BROADENING/SMOOTHING OF FLOOR RESPONSE SPECTRA – HOW TO DEAL WITH "NEEDLE PEAKS"

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ABSTRACT

Linear analyses of nuclear facilities often result in floor response spectra or tertiary (component) spectra that exhibit sharp "Needle Peaks" which according to the current practice (e.g. USNRC Reg. Guide 1.122) need to be broadened and smoothed to derive floor design response spectra in order to achieve a robust design of the relevant components. The strict obedience of the customary rules thus results in design spectra that are very conservative over relatively narrow frequency bands.

The paper investigates potential reasons that lead to such needle peaks and presents corresponding literature and analytical/numerical results of sensitivity analyses addressing the following aspects:

- Deterministic/probabilistic analysis
- Effects of coupled/decoupled analysis
- Nonclassical damping
- Nonlinear effects

The results are discussed and an alternative method for the smoothing/broadening process of "needle peaks" will be presented that allows for a certain amount of clipping of unrealistic spectral peaks.

INTRODUCTION

In Germany, the KTA-rules for the design of nuclear power plants against seismic events are in the process of being revised [1], [2]. For the section "Floor and Component Design Response Spectra" recent findings and publications were analyzed [4 – 10], based on the present state of the art such as is stipulated in [3]. On the basis of the results of such analysis a modified procedure for the revised rules [1] [2] was elaborated.

CURRENT PRACTICE

Since 1978 it has been suggested in [3] that computed floor response spectra be smoothed and peaks associated with each of the structural frequencies be broadened. This accounts for uncertainties in the structural frequencies owing to uncertainties in the material properties of structure and soil and to approximations in the modeling techniques used in seismic analysis. Figure 1 shows a sample of a smoothed floor response spectrum curve from [3], where the peaks are broadened by ± 15 % in the frequency domain when median soil conditions are used.

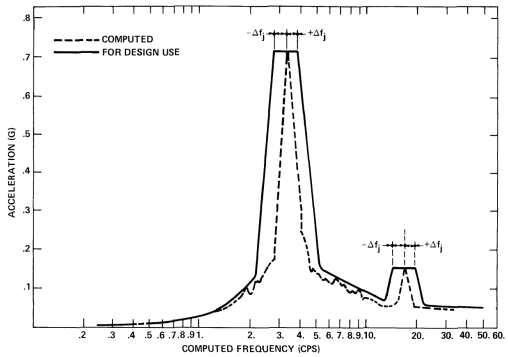


Fig.1: Response spectrum peak broadening and smoothing

Since then research in in-structure response spectra brought deeper understanding of parameters and sensitiveness of spectra peaks. In the following, four parameters will be considered in more detail.

EXAMINED PARAMETERS

Deterministic versus probabilistic Analysis

In [5] studies were performed which compare equal-probability-of exceedance in-structure spectra with deterministic in-structure spectra. The studies show that for 2 % damping the deterministic spectrum peaks may be more than a factor of two greater than the equal-probability-of exceedance spectrum peaks. [5] states that in lieu of performing a probabilistic evaluation, a 15 % reduction is reasonable and conservative.

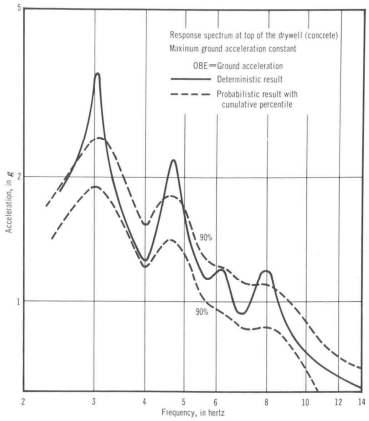


Fig. 2: Deterministic versus probabilistic results

Today, this rule is used in practice. But as the 15 % reduction is applicable for in-structure floor response spectra with low damping levels only, it is necessary that the analyst should confirm that the 15 % margin to the 90 % non-exceedance probability is still maintained. This condition makes the application of the rule laborious.

Coupled / decoupled Analysis

Seismic analysis of coupled primary-secondary systems gives responses that are more accurate than those of the decoupled analysis [7]. A coupled analysis accounts for the mass interaction between uncoupled systems. If the system is tuned, i.e. $f_{primary} \approx f_{secondary}$ the secondary mass works as tuned absorber. In [8, 9, 10] for many m_s/m_p-relations the differences between decoupled and coupled primary-secondary systems are shown. The decoupled analysis results in higher (conservative) values for the secondary system, as is shown in Fig. 3.

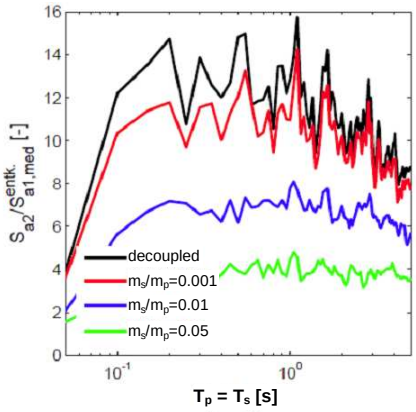
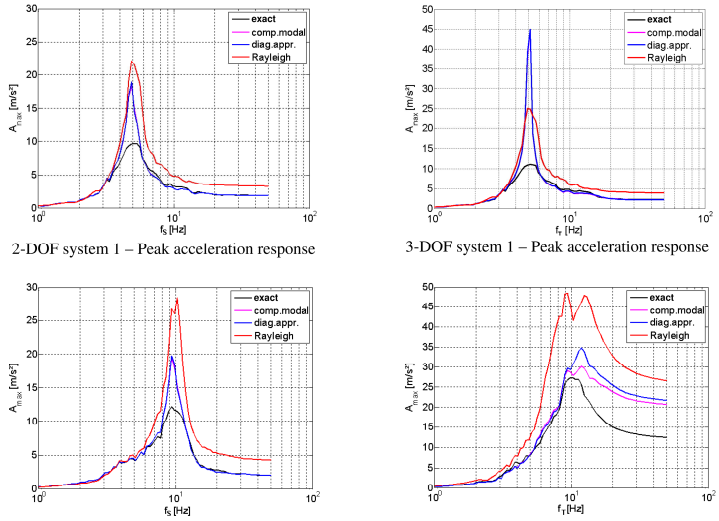


Fig.3: Scaled floor spectra S_{as} / $S_{ap}^{decoupled}$ for ζ_p = 5 % ζ_s = 0.5 %

By means of a decoupled analysis, the vibration response of the secondary structure with $T_p = T_s$ is overestimated by up to 10 % for $m_s/m_p = 0.001$ for a damping of the primary structure of 5 % and a damping of the secondary structure of 0.5 %.

Nonclassical Damping

If the primary and the secondary system have different damping characteristics then the coupled system is nonclassically damped. In conventional seismic analysis, the nonclassical nature of the coupled damping matrix is not considered (off-diagonal terms in the transformed damping matrix are ignored). Ignoring the nonclassical nature of the damping matrix can lead to incorrect results when the uncoupled primary and secondary systems are tuned or nearly tuned. In [7] a 2 DOF-system and a 9 DOF-system with nearly tuned eigenfrequencies are investigated. The ratio of the forces of classical to nonclassical damping cases is between 1.4 and 2.5; classical damping leads to higher results. A similar investigation [6] shows equivalent factors for response spectra.



2-DOF system 1 – Peak acceleration response

3-DOF system 1 – Peak acceleration response

2-DOF system 2 – Peak acceleration response

3-DOF system 2 – Peak acceleration response

Fig.4: Comparison of nonclassical to classical damping on subsystem floor response spectra

Nonlinear Effects

With low nonlinearity – which in reality always exists – the resonance peak bends, as is shown in [4] for a nonlinear stiffness with progressive spring characteristic.

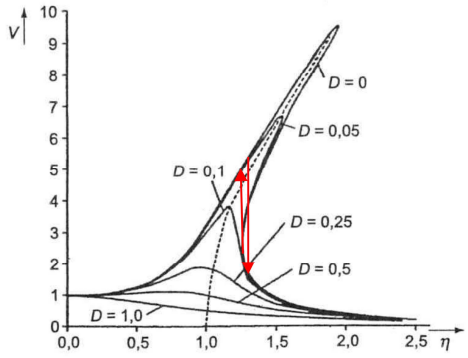


Fig.5: Magnification factor of a harmonically excited 1-DOF oscillator in the case of a progressive spring characteristic

In the resonance case the curves remain finite, even with vanishing damping. Owing to the bending of the skeleton line there are frequency ranges $\eta = f_{excitation} / f_{eigen}$ in which the result is ambiguous i. e. there may be different amplitudes, so that the result is no longer clear. If there is a passage through such a frequency range during

a test, there may appear, and this is typical of nonlinear systems, a jump in the amplitudes. The peak, especially the one determined by an appreciative linear analysis, cannot be held.

KTA 2201

Based on these factors a new design rule for KTA 2201 was developed:

- Needle peaks may be cut where the width of their basis is not greater than 10 % (in-structure response spectrum) / 15 % (component response spectrum) of their center frequency

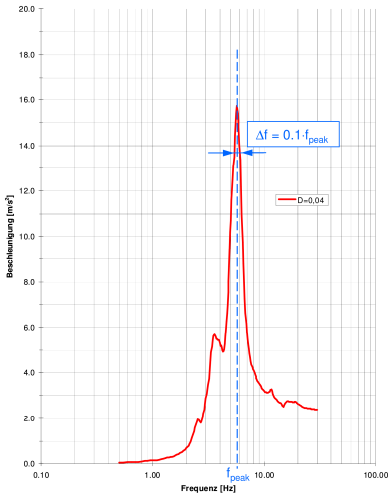


Fig.6: Reduction of the “needle peaks” to a level with $\Delta f = 0.1\ f_{peak}$

The advantage of such rule consists in the fact that it does not apply

- with high damping, since no “needle peaks” occur
- if after the averaging of different time-histories the peaks are already reduced and broadened.

The difference between the clipping of 10 % for in-structure response spectra and 15 % for component response spectra consists in the low damping of the components resulting in much higher needles occurring.

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