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IMPACT OF POWER SPECTRAL DENSITY FUNCTION LICENSING REQUIREMENT ON REPLICATE NUCLEAR POWER PLANT SEISMIC DESIGN

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ABSTRACT

Recent revisions to USNRC regulatory seismic design criteria require consideration when replicating nuclear power plants (NPP). The impact of the revised criteria on in-structure response spectra (IRS) is investigated to determine the effects of the revisions on replication of seismic design.

INTRODUCTION

In November 1989, the USNRC issued a revision to Section 3.7 of the Standard Review Plan (SRP)[1]. Section 3.7 provides the primary licensing criteria for the seismic analysis of NPP structures. The revision requires that acceleration time histories (ATH) used in the seismic analysis of NPP structures meet a power spectral density function (PSDF) requirement in addition to meeting the USNRC RG 1.60 standard design ground response spectrum (DGRS)[2] as was previously required. Discussions on appropriate PSDF target levels leading to the SRP revision are found in References 3 and 4.

Prior to the 1989 revision, three statistically independent ATH were used for NPP seismic analysis and qualification (*Original* ATH). These *Original* ATH do not fully meet the new target PSDF as specified in Appendix A of the revised SRP. Consequently, the ATH were modified by directly increasing the ATH Fourier amplitudes at the frequencies where the target PSDF is not met (*Modified* ATH). At the same time, a new set of ATH (*New* ATH) was generated which envelops the RG 1.60 DGRS and the SRP target PSDF. The *New* ATH were selected from several different sets based on best matching the RG 1.60 DGRS requirement and meeting the SRP target PSDF.

This paper compares the dynamic characteristics of the three sets of horizontal ATH and the resultant IRS when the ATH are used in a seismic analysis. Comparison of the IRS provides a means of evaluating the impact the new SRP requirement has on seismic replication.

ACCELERATION TIME HISTORIES

All of the ATH have a 24 second duration and a 0.005 second time step. The ATH represent a nominal 0.20 g SSE earthquake. Figure 1 shows the ATH waveforms. The *Original* ATH have been developed by synthesizing earthquake records and modifying them to meet the RG 1.60 DGRS criteria. The *New* ATH are artificially generated and have a 3 second rise time, 9 seconds of strong motion and a 12 second decay time. Figure 2 shows the cumulative energy curves for the ATH. The cumulative energy curves provide a general indication of the ATH strong motion duration and wave form stationarity.

POWER SPECTRAL DENSITY FUNCTIONS

Meeting the SRP target PSDF demonstrates the ATH have sufficient energy for the frequencies of interest[1]. Comparisons of the ATH PSDF with the SRP target PSDF are shown in Figure 3. The *Original* ATH does not meet the target PSDF at 1 hz, 2 hz and the 16 to 23 hz region in the H1 direction, and the 5 to 20 hz region in the H2 direction. The PSDF of the *Modified* ATH closely match the target PSDF at the frequencies not met by the *Original* ATH PSDF. The PSDF for the *New* ATH are significantly higher than the target PSDF.

DESIGN GROUND RESPONSE SPECTRA

Figure 4 shows the comparisons of the ATH response spectra compared with the RG 1.60 DGRS for 2% damping. The *Original* ATH response spectra conservatively envelop the DGRS in the H1 direction and closely match the DGRS in the H2 direction. It is seen that the *Modified* ATH generally have the highest spectra, especially in the H2 direction. The *New* ATH response spectra closely match the DGRS for both directions at frequencies higher than 4 hz.

STRUCTURE SEISMIC ANALYSIS

The ATH are used as simultaneous input to a containment building seismic analysis. IRS are obtained for the H1 and H2 directions at the top of the interior structure for 2% equipment damping. The interior structure seismic model has a single fundamental cantilever mode for the H1 and H2 directions at frequencies of 12.53 hz and 15.03 hz, respectively. It is noted that the *Original* ATH envelops the SRP target PSDF at 12.53 hz for the H1 direction but does not envelop the target PSDF at 15.03 hz for the H2 direction. The *Modified* ATH closely meet and *New* ATH significantly exceed the target PSDF at the respective structure frequencies.

IN-STRUCTURE RESPONSE SPECTRA

Unbroadened IRS developed for 2% damping are shown in Figure 5. Spectral responses are calculated at frequency sampling intervals recommended by SRP Table 3.7.1-1[1] and at structural frequencies. It is generally expected the IRS peak spectral responses would occur at the structure natural frequencies; 12.53 hz for the H1 direction and 15.03 hz for the H2 direction. However, this does not occur herein.

In the H1 direction the *Original* ATH result in three peaks at 11.5, 12.5 and 14.5 hz, with the 12.5 hz structure frequency peak being the lowest. The *Modified* ATH has the same amplitude spectral peaks at 11.5 and 12.5 hz as the *Original* ATH but has a greatly increased peak at the 14.5 hz non-structure frequency which dominates the response. Reference 5 indicates that such frequency response shifting from structure frequencies may be characteristic of low ATH energy at the structure frequency. However, it is noted that both the *Original* and *Modified* ATH meet the SRP target PSDF at 12.5 hz. The 14.5 hz peaks of the *Original* and *Modified* ATH IRS are at a sampling frequency and not at the structure frequency. The *New* ATH has similar IRS peaks at 12.0 hz and 12.5 hz although it significantly envelops the target PSDF for both frequencies.

In the H2 direction all the ATH have the IRS spectral peak at 16 hz instead of the 15.03 hz structure frequency. In this case, the *Original* ATH which does not envelop the SRP target PSDF at the structure frequency or the 5 to 20 hz region has a greater IRS response than the *New* ATH. The *Modified* ATH results in significantly greater IRS amplitudes over this region showing the importance of Fourier amplitude changes. The *New* ATH which has a significantly higher PSDF than the *Original* or *Modified* ATH has the lowest IRS with the exception of a minor peak at the 13.0 hz sampling frequency.

DESIGN IRS

The IRS shown in Figure 5 are frequency broadened at spectral peaks by ±15% and are shown in Figure 6. The broadened spectra are applicable for subsystem seismic design. It is seen that the *Modified* ATH design spectra for both directions are heavily influenced by non-structural frequency spectral peaks. Since the *Modified* and *New* ATH design IRS are not completely enveloped by the *Original* ATH design IRS, seismic qualification by direct replication cannot be done.

DISCUSSION

There does not seem to be a direct correlation of IRS amplitude with the SRP PSDF requirement for the specific sets of ATH investigated herein. Clearly the *Modified* ATH shows that increasing ATH Fourier amplitudes significantly increase responses. However, the *New* ATH which are selected from many ATH to best match the DGRS generally result in lower responses even though they have a significantly higher PSDF. In the H2 direction, the *New* ATH has a lower IRS response than the *Original* ATH which does not envelop the target PSDF at the structural frequency of 15.03 hz.

Other factors not investigated herein such as the Fourier amplitude spectra (FAS), phasing and strong motion duration may be more significant in affecting seismic response than may be indicated by a PSDF. The FAS is the true frequency characterization of the ATH which couples directly with the dynamic characteristics of the seismic model in the seismic analysis. The FAS does not have any subjectivity such as strong motion time duration, stationarity and frequency averaging windows used in PSDF development. From the investigation herein it is not clear whether the non-structure frequency peaks in the IRS of the *Original* and *Modified* ATH are due to a deficiency of energy at the structure frequency or excess energy at sampling frequencies. The *New* H2 ATH demonstrates that an ATH can exceed the target PSDF requirement and result in low IRS responses. The *Original* H2 ATH demonstrates that an ATH can be below the SRP target PSDF and still provide conservative results. A different *New* H1 ATH may be found that produces a result similar to the *New* H2 ATH with respect to generating a lower IRS. The effect of the SRP PSDF averaging frequency window (±20%) may obscure actual energy distribution at specific frequencies and is not evaluated in this study.

CONCLUSIONS

- The results of this study show that the USNRC ATH PSDF licensing requirement can affect NPP seismic design replication.

- The differences in the design IRS due to the different ATH cannot be directly correlated with enveloping the SRP target PSDF and are more closely correlated with the DGRS.

- It is not determined herein whether the differences in the IRS are due more to an initial deficiency of energy in the *Original* ATH or due to excess energy in the *New* and *Modified* ATH for the relatively high structure frequencies considered in this study.

- Factors such as Fourier amplitudes, phasing, strong motion duration or PSDF development methods may be more important than SRP PSDF levels at structural frequencies in determining seismic responses.

REFERENCES

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2. USNRC (1973). "Design Response Spectra for Seismic Design of Nuclear Power Plants," Regulatory Guide 1.60, Revision 1.

3. USNRC (1988). Recommendations for Resolution of Public Comments on USI A-40, "Seismic Design Criteria," Report No. NUREG/CR-5347.

4. USNRC (1988). Power Spectral Density Functions Compatible with USNRC Regulatory Guide 1.60 Response Spectra, Report No. NUREG/CR-3509.

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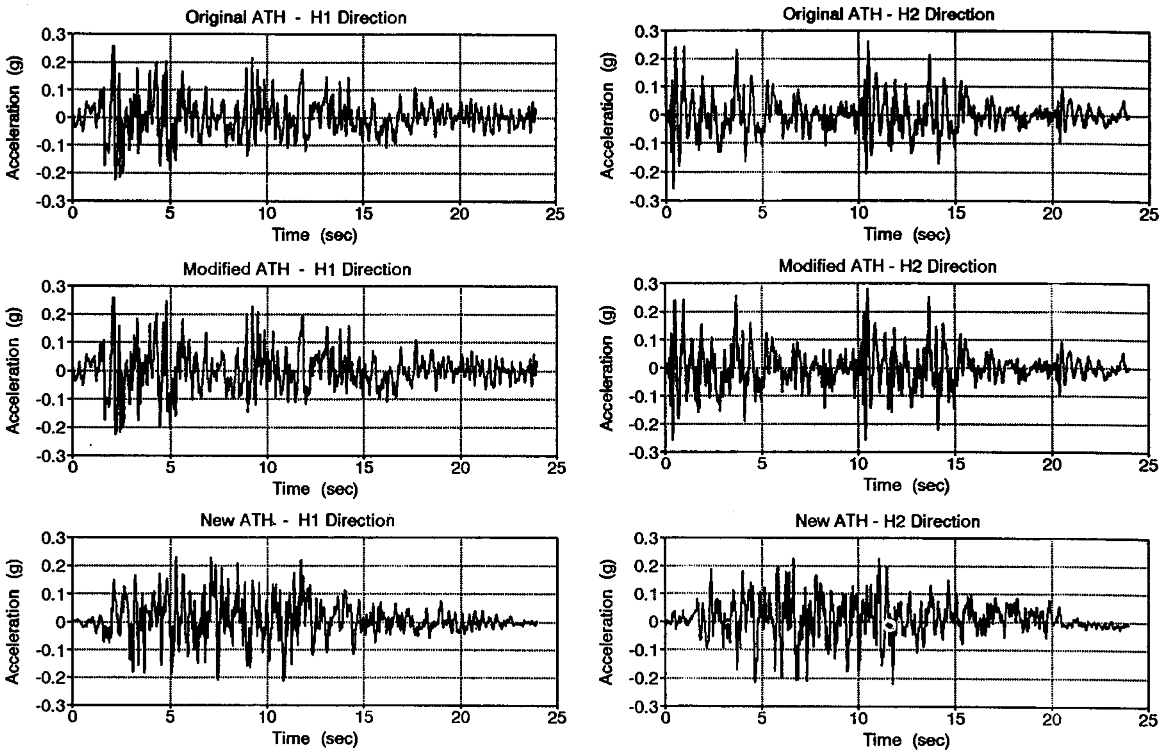

Figure 1. Acceleration Time History Waveforms

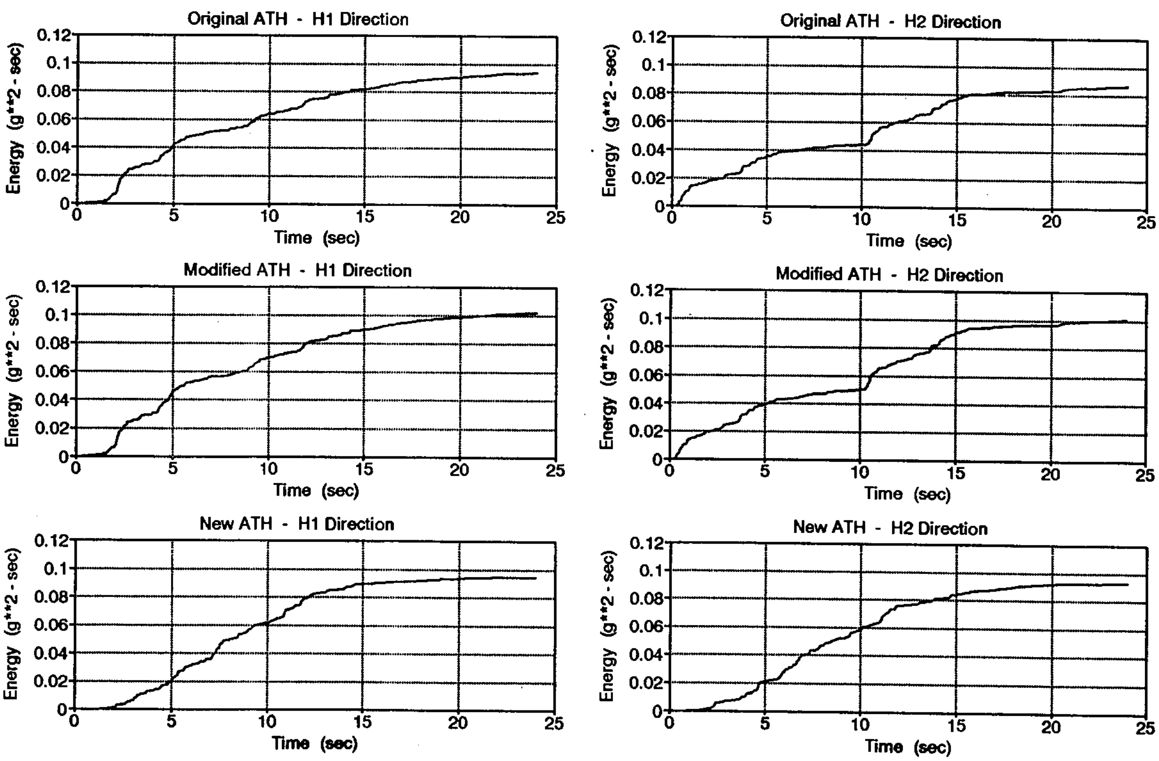

Figure 2. Acceleration Time History Cumulative Energy Curves

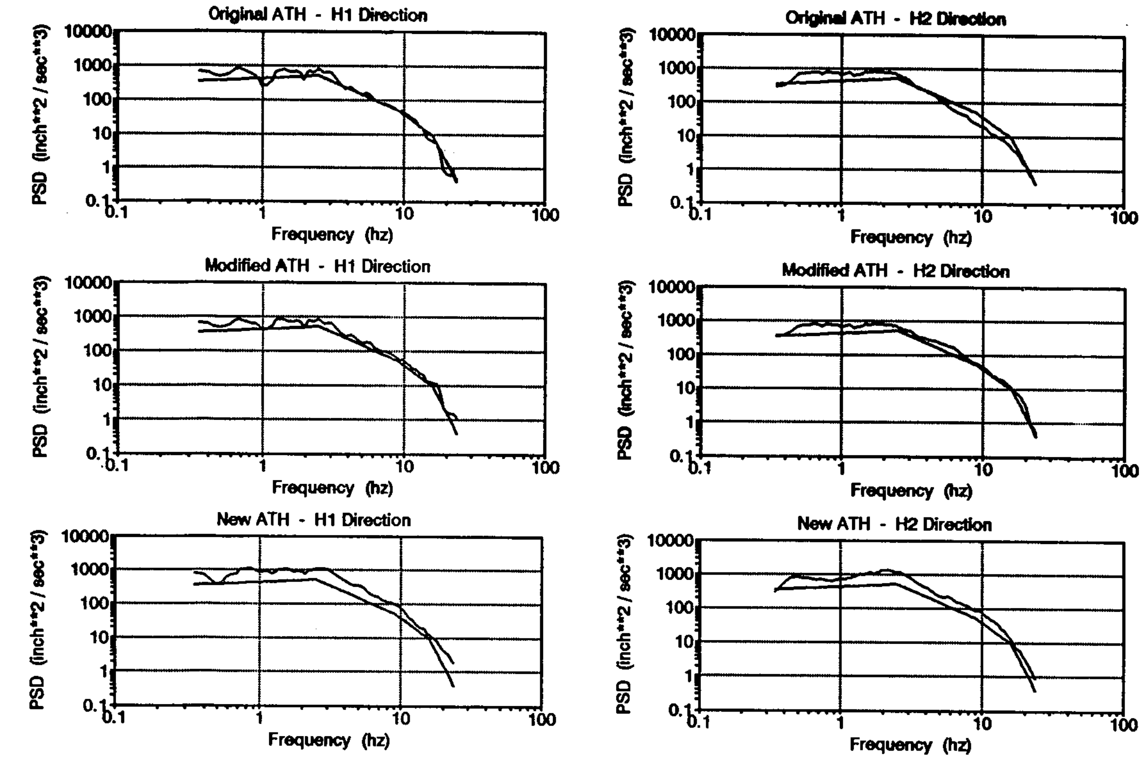

Figure 3. SRP Power Spectral Density Function Comparisions

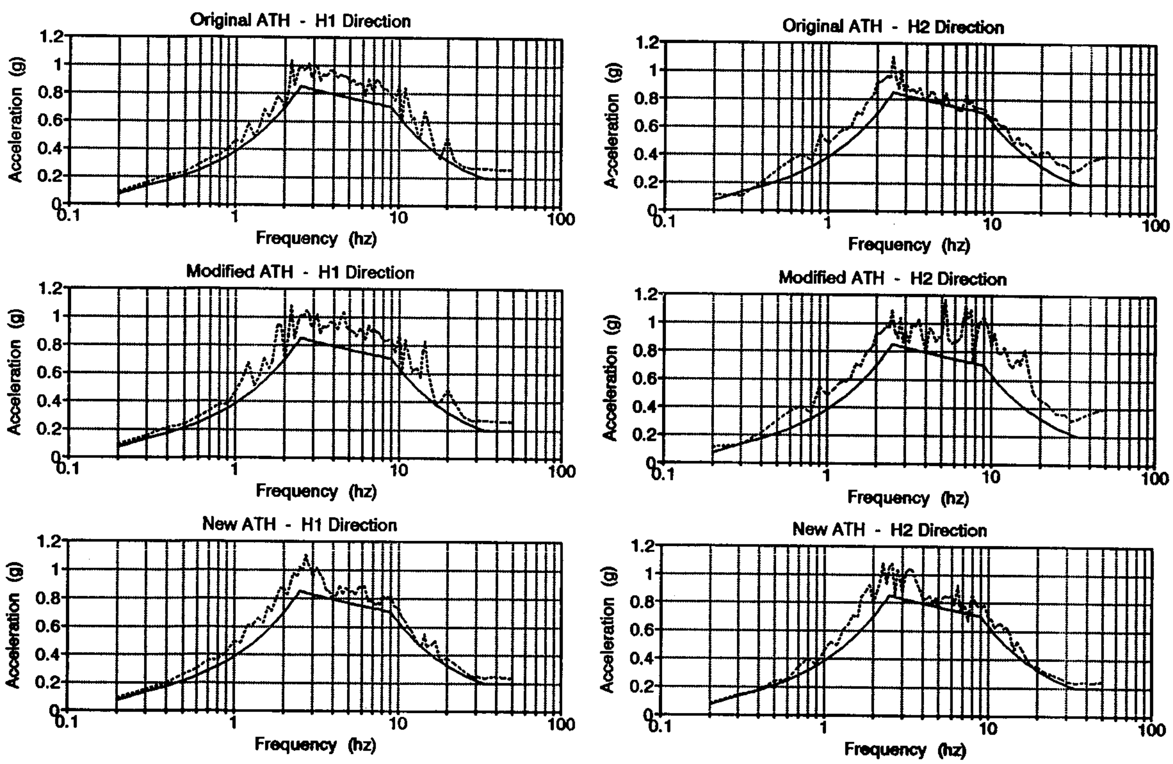

Figure 4. RG 1.60 Design Ground Response Spectra Comparisions

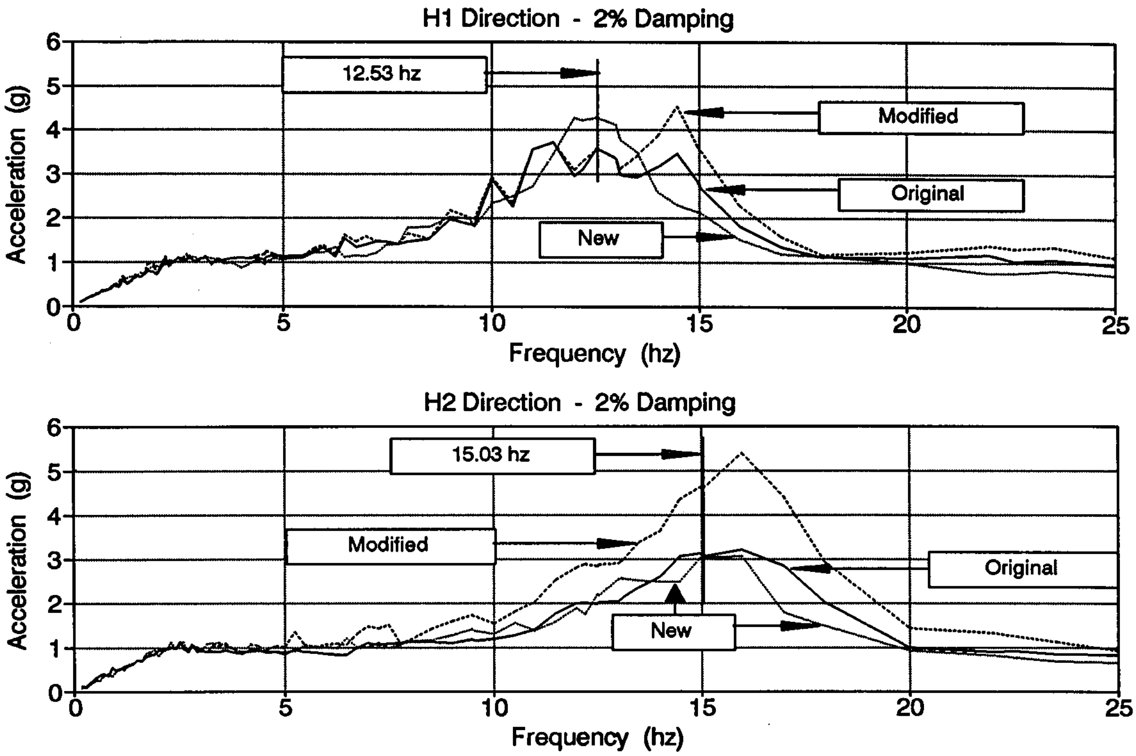

Figure 5. In-Structure Response Spectra Comparisions

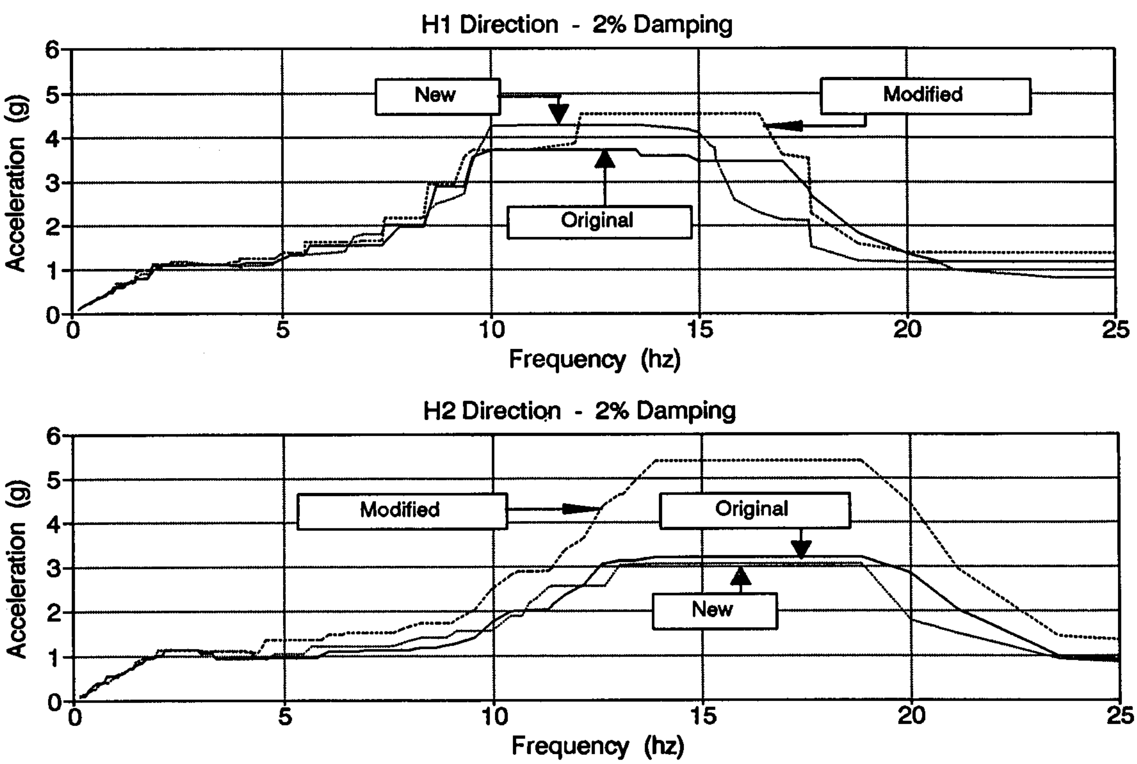

Figure 6. Broadened Design In-Structure Response Spectra Comparisions