7-38 through 3.7-40 for H1, H2 and vertical components, respectively. Spectral matching tests for 5% damping only is consistent with the recommendations of NUREG/CR-6728 of specifying ground-motions in terms of 5% spectra. Use of 5% only is considered sufficient because there is a strong correlation among the response-spectral ordinates at damping ratios from 1 to 20%. Thus, if a time history matches the 5% target, it is likely to match the targets at other damping ratios. Since a more stringent matching criteria of NUREG/CR-6728 is used, a separate PSD check per SRP 3.7.1.II.1 is not required. Tests performed in NUREG/CR-6728 indicate that the response-spectrum tests are sufficient.

The acceleration time histories are shown in Figures 3.7-41 through 3.7-43, together with corresponding velocity and displacement time histories. Each time history has a total duration of 40 seconds with time steps of 0.005 seconds. The strong motion duration is 7.8 seconds for H1, 12 seconds for H2 and 8.9 seconds for vertical. The cross-correlations between the three individual components are all less than the 0.16 requirement.

The single envelope ground motion is considered in the design basis seismic analysis for all generic uniform and layered sites using DAC3N and SASSI computer codes, respectively.

### *3.7.1.2 Percentage of Critical Damping Values*

Damping values of various structures and components are shown in Table 3.7-1 for use in SSE dynamic analysis. These damping values are consistent with Regulatory Guide 1.61 SSE damping except for the damping value of cable trays and conduits.

The damping values shown in Table 3.7-1 for cable trays and conduits are based on the results of over 2000 individual dynamic tests conducted by Bechtel/ANCO for a variety of raceway

$R_f$ = fundamental frequency of the supported subsystem/dominant frequency of the support motion.

If the subsystem is comparatively rigid in relation to the supporting system, and also is rigidly connected to the supporting system, it is sufficient to include only the mass of the subsystem at the support point in the primary system model. On the other hand, in case of a subsystem supported by very flexible connections (e.g., pipe supported by hangers), the subsystem need not be included in the primary model. In most cases, the equipment and components, which come under the definition of subsystems, are analyzed (or tested) as a decoupled system from the primary structure and the dynamic input for the former is obtained by the analysis of the latter. One important exception to this procedure is the reactor pressure vessel (RPV), which is considered as a subsystem but is analyzed using a coupled model of the RPV and primary structure.

In general, three-dimensional models are used with six degrees of freedom assigned to each mass (node) point (i.e., three translational and three rotational). Some dynamic degrees of freedom, such as rotary inertia, may be neglected, since their contribution to the total kinetic energy of the system is small compared to the contribution from translational inertia. A two- or one-dimensional model is used if the directional coupling effect is negligible. Coupling between two horizontal motions occurs when the center of mass, the centroid, and the centroid of rigidity do not coincide. The degree of coupling depends on the amount of eccentricity and the ratio of uncoupled torsional frequency to the uncoupled lateral frequency. Structures are generally designed to keep eccentricities as small as practical to minimize lateral/torsional coupling and torsional response.

Nodal points are generally selected to coincide with the locations of large masses, such as floors or at heavy equipment supports, at all points where significant changes in physical geometry occur, and locations where the responses are of interest. The mass properties in the model include all contributions expected to be present at the time of dynamic excitation, such as dead weight, fluid weight, attached piping and equipment weight, and appropriate part (25% of floor live load or minimum 75% of roof snow load, as applicable) of the live load. For design purposes, 100% of roof snow load is used. The hydrodynamic effects of any significant fluid mass interacting with the structure are considered in modeling of the mass properties. Masses are lumped to node points. Alternatively, the consistent mass formulation may be used. The number of masses or dynamic degrees of freedom is considered adequate when additional degrees of freedom do not result in more than a 10% increase in response. Alternatively, the number of dynamic degrees of freedom is no less than twice the number of modes below the cutoff frequency in Subsection 3.7.2.1.1. For the stick models of the primary building structures, the number of dynamic degrees of freedom is no less than twice the number of modes below 50 Hz.

The RPV, including its major internal components, is analyzed together with the primary structure using a coupled RPV and supporting structural model. The RPV model is constructed following the general modeling procedures described above for the primary structures. The RPV model includes major internal components such as the fuel assemblies, control rod (CR) guide tubes, control rod drive (CRD) housings, shroud, chimney, standpipes, and steam separators. Stiffness of light components such as in-core guide tubes and housings, spargers, and their

## Table 3.7-2

## 5%-Damped Target Spectra of Single Envelope Design Ground Motion

| Horizontal | | Vertical | |
|---|---|---|---|
| Frequency (Hz) | Sa (g) | Frequency (Hz) | Sa (g) |
| 0.1 | 0.023 | 0.1 | 0.015 |
| 0.25 | 0.141 | 0.25 | 0.094 |
| 2.5 | 0.939 | 3.5 | 0.894 |
| 9 | 0.783 | 9 | 0.783 |
| 10 | 0.92 | 10 | 0.724 |
| 20 | 1.35 | 20 | 1.11 |
| 30 | 1.35 | 30 | 1.24 |
| 50 | 1.1 | 50 | 1.21 |
| 100 | 0.5 | 100 | 0.5 |

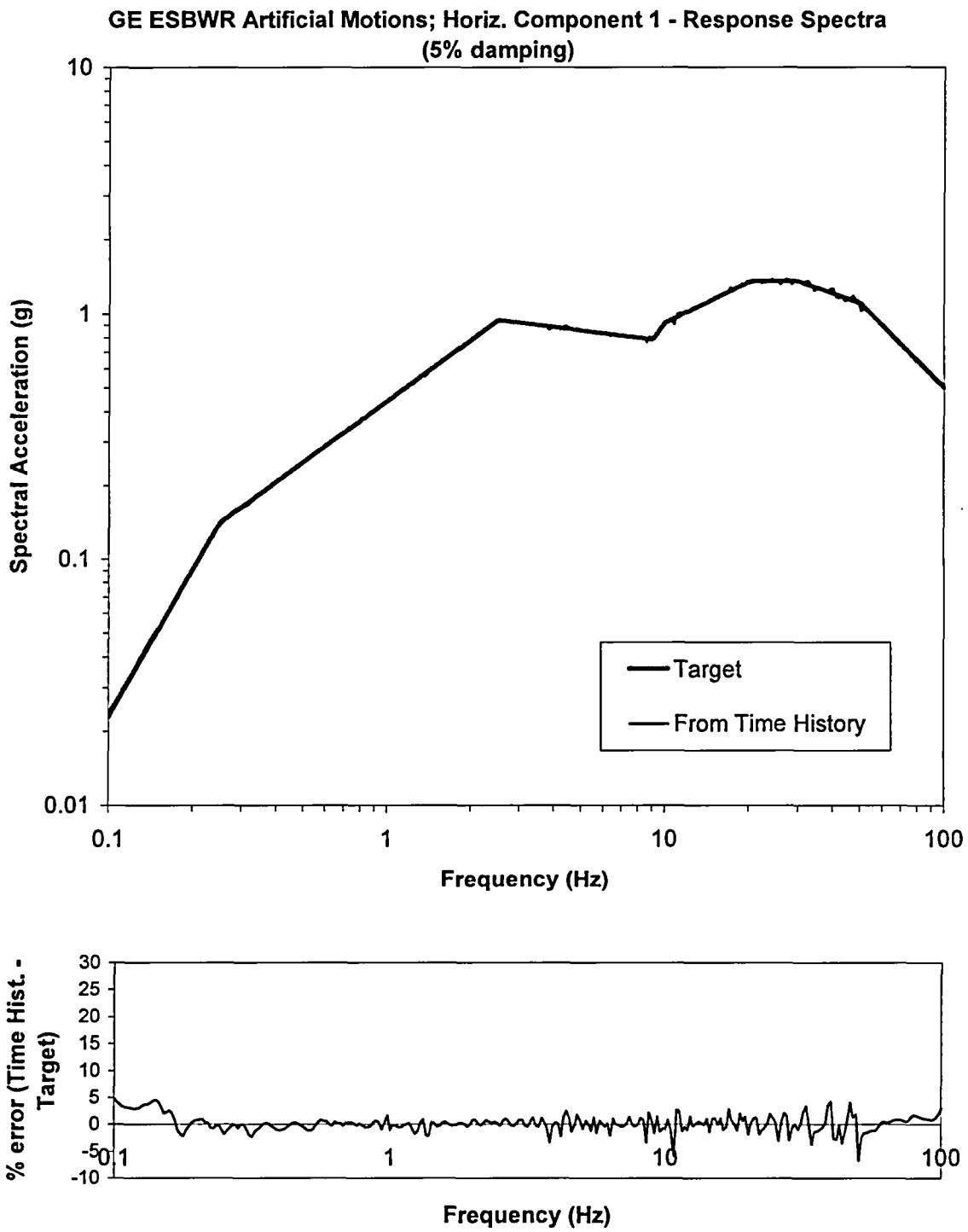



Figure 3.7-38. Single Envelope Spectrum Match – H1 Component

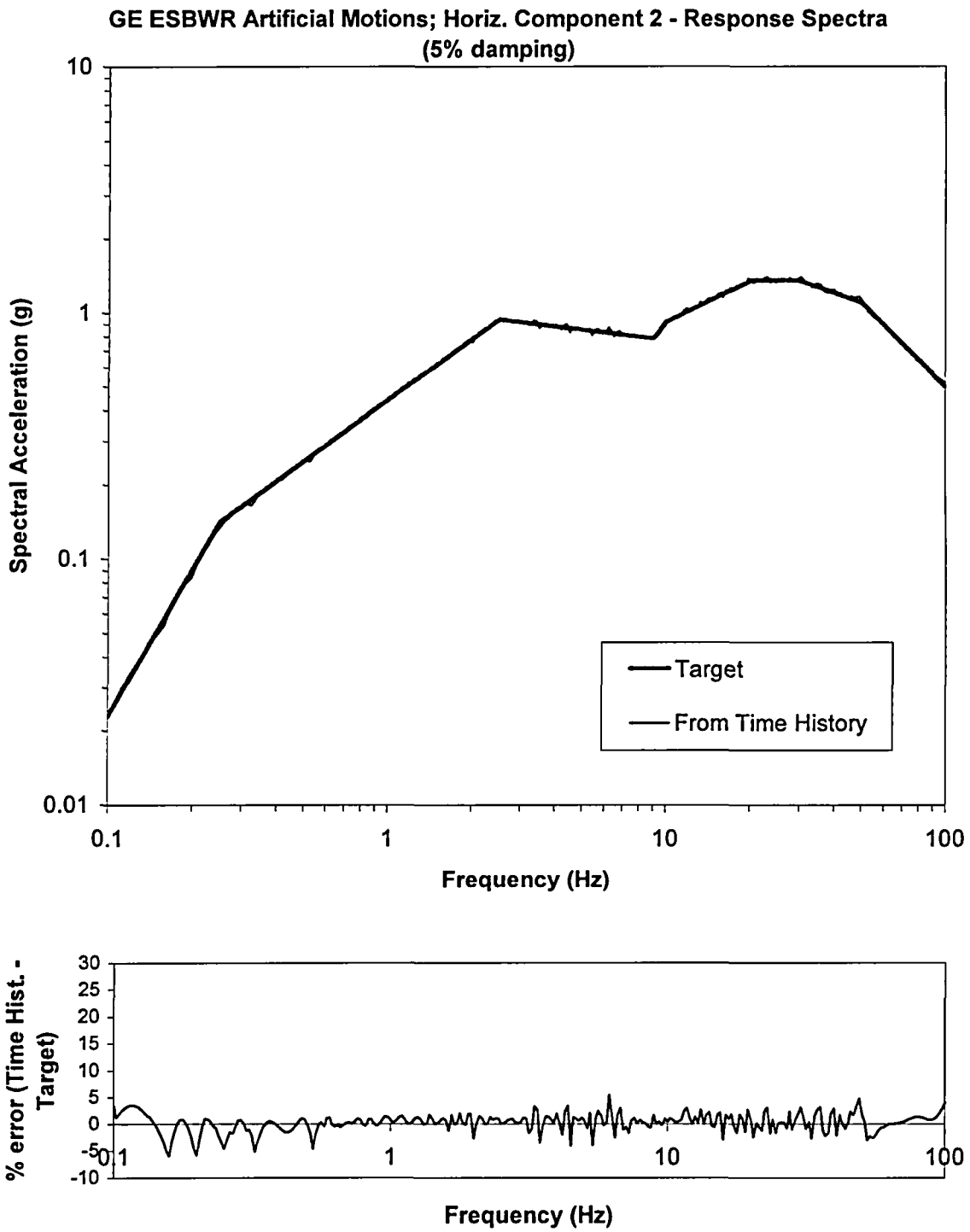



Figure 3.7-39. Single Envelope Spectrum Match – H2 Component

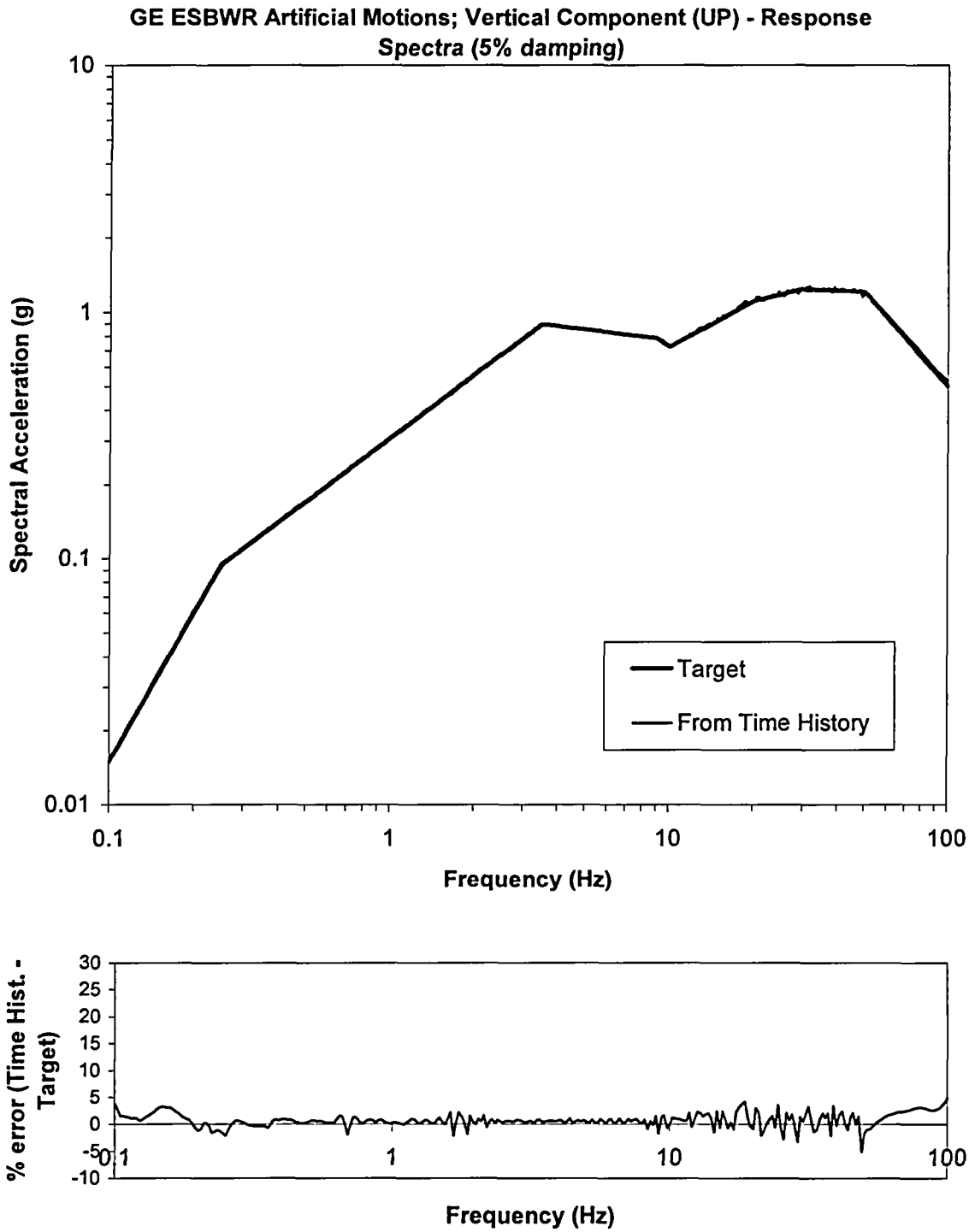



Figure 3.7-40. Single Envelope Spectrum Match – Vertical Component

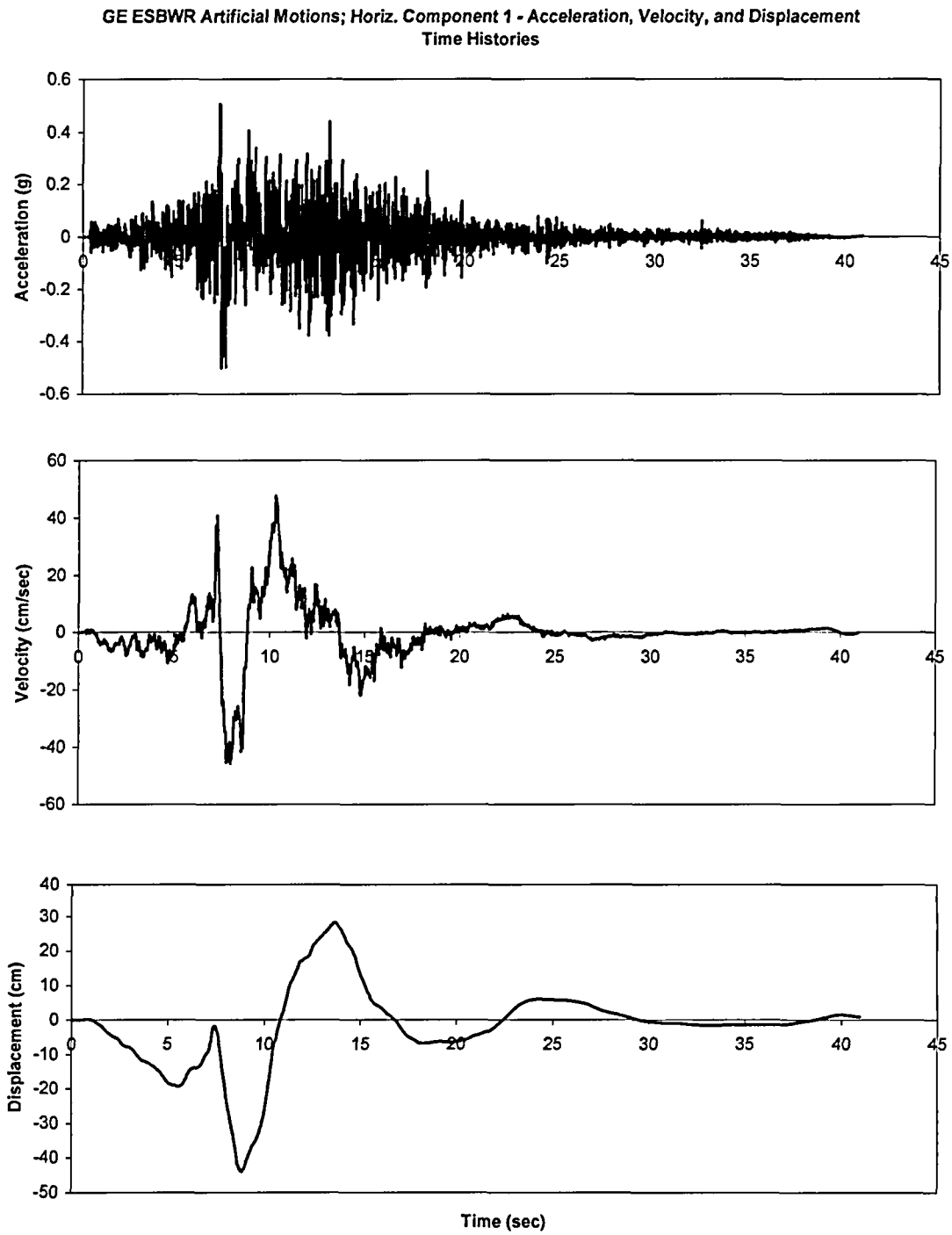



**Figure 3.7-41. Single Envelope Time Histories – H1 Component**

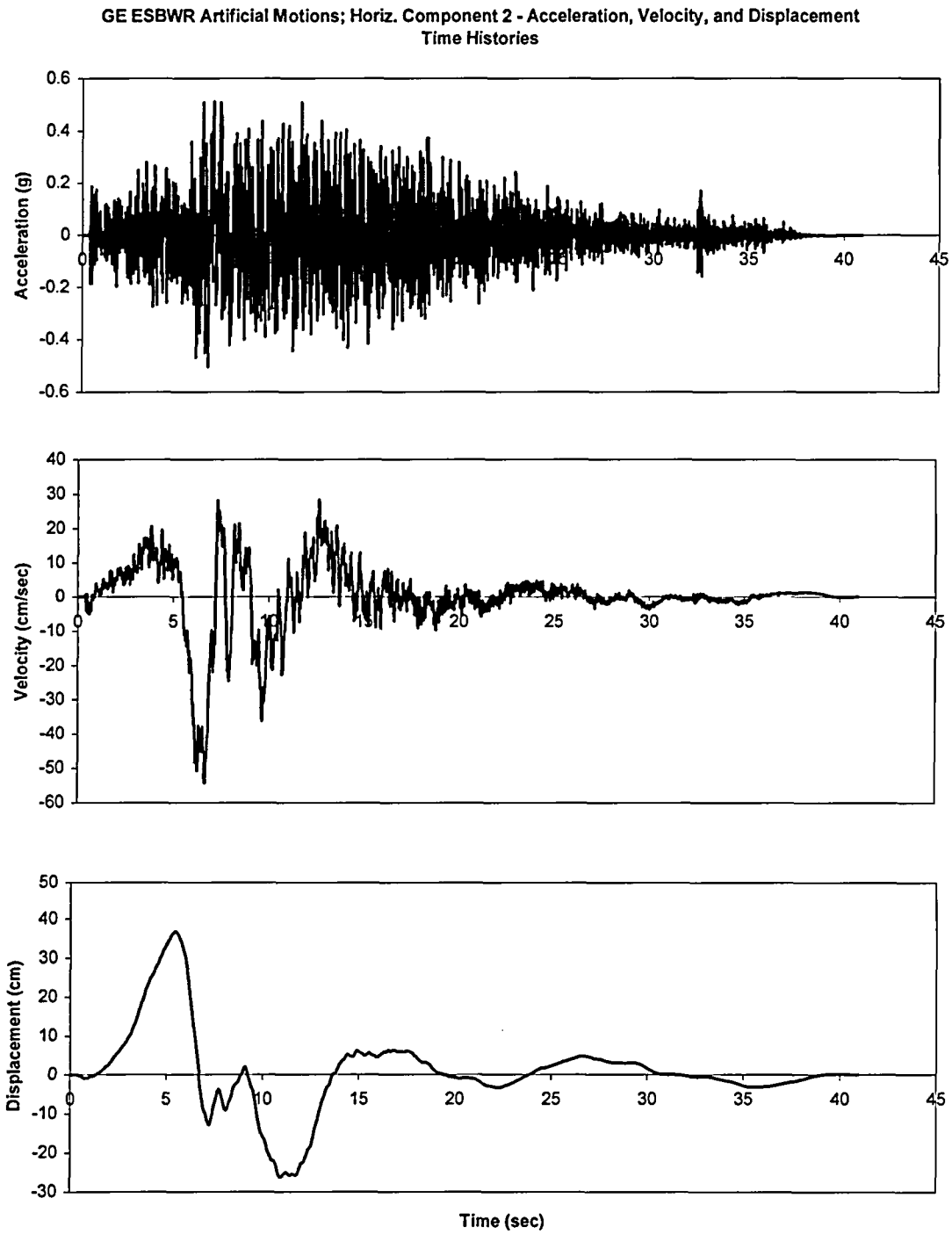



**Figure 3.7-42. Single Envelope Time Histories – H2 Component**

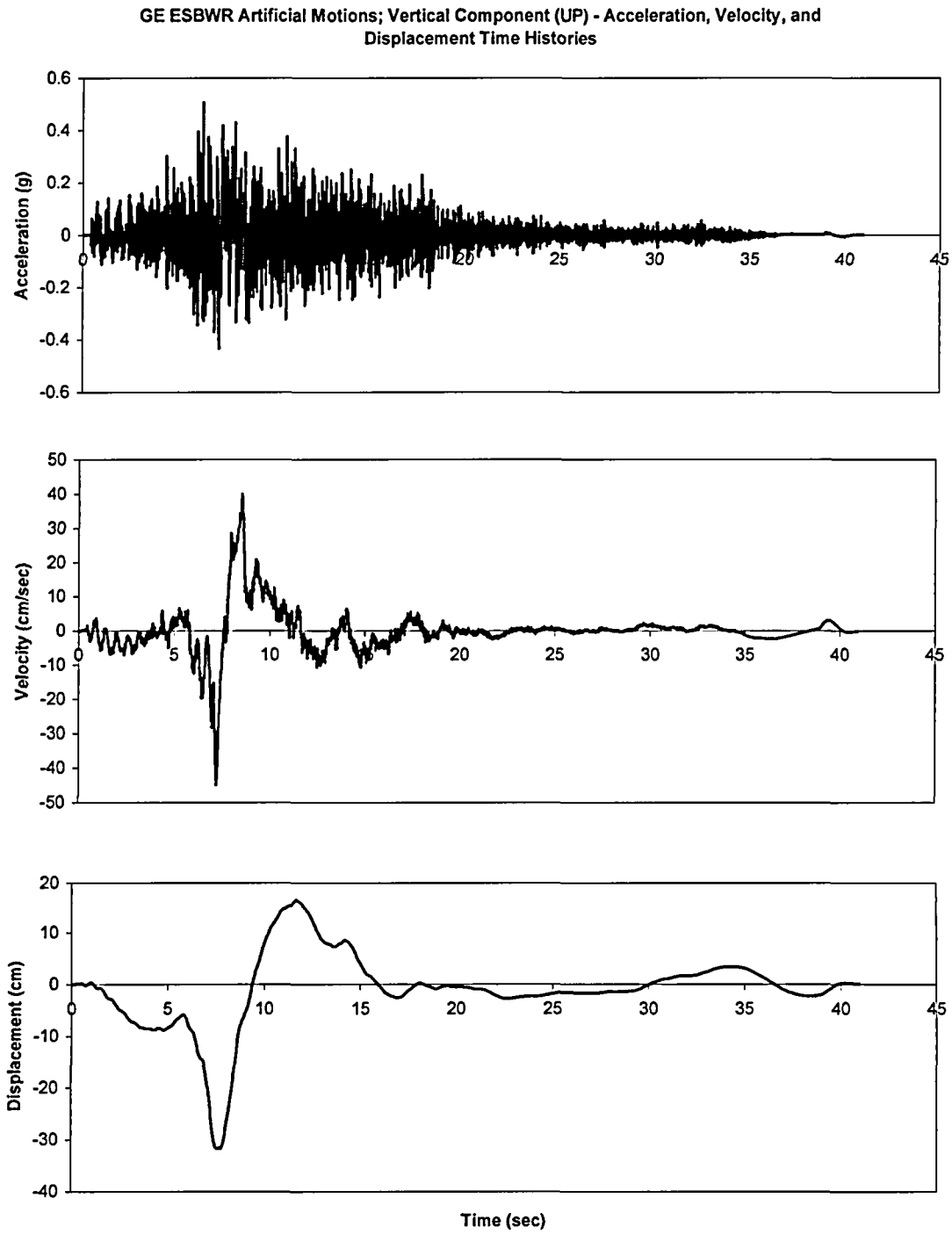



**Figure 3.7-43. Single Envelope Time Histories – Vertical Component**

## 3A.3 SITE CONDITIONS

This section describes the generic site conditions and the North Anna ESP site-specific conditions used in the SSI analysis.

### 3A.3.1 Generic Site Conditions

Design philosophy of the standard plant stipulates that the design should be applicable to as many practical sites as possible suitable for nuclear plant construction. To implement this philosophy, the effects of a wide range of subsurface conditions are considered in the seismic design. To evaluate these effects, a series of seismic soil-structure interaction (SSI) analyses in various subsurface conditions are performed. However, performing SSI analysis for combinations of all possible site properties and conditions where a nuclear power plant may be sited would be a formidable task. The purpose of this section is to define a limited number of bounding subsurface conditions selected according to experience gained from previous generic SSI studies. Three subsurface conditions are finally selected to encompass a wide range of applicable site properties and conditions. They are classified as soft, medium and hard sites. The soft site is intended to cover a spectrum of soft soil conditions. The medium site is for medium stiff soil and soft rock conditions, and the hard site for competent rock conditions. For hard sites a fixed-base case is also considered to account for very stiff sites. These sites are considered to be uniform half-space with final enveloping properties provided in Table 3A.3-1 for SSI analysis. These values are considered to be compatible with the strain level expected during SSE. They were used directly in computing soil spring and damper properties.

In addition to these uniform sites, four layered sites are also considered. They are composed of soft, medium and hard soil layers of varying depths as shown in Table 3A.3-3, taking into account variation of shear wave velocity with depth so that the effect of impedance mismatches between layers can be captured.

### 3A.3.2 North Anna ESP Site Conditions

As described in Subsection 3.7.1, the North Anna ESP site-specific conditions are also considered for the ESBWR design. North Anna is a rock site. The foundation properties considered in the SSI analysis are presented in Table 3A.3-2.

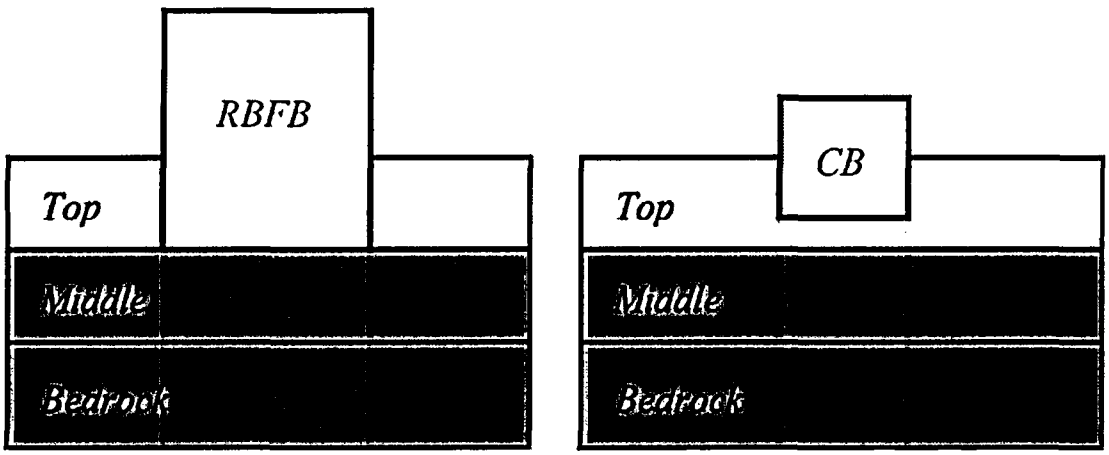
**Table 3A.3-3(1), (2)**

**Layered Site Cases**

| Layer | Shear Wave Velocity (m/s)/Depth (m) | | | |
|---|---|---|---|---|
| | CASE 1 | CASE 2 | CASE 3 | CASE 4 |
| Top | 300/20 | 300/20 | 300/20 | 300/20 |
| Middle | 300/20 | 800/20 | 300/40 | 800/40 |
| Bedrock | 1700 | 1700 | 1700 | 1700 |

(1) The 20 m depth of the middle layer corresponds to the embedded depth of the RBFB and the 40 m depth corresponds to about one-half the largest plan dimension of the RBFB foundation.

(2) Properties of the three layers of soils are the same as the generic site properties for soft, medium, and hard soils in Table 3A.3-1.



## 3A.5 SOIL-STRUCTURE INTERACTION ANALYSIS METHOD

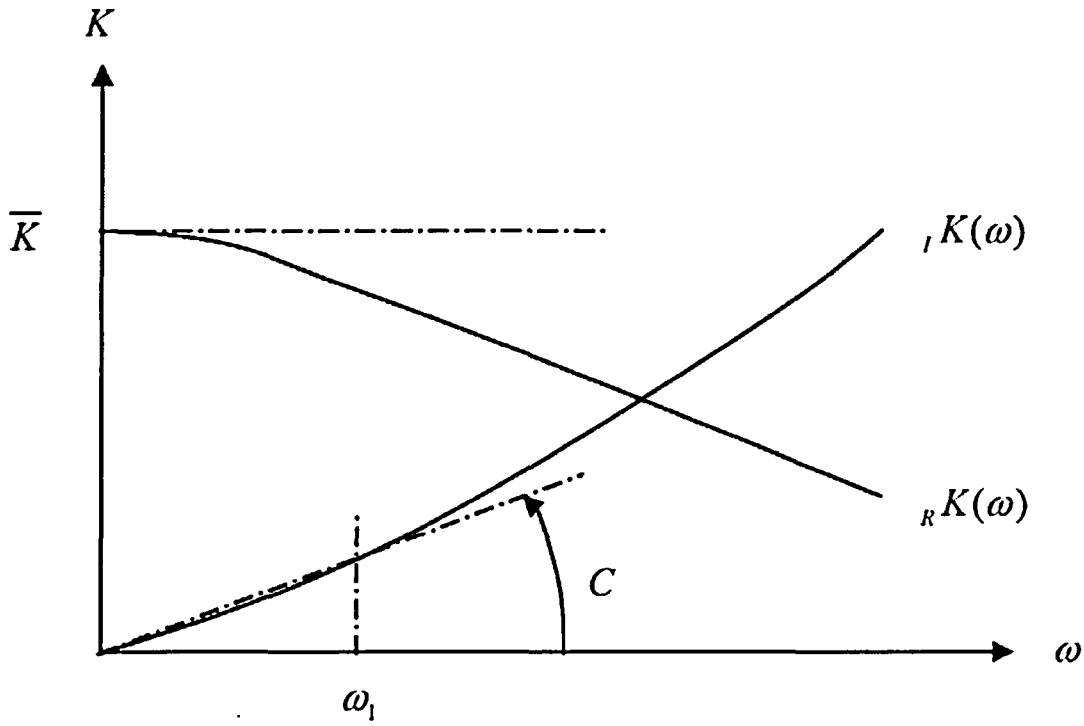
The seismic analysis is performed using the sway-rocking soil-structure interaction model.

The analysis model is a lumped mass-beam model with soil springs. The structural models are described in Subsection 3.7.2, and in Subsection 3A.7 in more detail.

To account for soil-structure interaction effect, sway-rocking base soil springs are attached to the structural model. The base spring is evaluated from vibration admittance theory, based on three-dimensional wave propagation theory for uniform half space soil. For this evaluation, soil material damping values are conservatively neglected. Though the spring values consist of frequency dependent real and imaginary parts, they are simplified and replaced with frequency independent soil spring Kc, and damping coefficient Cc, respectively, for the time history analysis solved in time domain. The method used to obtain the equivalent frequency-independent soil stiffness and damping is illustrated in Figure 3A.5-1. The calculated Kc and Cc values are tabulated in Tables 3A.5-1 and 3A.5-2 for the RBFB complex and the CB, respectively.

The effect of lateral soil/backfill on embedded foundations is conservatively accounted for by applying the control motion directly at the foundation level. Dynamic lateral soil pressures are calculated separately and considered in the design of external walls, using the elastic solution procedures in Section 3.5.3.2 of ASCE 4-98.

Because the three component ground motion time histories are statistically independent as described in Subsections 3.7.1.1.2 and 3.7.1.1.3, they are input simultaneously in the response analysis using the time history method of analysis solved by direct integration. The numerical integration time step is 0.002 sec. for the generic site cases and 0.001 sec. for the North Anna site cases. Structural responses in terms of accelerations, forces, and moments are computed directly. Floor response spectra are obtained from the calculated response acceleration time histories (Subsection 3.7.2.5).




Note:

(1) The translational and rotational components of the soil springs $(\overline{K}_S, \overline{K}_R)$ are represented by the static theoretical solutions of the elastic wave theory with frequency $(\omega = 0)$.

(2) The damping constants $(h_{S1}, h_{R1})$ of the translational and rotational components of the soil springs corresponding to the fundamental frequency $(\omega_1)$ of the soil/building coupled system are calculated as follows:

$$h_{S1} = \frac{{}_I K_S(\omega_1)}{2_R K_S(\omega_1)}, \qquad h_{R1} = \frac{{}_I K_R(\omega_1)}{2_R K_R(\omega_1)}$$

(3) The damping constants $(h_S, h_R)$ of the soil spring is approximated linearly as follows:

$$h_S(\omega) = \frac{h_{S1}}{\omega_1}\omega, \qquad h_R(\omega) = \frac{h_{R1}}{\omega_1}\omega$$

(4) The viscous damping coefficient is derived as follows:

$$C_S = \frac{2h_{S1}}{\omega_1}\overline{K}_S \qquad C_R = \frac{2h_{R1}}{\omega_1}\overline{K}_R$$

**Figure 3A.5-1. Method for Frequency-Independent Soil Properties**

**Enclosure 2**

**MFN 06-274**

**SER-ESB-033**

**PARAMETRIC EVALUATION OF EFFECTS ON**

**SSI RESPONSE, REV. 0**

**RAIs 3.7-30, 3.7-33, 35, 39 & 50**

MFN 06-274
Enclosure 2

# Shimizu Engineering Report

| | | | |
|---|---|---|---|
| Project | General Electric Company<br>ESBWR Project | Shimizu Document No. | SER-ESB-033 |
| Title | Parametric Evaluation of Effects on SSI Response | Rev. | 0 |
| | | Issued Date | 8/14/06 |
| | | Revised Date | |

NOTE:

This document provides additional SSI analyses performed and results obtained for the Reactor/Fuel Building Complex (RBFB) the Control Building (CB) to address the following issues identified in RAIs.

1) Design input motion spectra (Single envelope spectra) (RAI 3.7-5)
2) Frequency-dependent soil properties (Layered soil sites) (RAI 3.7-30)
3) Embedment effects (RAI 3.7-35)
4) Lateral soil pressure (RAI 3.7-33)
5) Concrete cracking (RAI 3.7-50)
6) Structure-to-structure interaction (RAI 3.7-39)

Verification has been performed. (ES0608-V08)

| Rev. | Date | Note | Approve | Review | Prepare |
|---|---|---|---|---|---|
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| 0 | 8/14/06 | Initial Issue | Y.O. | N.M. | S.O. |

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|---|---|---|---|
| Shimizu Corporation | Prepared by | S. Oguri | 8/14/06 |
| | Reviewed by | N. Miura | 8/14/06 |
| | Approved by | Y. Orito | 8/14/06 |

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## 1. Scope

This document provides additional SSI analyses performed and results obtained for the Reactor/Fuel Building Complex (RBFB) the Control Building (CB) to address the following issues identified in RAIs.

| | |
|---|---|
| 1) Design input motion spectra (Single envelope spectra) | (RAI 3.7-5) |
| 2) Frequency-dependent soil properties (Layered soil sites) | (RAI 3.7-30) |
| 3) Embedment effects | (RAI 3.7-35) |
| 4) Lateral soil pressure | (RAI 3.7-33) |
| 5) Concrete cracking | (RAI 3.7-50) |
| 6) Structure-structure interaction | (RAI 3.7-39) |

## 2. Building Stick Model

The stick model used in this evaluation is an updated version from the one used in the existing DCD seismic analysis. The updated RBFB model is documented in report SER-ESB-023 and CB model in SER-ESB-024 (see response to RAI 3.7-24).

## 3. Site Conditions

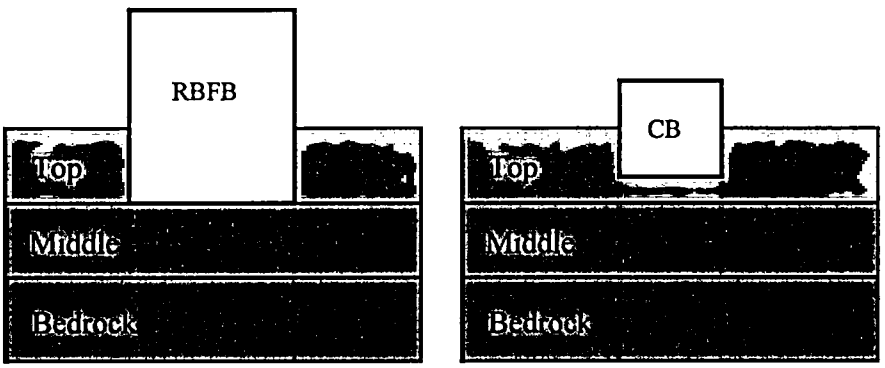
In addition to the generic uniform sites and North Anna ESP site defined in DCD Tables 3A.3-1 and 3A.3-2, respectively, generic layered sites shown in Table 3-1 are also considered in this evaluation.

**Table 3-1 Layered Site Cases**

| Layer | Shear Wave Velocity (m/s) / Depth (m) | | | |
|---|---|---|---|---|
| | CASE 1 | CASE 2 | CASE 3 | CASE 4 |
| Top | 300/20 | 300/20 | 300/20 | 300/20 |
| Middle | 300/20 | 800/20 | 300/40 | 800/40 |
| Bedrock | 1700 | 1700 | 1700 | 1700 |

Note: 1) The 20 m depth of the middle layer corresponds to the embedded depth of the RBFB and the 40 m depth corresponds to about one-half the largest plan dimension of the RBFB foundation.

2) Properties of the three layers of soils are the same as the generic site properties for soft, medium, and hard soils in DCD Table 3A.3-1.



## 4. Input Motions

In addition to the two separate input motions, 0.3g RG 1.60 and North Anna site-specific considered in the existing DCD Appendix 3A seismic analysis, a single envelope input motion is also considered in this evaluation. Details of the single envelope input motion can be found in the DCD markup associated with RAI 3.7-30 response.

## 5. SSI Analysis Methods

For uniform sites the SSI analysis method follows the lumped soil spring approach same as the existing DCD Appendix 3A using DAC3N computer code. For layer sites described in Section 3, the finite element method using SASSI computer code is employed for SSI analysis.

A typical SASSI model of the excavated soil volume is shown in Figure 5-1 for the RBFB and Figure 5-2 for the CB.

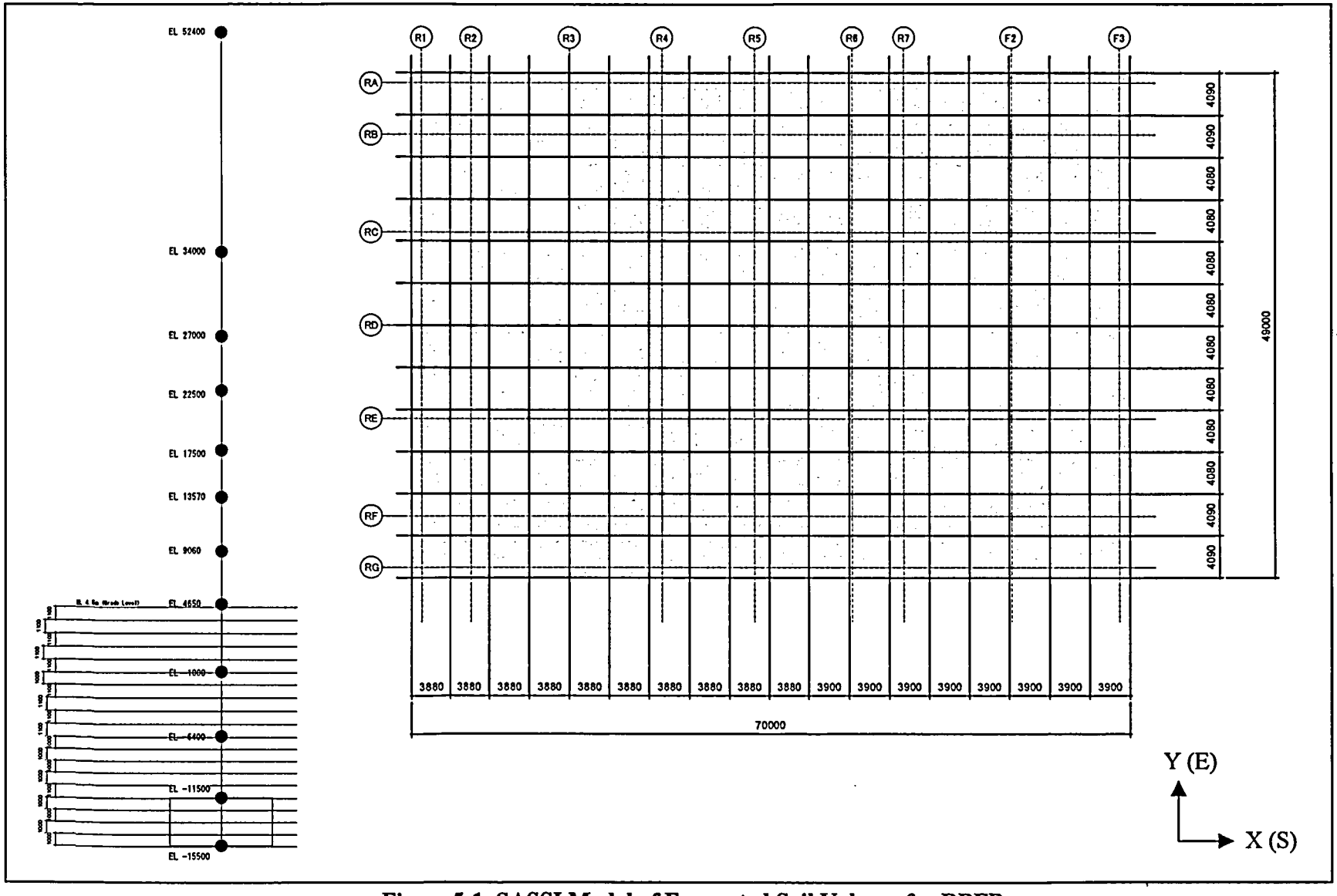



**Figure 5-1 SASSI Model of Excavated Soil Volume for RBFB**

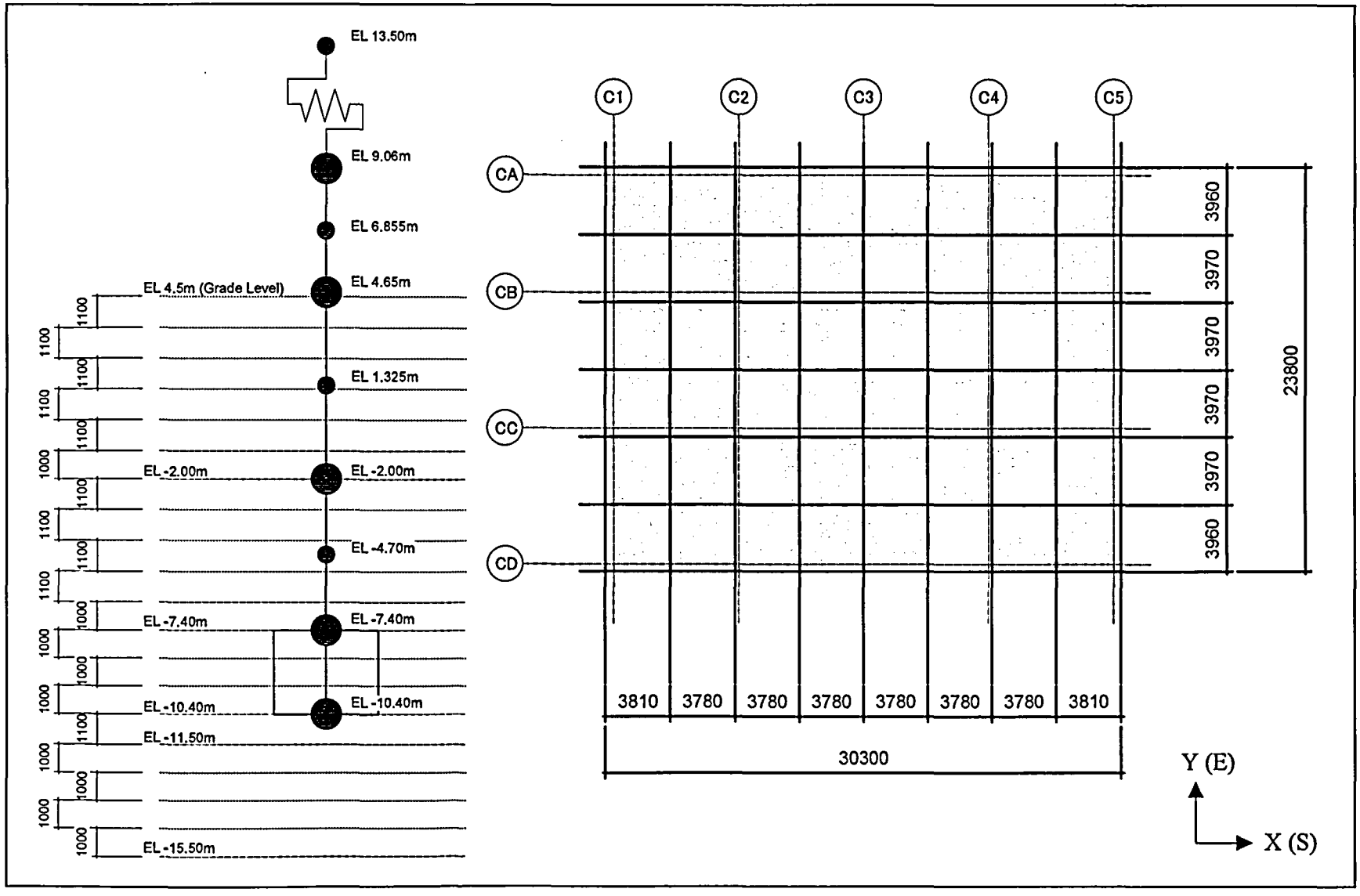



**Figure 5-2 SASSI Model of Excavated Soil Volume for CB**

## 6. Analysis Cases

The analysis cases considered are shown in Tables 6-1 and 6-2, grouped for the uniform sites and layered sites, respectively.

**Table 6-1 Analysis Cases for Uniform Soil Sites**

| No. | Building | | Uniform Soil Condition | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Input Motion | Soft | Medium | Hard | Fixed | NA-BE | NA-UB | NA-LB |
| U-1 | RBFB | RG 1.60 (0.3g) | * | * | * | * | | | |
| U-2 | RBFB | NA site wave | | | | | * | * | * |
| U-3 | RBFB | Single Enveloping Spectra Wave | * | * | * | * | | | |
| U-4 | CB | RG 1.60 (0.3g) | * | * | * | * | | | |
| U-5 | CB | NA site wave | | | | | * | * | * |
| U-6 | CB | Single Enveloping Spectra Wave | * | * | * | * | | | |

**Table 6-2 Analysis Cases for Layered Soil Sites**

| No. | Building | Input Motion | Concrete Stiffness | | Layered Soil Conditions | | | |
|---|---|---|---|---|---|---|---|---|
| | | Single Enveloping Spectra Wave | uncracked | 50% cracked | case1 | case2 | case3 | case4 |
| L-1 | RBFB | * | * | | * | | | |
| L-2 | RBFB | * | * | | | * | | |
| L-3 | RBFB | * | * | | | | * | |
| L-4 | RBFB | * | * | | | | | * |
| L-5 | CB | * | * | | * | | | |
| L-6 | CB | * | * | | | * | | |
| L-7 | CB | * | * | | | | * | |
| L-8 | CB | * | * | | | | | * |
| L-9 | RBFB | * | | * | (critical case from L-1 to L-4) | | | |
| L-10 | CB | * | | * | (critical case from L-5 to L-8) | | | |
| L-11 | (RBFB+)CB | *(1) | * | | (critical case from L-5 to L-8) | | | |

(1) Soil response obtained from the RBFB analysis is used as input motion for CB model.

# 7. Analysis Results

The analysis results are presented in the following subsections for the evaluation of the effect of various parameters.

## 7.1 Effect of Single Envelope Ground Motion – RAI 3.7-5

The effect of single envelope ground motion is evaluated by comparing the results of Case U-3 (single envelope input motion) with the envelope results of Cases U-1and U-2 (two separate input motions) for the RBFB and Case U-6 with the envelope of Cases U-4 and U-5 for the CB.

Comparisons of floor response spectra (FRS) (5% damping) at selected RBFB locations are shown in Figures 7.1-1 through 7.1-18. Similarly, FRS (5% damping) at selected CB locations are compared in Figures 7.1-19 through 7.1-21. Please note that X direction in analysis model is corresponding to North-South direction and Y direction is corresponding to East-West direction.

It is found from the results that the responses due to the single envelope input motion are generally bounded by the envelope responses of RG 1.60 input motion and NA site input motion, analyzed separately, in the lower frequency range, however, for the fixed case and hard site case, they exceed the envelope responses of RG 1.60 input motion and NA site input motion in the higher frequency range. This is because the effect of high-frequency component of the ground motion is more pronounced for stiffer sites. The fixed case was analyzed for 0.3g RG 1.60 input only in the original analysis.

The existing DCD design load will be updated to incorporate these higher values in the high frequency range. The impact on the building structures is considered to be small; however, the subsystems, which have fundamental frequencies in the high frequency domain, need to be designed considering this increase of load.

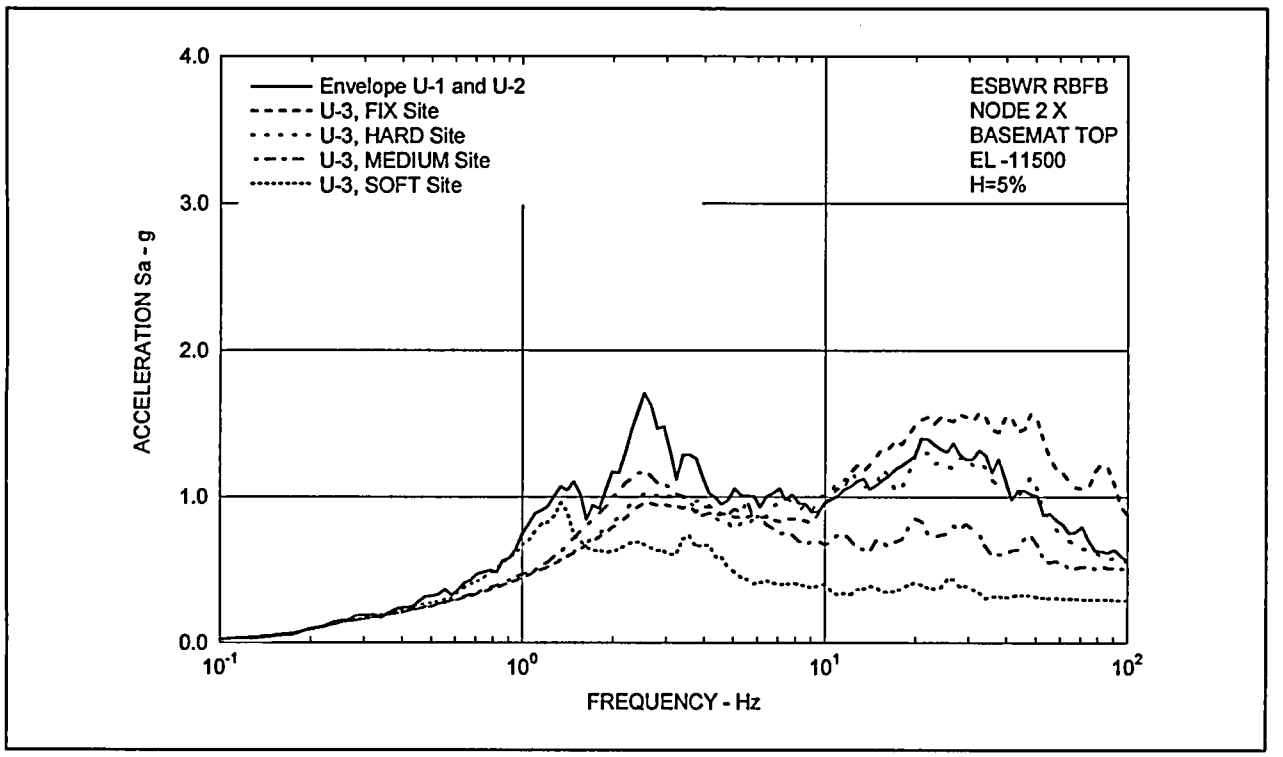



**Figure 7.1-1 Floor Response Spectra - RBFB Basemat X**

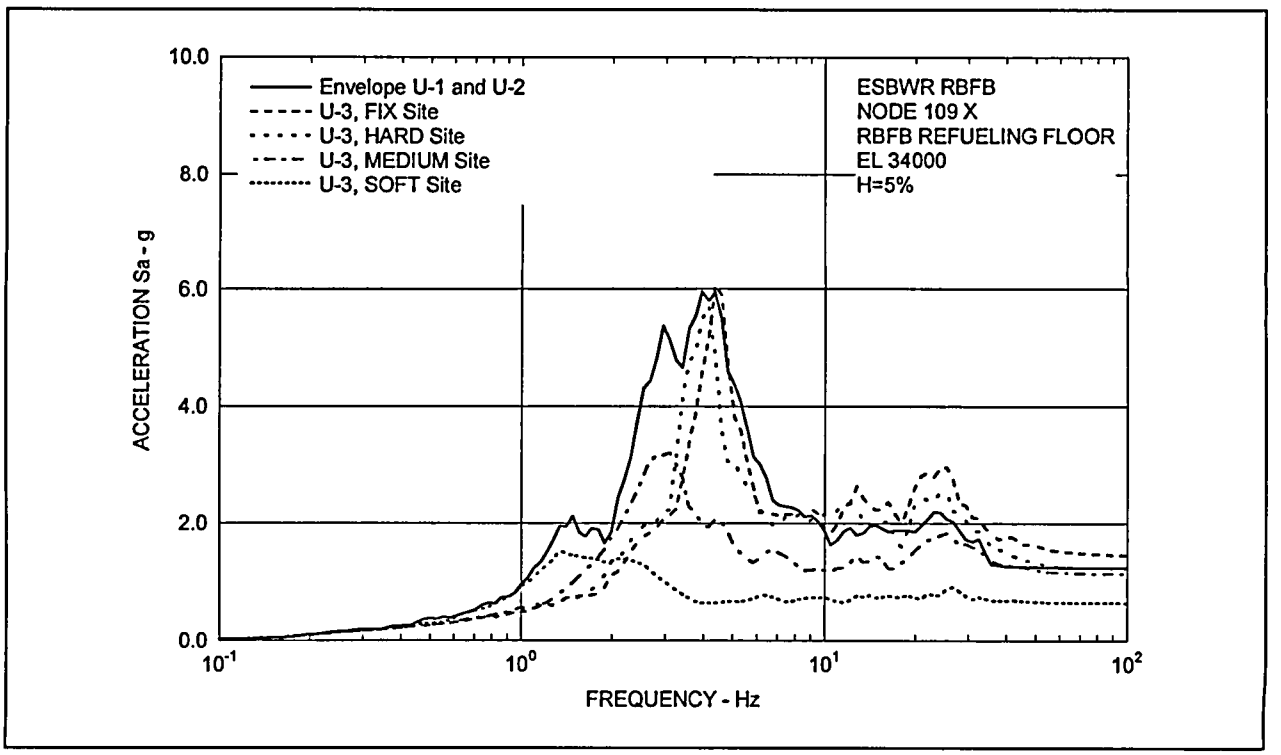



**Figure 7.1-2 Floor Response Spectra - RBFB Refueling Floor X**

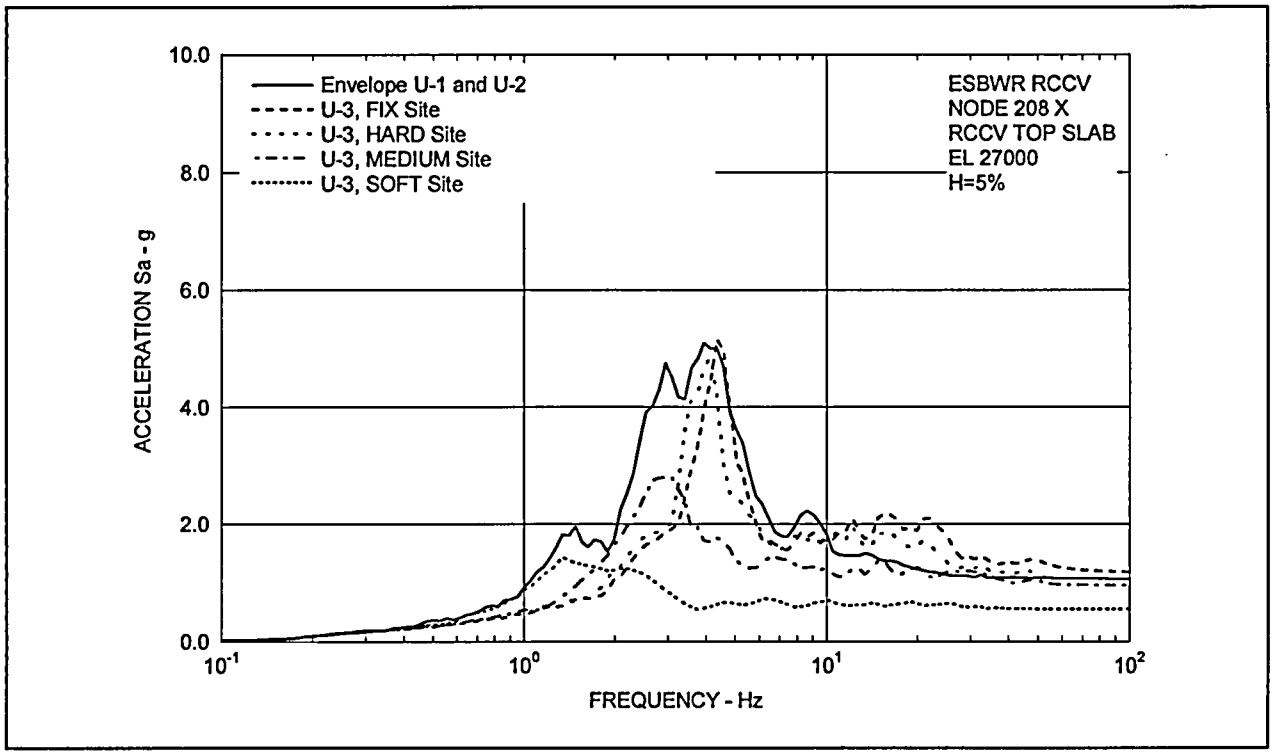



**Figure 7.1-3 Floor Response Spectra - RCCV Top Slab X**

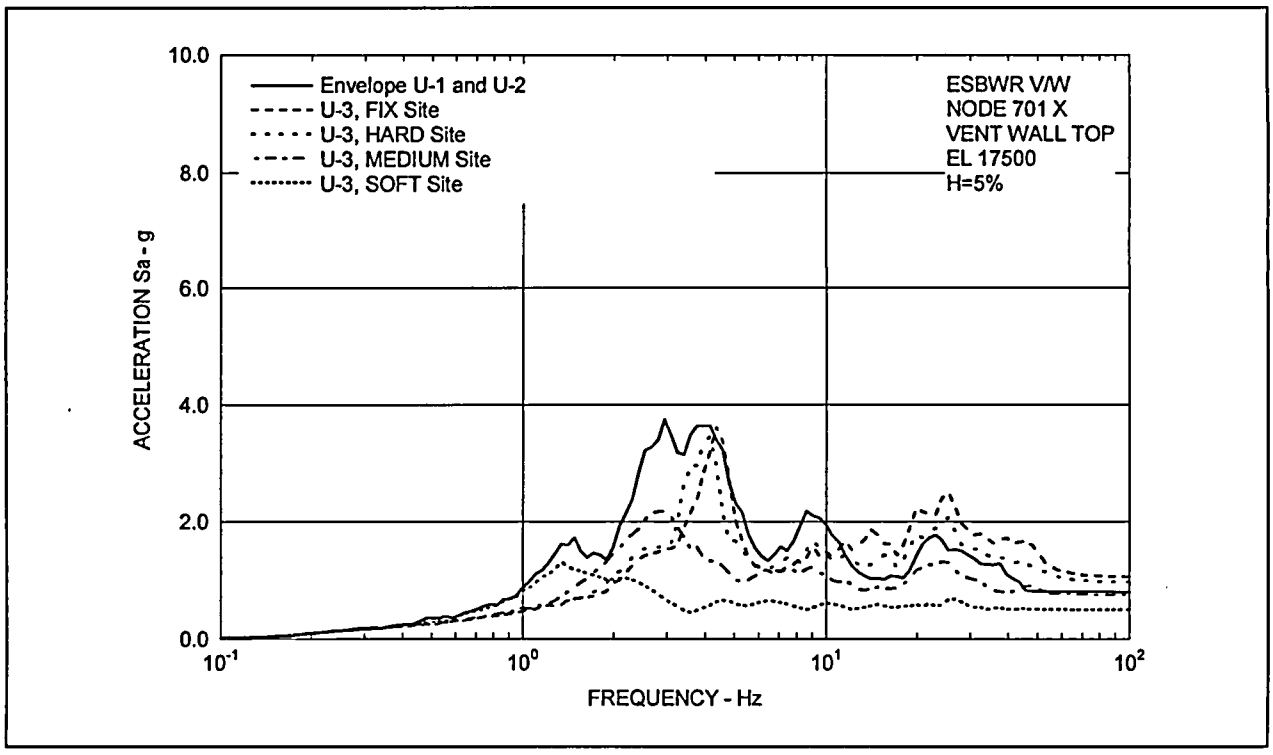



**Figure 7.1-4 Floor Response Spectra - Vent Wall Top X**

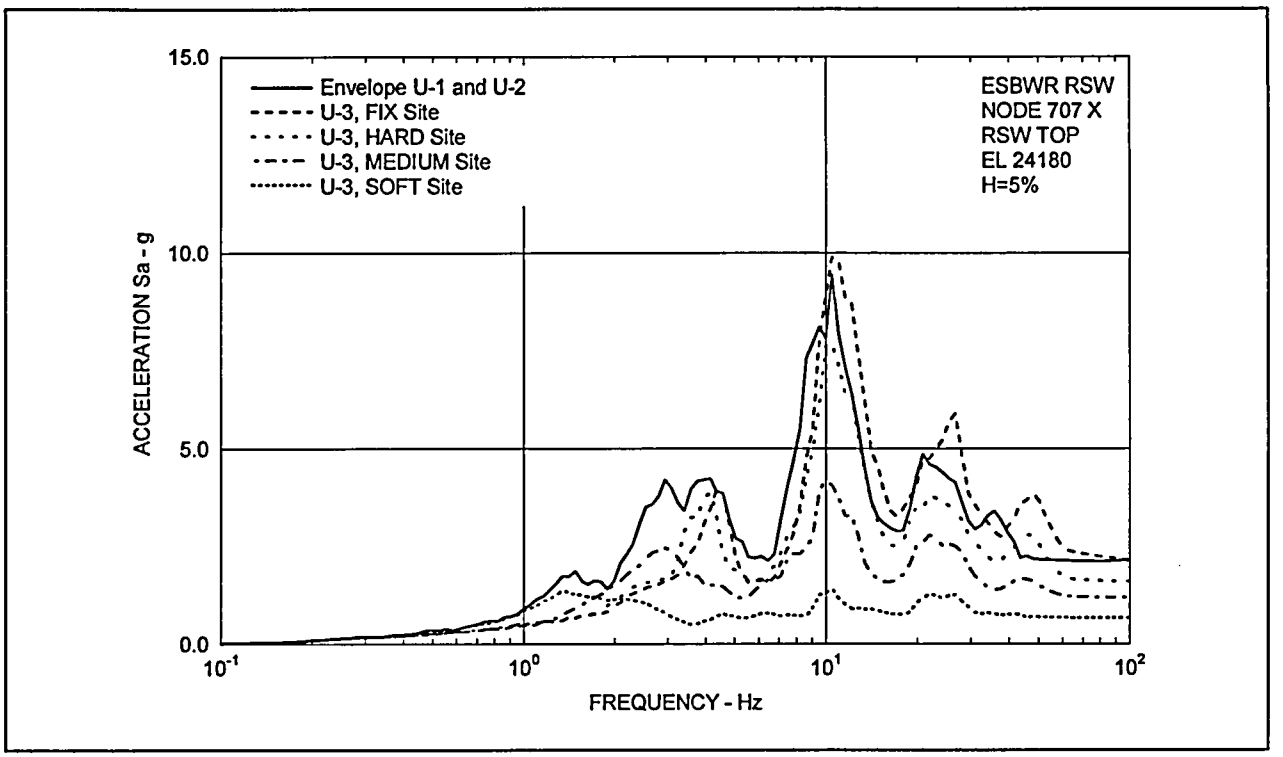



**Figure 7.1-5 Floor Response Spectra - RSW Top X**

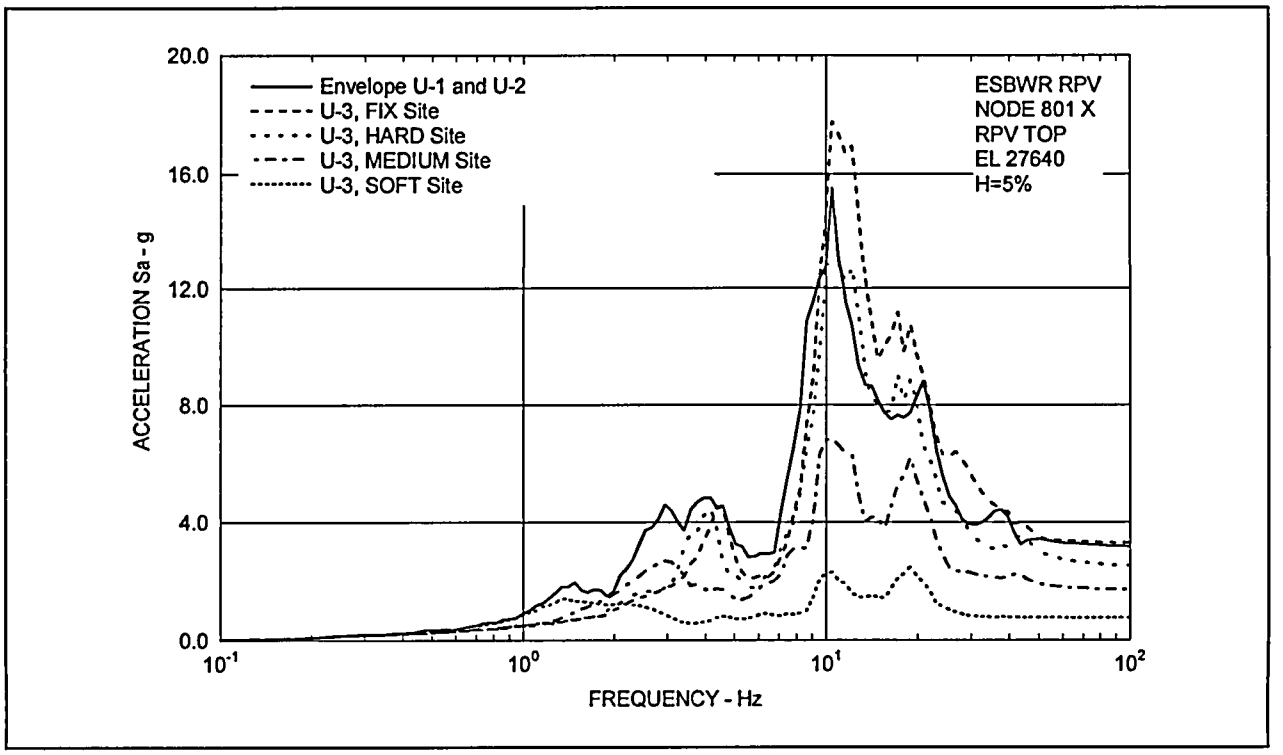



**Figure 7.1-6 Floor Response Spectra - RPV Top X**

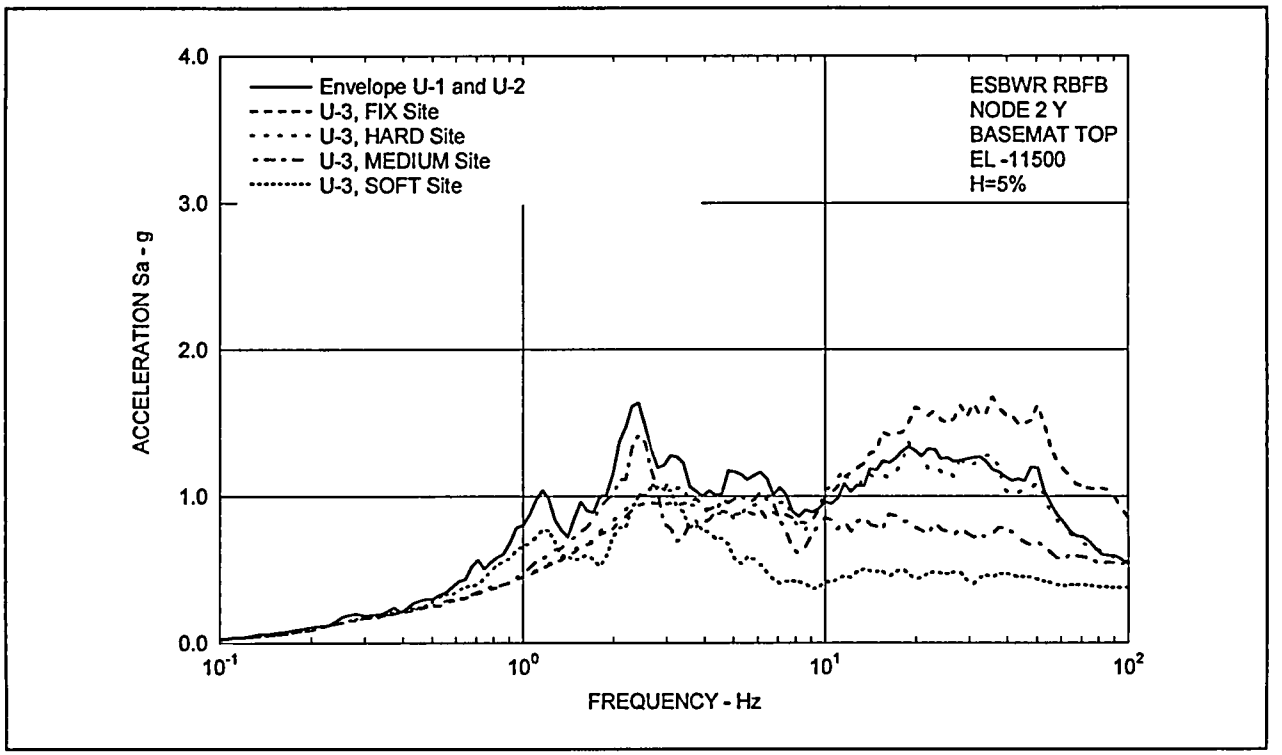



**Figure 7.1-7 Floor Response Spectra - RBFB Basemat Y**

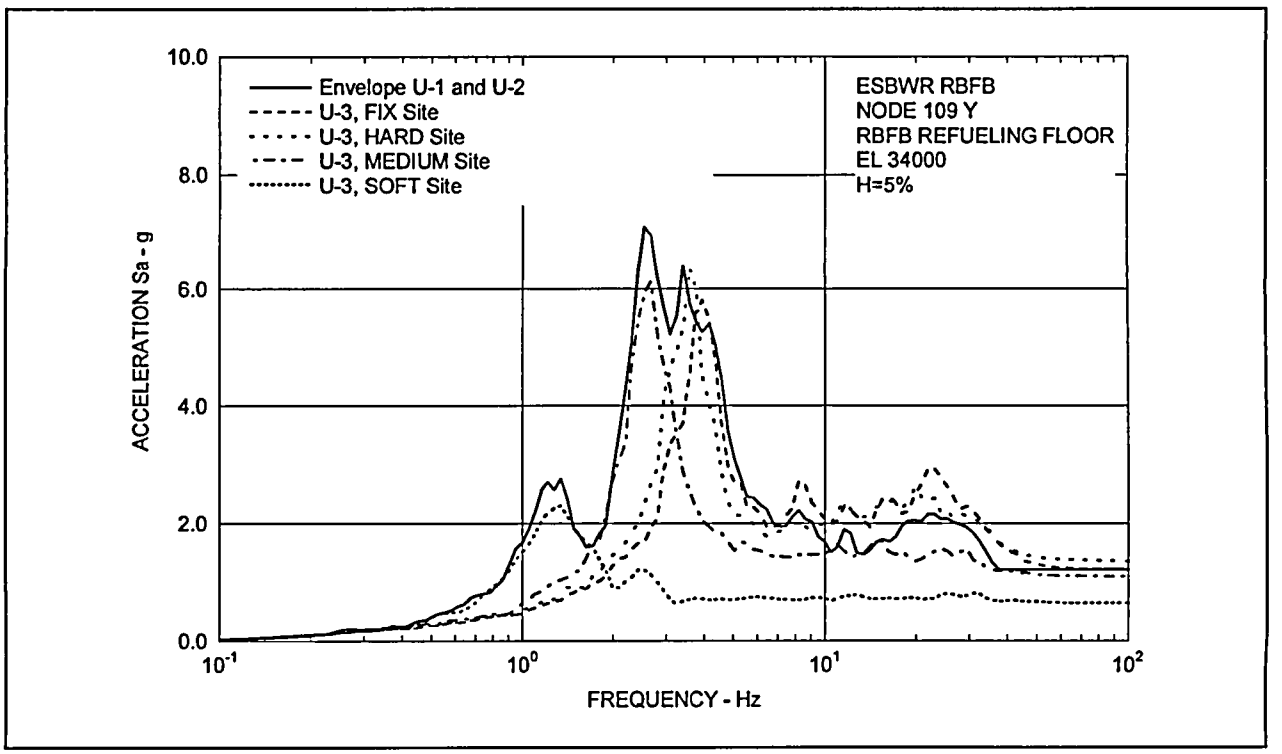



**Figure 7.1-8 Floor Response Spectra - RBFB Refueling Floor Y**

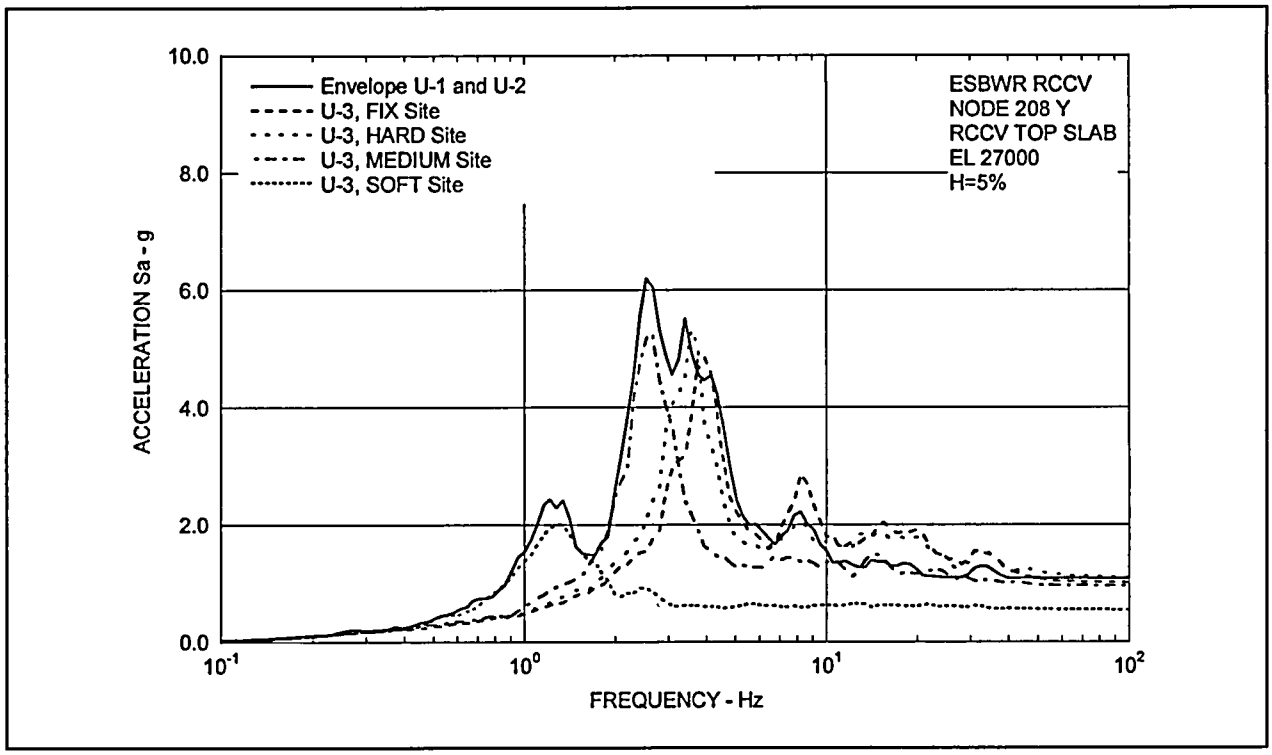



**Figure 7.1-9 Floor Response Spectra - RCCV Top Slab Y**

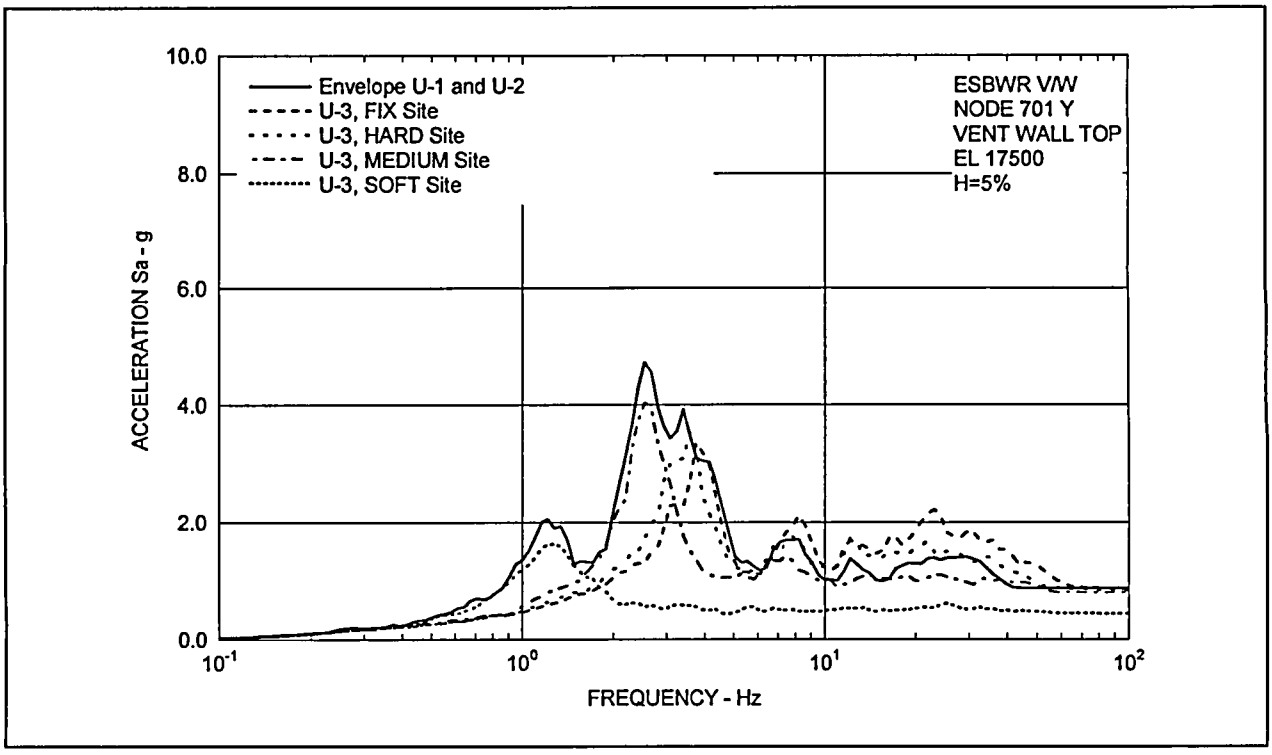



**Figure 7.1-10 Floor Response Spectra - Vent Wall Top Y**

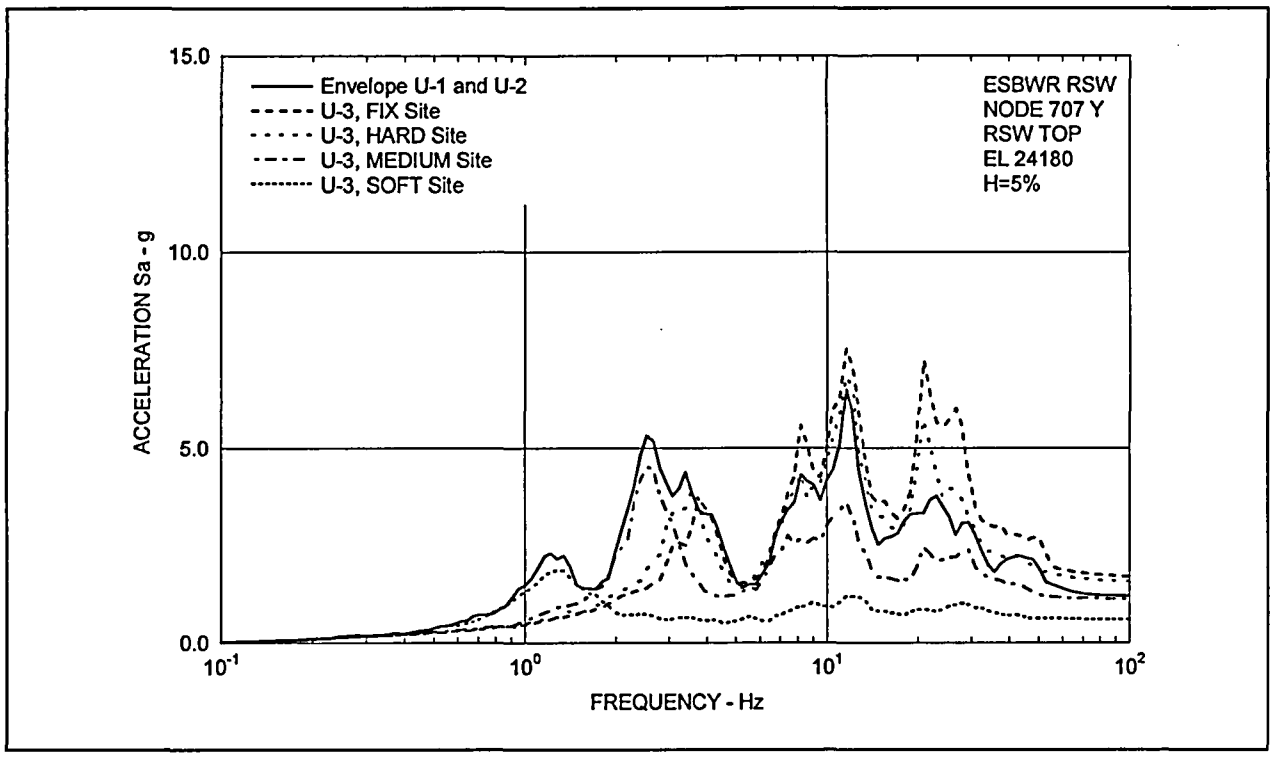



**Figure 7.1-11 Floor Response Spectra - RSW Top Y**

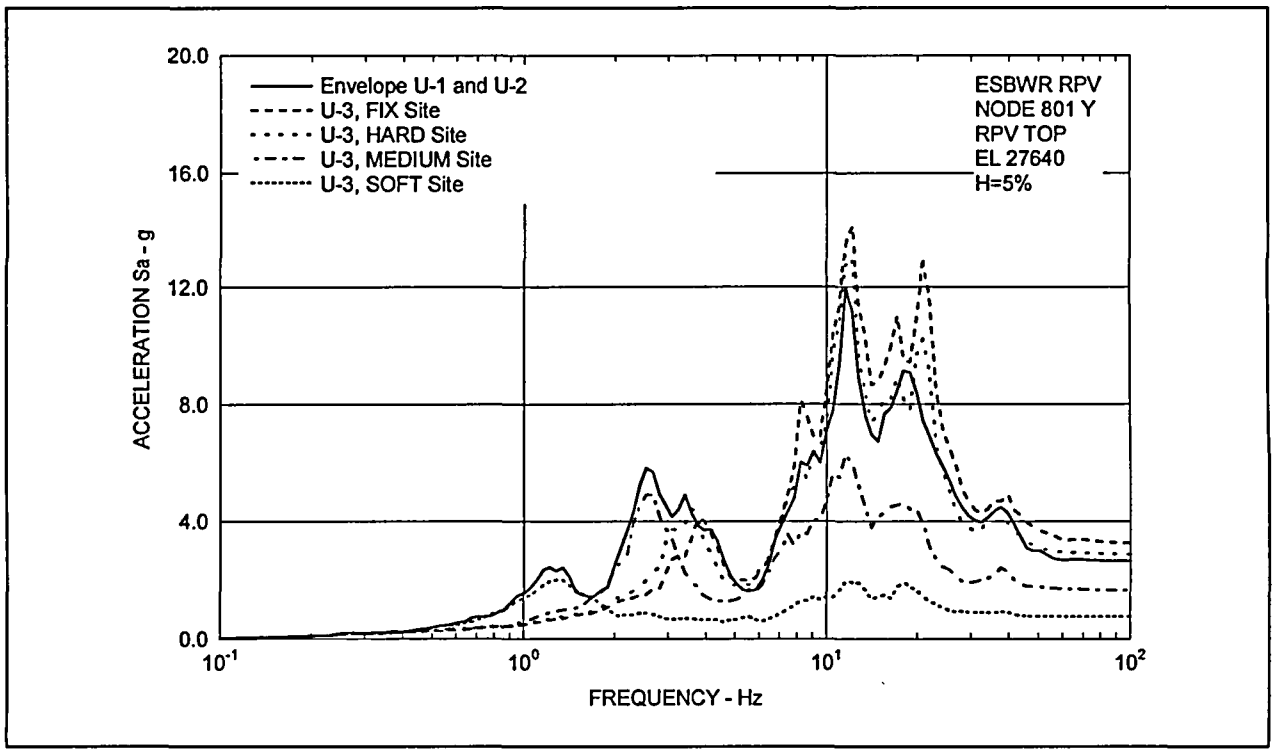



**Figure 7.1-12 Floor Response Spectra -RPV Top Y**

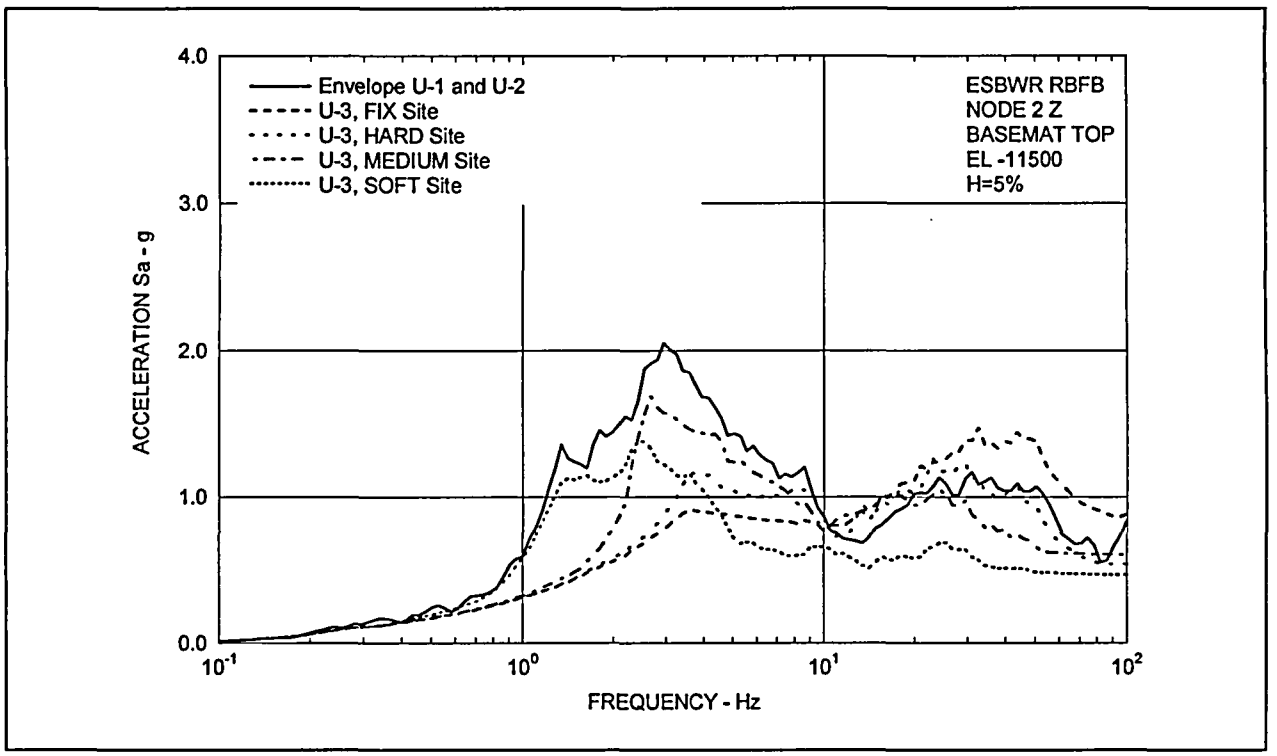



**Figure 7.1-13 Floor Response Spectra - RBFB Basemat Z**

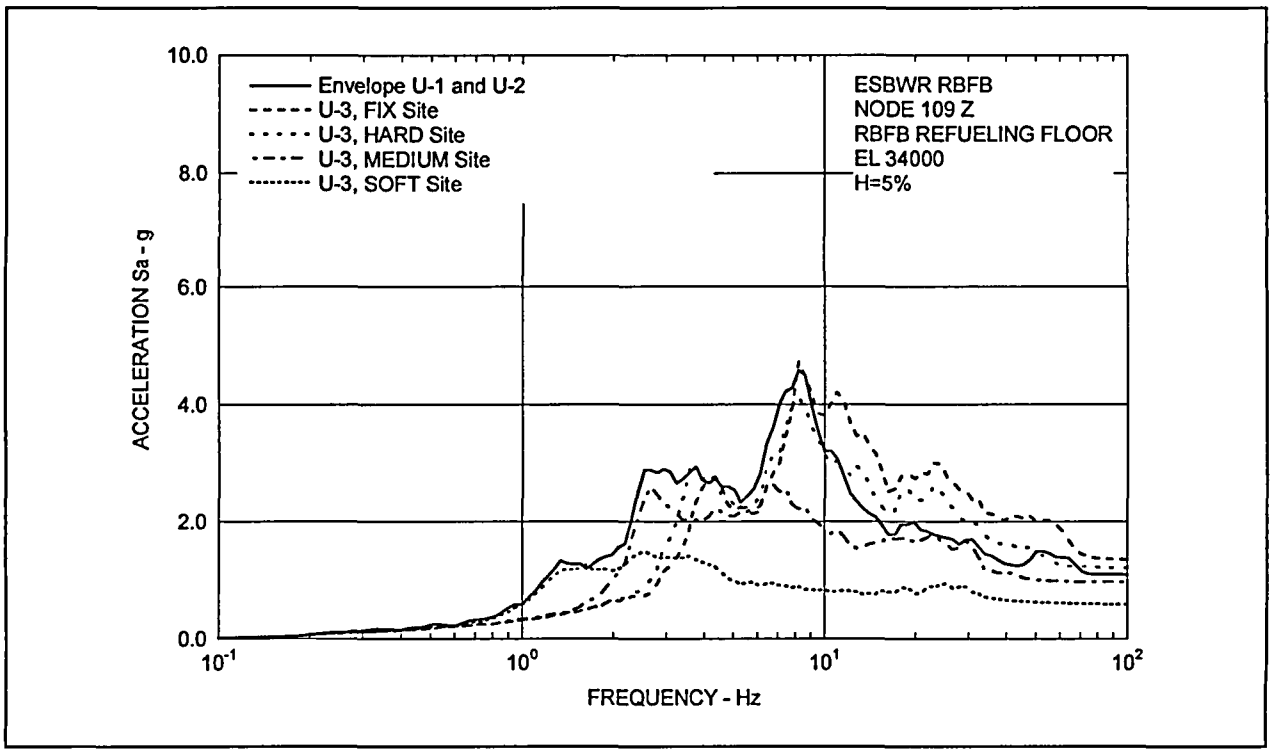



**Figure 7.1-14 Floor Response Spectra - RBFB Refueling Floor Z**

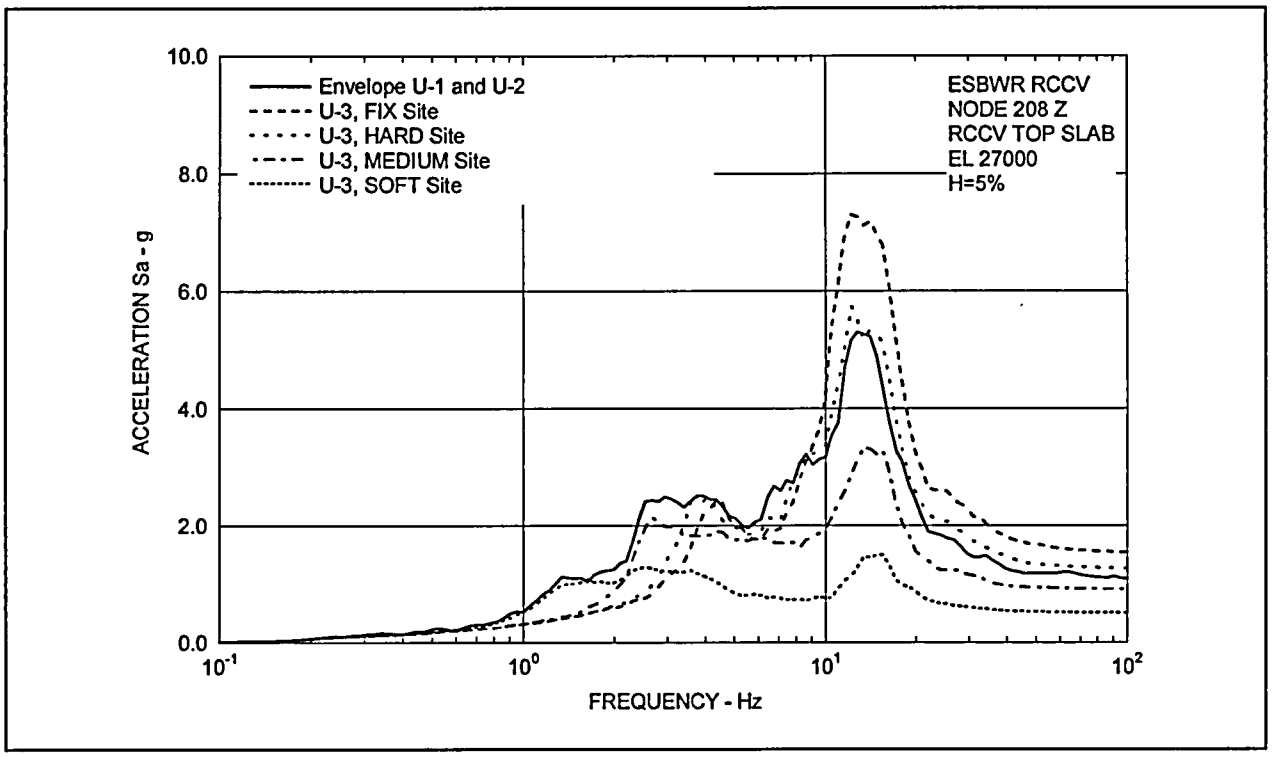



**Figure 7.1-15 Floor Response Spectra - RCCV Top Slab Z**

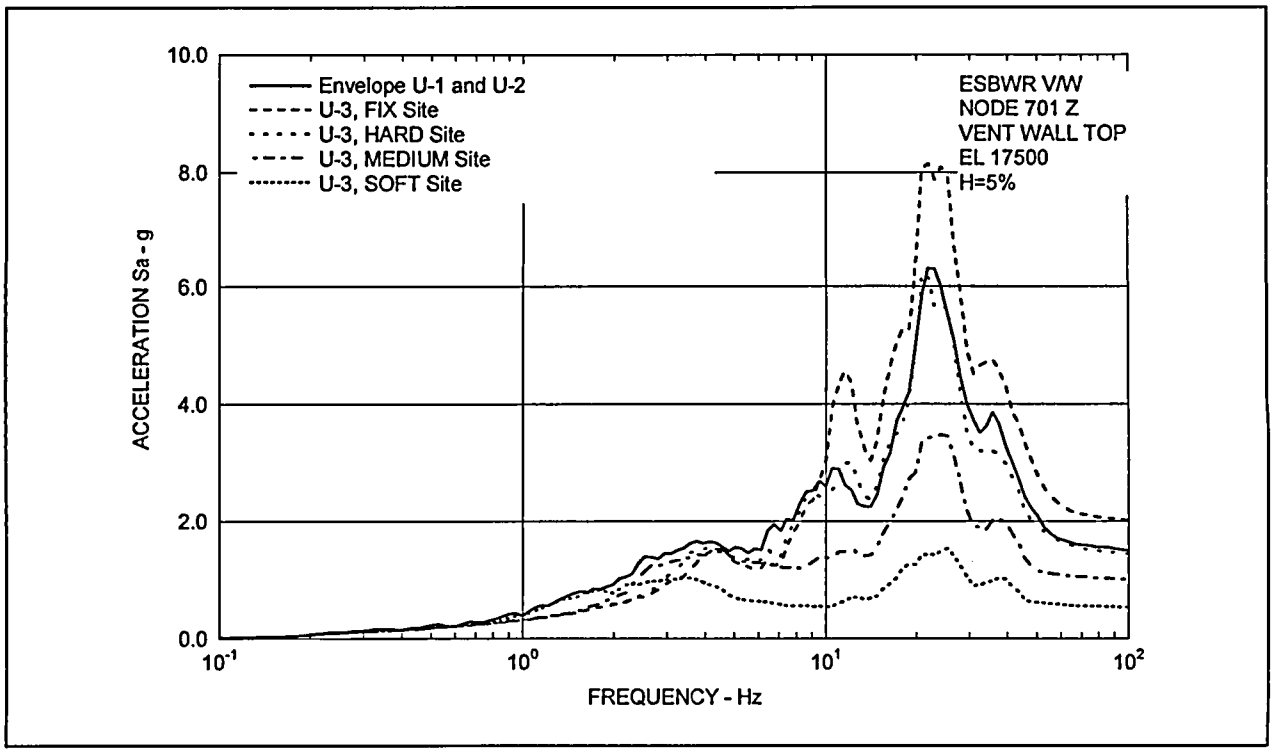



**Figure 7.1-16 Floor Response Spectra - Vent Wall Top Z**

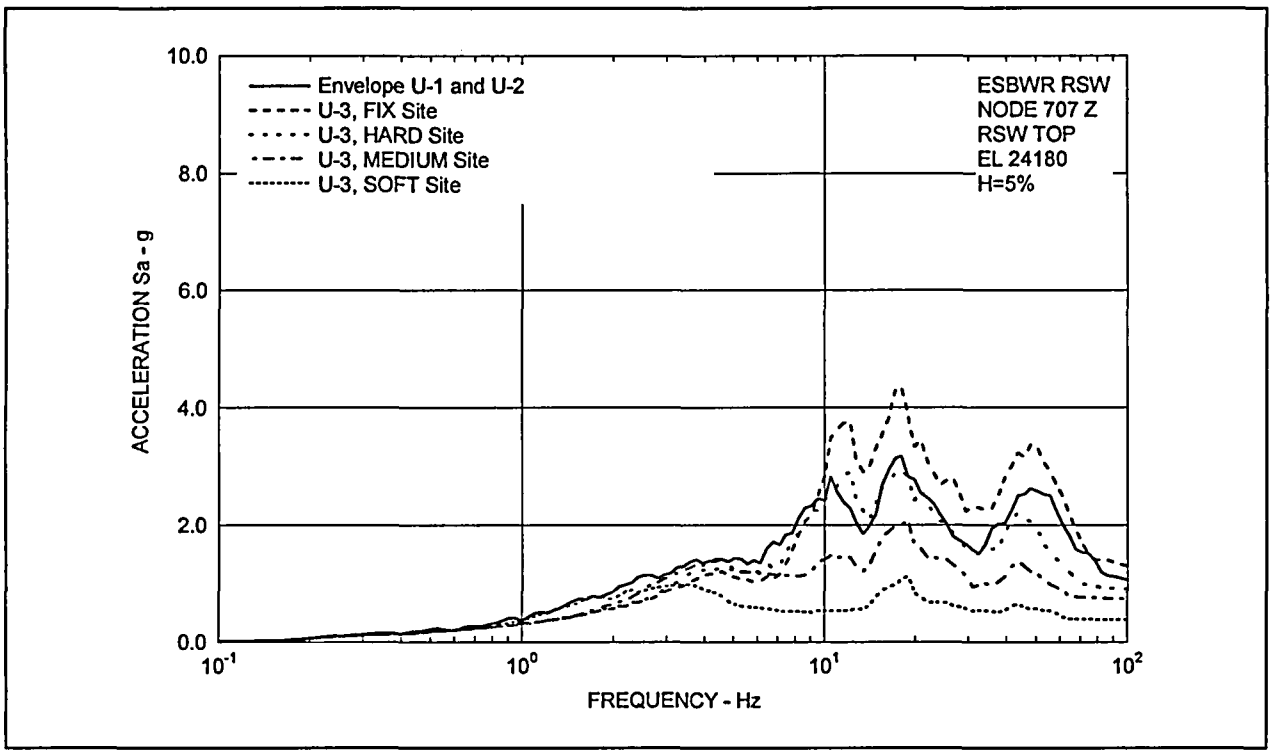



**Figure 7.1-17 Floor Response Spectra - RSW Top Z**

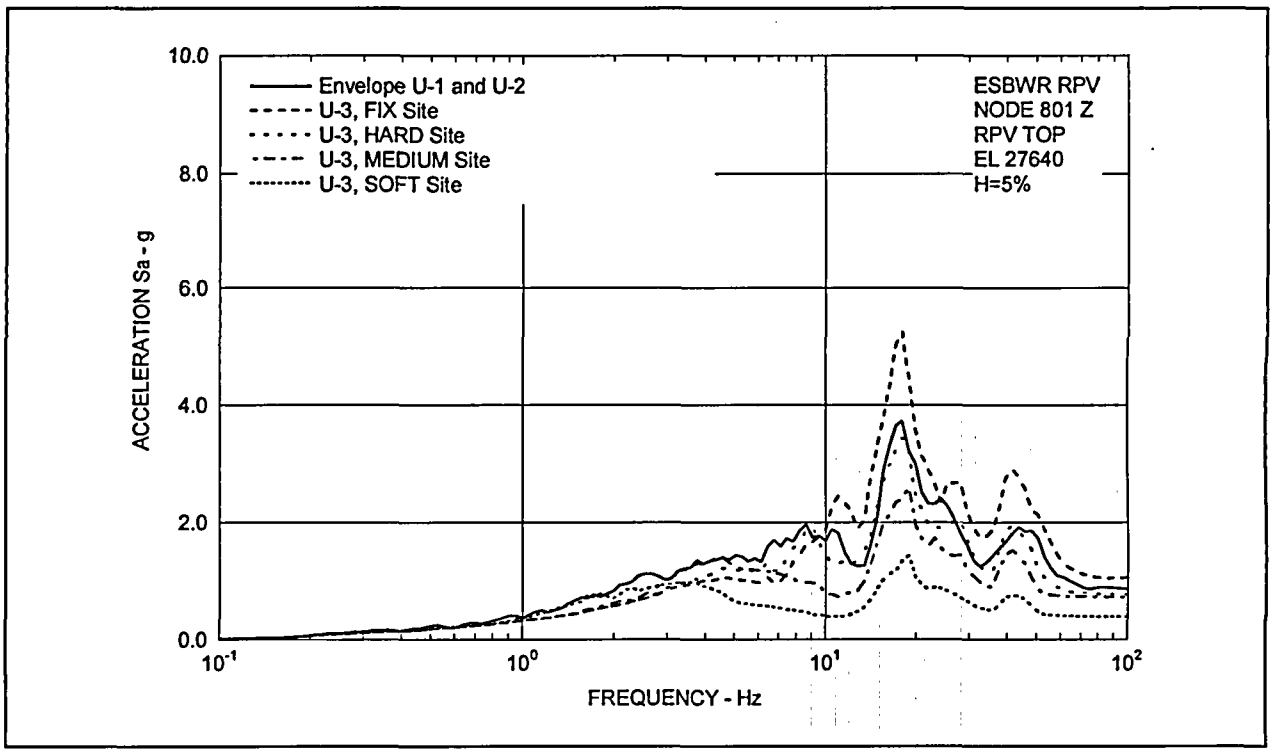



**Figure 7.1-18 Floor Response Spectra - RPV Top Z**

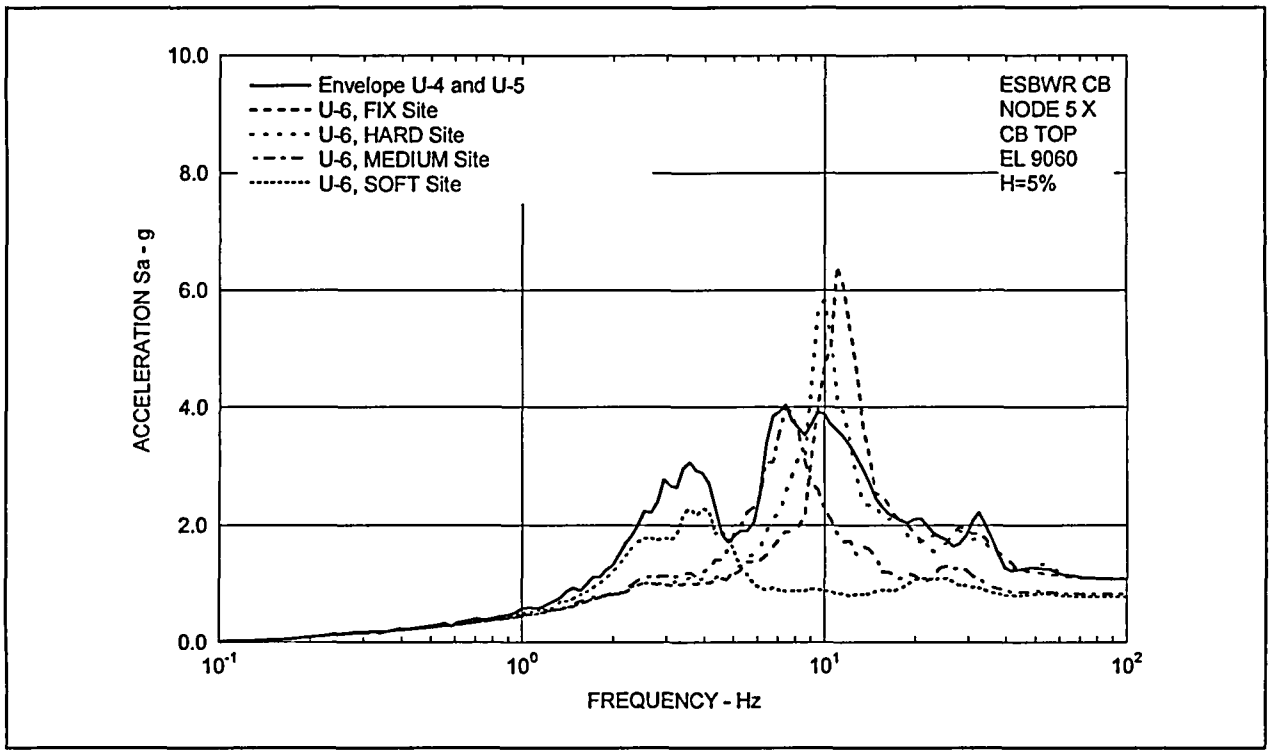



**Figure 7.1-19 Floor Response Spectra - CB Top X**

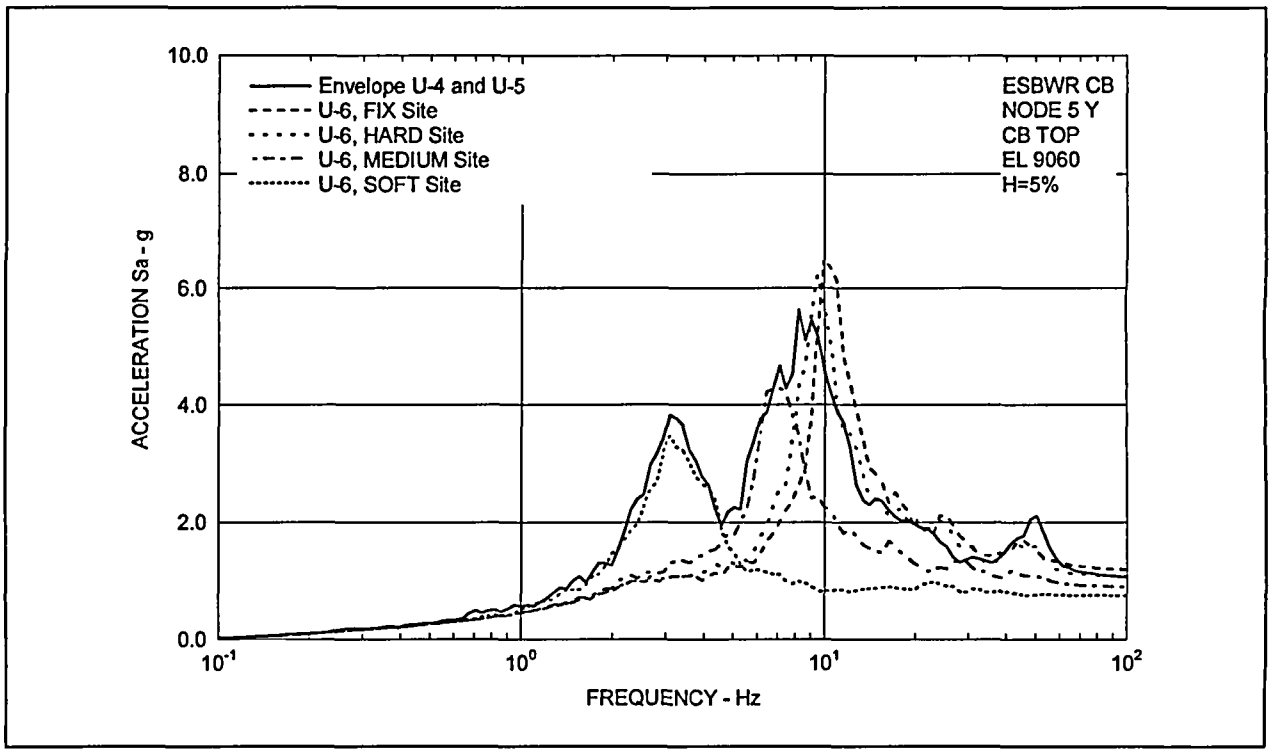



**Figure 7.1-20 Floor Response Spectra - CB Top Y**

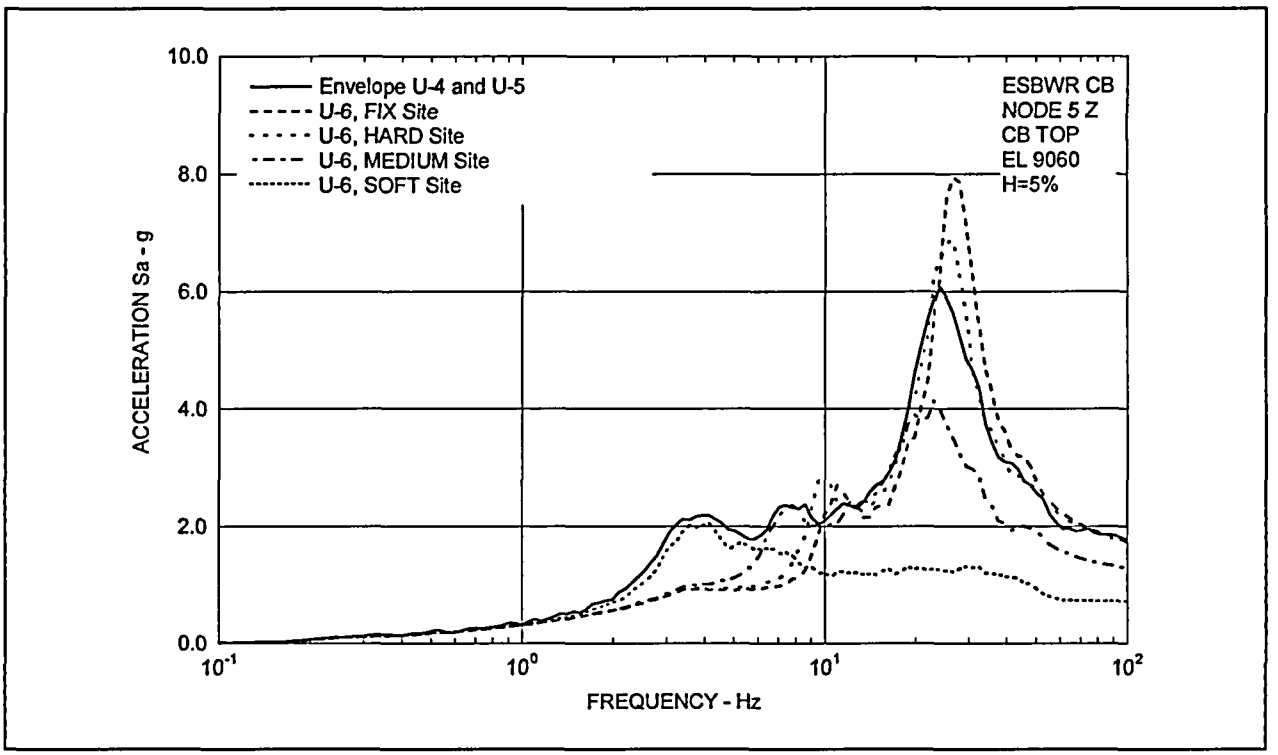



**Figure 7.1-21 Floor Response Spectra - CB Top Z**

## 7.2 Effect of Layered Sites – RAI 3.7-30

The effect of layered sites is evaluated by comparing the results of Cases L-1 through L-4 (layered site cases) with the broadened envelope results of Case U-3 (uniform site cases) for the RBFB and the results of Cases L-5 through L-8 with the envelope of Case U-6 for the CB.

Comparisons of floor response spectra (FRS) (5% damping) at selected RBFB locations are shown in Figures 7.2-1 through 7.2-18. Similarly, FRS (5% damping) at selected CB locations are compared in Figures 7.2-19 through 7.2-21.

It is found from the results that the responses for the layered site cases are bounded by the broadened envelope responses of uniform site cases in the whole frequency range.

As stated in Section 7.1, the existing DCD design load will be updated to incorporate the responses due to the single envelope input motion at the uniform sites. The revised DCD design load has no impact from the response results for the layered sites.

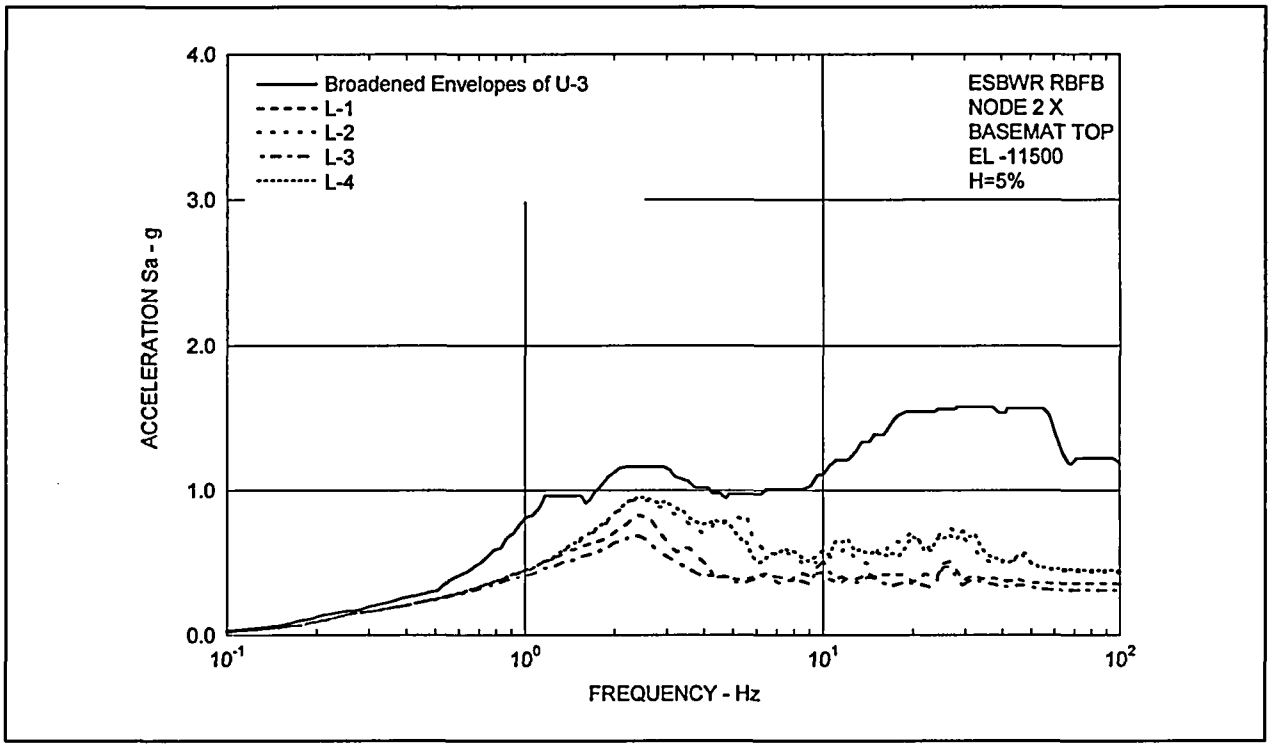



**Figure 7.2-1 Floor Response Spectra - RBFB Basemat X**

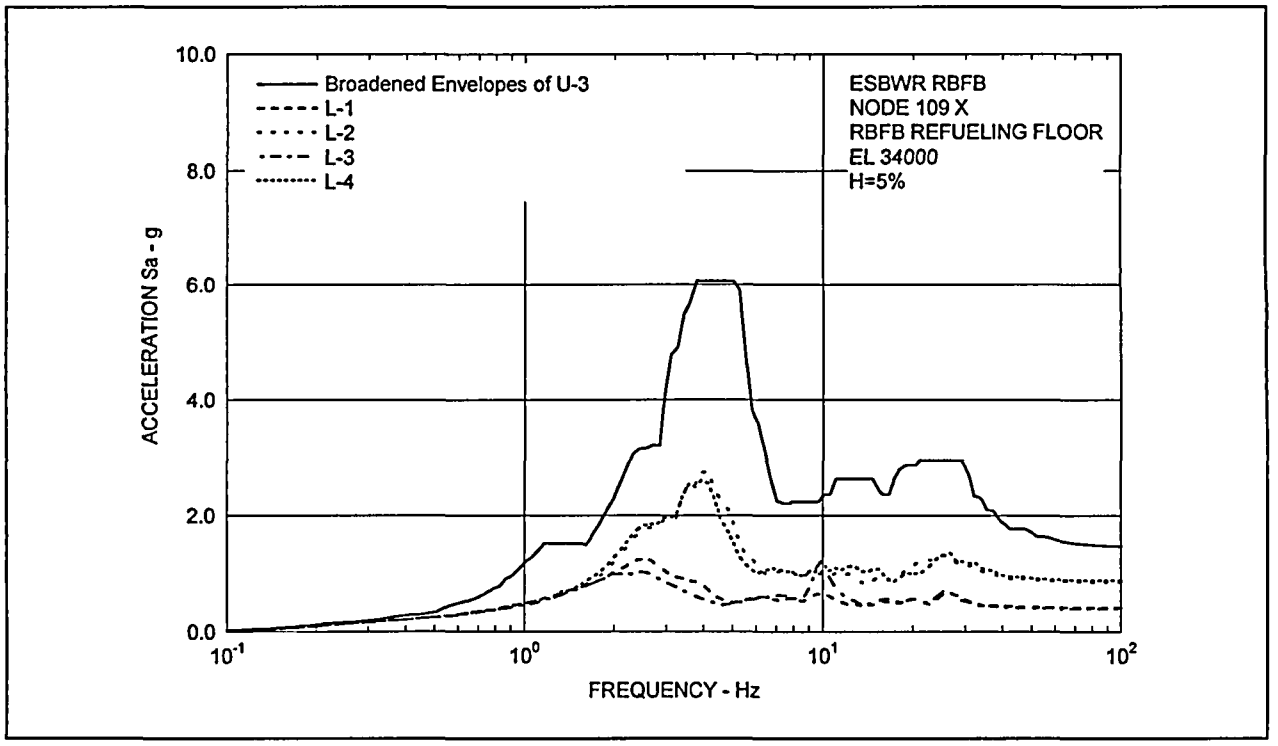



**Figure 7.2-2 Floor Response Spectra - RBFB Refueling Floor X**

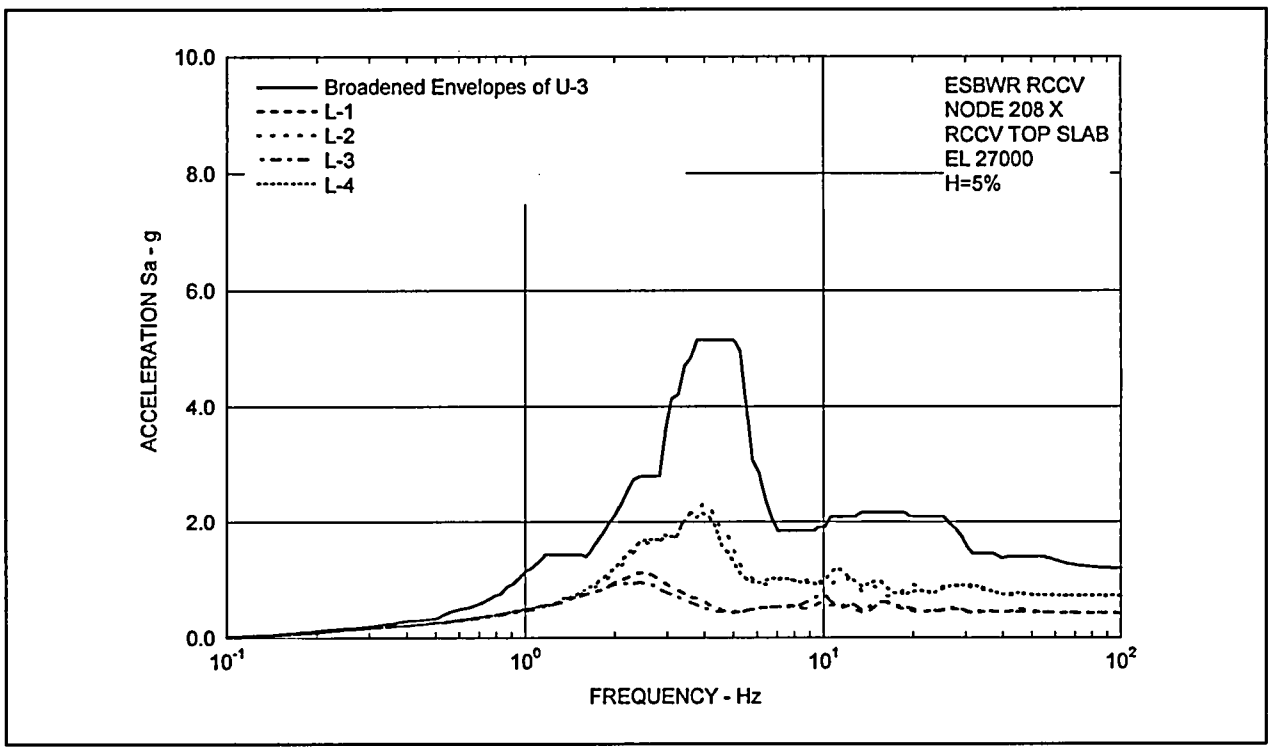



**Figure 7.2-3 Floor Response Spectra - RCCV Top Slab X**

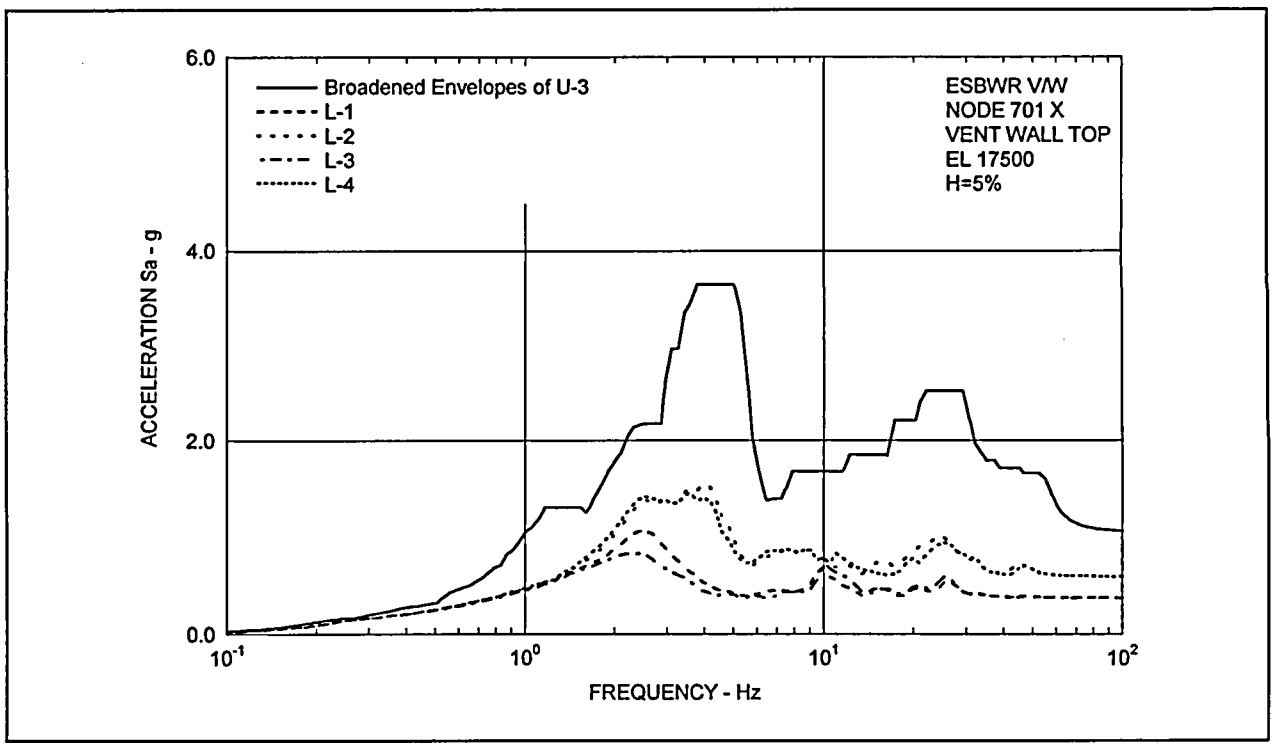



**Figure 7.2-4 Floor Response Spectra - Vent Wall Top X**

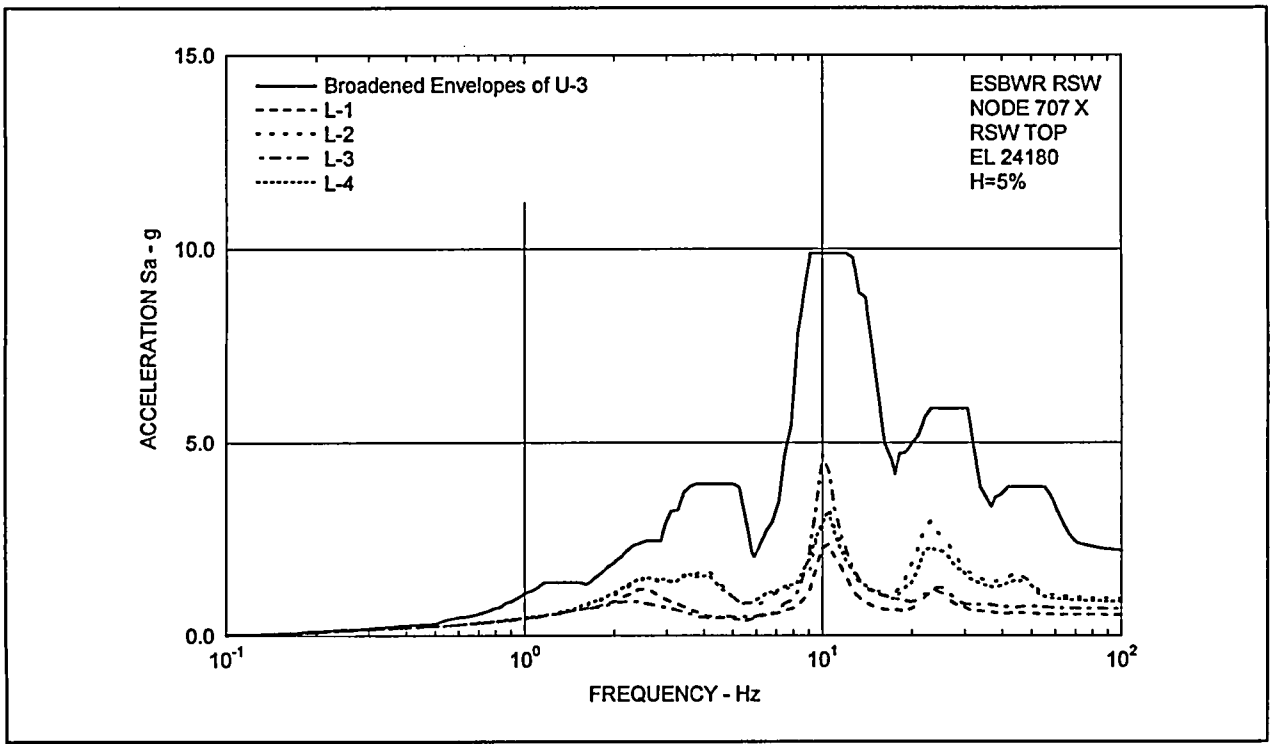



**Figure 7.2-5 Floor Response Spectra - RSW Top X**

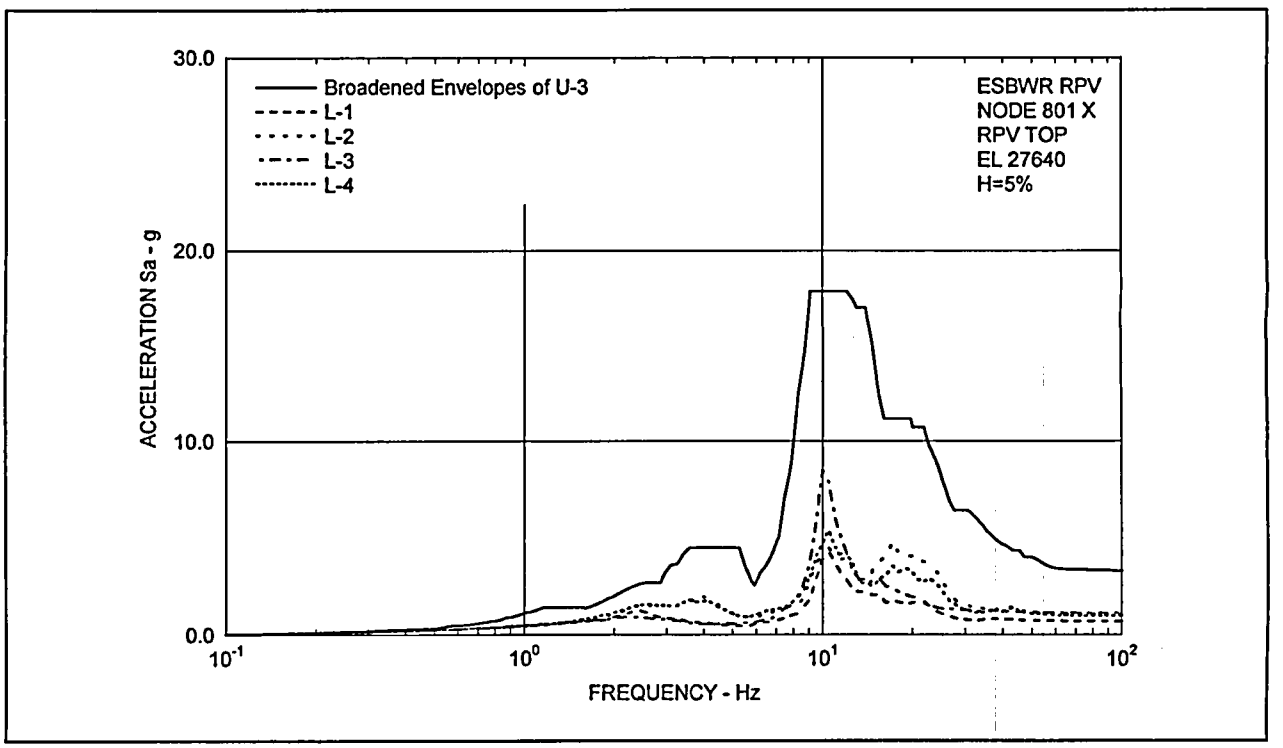



**Figure 7.2-6 Floor Response Spectra - RPV Top X**

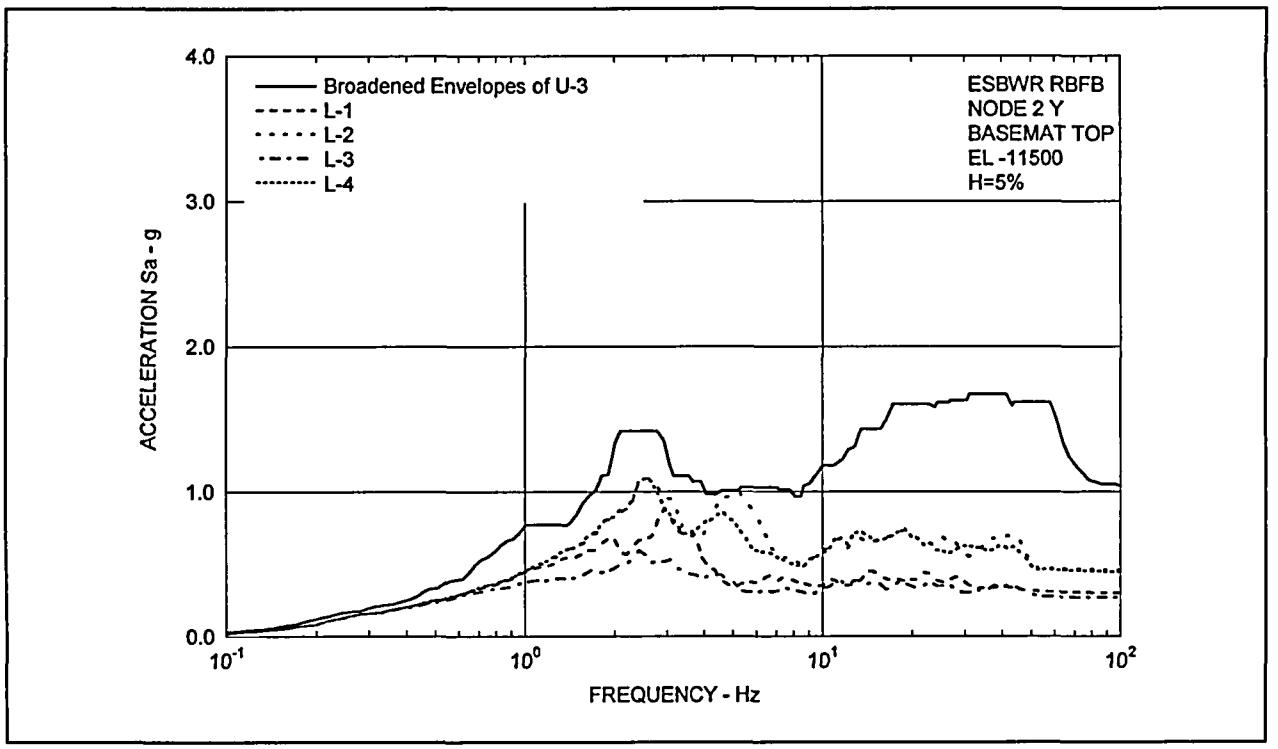



**Figure 7.2-7 Floor Response Spectra - RBFB Basemat Y**

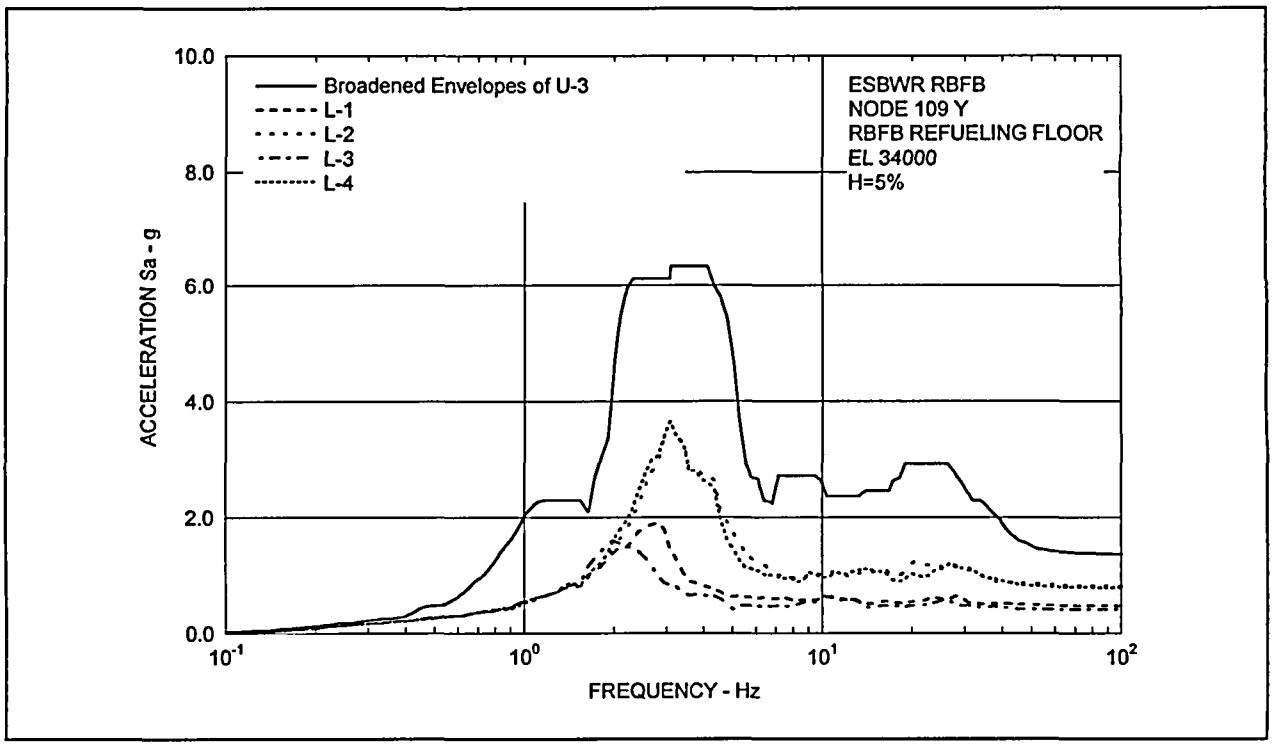



**Figure 7.2-8 Floor Response Spectra - RBFB Refueling Floor Y**

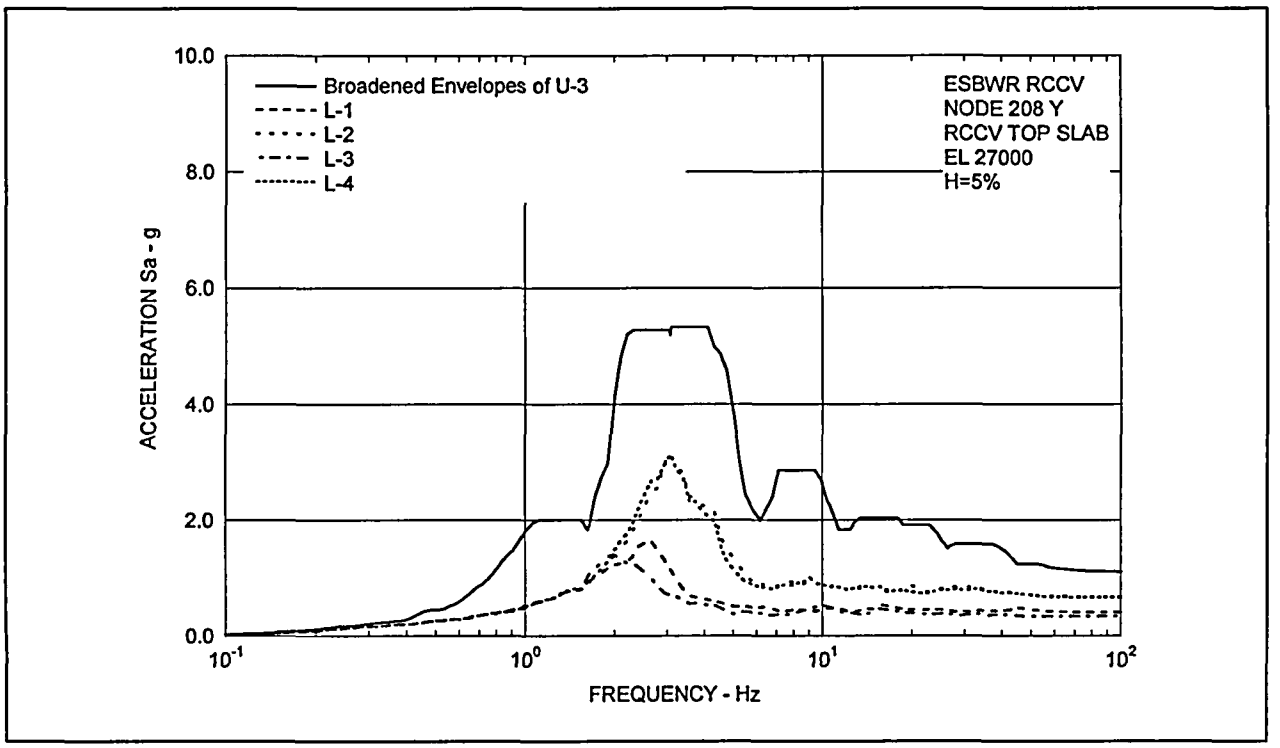



**Figure 7.2-9 Floor Response Spectra - RCCV Top Slab Y**

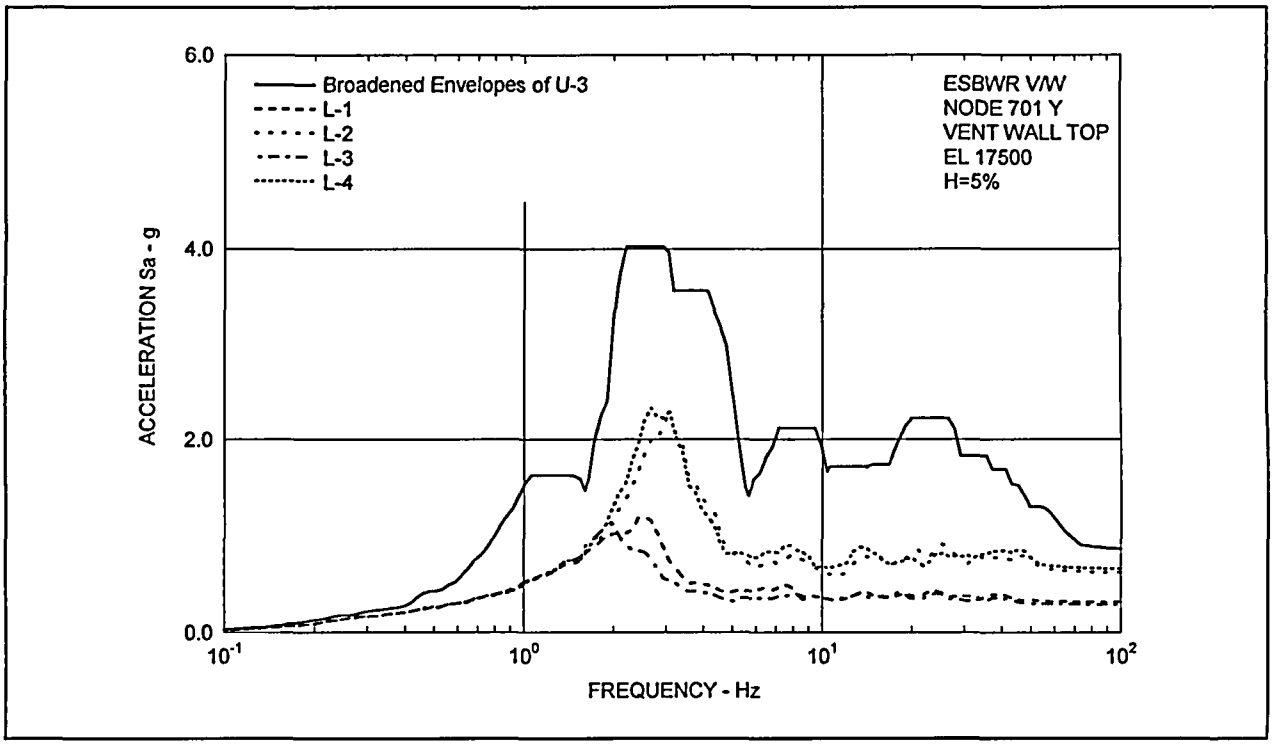



**Figure 7.2-10 Floor Response Spectra - Vent Wall Top Y**

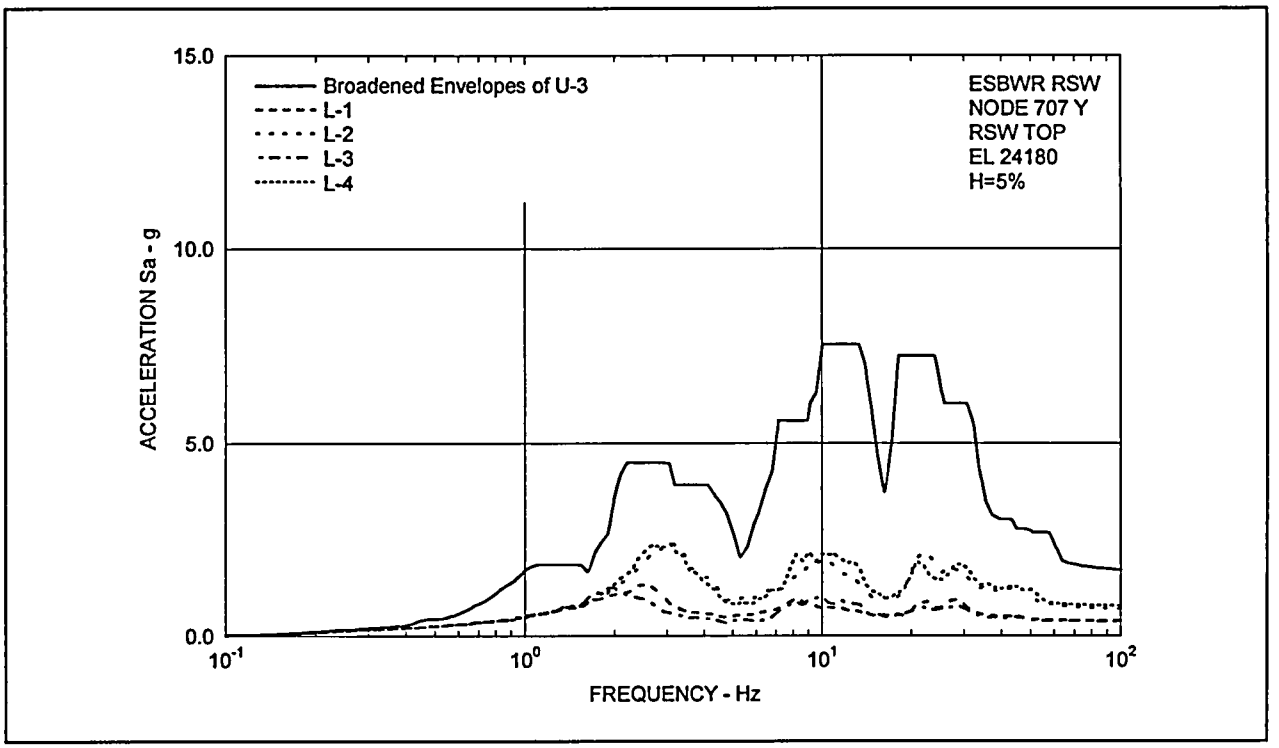



**Figure 7.2-11 Floor Response Spectra - RSW Top Y**

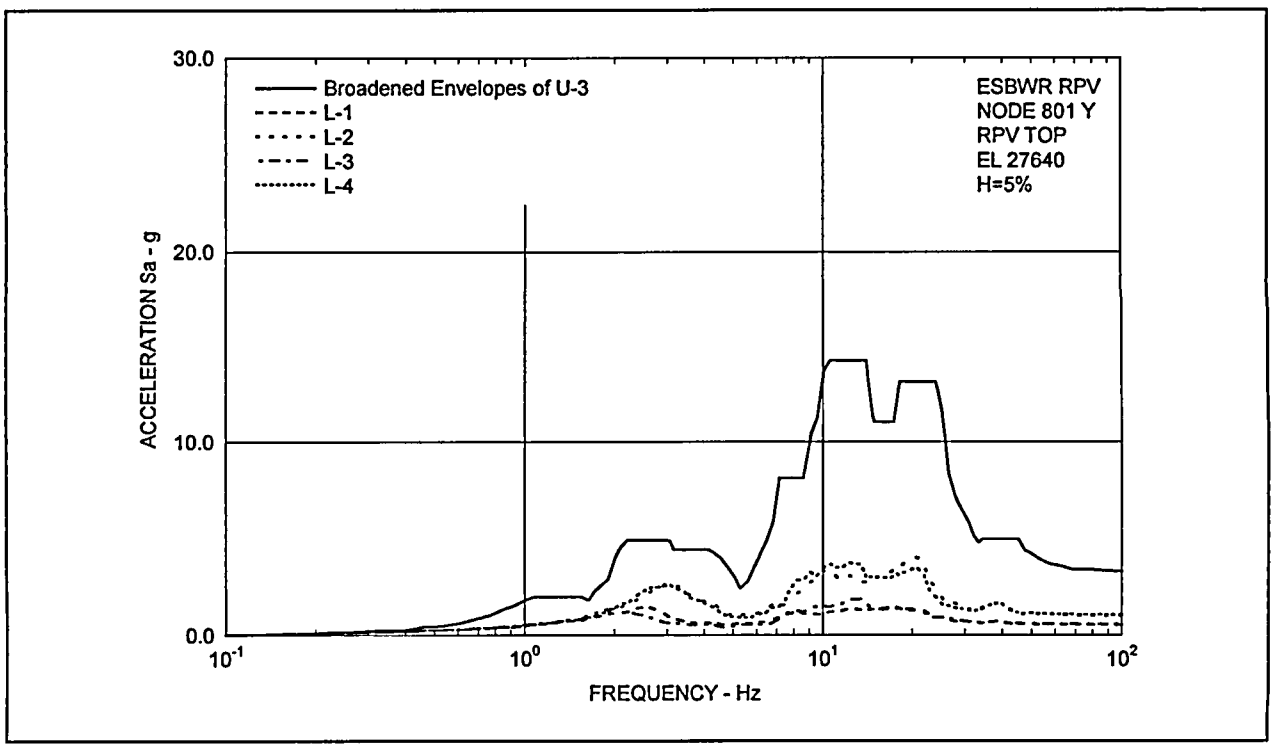



**Figure 7.2-12 Floor Response Spectra -RPV Top Y**

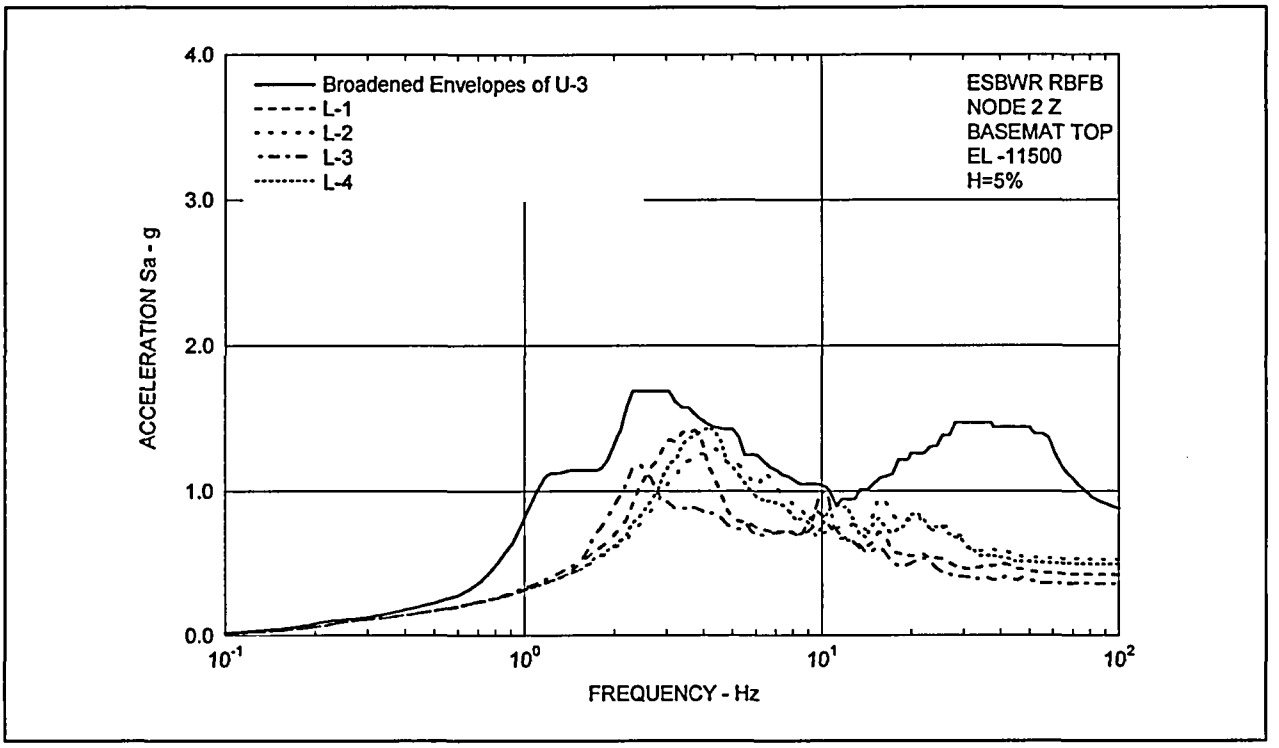



**Figure 7.2-13 Floor Response Spectra - RBFB Basemat Z**

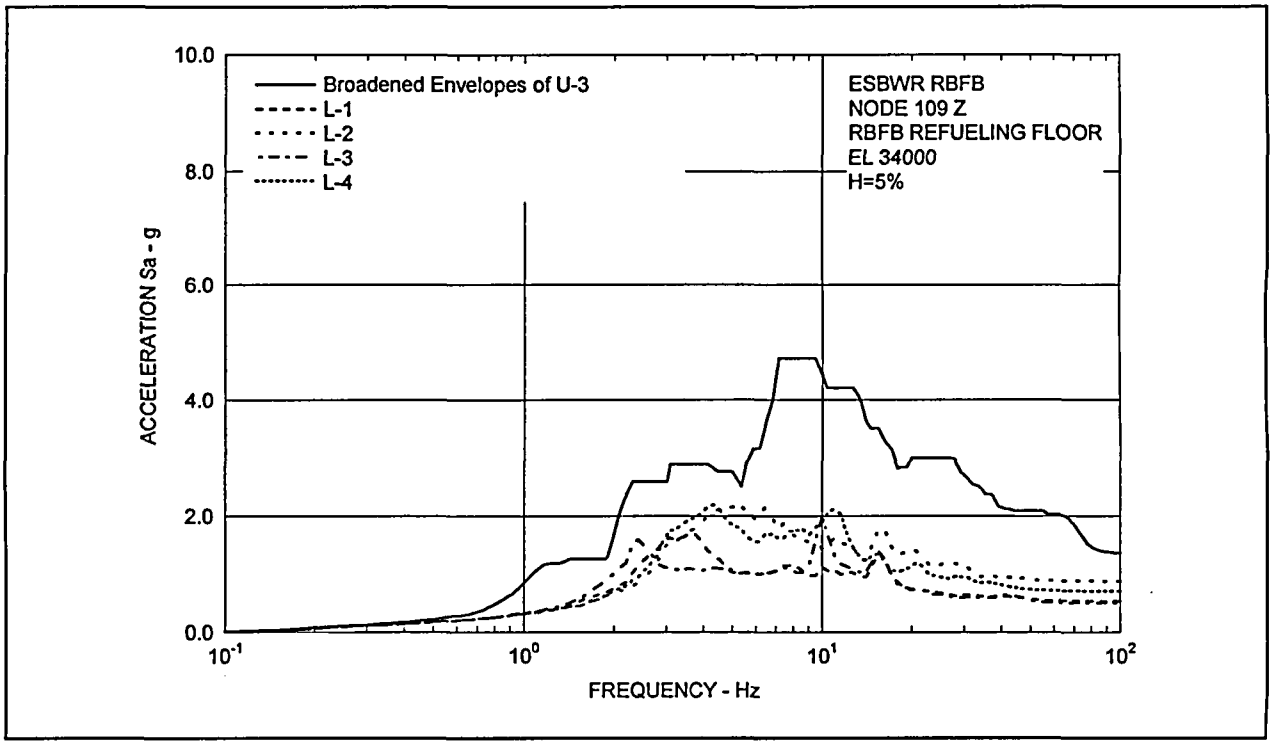



**Figure 7.2-14 Floor Response Spectra - RBFB Refueling Floor Z**

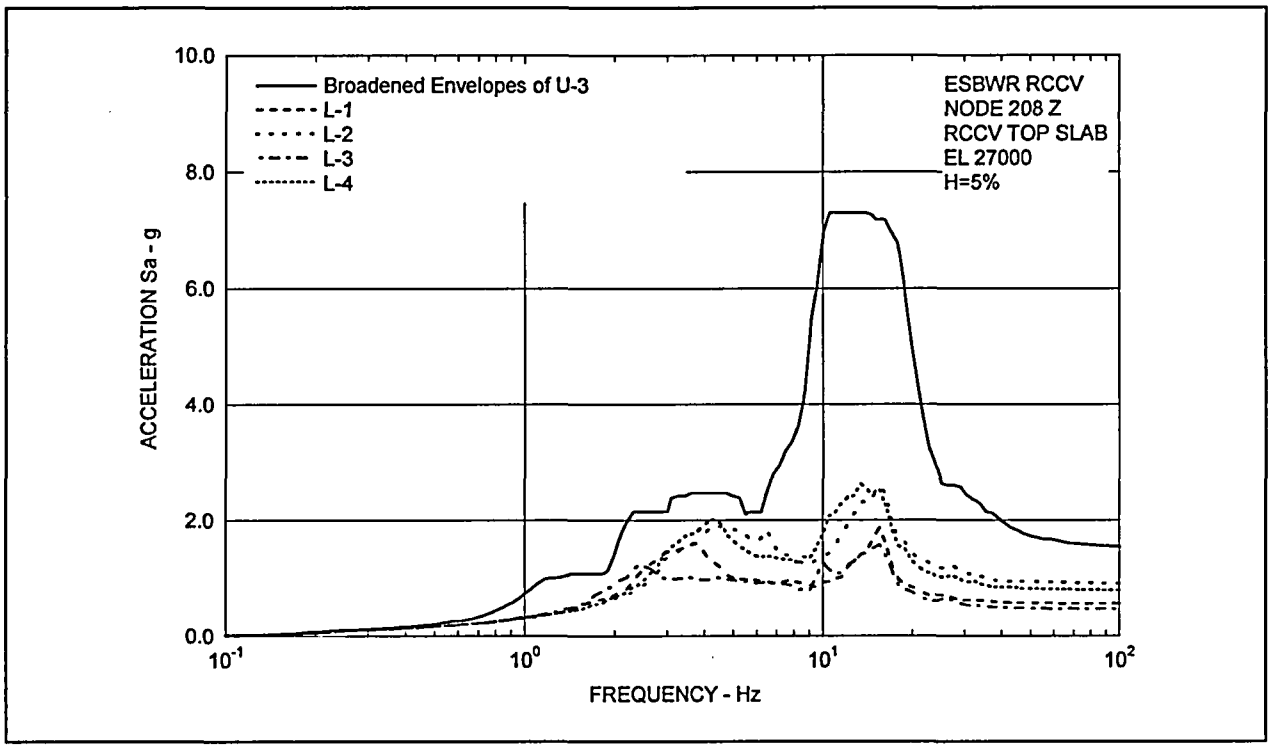



**Figure 7.2-15 Floor Response Spectra - RCCV Top Slab Z**

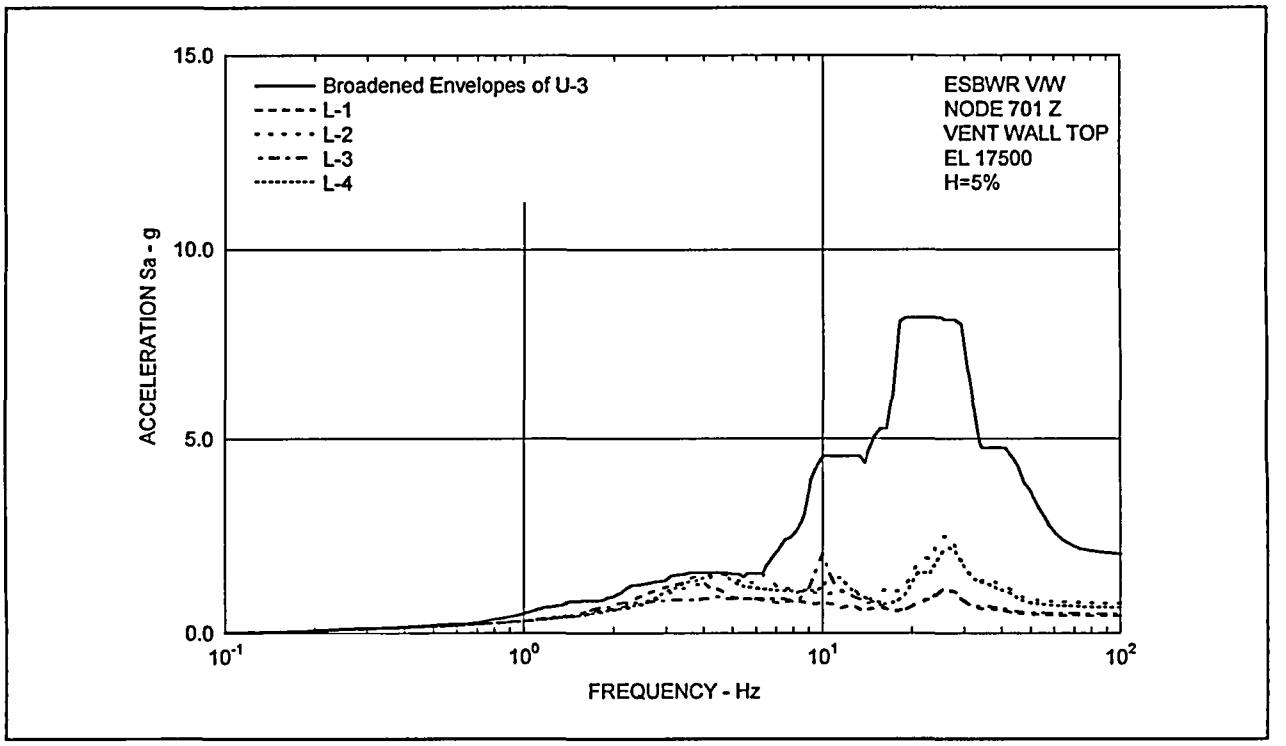



**Figure 7.2-16 Floor Response Spectra - Vent Wall Top Z**

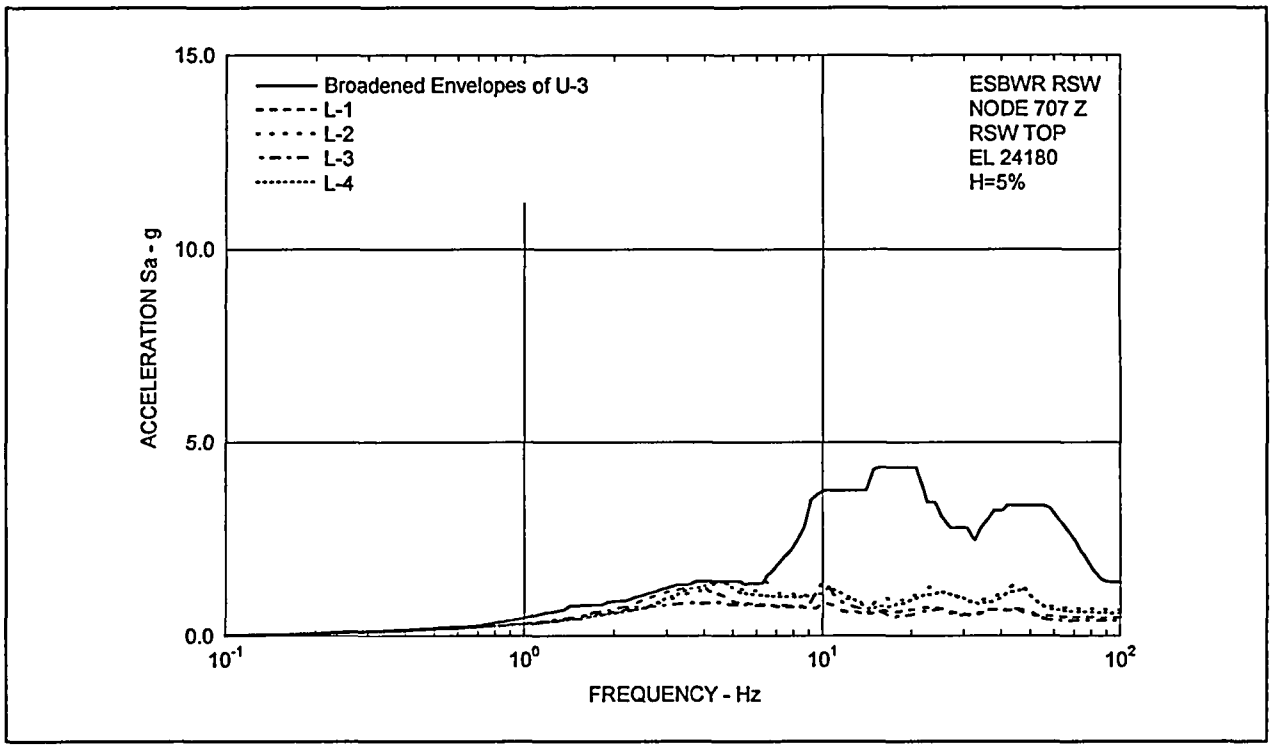



**Figure 7.2-17 Floor Response Spectra - RSW Top Z**

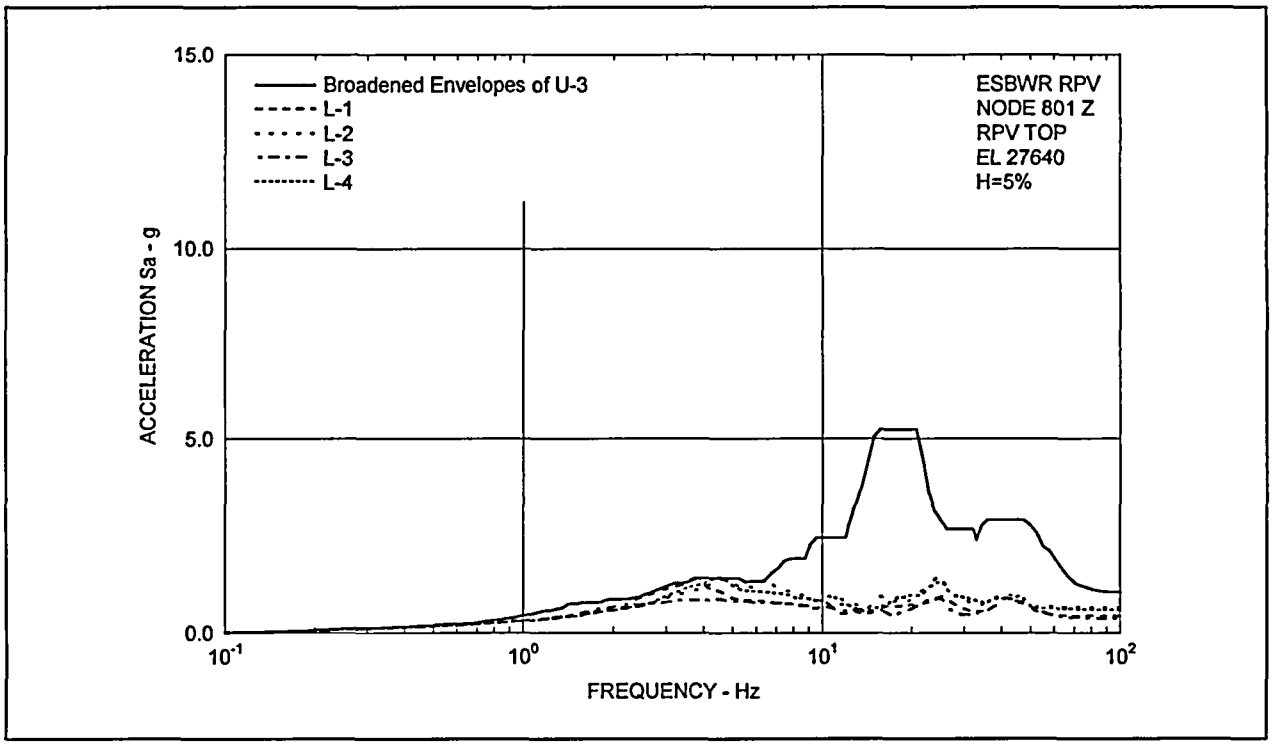



**Figure 7.2-18 Floor Response Spectra - RPV Top Z**

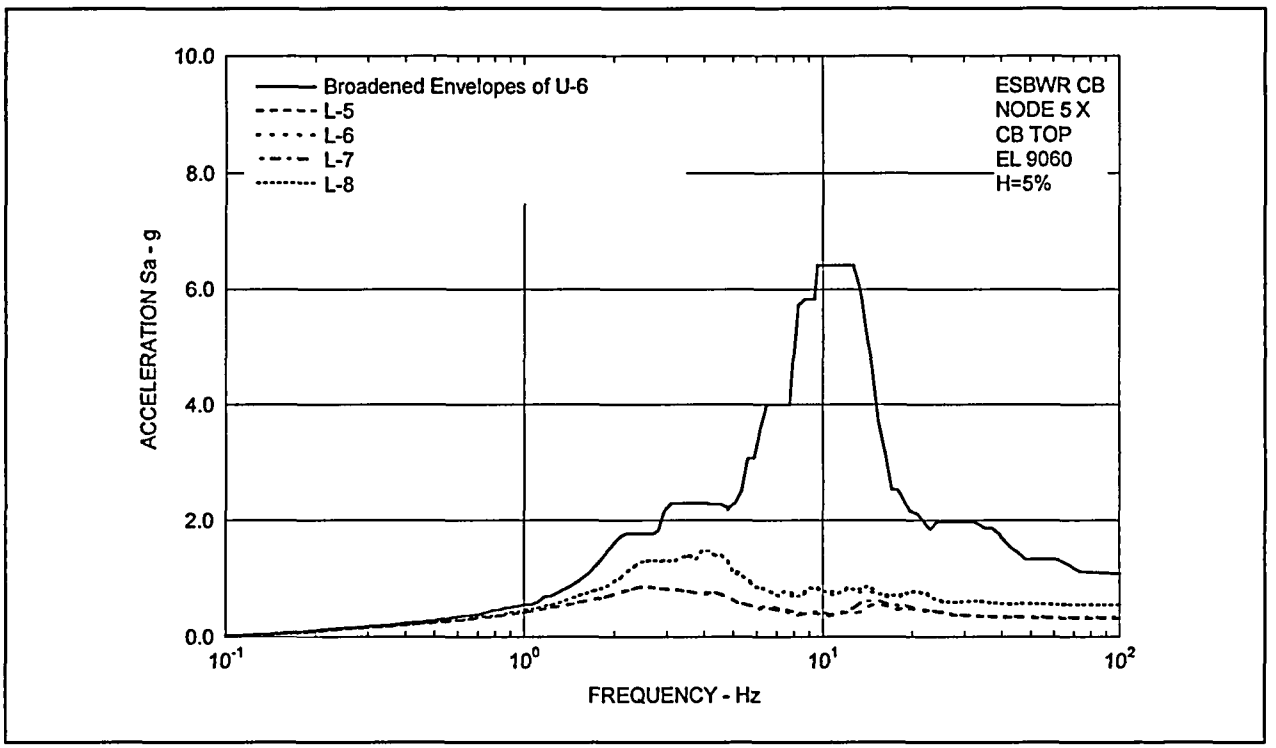



**Figure 7.2-19 Floor Response Spectra - CB Top X**

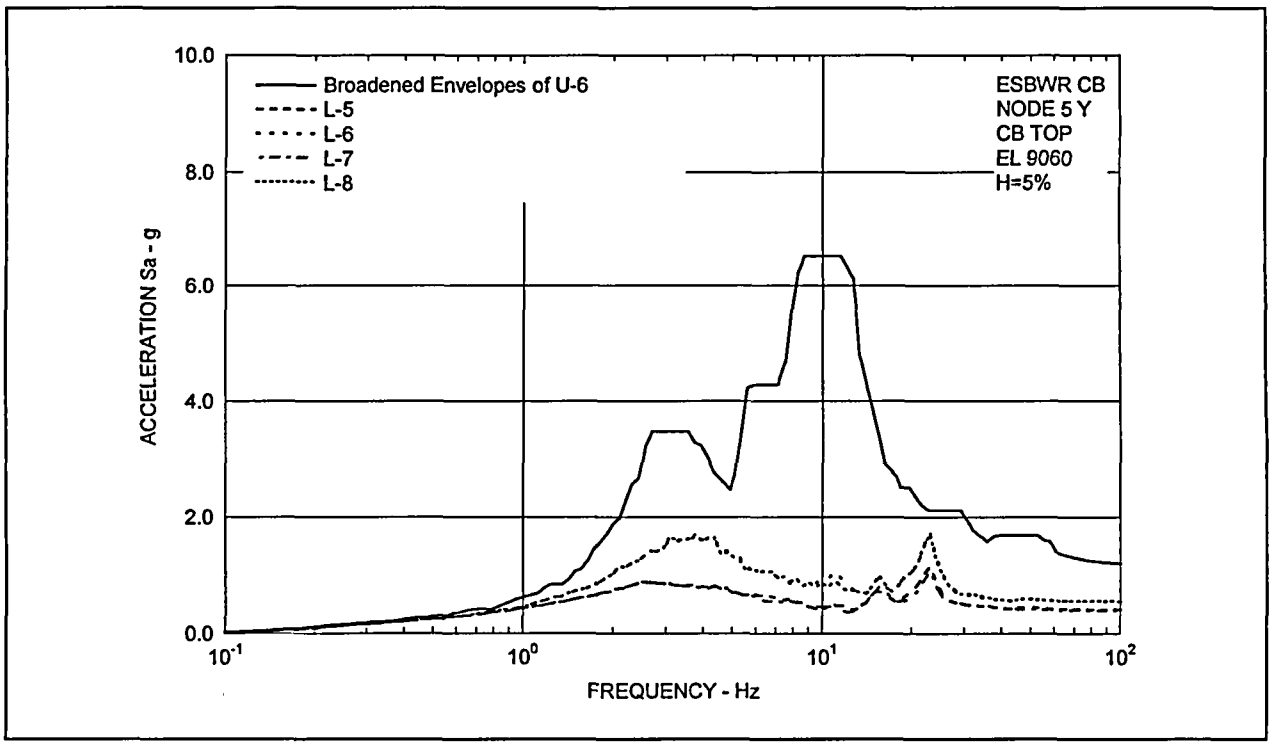



**Figure 7.2-20 Floor Response Spectra - CB Top Y**

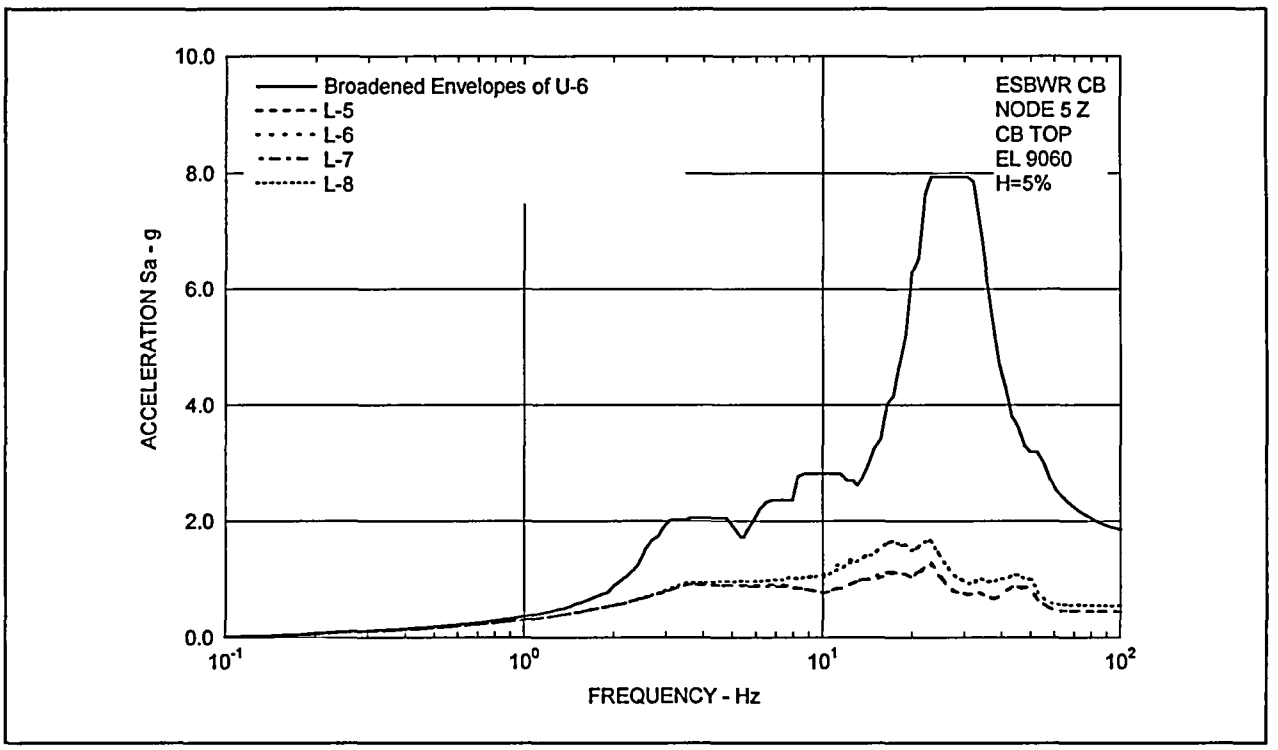



**Figure 7.2-21 Floor Response Spectra - CB Top Z**

## 7.3 Effect of Embedment – RAI 3.7-35

It was shown in Section 7.2 that the responses for the layered site cases are bounded by the broadened envelope responses of uniform site cases in the whole frequency range. One of reasons for this difference is considered to be effect of embedment.

As explained in Section 5, for uniform sites, the SSI analysis method follows the lumped soil spring approach same as the existing DCD Appendix 3A using DAC3N computer code. This model neglects the effect of embedment. On the other hand, for layer sites, the finite element method using SASSI computer code is employed for SSI analysis including the effect of embedment.

Table 7.3-1 shows the comparisons of the RBFB basemat reaction shear forces between Case U-3 (Soft uniform site) and Case L-3 (Soft layered site) and between Case U-3 (Medium uniform site) and Case L-4 (Medium layered site). Please note that the Cases L-3 has a deeper soft soil layer (40m) supporting basemat and that the Cases L-4 has a deeper medium soil layer (40m) supporting basemat.

It is found from the results that the effect of embedment works to reduce basemat reaction shear forces. This is because the building shear force is partially transferred to the lateral soil layers. Regarding the lateral soil pressure, the analysis results are shown in Section 7.4.

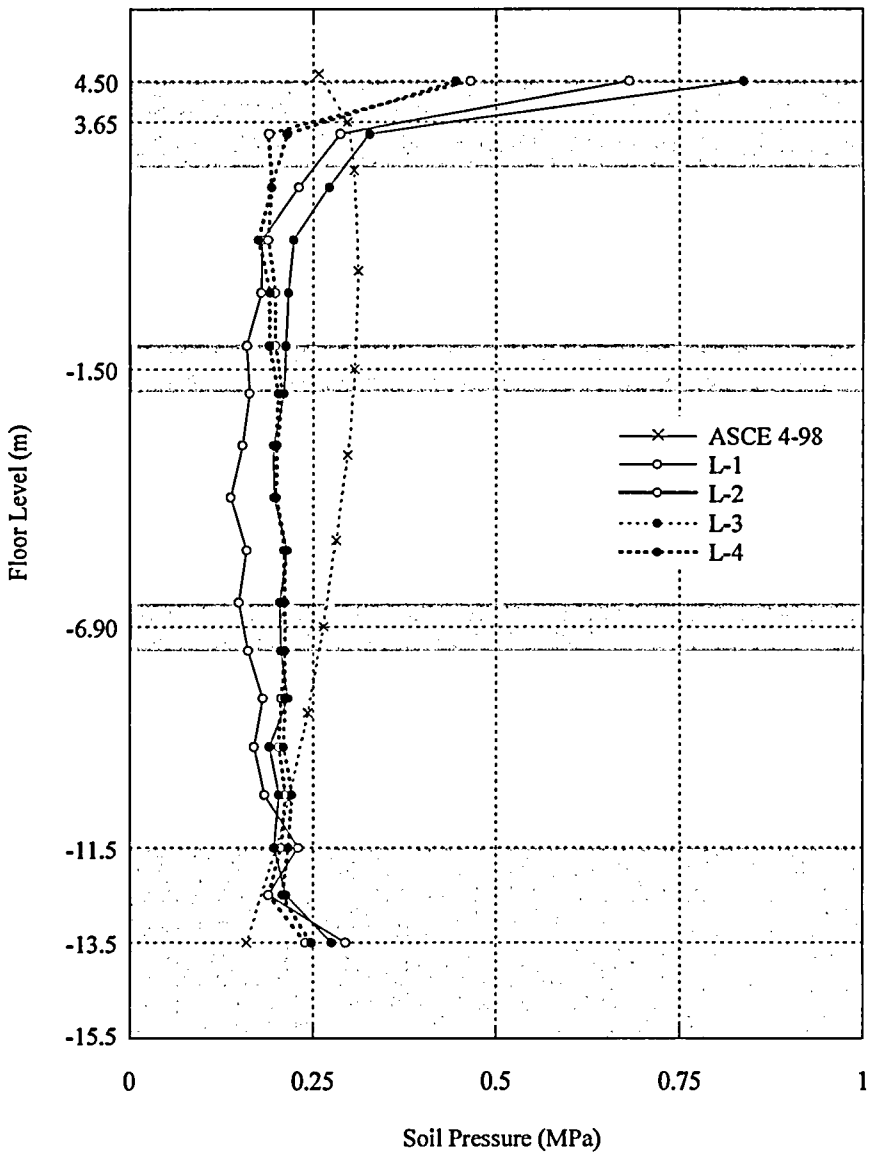
**Table 7.3-1 Comparisons of RBFB Basemat Reaction Shear Force**

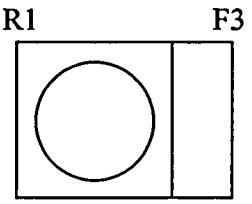
| Analysis Method | Effect of Embedment | Soft site (Vs 300 m/s) (MN) | | | Medium site (Vs 800 m/s) (MN) | | |
|---|---|---|---|---|---|---|---|
| | | Case | NS | EW | Case | NS | EW |
| DAC3N | Neglect | U-3 | 900 | 760 | U-3 | 1450 | 1500 |
| SASSI | Consider | L-3 | 600 | 540 | L-4 | 1380 | 1310 |

## 7.4 Effect of Lateral Soil Pressures – RAI 3.7-33

In the existing DCD, the lateral pressure computed from the equivalent static pressure analysis listed in ASCE 4-98 is used for the design soil pressure. To confirm the ASCE 4-98 method is conservative, the soil pressures calculated from the SASSI analysis for the layered sites described in Section 7.2 was compared with the ASCE 4-98 method soil pressures in Figures 7.4-1 through 7.4-4.

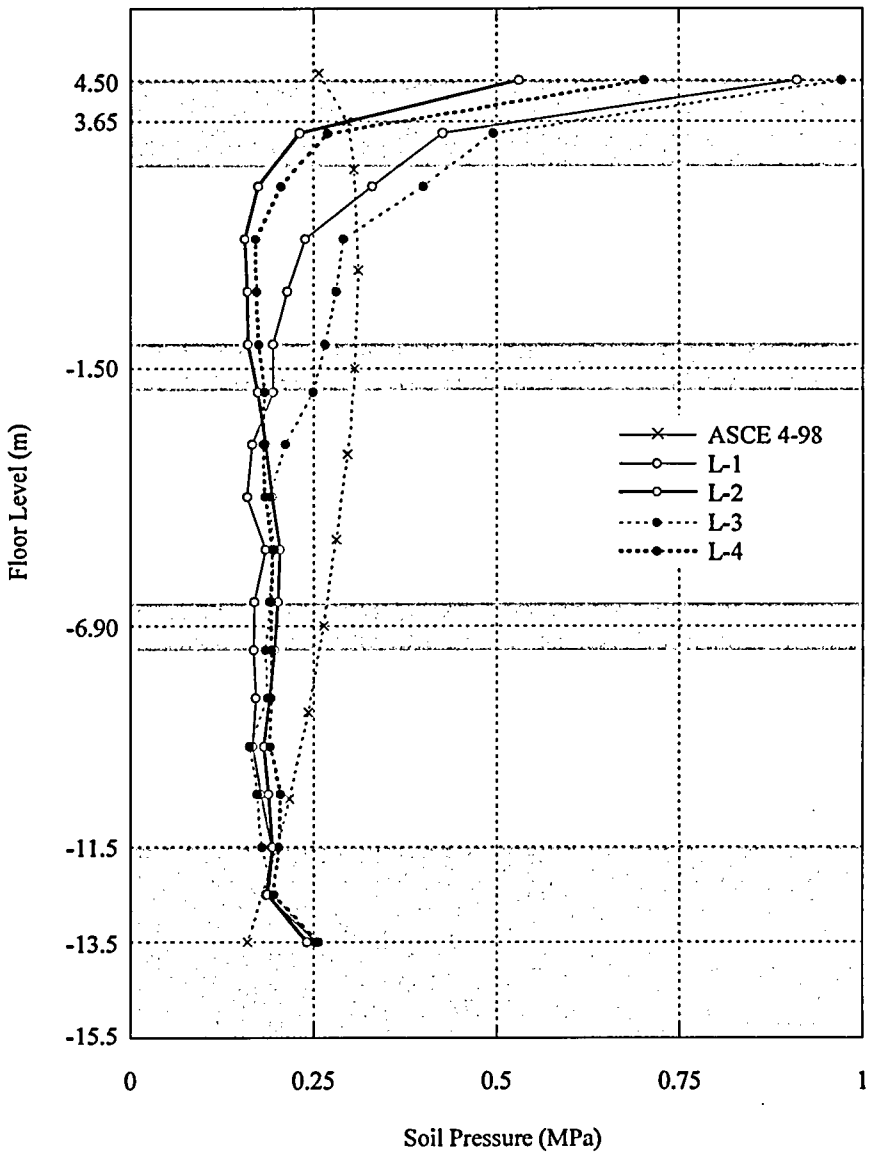
It is found from the results that the SASSI soil pressures are generally bounded by the ASCE 4-98 soil pressures; however, at the elevation close to the ground surface and the basemat elevation, the SASSI soil pressure exceeds the ASCE 4-98 soil pressure. The design soil pressure loads for the exterior walls are calculated by averaging soil pressures which each wall is subjected to. The calculated design soil pressures are summarized in Tables 7.4-1 and 7.4-2, comparing between the SASSI soil pressures and the ASCE 4-98 soil pressures. The envelope of the two values will be used for the exterior wall design.

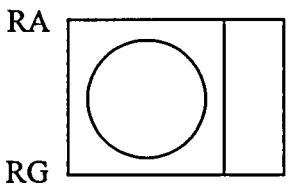



Note: The shaded area shows thickness of the floor slabs and basemat.

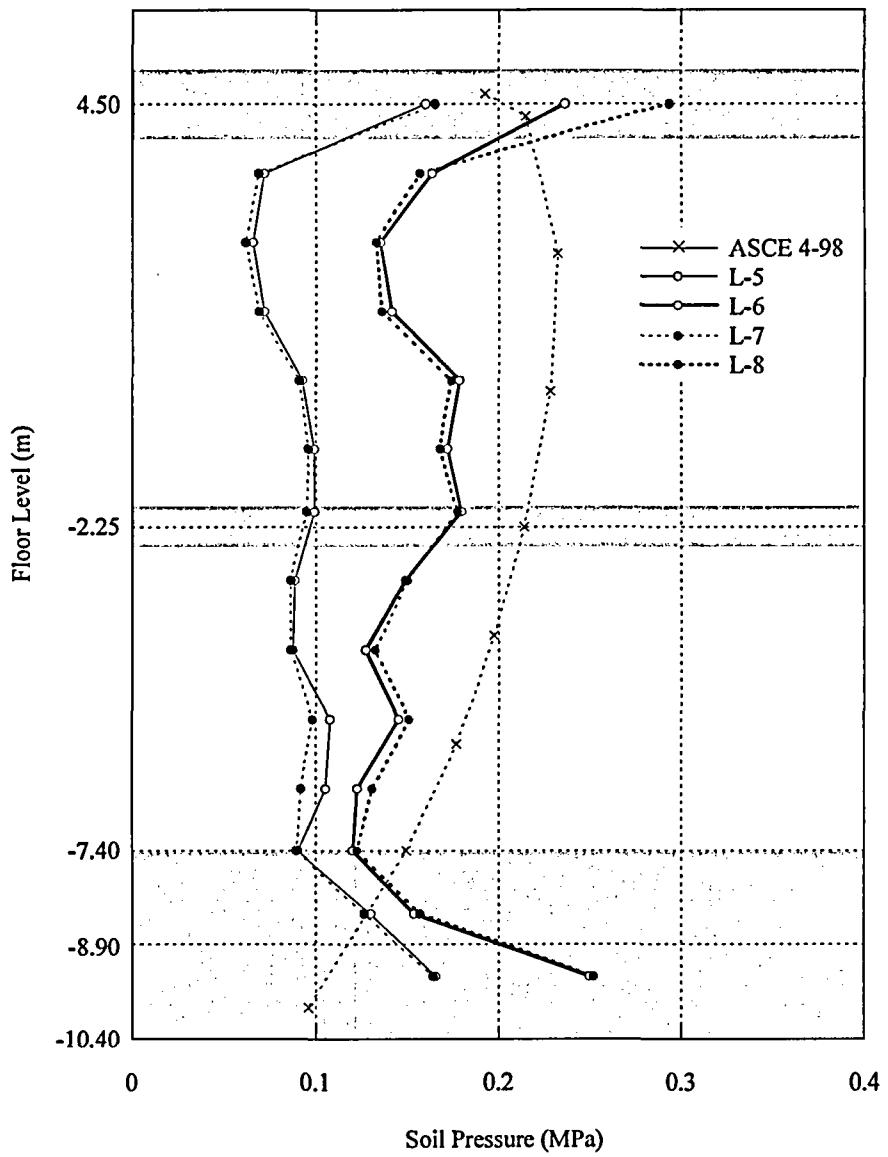
**Figure 7.4-1 Lateral Soil Pressure - RBFB R1 and F3 Wall**

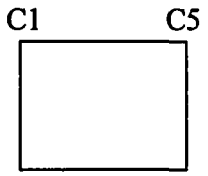



Note: The shaded area shows thickness of the floor slabs and basemat.

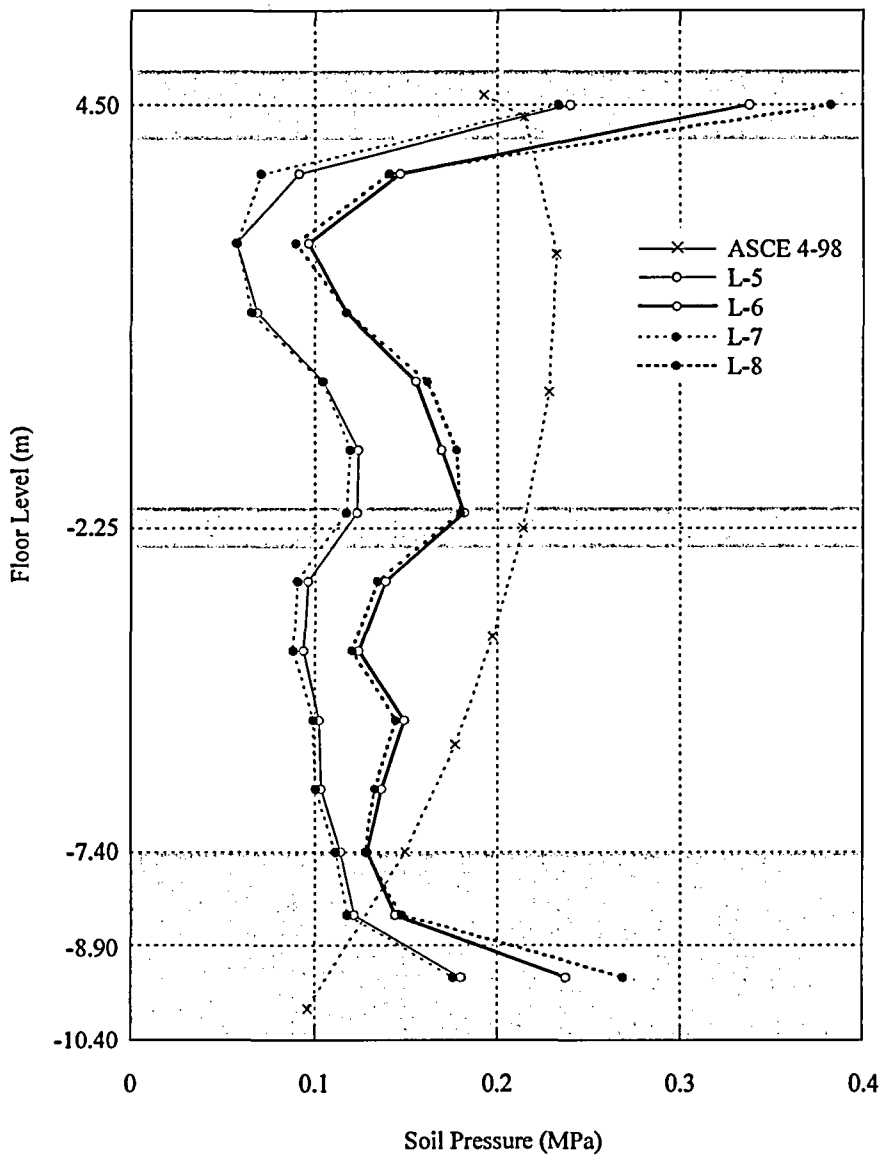
**Figure 7.4-2 Lateral Soil Pressure - RBFB RA and RG Wall**




Note: The shaded area shows thickness of the floor slabs and basemat.

**Figure 7.4-3 Lateral Soil Pressure - CB C1 and C5 Wall**




CA

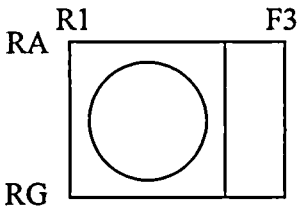
CD

Note: The shaded area shows thickness of the floor slabs and basemat.

**Figure 7.4-4 Lateral Soil Pressure - CB CA and CD Wall**

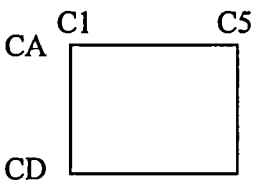
## Table 7.4-1 Lateral Soil Pressure - RBFB

| Floor Level | R1 and F3 Wall Soil Pressure (MPa) | | | | RA and RG Wall Soil Pressure (MPa) | | | | ASCE 4-98 | Envelope (MPa) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | L-1 | L-2 | L-3 | L-4 | L-1 | L-2 | L-3 | L-4 | (MPa) | R1 and F3 Wall | RA and RG Wall |
| 4.65 | | | | | | | | | | | |
| Slab | | | | | | | | | | | |
| 2.65 | | | | | | | | | | | |
| | 0.20 | 0.19 | 0.24 | 0.19 | 0.27 | 0.17 | 0.33 | 0.19 | 0.31 | 0.31 | 0.33 |
| -1.00 | | | | | | | | | | | |
| Slab | | | | | | | | | | | |
| -2.00 | | | | | | | | | | | |
| | 0.15 | 0.21 | 0.20 | 0.21 | 0.17 | 0.19 | 0.21 | 0.19 | 0.29 | 0.29 | 0.29 |
| -6.40 | | | | | | | | | | | |
| Slab | | | | | | | | | | | |
| -7.40 | | | | | | | | | | | |
| | 0.19 | 0.21 | 0.20 | 0.21 | 0.18 | 0.19 | 0.18 | 0.20 | 0.23 | 0.23 | 0.23 |
| -11.50 | | | | | | | | | | | |
| Basemat | | | | | | | | | | | |




## Table 7.4-2 Lateral Soil Pressure - CB

| Floor Level | C1 and C5 Wall Soil Pressure (MPa) | | | | CA and CD Wall Soil Pressure (MPa) | | | | ASCE 4-98 | Envelope (MPa) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | L-1 | L-2 | L-3 | L-4 | L-1 | L-2 | L-3 | L-4 | (MPa) | C1 and C5 Wall | CA and CD Wall |
| 4.65 | | | | | | | | | | | |
| Slab | | | | | | | | | | | |
| 3.95 | | | | | | | | | | | |
| | 0.09 | 0.17 | 0.09 | 0.17 | 0.10 | 0.16 | 0.10 | 0.16 | 0.22 | 0.22 | 0.22 |
| -2.00 | | | | | | | | | | | |
| Slab | | | | | | | | | | | |
| -2.50 | | | | | | | | | | | |
| | 0.10 | 0.14 | 0.09 | 0.14 | 0.10 | 0.14 | 0.10 | 0.14 | 0.18 | 0.18 | 0.18 |
| -7.40 | | | | | | | | | | | |
| Basemat | | | | | | | | | | | |



## 7.5 Effect of Concrete Cracking – RAI-50

In order to address the effect of the cracked concrete stiffness, an additional evaluation is performed using SASSI, assuming that the cracked concrete stiffness is 50% of the uncreacked value in accordance with ASCE 43-05.

For the comparison, Case L-2 was selected for the RBFB and Case L-6 was selected for the CB, because they show the largest responses among various layered sites. Case L-9 is the RBFB cracked case, which has the same layered site as Case L-2. Case L-10 is the CB cracked case, which has the same layered site as Case L-6.

Comparisons of floor response spectra (FRS) (5% damping) at selected RBFB locations are shown in Figures 7.5-1 through 7.5-12. The broadened envelope results of Case U-3 (uniform site, single envelope input motion case) are also shown in the figures for comparison.

Similarly, FRS (5% damping) at selected CB locations are compared in Figures 7.5-13 and 7.5-14, together with the broadened envelope results of Case U-6 (uniform site, single envelope input motion case).

It is found from the results that the FRS peaks move to lower frequencies by concrete cracking; however, both FRSs of uncracked and cracked cases are bounded by the broadened envelope responses of uniform site cases in the whole frequency range.

As stated in Section 7.1, the existing DCD design load will be updated to incorporate the responses due to the single envelope input motion at the uniform sites. The revised DCD design load has no impact from the effect of concrete cracking.

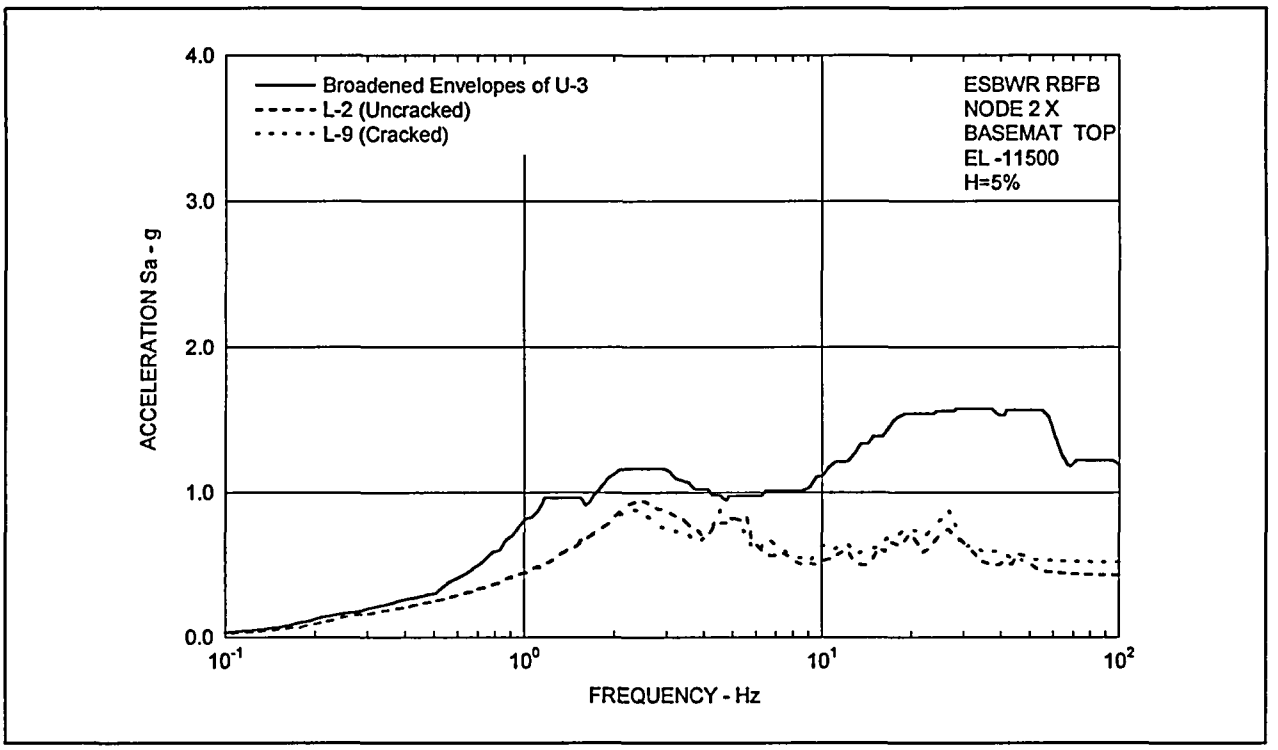



**Figure 7.5-1 Floor Response Spectra - RBFB Basemat X**

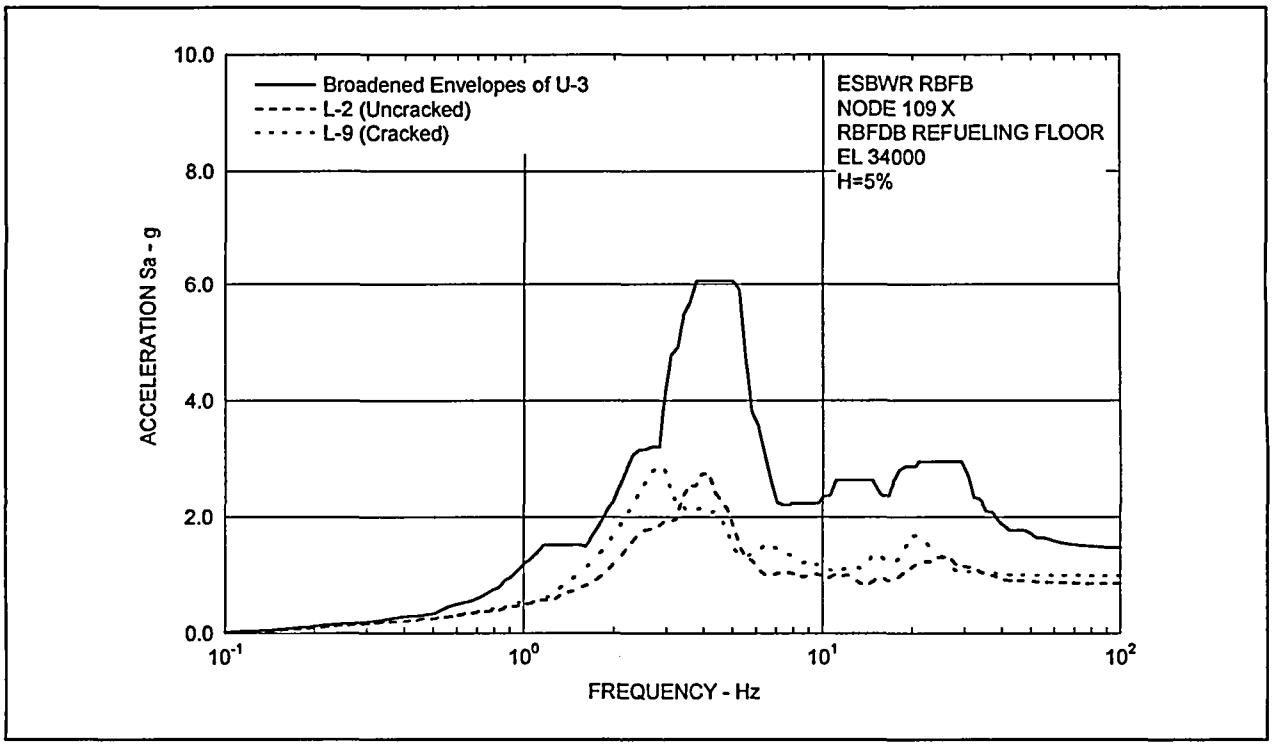



**Figure 7.5-2 Floor Response Spectra - RBFB Refueling Floor X**

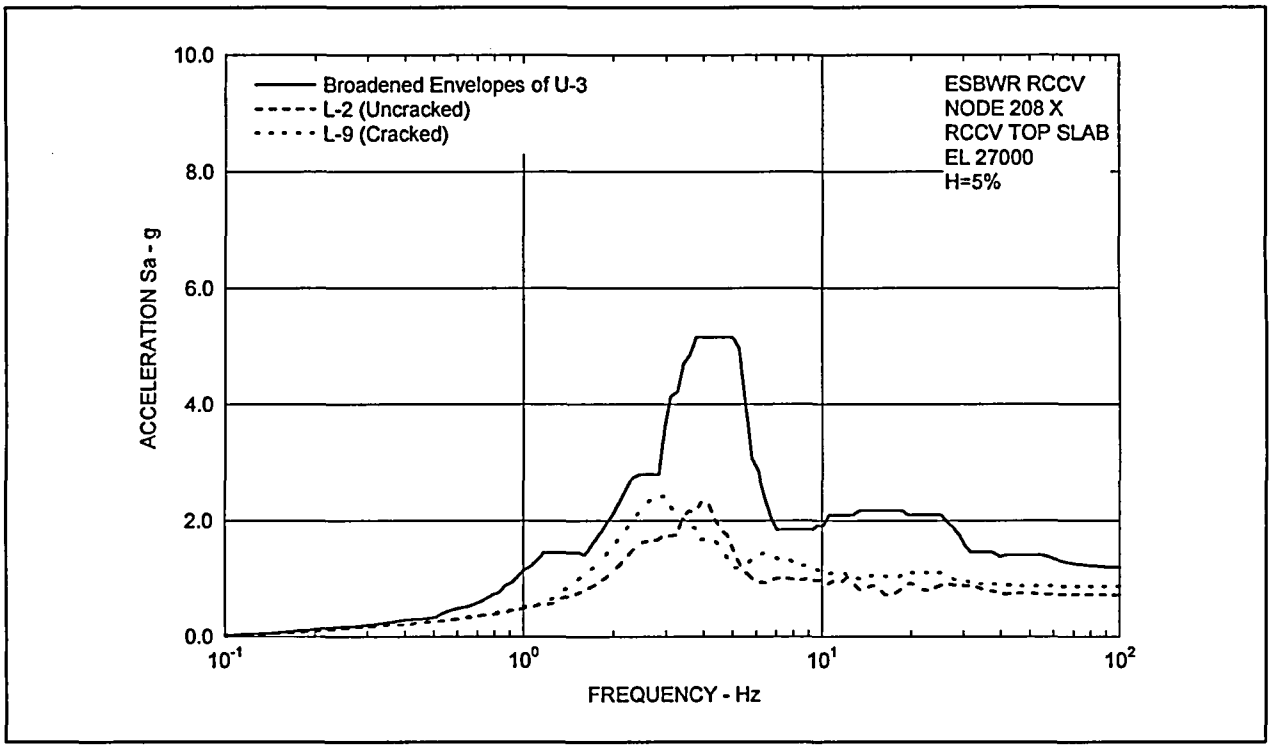



**Figure 7.5-3 Floor Response Spectra - RCCV Top Slab X**

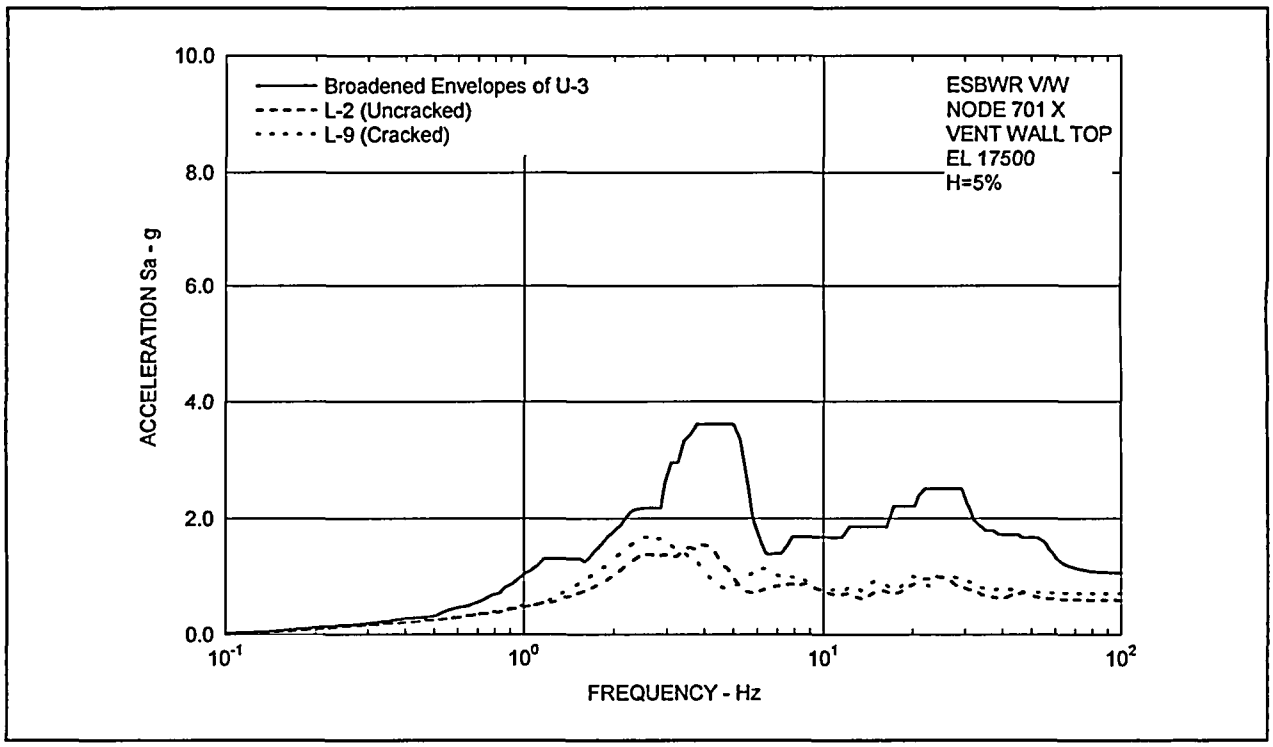



**Figure 7.5-4 Floor Response Spectra - Vent Wall Top X**

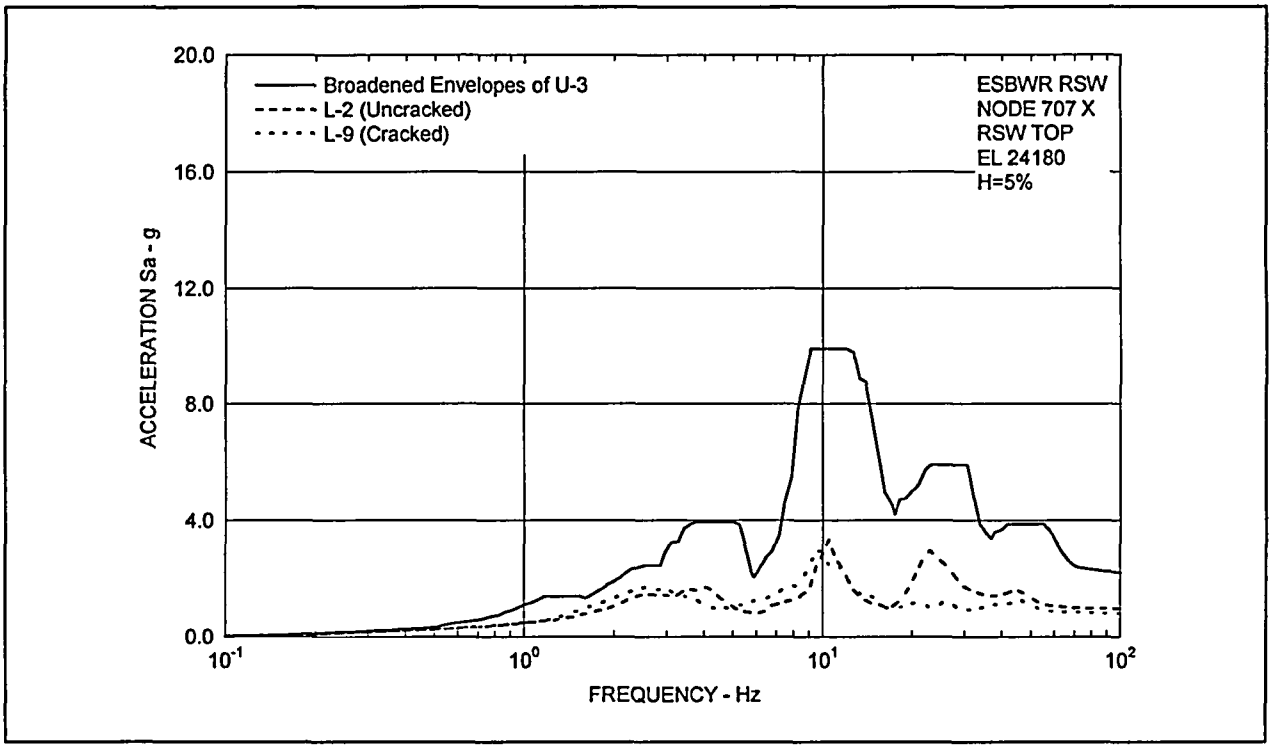



**Figure 7.5-5 Floor Response Spectra - RSW Top X**

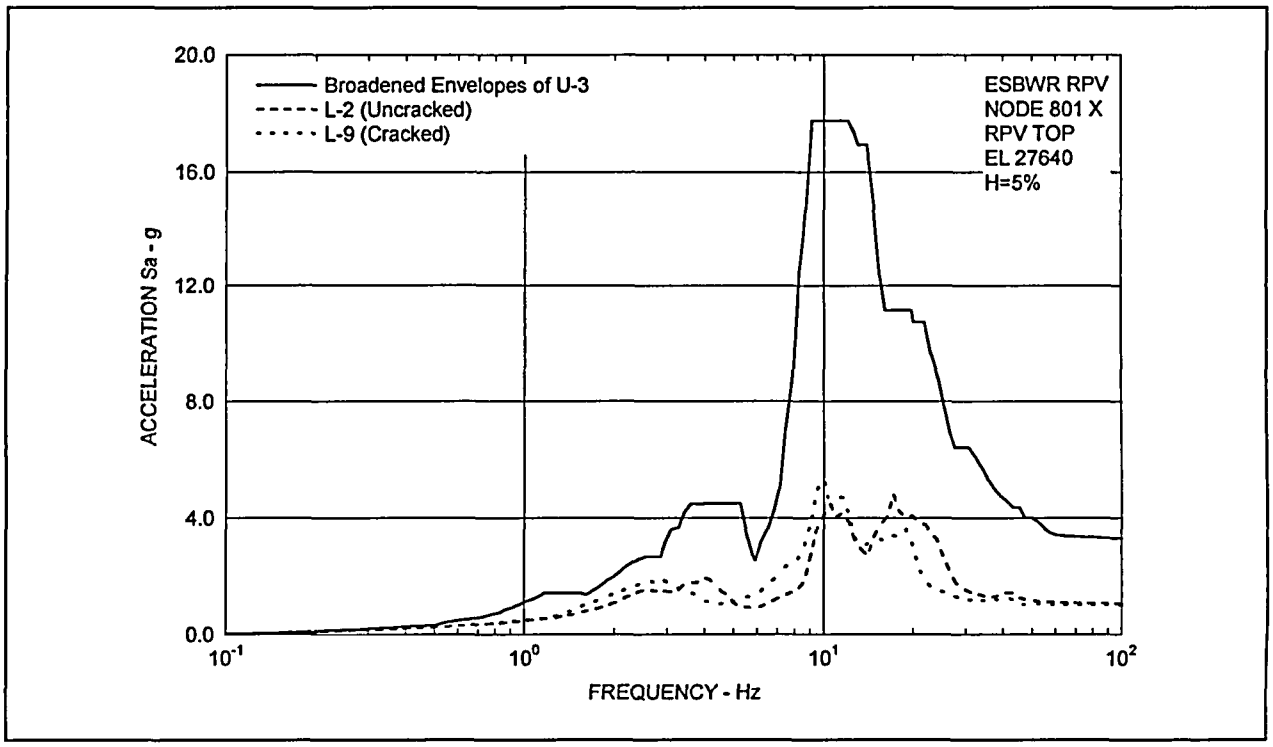



**Figure 7.5-6 Floor Response Spectra - RPV Top X**

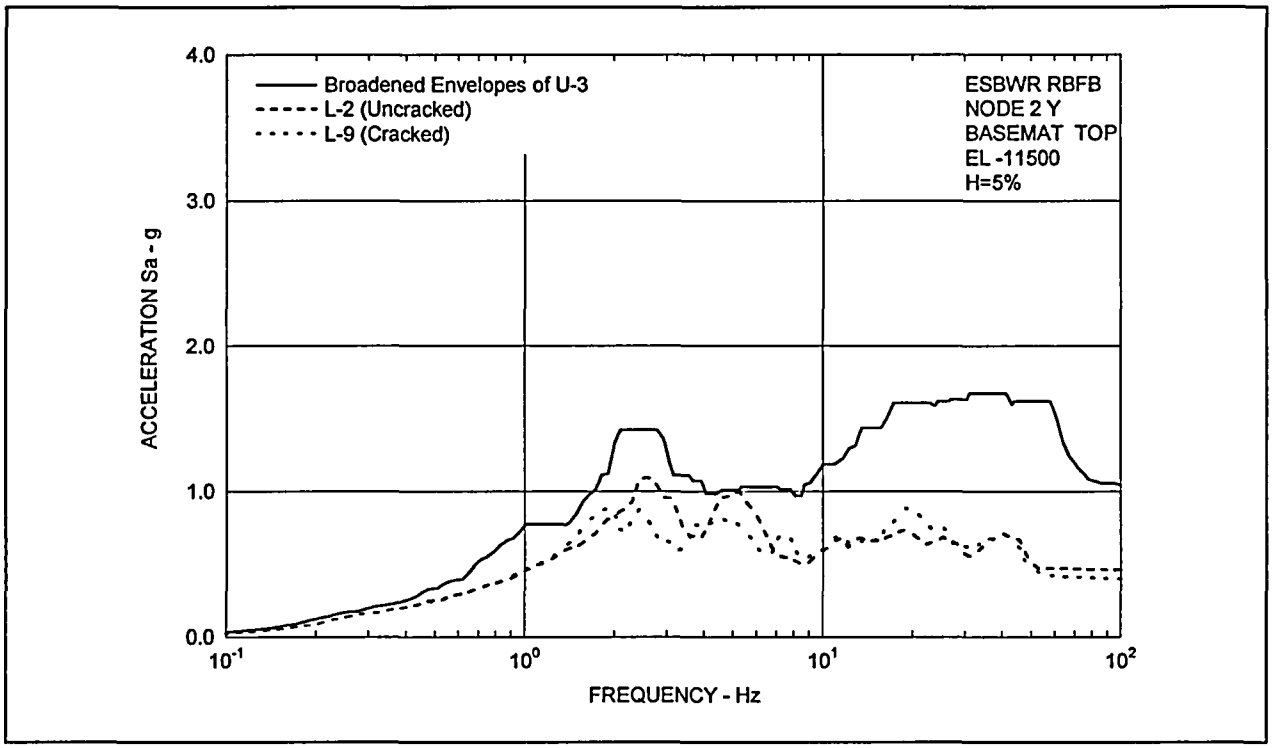



**Figure 7.5-7 Floor Response Spectra - RBFB Basemat Y**

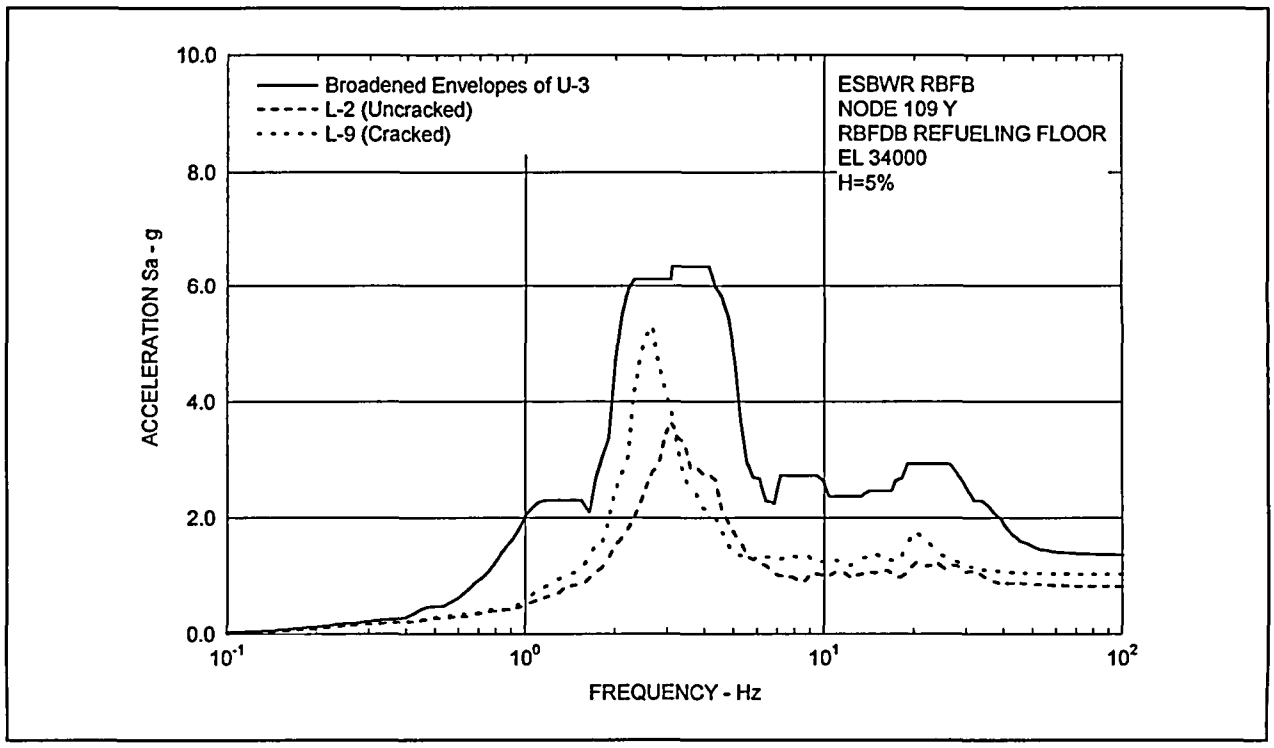



**Figure 7.5-8 Floor Response Spectra - RBFB Refueling Floor Y**

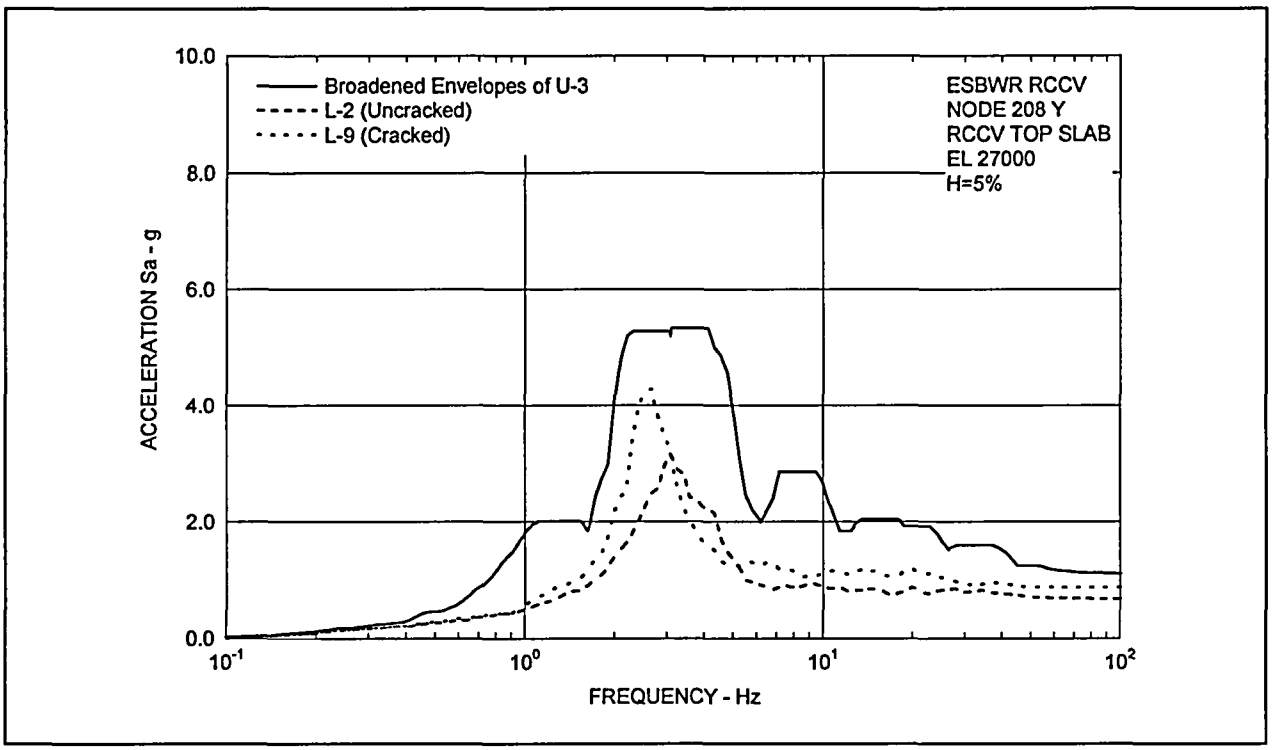



**Figure 7.5-9 Floor Response Spectra - RCCV Top Slab Y**

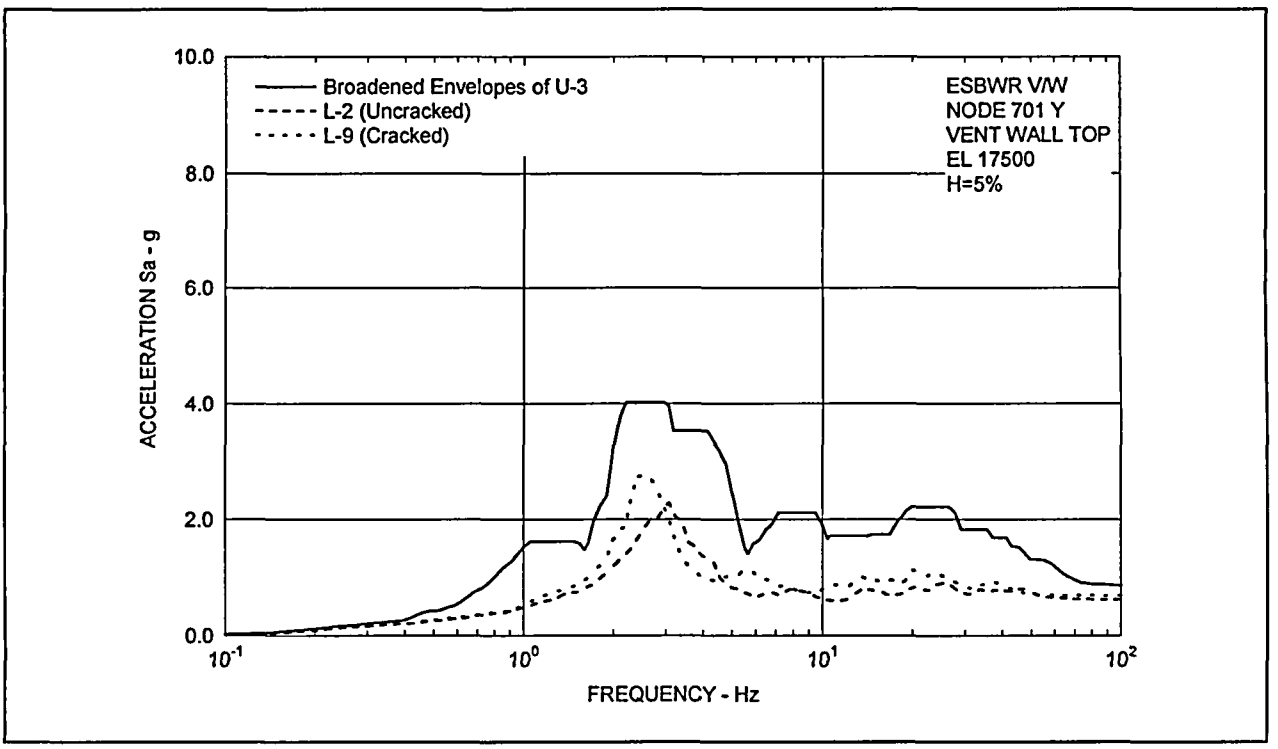



**Figure 7.5-10 Floor Response Spectra - Vent Wall Top Y**

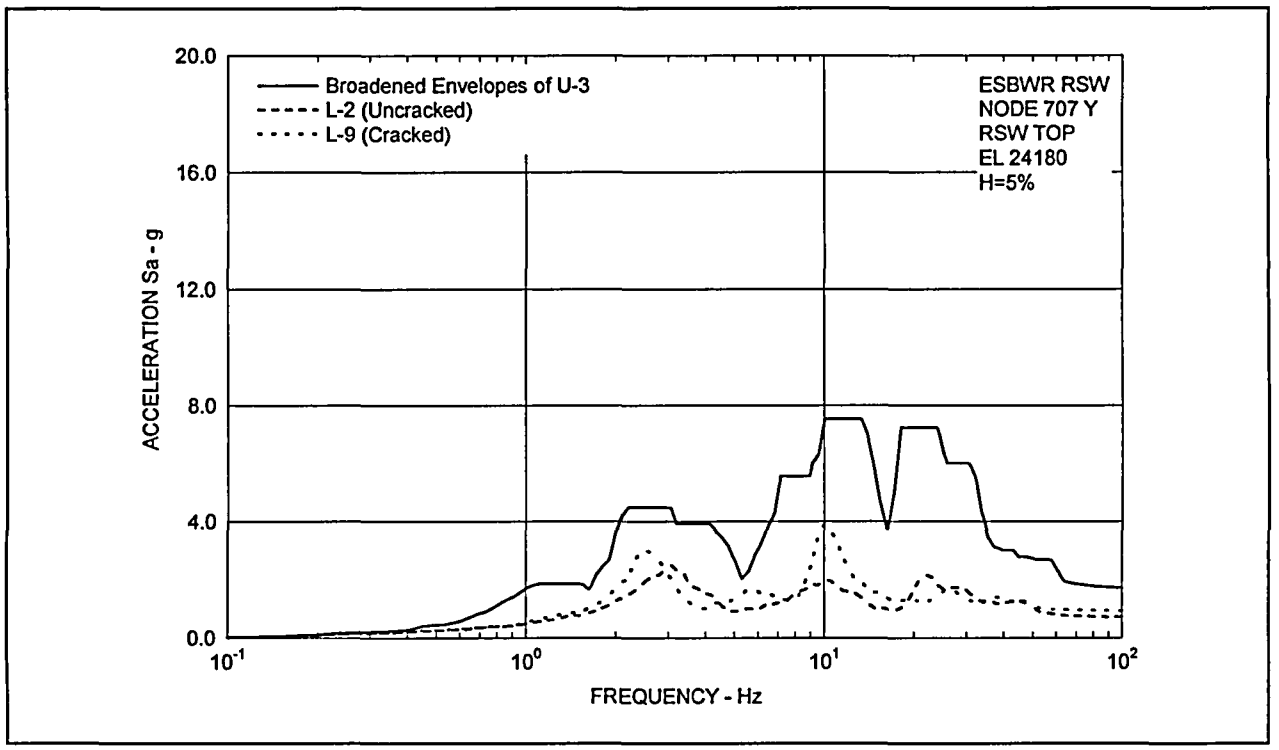



**Figure 7.5-11 Floor Response Spectra - RSW Top Y**

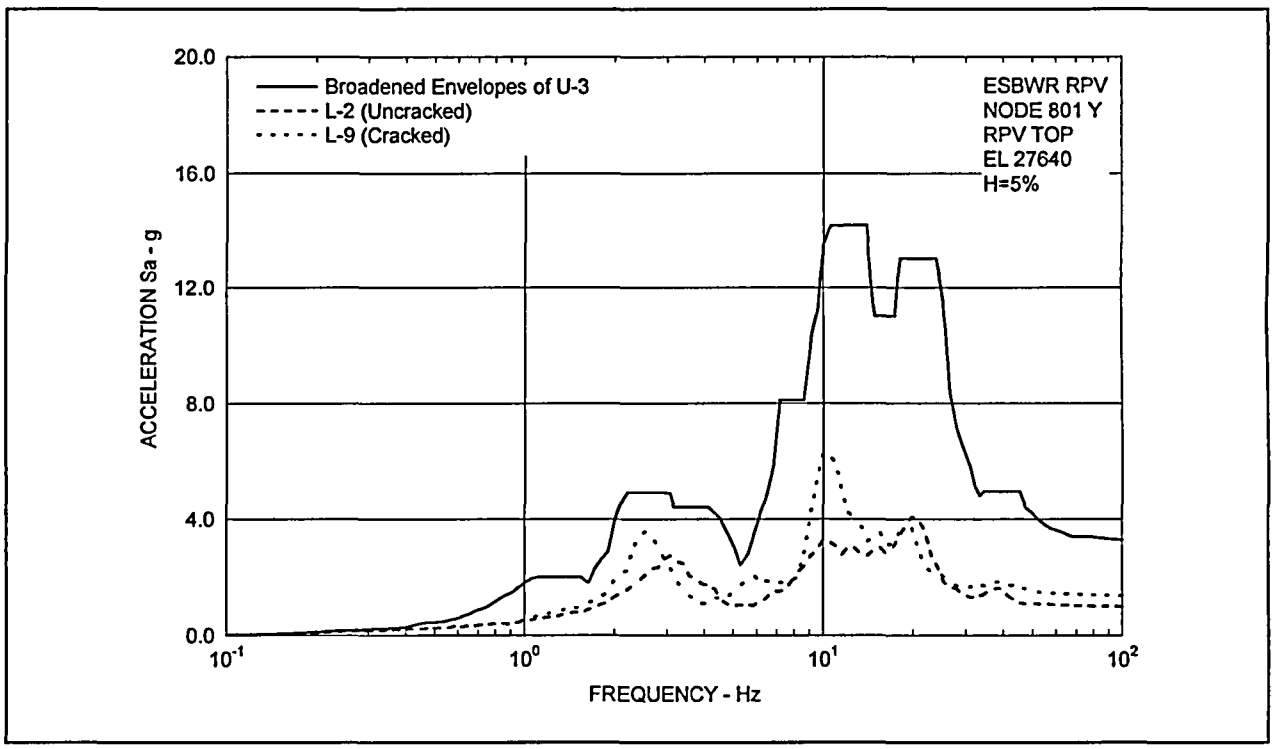



**Figure 7.5-12 Floor Response Spectra -RPV Top Y**

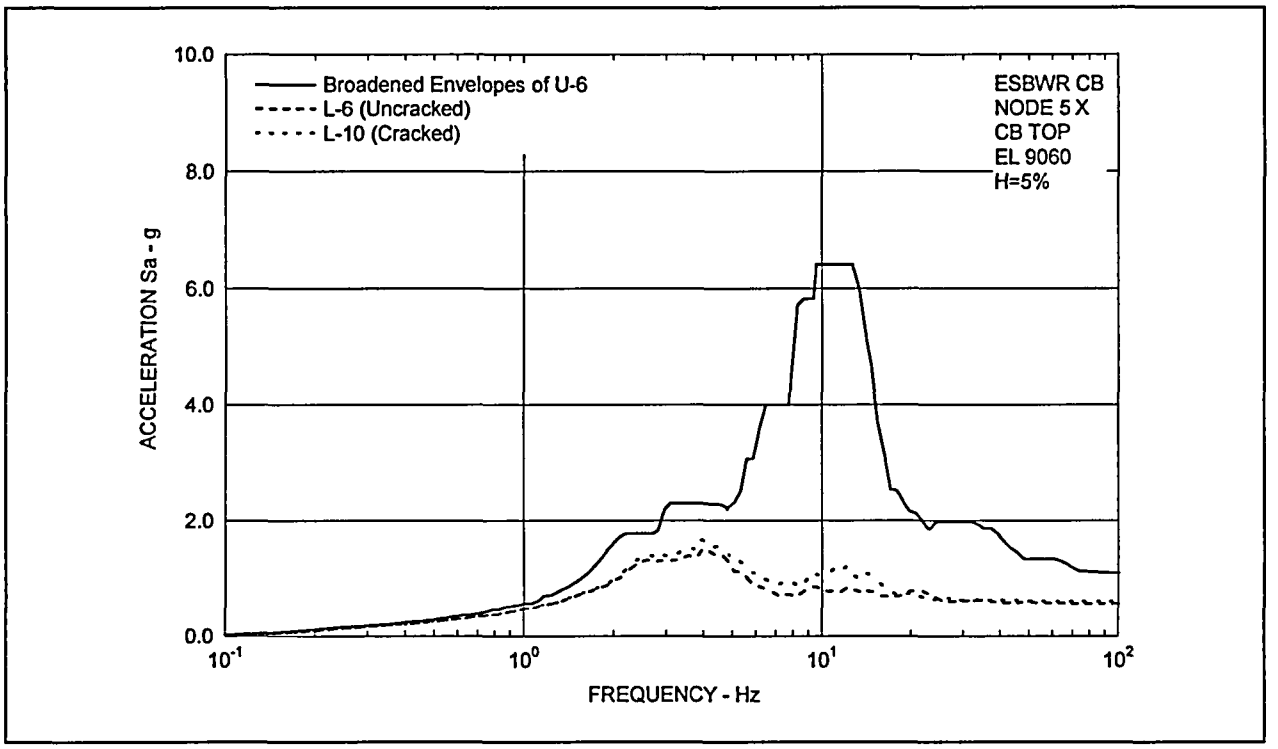



**Figure 7.5-13 Floor Response Spectra - CB Top X**

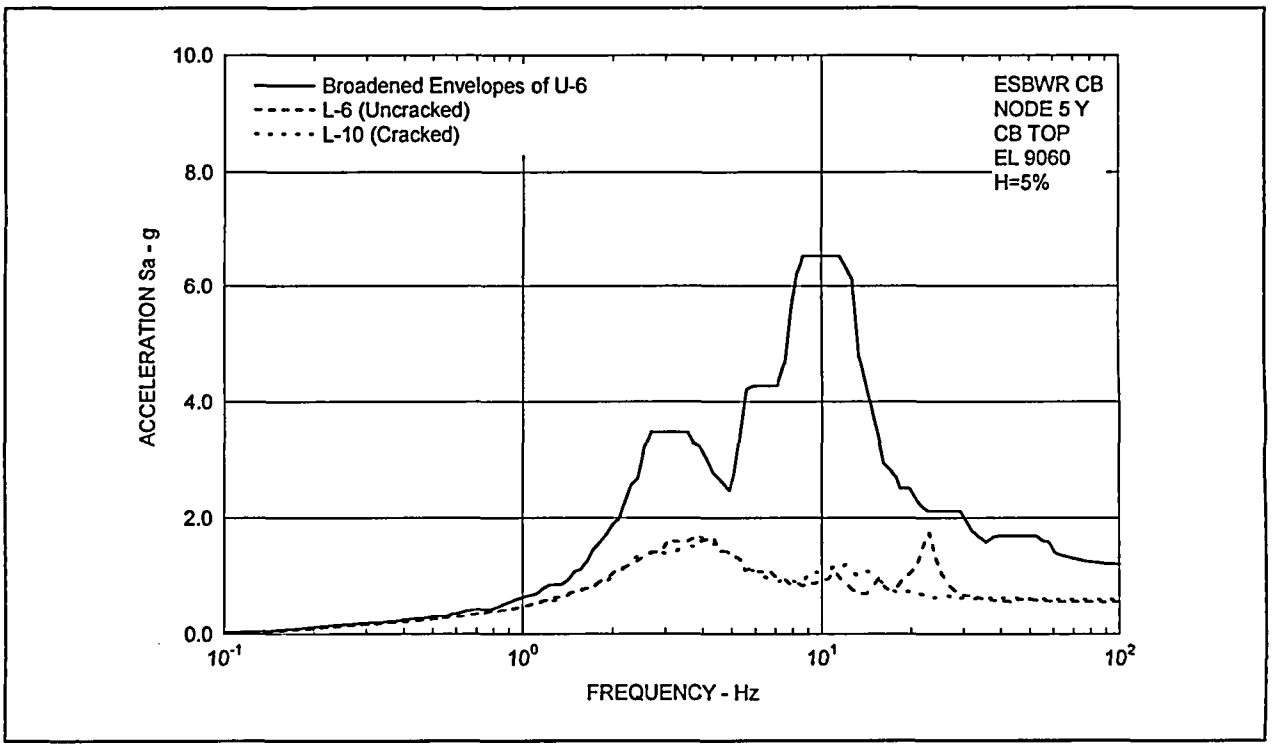



**Figure 7.5-14 Floor Response Spectra - CB Top Y**

## 7.6 Effect of Structure-to-Structure Interaction – RAI 3.7-39

In order to address the effect of structure-to-structure interaction, an additional evaluation is performed using SASSI. The RBFB effects on CB are more significant than the CB effects on RBFB, because the size of RBFB is much larger than that of CB. To evaluate the RBFB effects on CB, the analyses were performed by the following two steps.

1) Perform the RBFB SASSI analysis to obtain the ground surface response at the CB location.

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

For the comparison of without and with structure-to-structure interaction effect, Case L-6 layered site was selected, because the CB shows the largest responses at Case L-6 site among various layered sites. The corresponding RBFB case is Case L-2. The CB case considering structure-to-structure interaction effect is called as Case L-11.

Comparisons of floor response spectra (FRS) (5% damping) at the top of CB are shown in Figures 7.6-1 through 7.6-3. The broadened envelope results of Case U-6 (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-to-structure interaction is the largest in the Y direction (East-West) FRSs, however, both FRSs without and with structure-to-structure interaction effect are bounded by the broadened envelope responses of uniform site cases in the whole frequency range.

As stated in Section 7.1, the existing DCD design load will be updated to incorporate the responses due to the single envelope input motion at the uniform sites. The revised DCD design load has no impact from the effect of structure-to-structure interaction.

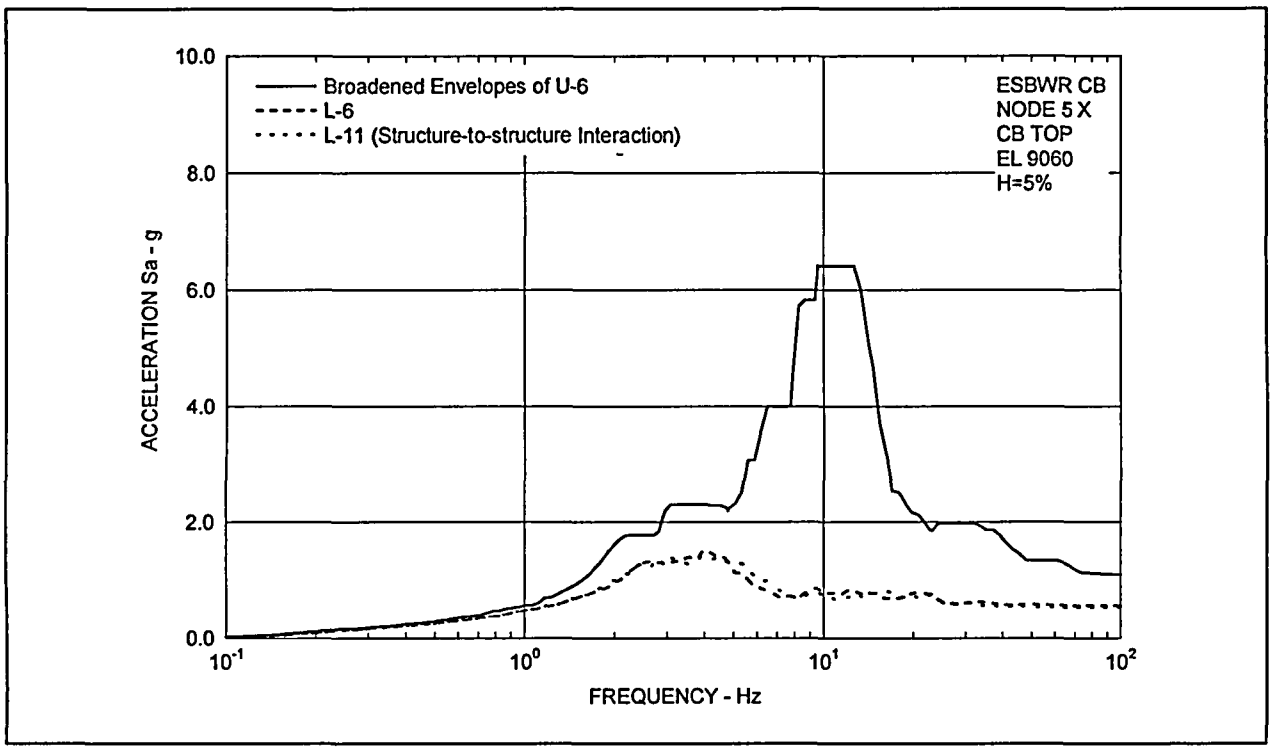



**Figure 7.6-1 Floor Response Spectra - CB Top X**

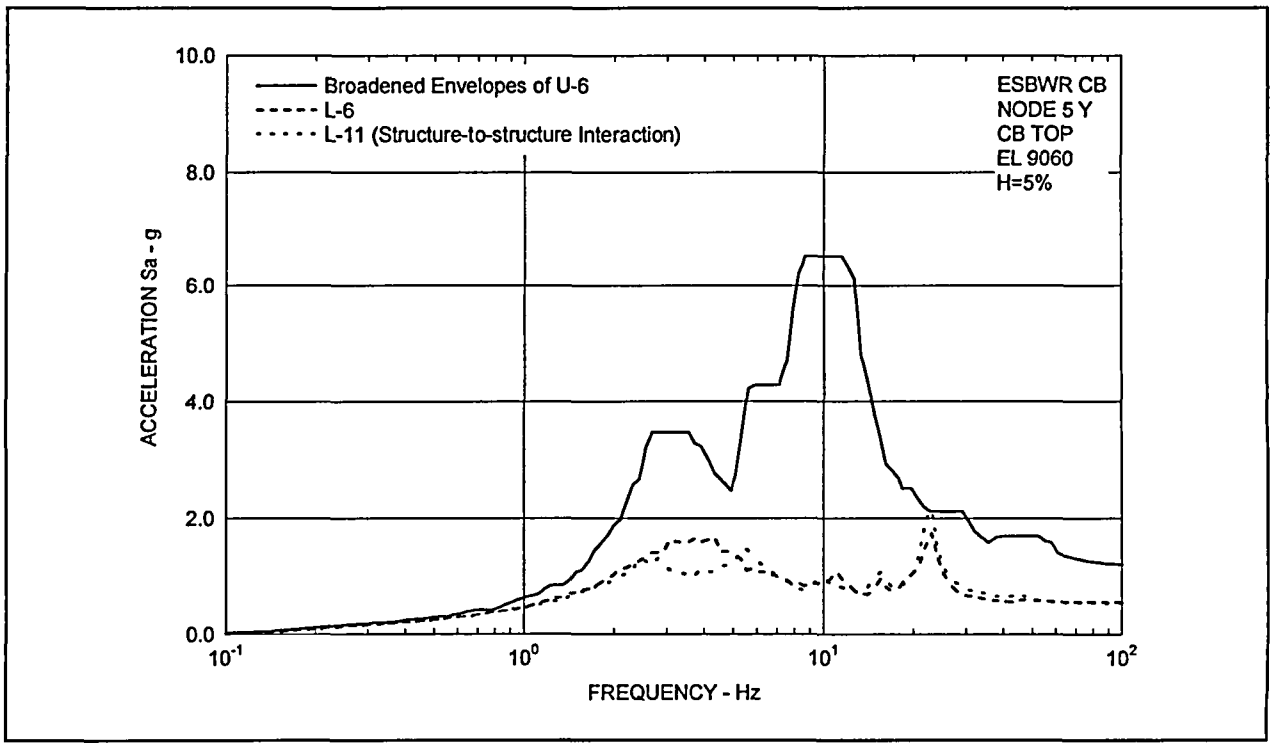



**Figure 7.6-2 Floor Response Spectra - CB Top Y**

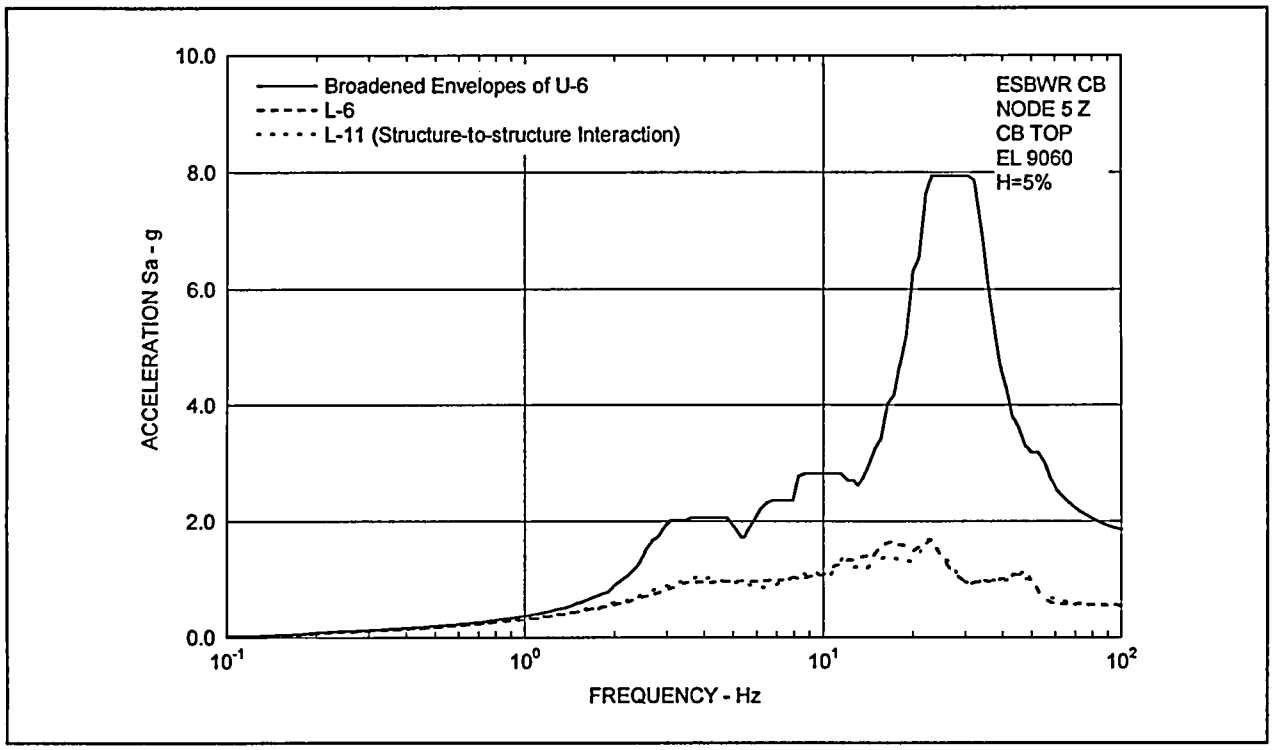



**Figure 7.6-3 Floor Response Spectra - CB Top Z**

## 8. Conclusions

In accordance with the analysis results obtained in this parametric evaluation, it can be concluded that the effects on SSI response are generally insignificant as compared to the envelope results using the lumped soil-spring SSI approach for a wide range of uniform sites subject to dual input motions without explicit consideration of embedment, concrete cracking and structure-to-structure interaction. For the purpose of additional design margins consideration, the results of all cases considered will be enveloped and DCD Appendix 3A will be revised accordingly.