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New Plant Seismic Issues Resolution Program

Update on Task S2.2
Effect of Limited Inelastic Behavior on High Frequency Response

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Summary of Additional S2.2 Studies (Phase 2)

- Revision of response modification procedure to address fillet weld low-cycle fatigue concerns
- Consideration of structures with f_1 > 10 Hz
- Verification of conservatism of in-structure spectra generated with modified design spectra
- Recommendations on qualification testing procedures for equipment and components to demonstrate function during and after high frequency seismic motion
- Development of vertical response modification evaluation model
- Additional studies on high frequency structural response behavior

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Fillet Weld Load-Deformation Behavior

- The original EPRI study (Reed, 1993) focused on the transverse loaded fillet weld as the worst case scenario with the non-linear behavior concentrated within the most highly loaded equipment anchorage interface region
- It was felt that the consideration of this "worst case" would serve as a surrogate for the effect of limited non-linear behavior in the primary loadpath of high frequency components
- Based on static load test results (basis of current LRFD design provisions for fillet welds), the load-deformation function was characterized by a yield deformation of 0.001 inch and an ultimate deformation of 0.0105 inch (Deformation Ratio, $\delta_u/\delta_y=10$)
- The prior study (and the S2.2 Task) *assumed* that the quarter-cycle hysteretic loop for the transverse loaded fillet weld is specified by the static load-deformation function and is fully effective for reverse cycle loading up to the ultimate deformation

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Low-Cycle Fatigue of Fillet Weld

- The assumption of multiple cycles at the ultimate (static failure) deformation has been questioned
- In general, the expected number of effective full load cycles during a seismic event is N < 20 which places the strength evaluation in the ultra low-cycle fatigue realm (N<100) which does not have extensive test data
- Two low-cycle fatigue test studies were found which indicate that an ultimate deformation ratio of δ_u/δ_y=7.5 can sustain at least N=50 full cycles
- It has been decided to utilize a lower value of maximum cyclic deformation δ_u=0.0075 inch instead of δ_u=0.01 inch for the 3/16" weld used in the S2.2 study
- This revised estimate of allowable ultimate weld deformation increases the modified design spectrum by 5-10%

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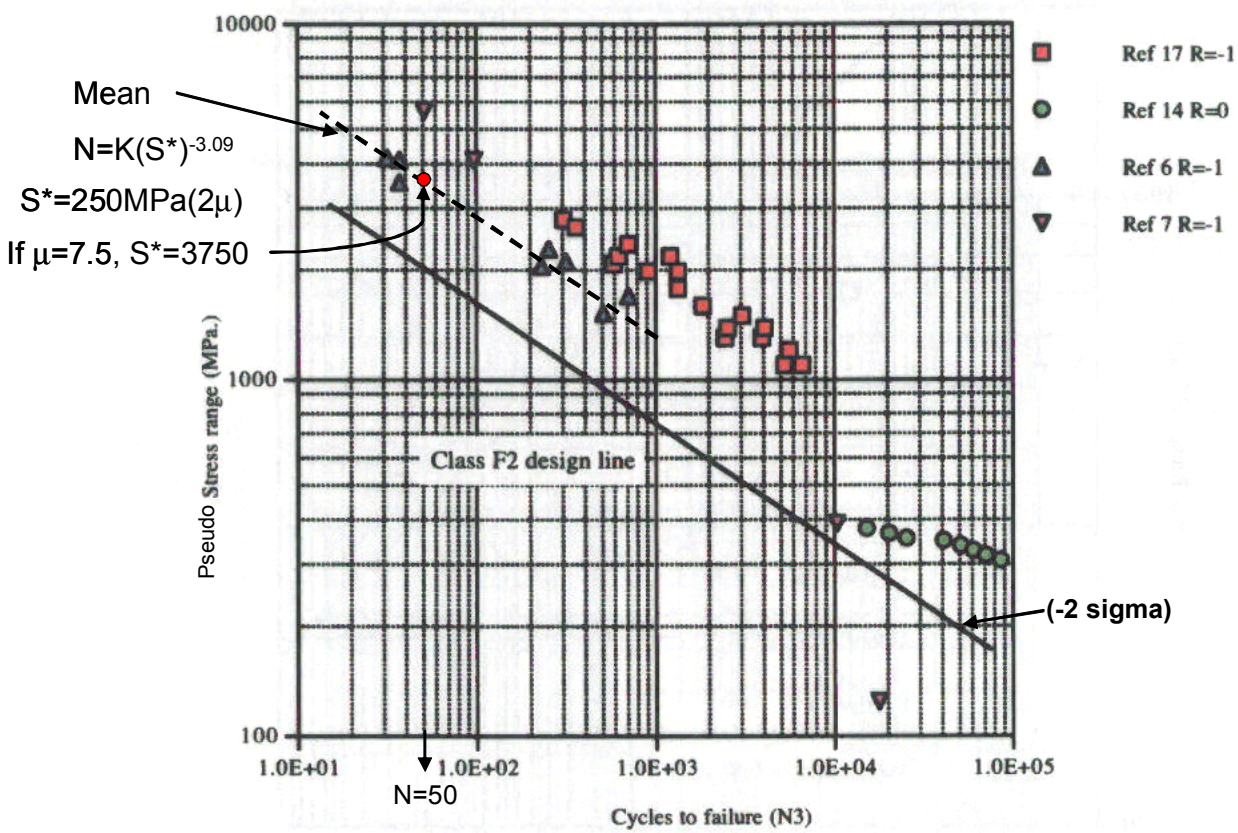
S-N Curve for Transversely Loaded Fillet Welds

Fillet Weld Low Cycle Fatigue Test Data



Endurance data for transverse load-carrying fillet welds

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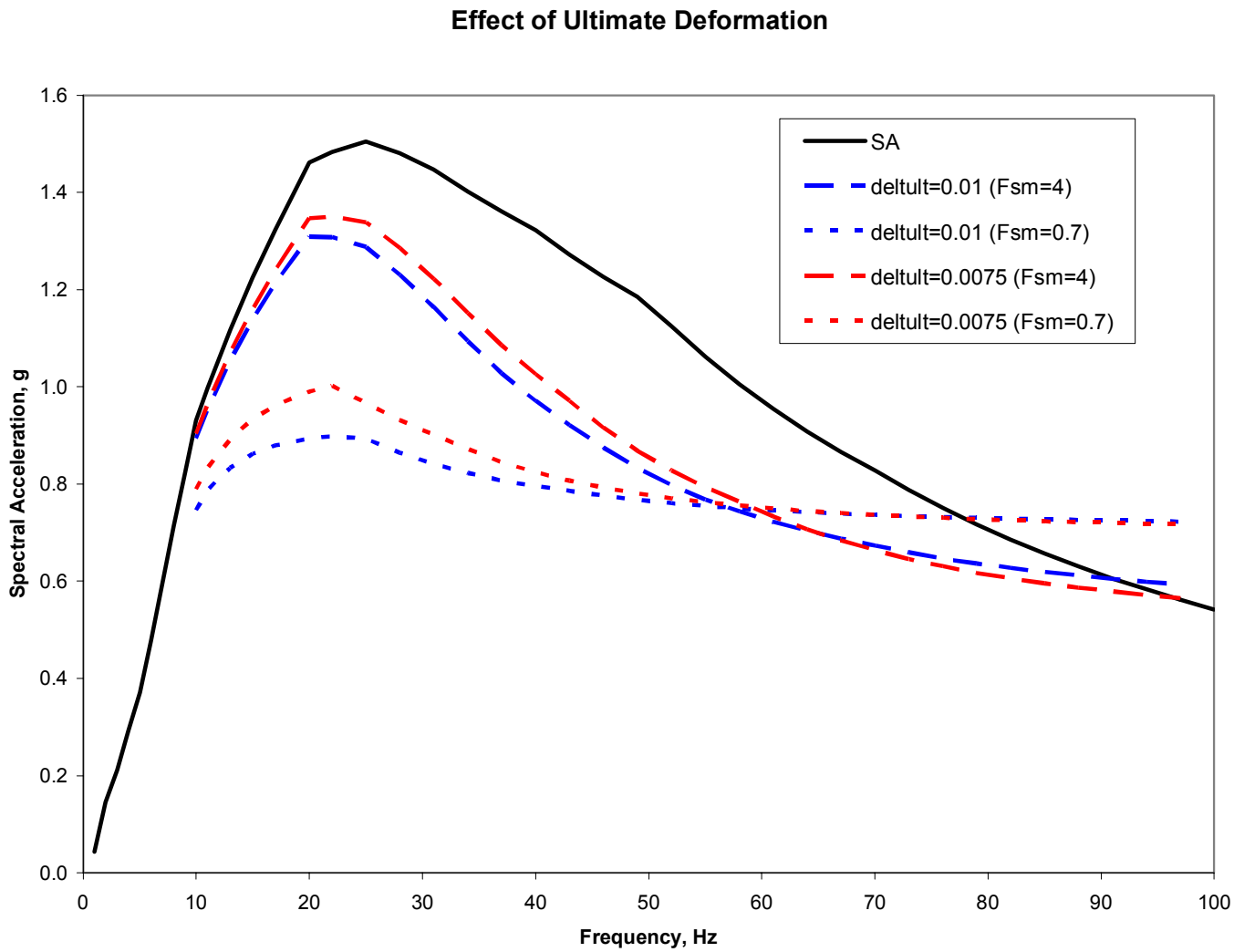
CEUS Rock Site Modified Spectra



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Consideration of Structures with Fundamental Frequency Greater than 10 Hz

- The S2.2 amplification studies assumed that the fundamental frequency of most plant structures will be less than 10 Hz
- Since the modification procedure affects high frequency systems with 10 Hz or greater, the spectral amplification of the higher modes > than 10 Hz was shown to be less than 2.5 for a Timoshenko beam structure model
- Plant structures with fundamental frequency greater than 10 Hz do exist, thus the higher amplification of the fundamental mode (~7.5) must be considered
- The response modification procedure is still applicable, however F_{sm}=1.6(7.5)=12 is the scale factor for this case

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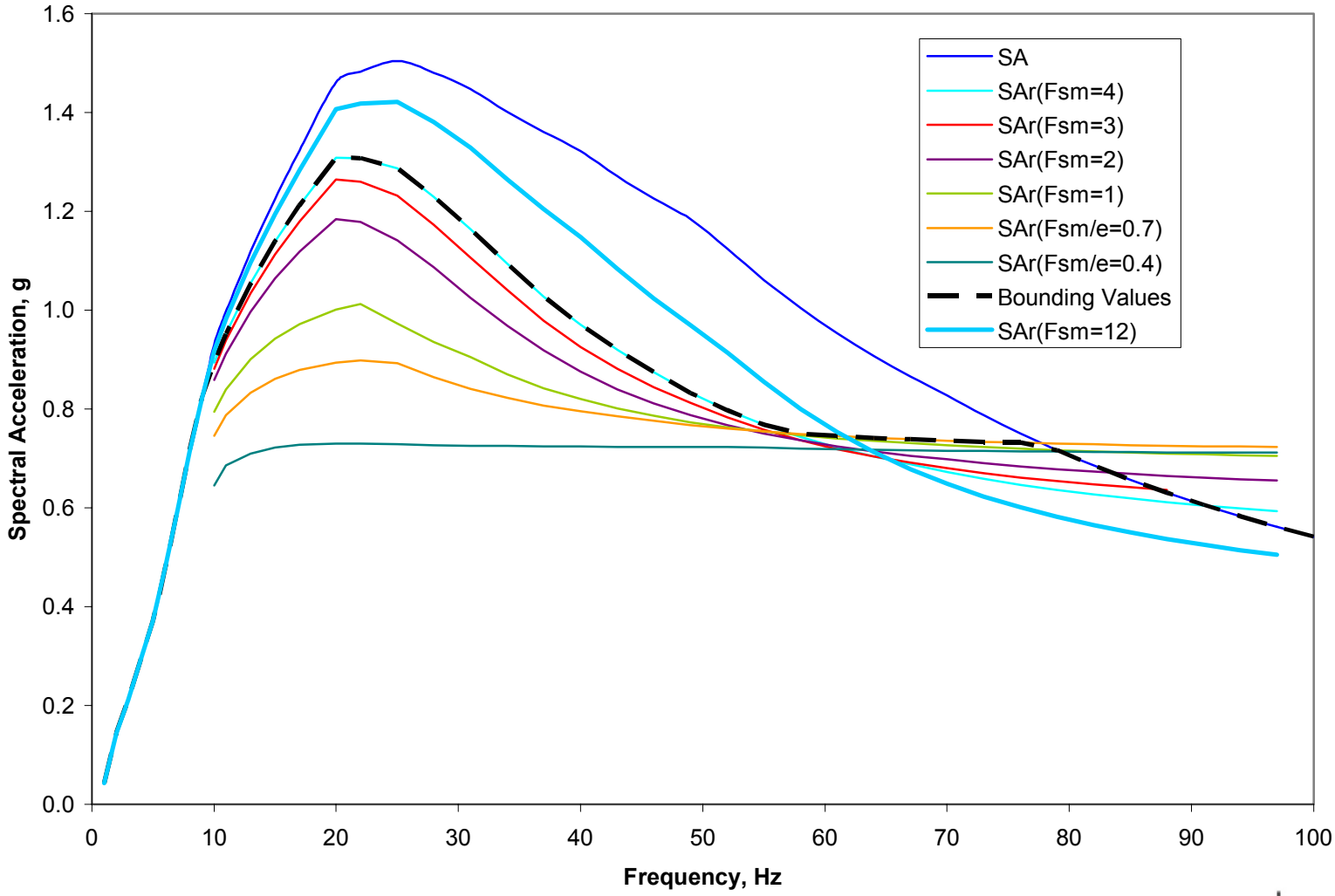
CEUS Rock Response Modification



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Indirect Spectra Generation vs. Direct Spectra Generation

- At the August project review meeting it was concluded that it was desirable to demonstrate that:
  1) in-structure spectra generated with a time history that is compatible with a modified design spectrum are equal to or greater than
  2) in-structure spectra generated with a time history that is compatible with the unmodified design spectrum and then individually modified at the structure level.
- The following sub-tasks were identified:

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Indirect Spectra Generation vs. Direct Spectra Generation (con't.)

- 1. Indirect In-Structure Spectrum Modification using Modified Ground Design Spectrum
  - a. Reduce CEUS rock design spectrum (use F_{SM} = 0.4-4)
  - b. Generate a time history compatible with the reduced spectrum
  - c Generate in-structure spectra at x/L = 0.38 and x/L = 0.9 using three Timoshenko Beam building models – f_1=3, 5, 9 Hz
- 2. Direct In-Structure Spectrum Reduction
  - a. Generate a time history compatible with the CEUS rock design spectrum
  - b. Generate in-structure spectra at x/L = 0.38 and x/L = 0.9 using three Timoshenko Beam building models – f_1=3, 5, 9 Hz
  - c. Reduce in-structure spectra using S2.2 procedure (use F_{SM} = 1.6)
- 3. Compare in-structure spectra generated both ways

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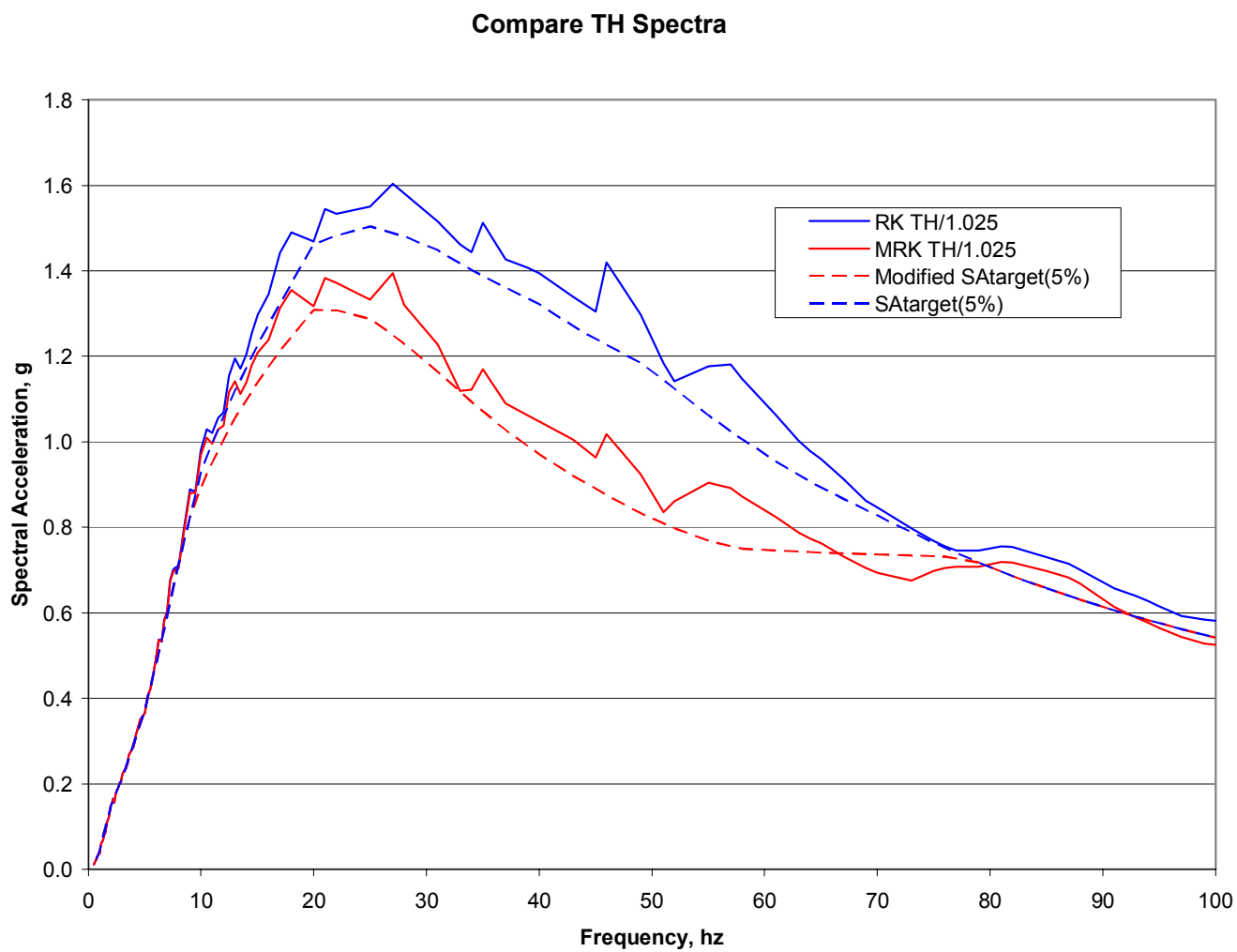
Comparison of Input Motion for Timoshenko Beam



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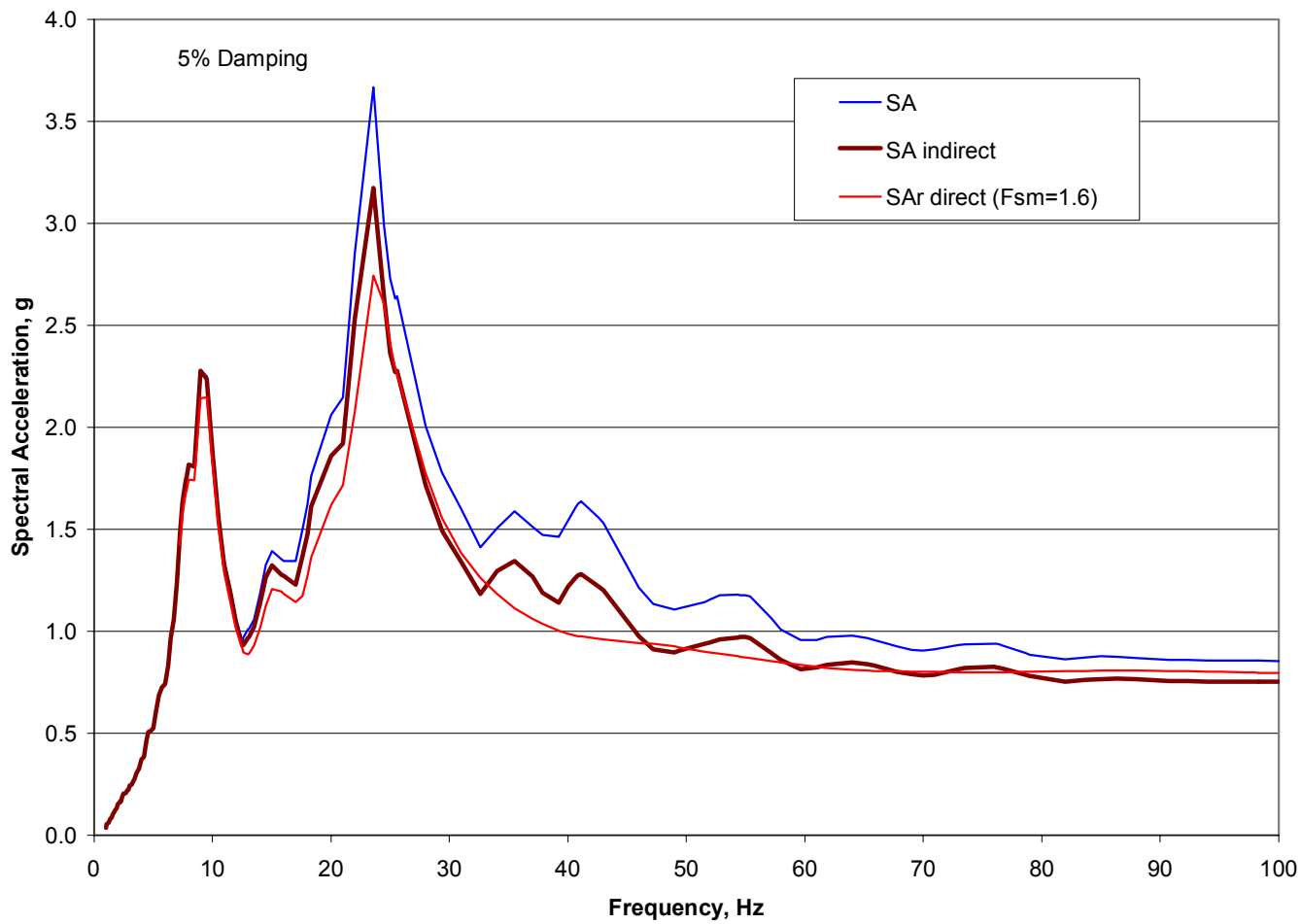
Comparison of Directly Modified In-Structure Spectrum with Indirectly Modified In-Structure Spectrum for Timoshenko Beam

f1 = 9 Hz, x/l = 0.38



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Qualification Procedures for Equipment Requiring Functional Demonstration

- Specification of in-structure response for use in seismic equipment qualification has in the past been accomplished using in-structure response spectra generated from the response of a structure model
- However, response spectra tend to reflect the peak response of the lower modes in the high frequency regime resulting in a false level of motion being specified for the high frequency range
- For this reason, the specification of non-seismic dynamic environments (transportation, aerospace, military, etc.) is accomplished using Power Spectral Density functions for the definition of the required motion for qualification of equipment and components
- The following figures show example ground motion spectra being using for the design of new plants along with the PSD functions compatible with these motions

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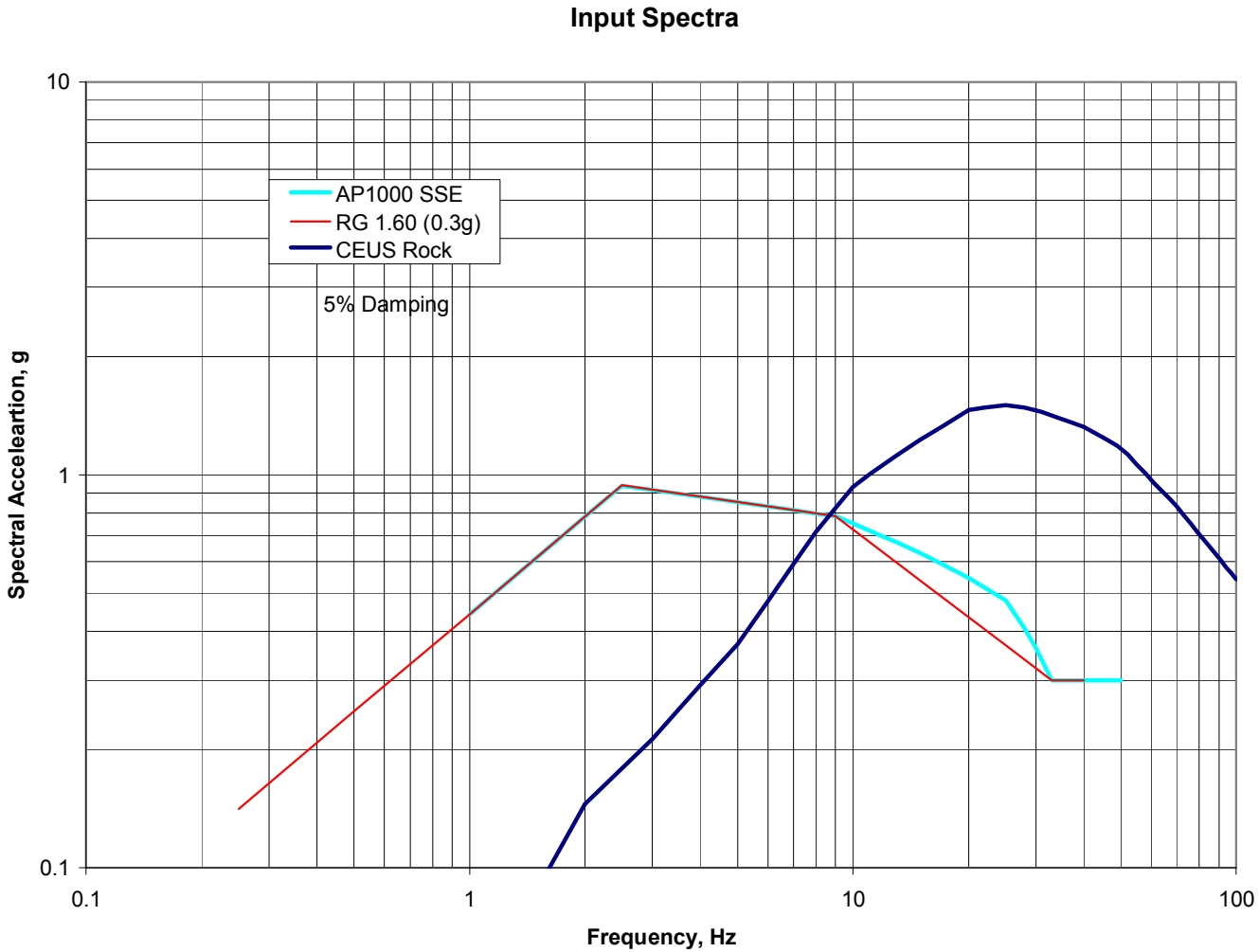
Example Input Ground Design Spectra (conservative)



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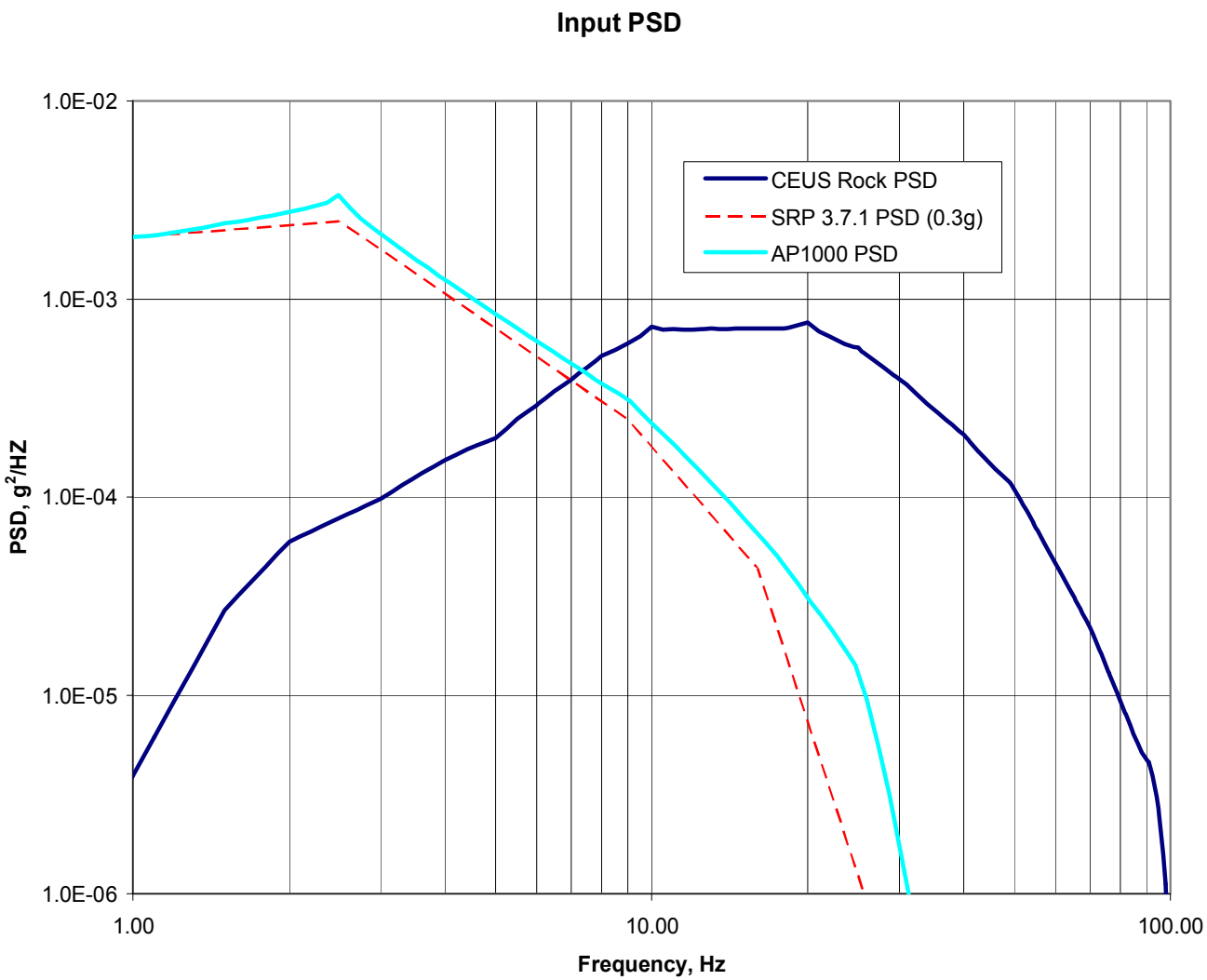
Input PSD Functions Compatible with the Example Design Response Spectra



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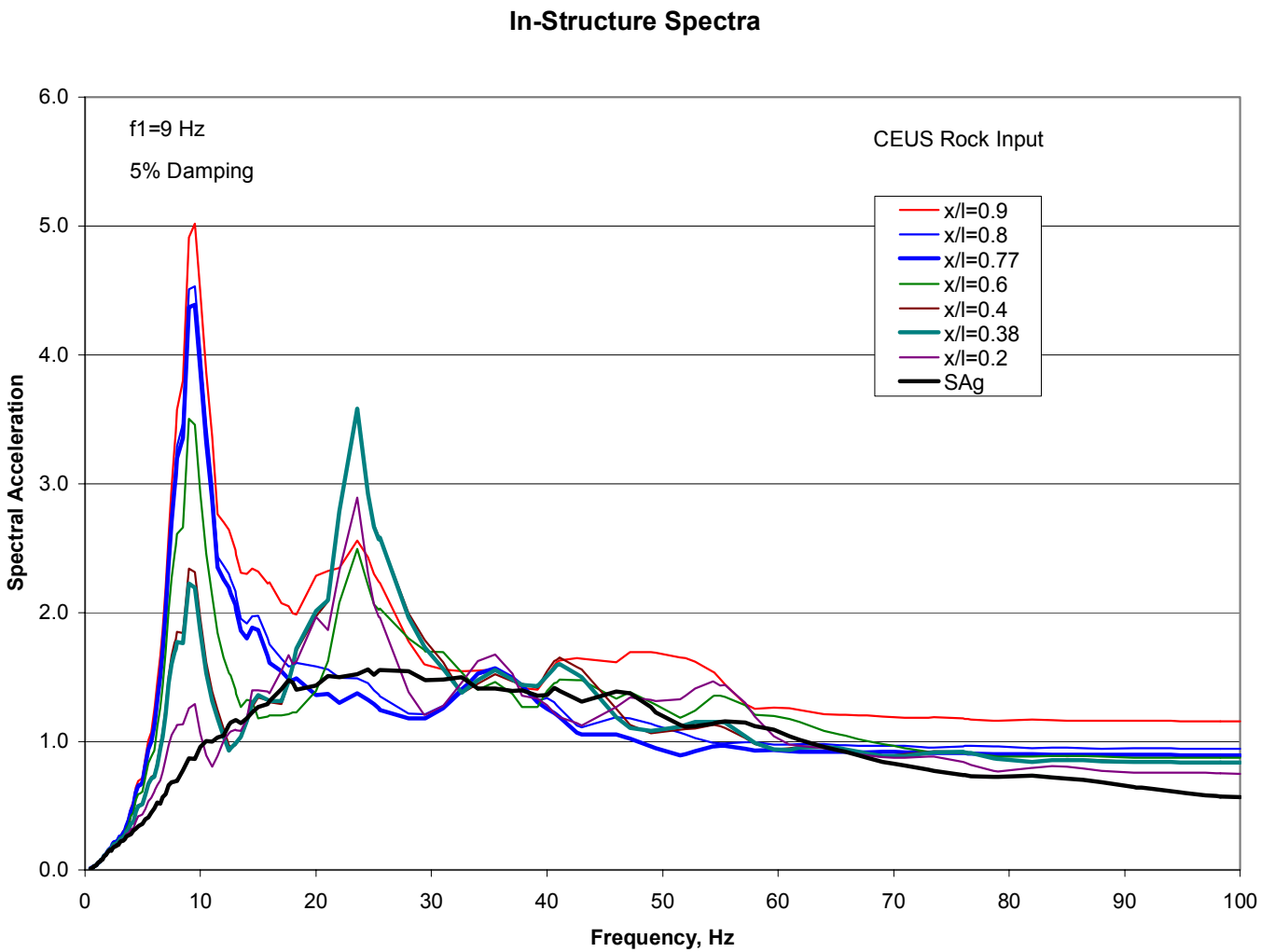
In-Structure Response Spectra for Timoshenko Beam (f_1=9 Hz, 7% Structure Damping)



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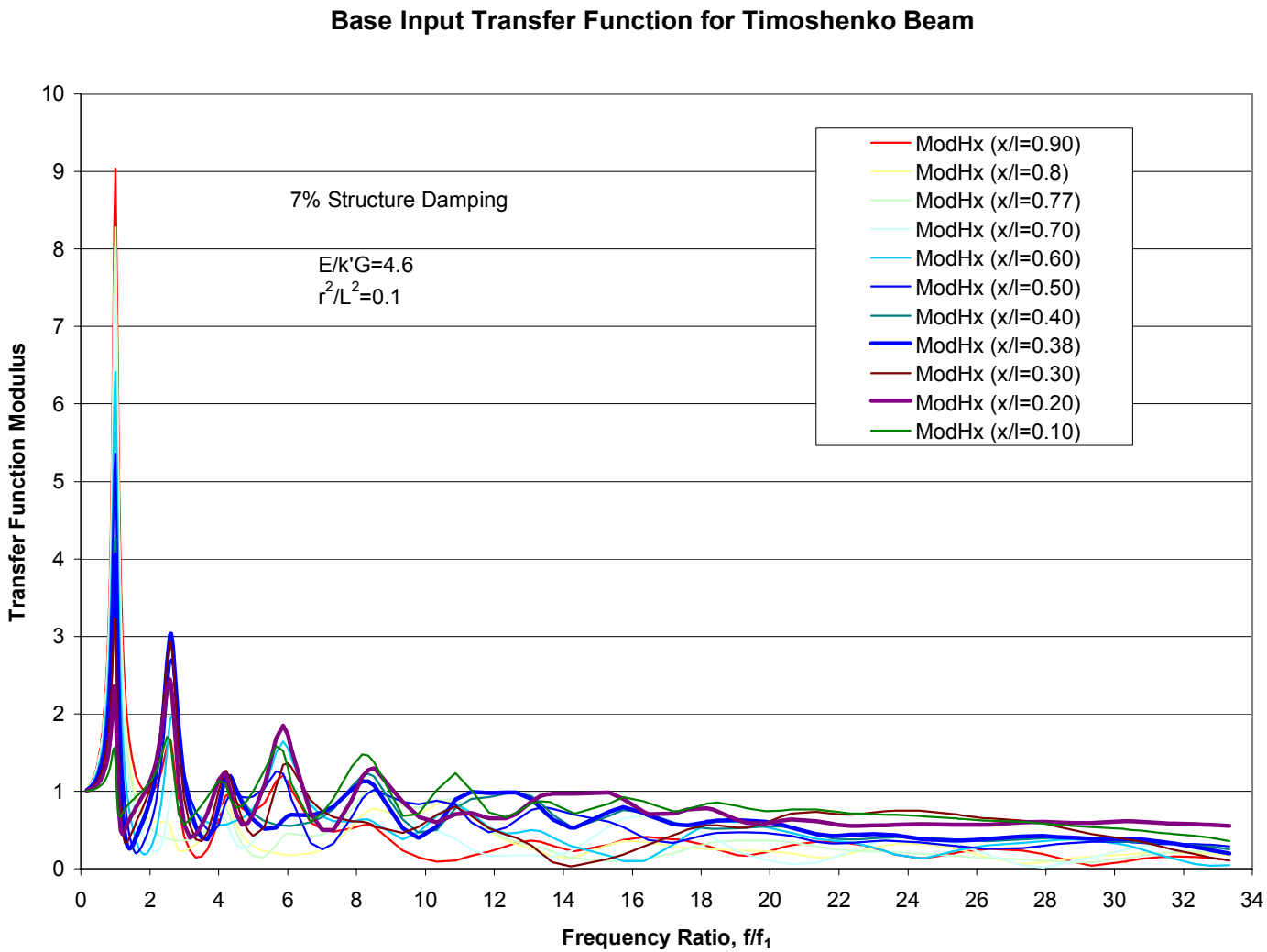
Base Input Transfer Function for Timoshenko Beam



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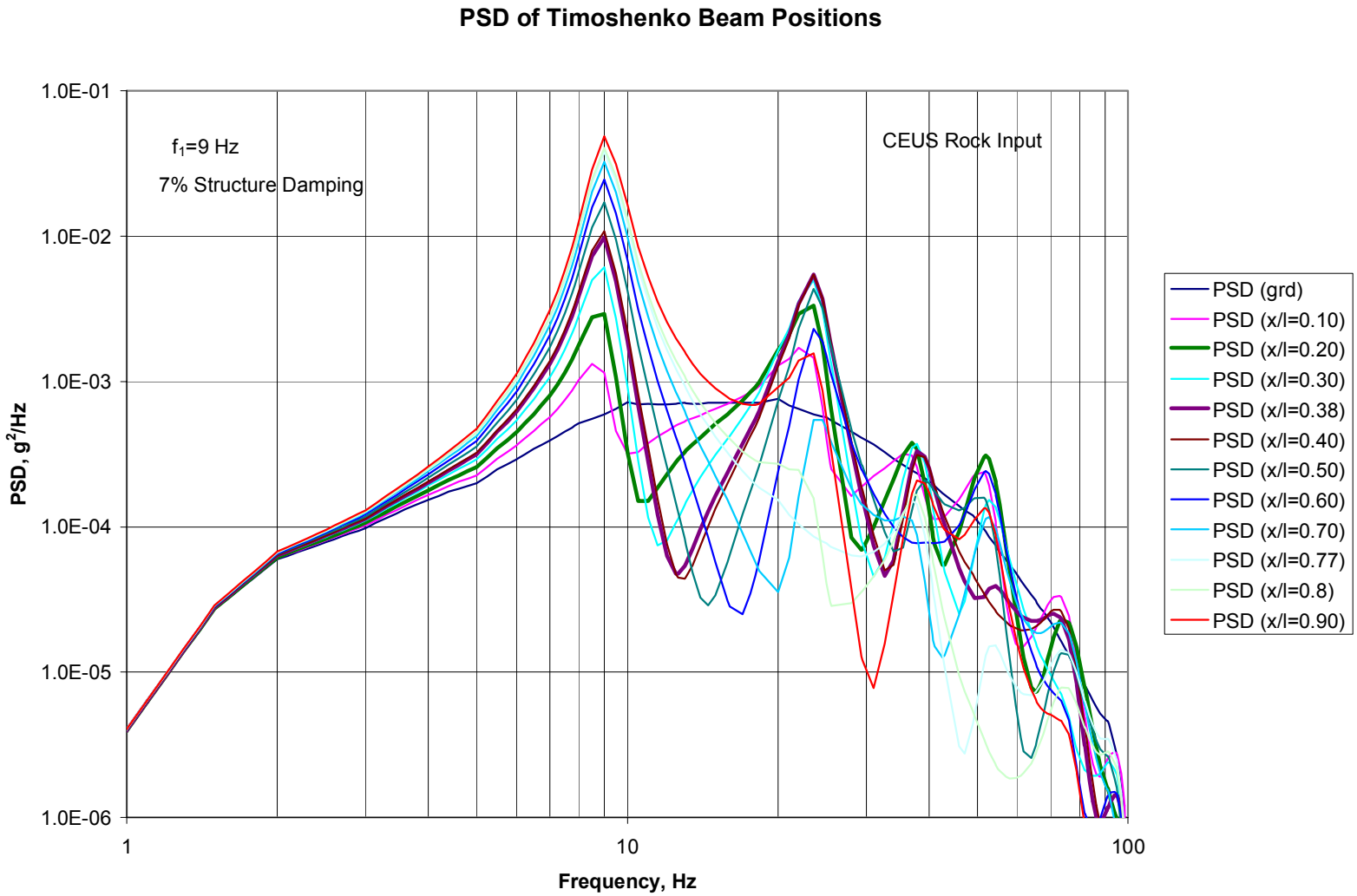
PSD for Timoshenko Beam (f_1=9 Hz, 7% Structure Damping)



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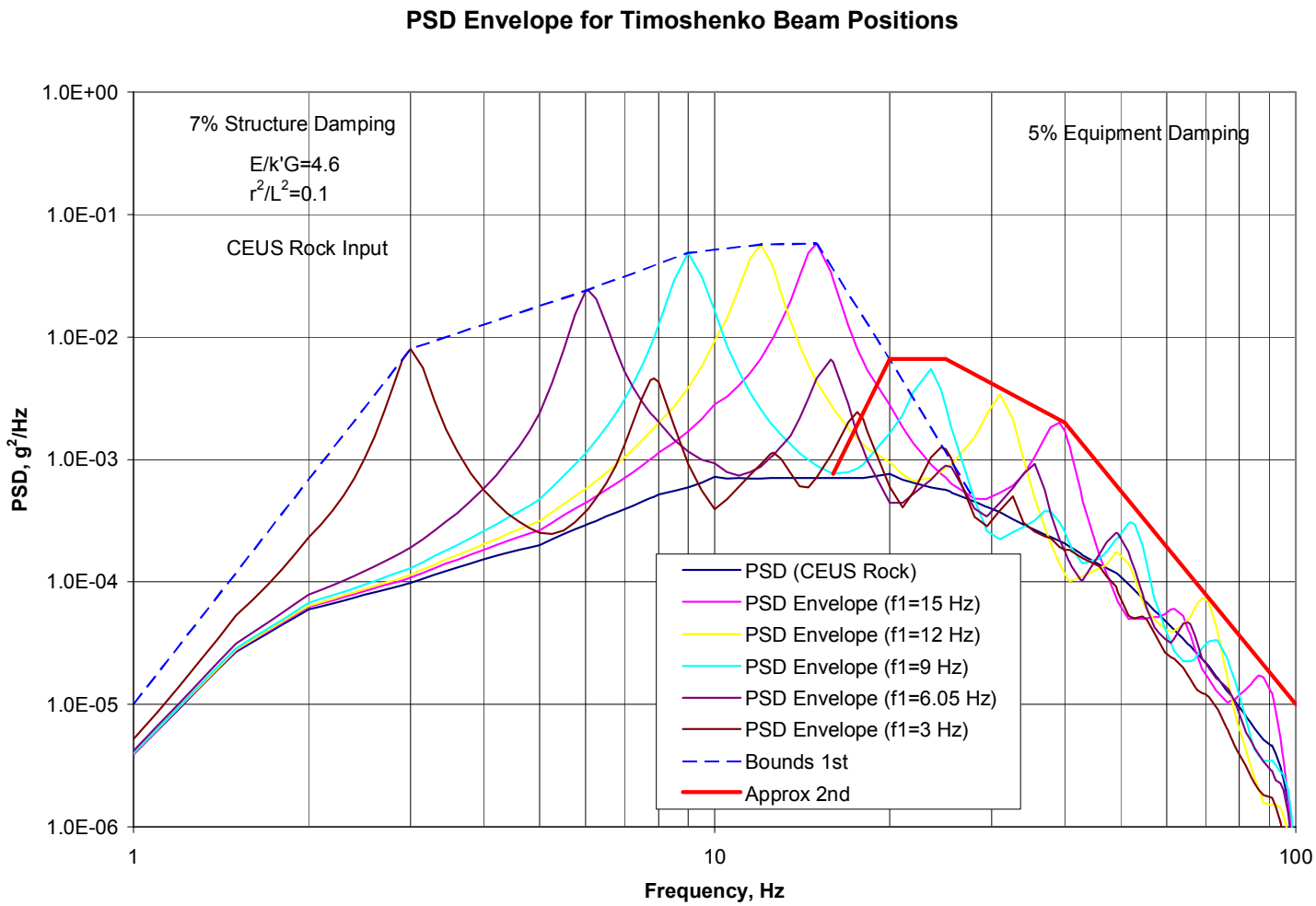
PSD Envelope for All Beam Positions



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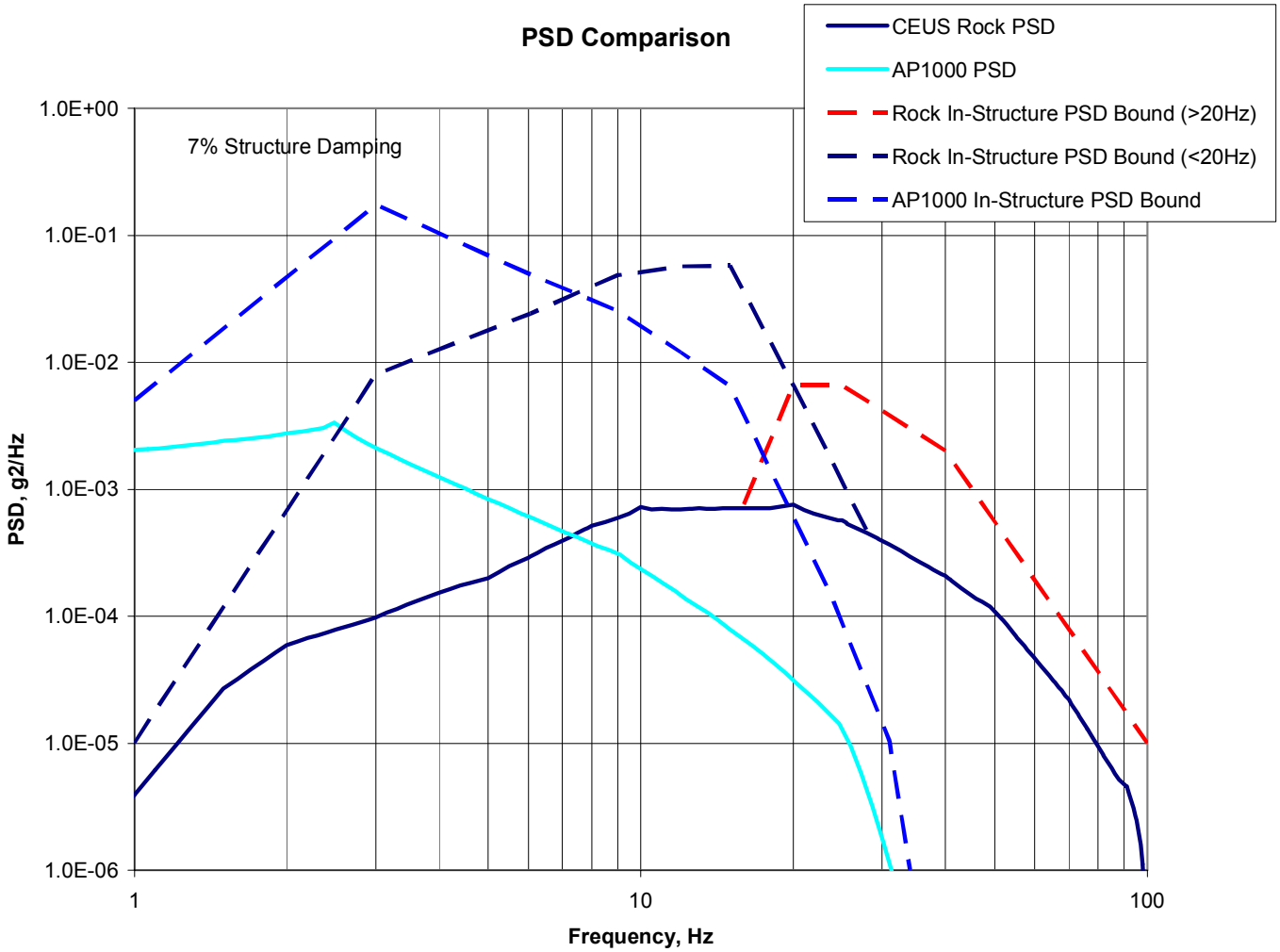
PSD Envelope Comparison



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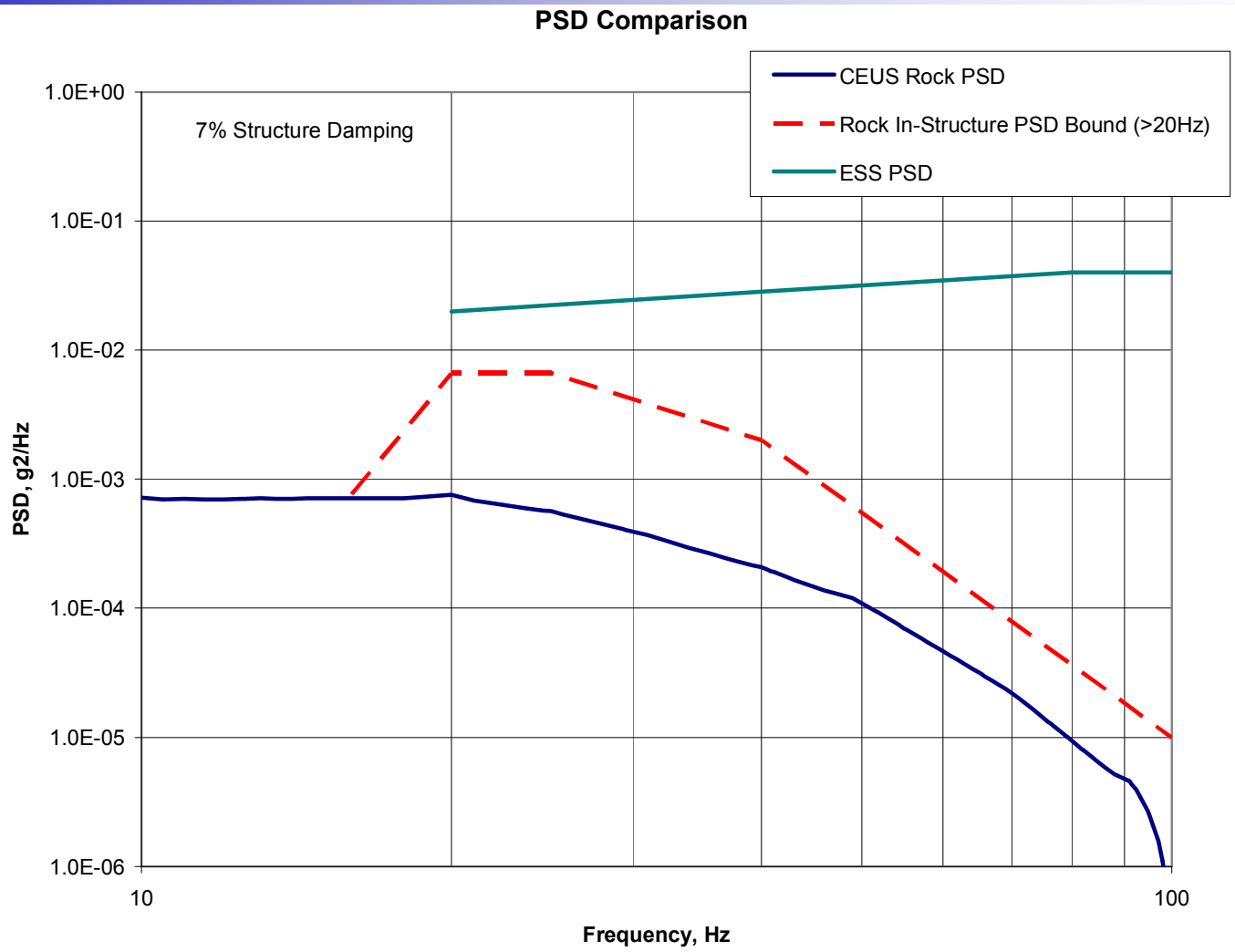
High Frequency Region (>20 Hz)



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Environmental Stress Screening (ESS)

- ESS (also referred to as HASS/HALT) is a technique used for quality control of military and commercial electronics. The PSD level shown is a commonly used random vibration level known as the Willoughby spectrum originally provided in NAVMAT P-9492 (1979)
- The concept was to screen electronic components with random vibration as a means of insuring that the components do not have common manufacturing defects and meet functional requirements while being shaken

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Qualification Approach Being Studied

- Test equipment to RRS defined from in-structure spectra in the 1-25(33) Hz regime as is currently done under IEEE-344 or ASME QME.
- Screen equipment with a random vibration level defined as either a constant PSD (say 0.01 g^2/Hz over 20-80 Hz) or a mounted component level established by applying a clipping factor to the envelope of the individual narrow-band modal PSD response levels and a clipped amplification factor

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Summary of Phase 2 Efforts

- Revised response modification procedure to accommodate low-cycle fatigue effects
- Considered building fundamental frequencies greater than 10 Hz
- Demonstrated that indirect generation of in-structure spectra using modified input motion is a conservative procedure
- Developed recommendations for high frequency screening of functional equipment
- Formulation of evaluation models for vertical response modification

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