Generation of In-Cabinet Response Spectra for Control Room Panels

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INTRODUCTION

It is well established that even relatively rigid control panels can significantly amplify seismic input motions. It is important to evaluate the effects of these amplifications when assessing the seismic adequacy of sub-components such as relays. The methods used to account for these amplifications in many of the recently licensed nuclear power plants in the United States have generally been very conservative. These conservatisms have resulted in unrealistically high predictions of control panel response. In addition, most of the original analyses only provided peak acceleration values as a measure of the in-cabinet seismic response. However, equipment qualification efforts generally require a full definition of the seismic response spectra.

A study was undertaken to more realistically establish in-cabinet seismic response at a U.S. nuclear power plant and to generate in-cabinet response spectra. Analytical models of typical control panels were developed. The validity of the models was confirmed with natural frequencies obtained from testing. In-cabinet seismic response spectra were developed using narrow band-direct generation techniques based on random vibration theory.

The predicted cabinet responses based on this method were substantially lower than those available to the utility for performing evaluations of panel subcomponents. Larger spectral amplification was observed at high frequencies then was expected by the project team. However, these results were considered reasonable based on the results of the sensitivity studies and on comparisons to shake table tests performed on similar panels.

This paper describes the methods of analysis used to establish more realistic estimates of in-cabinet response and the results of these analyses.

ORIGINAL DETERMINATION OF CONTROL PANEL RESPONSE

The original determination of control panel response was based on transmissibility data derived from low level single frequency shake table testing of sample control panels. Peak in-cabinet accelerations were taken to be equal the product of maximum transmissibility values (regardless of frequency) and the zero period acceleration (ZPA) of the floor response spectra.

This process resulted in considerable conservatism. Amplifications over floor ZPA used in sub-component qualifications were as high as 18. The major factors which lead to these conservatisms are as follows:

- Amplification factors did not consider the rigidity of the control panels. The amplification factors were taken to be equal to the maximum transmissibility values regardless of the panel's natural frequencies. This practice introduced considerable conservatism since the fundamental frequency of all the panels approaches the rigid range of the input spectra.

- Amplification factors were based on transmissibility data which represents amplifications from a single frequency input motion. This approach provides an upper bound estimate of panel amplifications for seismic motions.

- Panel transmissibilities were based on low level input. As a result, the original amplification factors were based on lower bound damping values.

Another limitation of the original control panel response evaluations is that they did not include the generation of in-cabinet response spectra required to directly qualify most panel sub-components.

EIGENVALUE ANALYSIS OF CONTROL PANELS

The control panels which were evaluated were typically 36 inches deep and are 90 inches high. The panels are constructed of 3/16 inch carbon steel plates with angle brackets attached to the top and bottom. Cold formed steel channels and 1/4 x 4 inch steel plates are used to stiffen the panels in the vicinity of major equipment. In some cases the channels are used as instrument mounting structures.

Detailed models of two of the control panels were developed. The panels selected for modeling represent worst cases based on transmissibility data and overall configuration. These models are illustrated in Figure 1. All relevent control panel structural attributes such as panel plate material, stiffener members, and equipment were directly included in the models. Natural frequencies and mode shapes were compared to test data to confirm the validity of the models. These data are summarized in Table 1.

In addition to the detailed models of the panels, two two-degree-of-freedom models were created as shown in Figure 2. In the first model, each of the spring-mass combinations shown in the figure had a natural frequency of 12 Hz. In the second model, each of the spring-mass combinations had a natural frequency of 19.8 Hz. The purpose of the two-degree-of-freedom models was to bound potential worst case configurations in which the panel framing and the front plate have closely spaced natural frequencies. The two-degree-of-freedom models where used only in the generation of spectra in the front-to-back direction of the panel.

DIRECT GENERATION OF IN-CABINET RESPONSE SPECTRA

In-cabinet seismic response spectra were developed using narrow band-direct generation techniques based on random vibration theory using the computer program FLORA [1]. The input response spectra in the horizontal and vertical directions used in these analyses are shown in Figure 3. As part of the analysis process performed by FLORA, the input motion was described in the form of a power spectral density function (PSDF). Structural response was determined by factoring the input PSDF by the system transfer function generated from the model parameters determined in the eigenvalue analysis. In-cabinet response spectra were then generated by FLORA from the output PSDF.

Response spectra were generated for several panel locations and for the two-degree-of-freedom models. Figure 4 shows the resulting enveloped spectra and the smoothed and broadened spectra used in sub-component evaluations. The resulting spectra had larger peaks at the high frequency end of the spectra then expected. To verify the reasonableness of the spectral peaks at 11 and 28 Hz, sensitivity studies were performed using time history analysis of a single-degree-of-freedom oscillator.

These sensitivity studies were also used to optimize the selection of the central frequency and band-width of the input PSDF.

The resulting in-cabinet spectra were amplified by approximately a factor of 4 to 5.5 above the floor response spectra in the frequency range of 10 to 20 Hz. This level of amplification correlates well with shake table testing of electrical panels reported in (2) and (3) which provides further verification of the reasonableness of the results.

CONCLUSIONS

The methods used to account for cabinet amplification of seismic response have typically been very conservative on many recently licensed nuclear power plants in the U.S.A. More realistic response levels can readily be established using the methods described in this paper.

REFERENCES

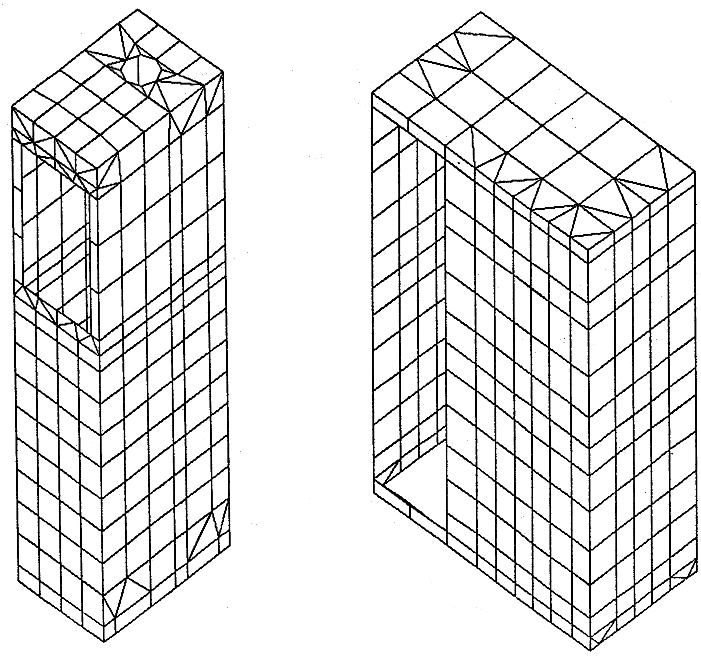
[1] Impell Proprietary Program "FLORA", Version 5, User Manual Rev. 0, 4/1/87.

[2] EPRI NP-5223, "Generic Seismic Ruggedness of Nuclear Plant Equipment", ANCO Engineers Inc., Culver City, California, May 1987.

[3] Merz, K.L., Ibanew, P., "Guidelines for Estimation of Cabinet Dynamic Amplification Factors", Orlando, Florida, December 1988.

Mode No.	Panel No. 1		Panel No. 2	
	Direction	Frequency	Direction	Frequency
1	Side/Side	10.84	Front/Back	14.91
2	Front/Back	27.48	Side/Side	17.67
3	Front/Back	34.32	Front/Back	18.85
4	Front/Back	36.10	Side/Side	21.95
5	Side/Side	38.48	Front/Back	27.51
6	Side/Side	45.60	Side/Side	29.64

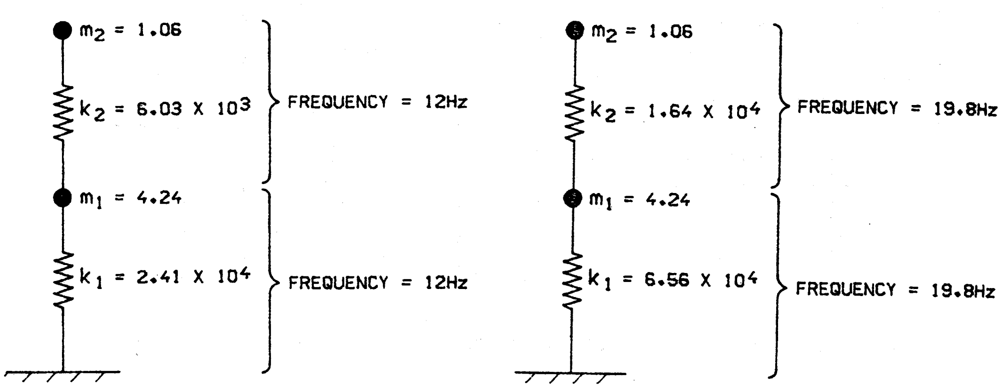
Table 1: Natural Frequency and Mode Shape Data for Panels 1 and 2



Panel 1

Panel 2

Figure 1. Control Panel Models



12Hz MODEL

19.8Hz MODEL

Figure 2: Two-degree of Freedom Models

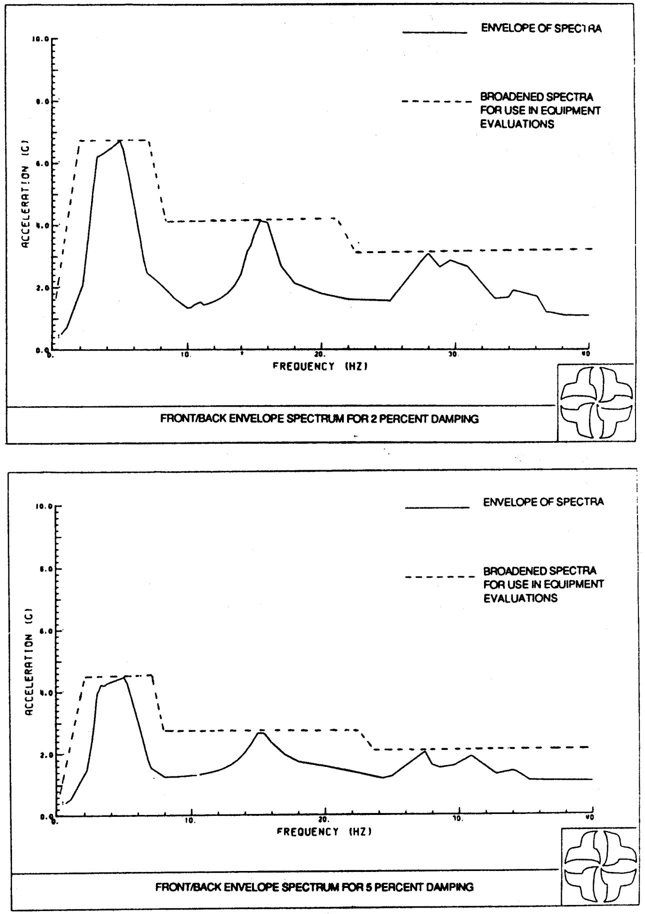


Figure 4a: Enveloped and Broadened Spectra for Front/Back Direction

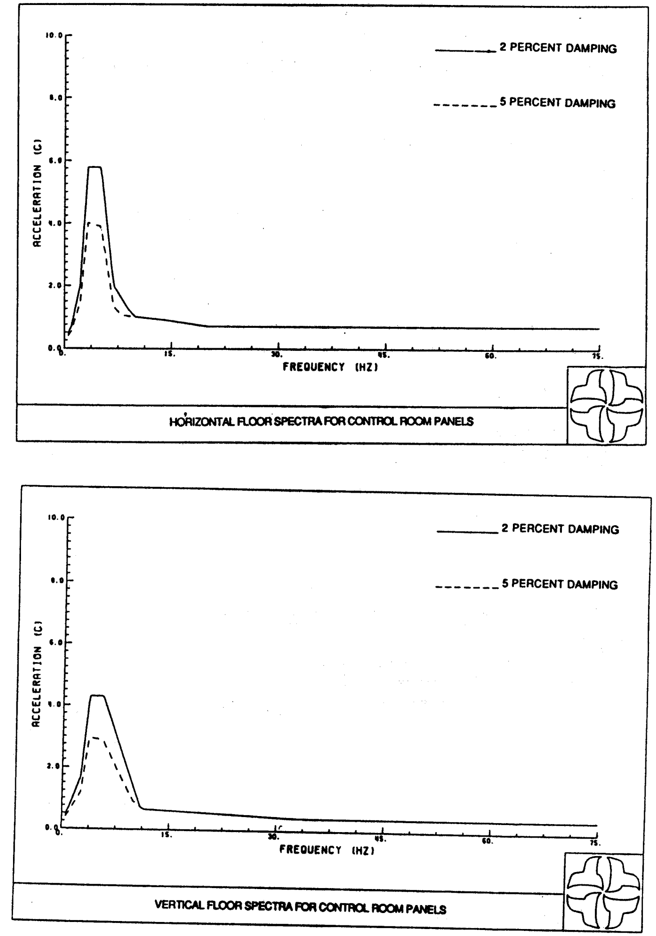


Figure 3: Vertical and Horizontal Floor Spectra

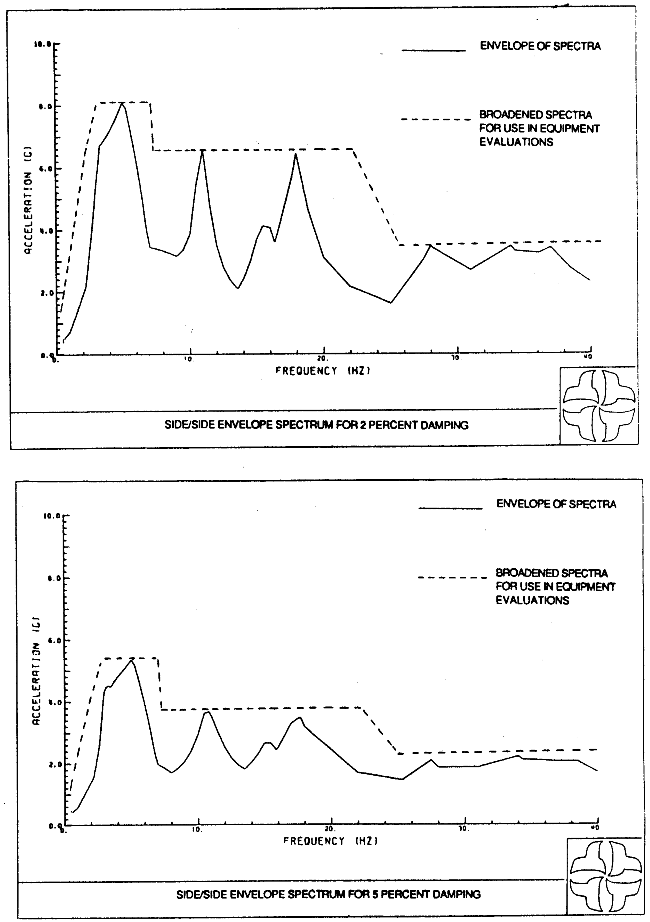


Figure 4c: Enveloped and Broadened Spectra for Side/Side Direction

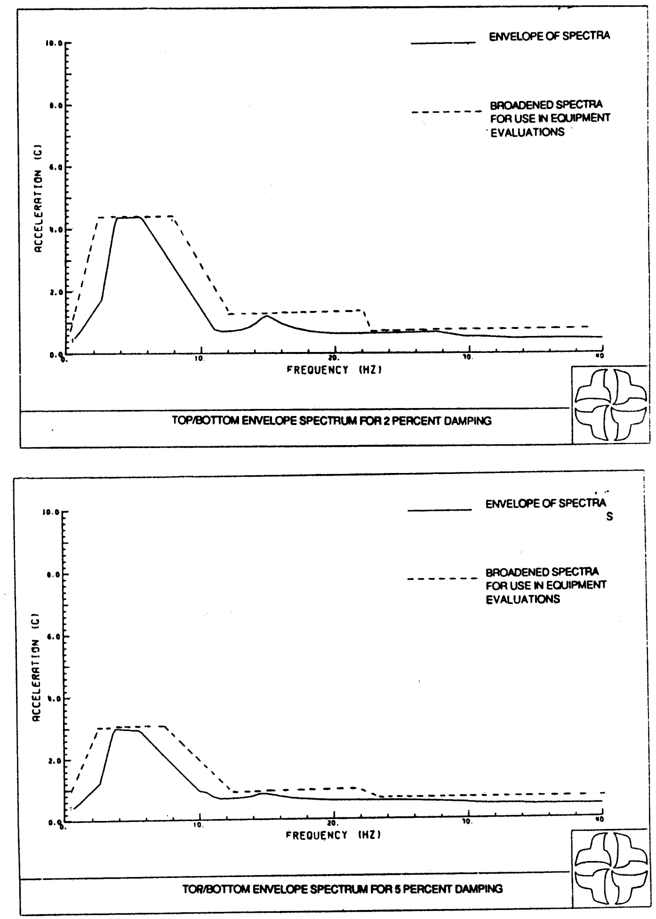


Figure 4b: Enveloped and Broadened Spectra for Top/Bottom Direction