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RESPONSE SPECTRUM BROADENING METHODDOLOGY

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ABSTRACT

The U.S. Nuclear Regulatory Commission Regulatory Guide 1.122 Revision 1 was issued in 1978, and was not able to leverage modern probabilistic methods for response spectrum modelling. As such, issues exist around the broadened response spectrum curve for design use in the 1978 regulation that result in unrealistic requirements for design. There are four areas that require changes in order to address the issues: 1) the sharp corners at ±15% of top peak, 2) the sloped straight-line on each side, 3) the much stronger intensity of the generated time history, and 4) the clipping of the generated time history zero-period-acceleration (ZPA) peaks.

This paper proposes using several methods to resolve issues with U.S. Nuclear Regulatory Commission Regulatory Guide 1.122, Revision 1. The proposed resolutions include broadening the response spectrum peak to eliminate the sharp corners at the broadened peak by replacing the sharp corners with an unbroadened response spectrum curve, replacing the sloped straight-line on each side by shifting the unbroadened spectrum curve at each -3dB point (i.e. 0.707 of the unbroadened spectrum peak) to ±15% of the peak frequency, reducing the response spectrum peak by 15% to match realistic seismic analysis, and increasing the ZPA value on the broadened response spectrum to eliminate the need for additional time history manipulation.

The methodology was validated using two sets of time history comparison. The proposed peak broadening and lowering response spectrum produces a time history has the same intensity as the un-broadened response spectrum that will accurately representing an earthquake frequency response signal. This paper provides the method for creating a more realistic peak broadening and lowering response spectrum that benefits the seismic design certification of floor-supported equipment or components.

INTRODUCTION

This paper proposed a methodology for revising the U.S. Nuclear Regulatory Commission Regulatory Guide 1.122, Revision 1 (1978), “Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components.” The detailed methodology is described in Li, D. (2019)

The proposed guideline described below reducing the bandwidth produces a more accurate time history that benefits the seismic design certification of floor-supported equipment or components.

In short, the proposed broadening method involves taking the unbroadened spectrum curve at the –3dB point (i.e. 0.707 of the unbroadened spectrum peak) and shifting the spectrum curve out ±15% of the peak frequency, while also providing a guideline for response spectrum peak broadening and lowering criteria for various damping ratio.

ISSUES OF CURRENT REGULATORY GUIDE 1.122

Figure 1 below shows a 3.3 Hz and 16 Hz response spectrum with a 3% damping value representing the NRC Regulatory Guide 1.122 Revision 1, Figure 1 “Response Spectrum Peak Broadening and Smoothing.” The time history generated from this broadened response spectrum contains the following concerns, which can result in unrealistic requirements for design:

1. The sharp corners at ±15% of top peak
2. The sloped straight-line on each side
3. The much stronger intensity of the generated time history
4. The clipping of the generated time history zero-period-acceleration (ZPA) peaks

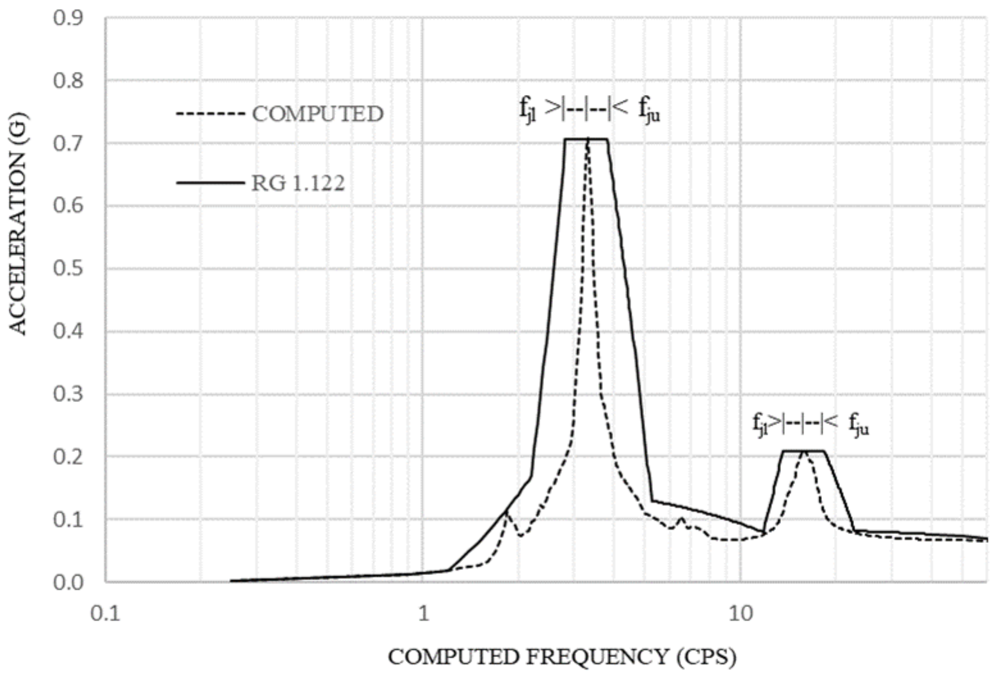

Figure 1. The Current Response Spectrum Peak Broadening and Smoothing

PROPOSED RESPONSE SPECTRUM BROADENING METHOD

The proposed method of broadening the response spectrum peak includes eliminating the sharp corners at the broadened peak by replacing the sharp corners with an unbroadened response spectrum curve, replacing the sloped straight-line on each side by shifting the unbroadened spectrum curve at each -3dB point (i.e. 0.707 of the unbroadened spectrum peak) to ±15% of the peak frequency, reducing the response spectrum peak by 15% to match realistic seismic analysis, and increasing the ZPA value on the broadened response spectrum to eliminate the need for additional time history manipulation. This peak broadening and lowering response spectrum is generated by the following steps:

The response spectrum (RS) peak broadening

The proposed method of response spectrum peak broadening and lowering is shown in Figure 2.

1. For each peak center frequency (f_j):

$$f_{jl} = 0.85*f_j \text{ and } f_{ju} = 1.15*f_j \quad (1)$$

Where f_j is peak center frequency
f_{jl} is lower broadened frequency
f_{ju} is upper broadened frequency

2. At the broadened frequency:

$$f_{jlb}=f_j-(f_{jl.707} - f_{jl}) \text{ and } f_{jub}=f_j+ (f_{ju}- f_{ju.707}) \qquad (2)$$

Where f_{jlb} is the proposed lower broadened frequency
$f_{jl.707}$ is lower frequency at 0.707 (-3dB point) of the unbroadened RS curve
f_{jub} is the proposed upper broadened frequency
$f_{ju.707}$ is upper frequency at 0.707 (-3dB point) of the unbroadened RS curve

Shifting the low frequency side of the unbroadened RS curve to f_{jlb} and shifting the high frequency side of the unbroadened RS curve to f_{jub}. The bandwidth (BW) is defined as total frequency range over spectral amplitudes that exceed 70.7% of the peak spectral amplitude:

$$BW= f_{ju.707} - f_{jl.707} \qquad (3)$$

3. The broadened response spectrum flattened peak width is f_{jub} - f_{jlb}, which is now shorter than the original flattened peak between f_{jl} and f_{ju}. Round the corners of the broadened peak with the original unbroadened RS peak curve, thus eliminating the sharp corners on both sides of the peak at f_{jl} and f_{ju}.

The response spectrum peak amplitude reduction
A 15% reduction in the narrow frequency peak amplitude is permissible if the subsystem damping is less than 10% with following conditions as shown in Table 1: Response Spectrum Peak Broadening and Lowering Criteria:

1. The narrow frequency peak is broadened with a 15% peak reduction (at 3% damping; for other damping values, see Table 1):

$$BW/CF < 0.2 \text{ and } ZPA/RS < 0.34 \qquad (4)$$

Where BW is bandwidth
CF is peak center frequency f_j
ZPA is Zero Period Acceleration
RS is Response spectrum amplitude at peak center frequency f_j

2. The narrow frequency peak is broadened with no peak amplitude reduction is required:

$$BW/CF > 0.2 \text{ and } ZPA/RS < 0.34 \qquad (5)$$

3. Use the unbroadened RS value:

$$ZPA/RS > 0.34 \qquad (6)$$

Table 1: Response Spectrum Peak Broadening and Lowering Criteria

	Damping	2%	3%	4%	5%	7%
Broadened & Reduced	BW/CF <	0.14	0.2	0.26	0.32	0.43
	ZPA/RS <	0.31	0.34	0.37	0.4	0.46
Broadened	BW/CF >	0.14	0.2	0.26	0.32	0.43
	ZPA/RS <	0.31	0.34	0.37	0.4	0.46
Unbroadened	ZPA/RS >	0.31	0.34	0.37	0.4	0.46

The response spectrum zero-period-acceleration adjustment

The ZPA should be adjusted as follows:

Select the frequency f_{zr}=26 Hz (the highest frequency of 16 Hz RS peak), calculate the broadened response spectrum area below f_{zr} ($AREA_{bd}$) and unbroadened raw response spectrum area below f_{zr} ($AREA_{un}$)

$$ZPA_{bd} = (AREA_{bd} / AREA_{un}) * ZPA_{un} \quad (7)$$

Where ZPA_{bd} is broadened RS ZPA
ZPA_{un} is unbroadened RS ZPA
$AREA_{bd}$ is broadened response spectrum area below f_{zr}
$AREA_{un}$ is unbroadened response spectrum area below f_{zr}
f_{zr} is highest frequency of response spectrum peak

Increase the ZPA of the broadened response spectrum to ZPA_{bd}

PROPOSED RESPONSE SPECTRUM RESULTS

The proposed peak broadening response spectrum curve is shown as FOR DESIGN USE in the Figure 2. The 3.3 Hz RS peak is broadened and lowered by 15%. The 16 Hz RS peak is broadened only (no lowering). The RS peaks at 1.85 Hz and 6.5 Hz use the unbroadened RS value. Based on the area ratio below 26 Hz of the COMPUTED and FOR DESIGN USE spectrum, the ZPA is raised from 0.066g to 0.077; 1.17 times greater than the unbroadened spectrum ZPA value.

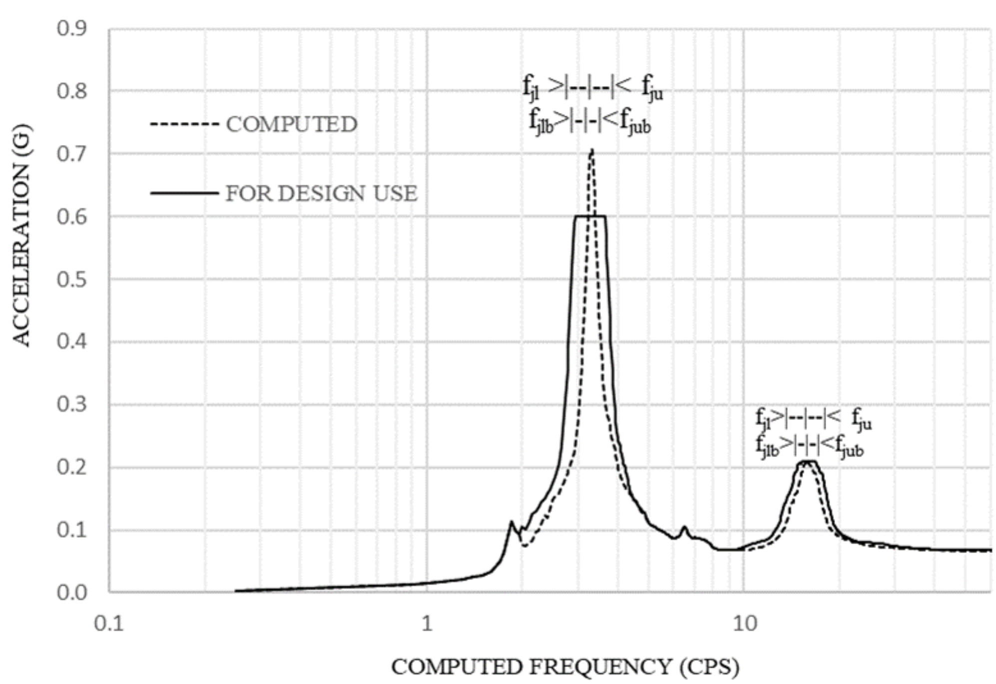

Figure 2. The Proposed Response Spectrum Peak Broadening and Lowering

TIME HISTORY GENERATION RESULTS

Two sets of time histories were generated using the COMPUTED and FOR DESIGN USE spectrum from Figure 2. The time history based on the COMPUTED spectrum is shown in Figure 3 and the time history based on the FOR DESIGN USE spectrum is shown in Figure 4.

The comparison below demonstrates the improvement of proposed method of broadening response spectra peak over the RG 1.122 spectrum. The proposed FOR DESIGN USE spectrum time history has the same intensity to the time history generated using the COMPUTED spectrum. The proposed broadened & reduced response spectrum produces a time history that has significant intensity reduction from the current broadened response spectrum.

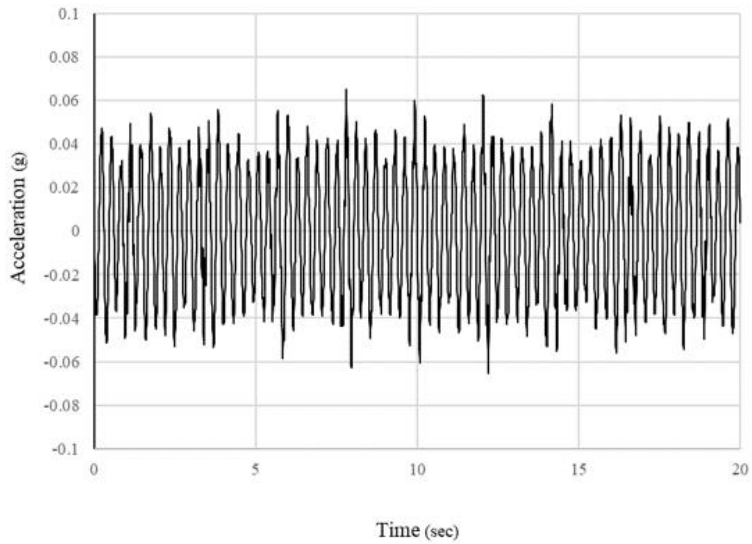

Figure 3. The Time History for the COMPUTED Response Spectrum

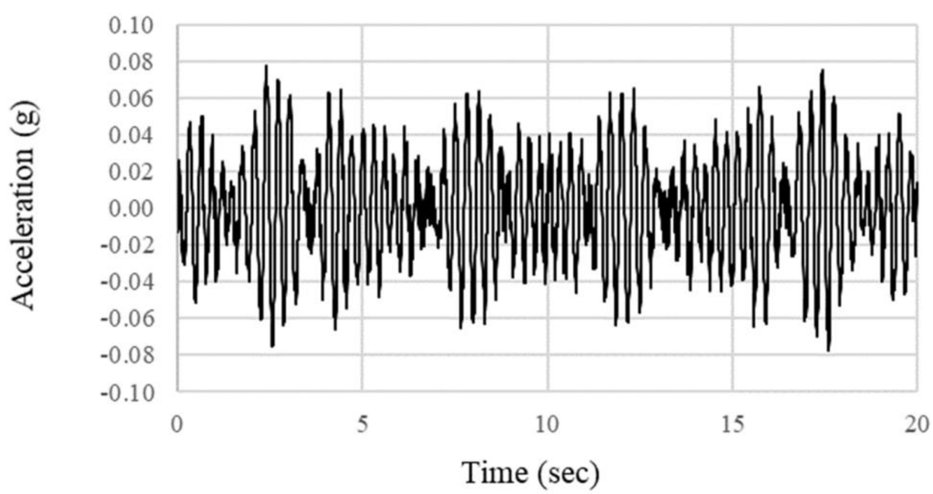

Figure 4. The Time History Generated from FOR DESIGN USE Response Spectrum

Figure 5 shows the response spectrum generated from time history in Figure 4 that enveloped the FOR DESIGN USE response spectrum.

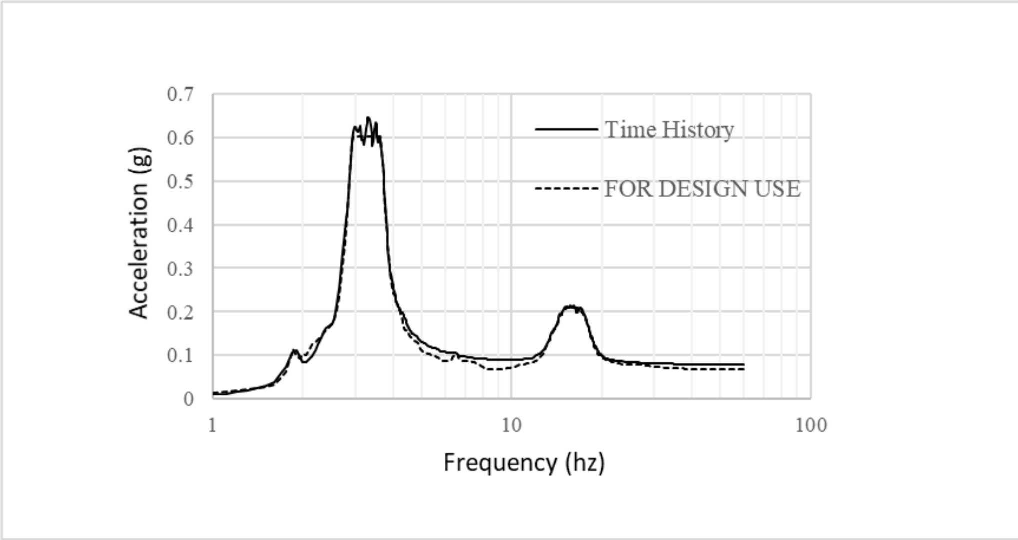

Figure 5. The Time History generated to envelope the FOR DESIGN USE RS

CONCLUSION

The methodology was validated using two sets of time history comparison. The proposed peak broadening and lowering response spectrum produces a time history that has the same intensity as the un-broadened response spectrum and will accurately represent an earthquake frequency response signal. This paper provides the method for creating a more realistic peak broadening and lowering response spectrum that benefits the seismic design certification of floor-supported equipment or components.

REFERENCES

U.S. Nuclear Regulatory Commission Regulatory Guide 1.122 (1978), *Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components, Revision 1.*

Li, D. (2019), *Method for Broadening Response Spectra Peaks*. ICONE27-1228,