Seismic Demand Evaluation Using Recorded Data in Power Plant Structures

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INTRODUCTION

In seismic design and evaluation of critical equipment located in nuclear power plant (NPP) structures, the seismic input, or demand, is taken as the response of the NPP structure at the floor supporting the equipment, typically represented by in-structure or floor response spectra (FRS). These are usually obtained by computer analysis of mathematical models of the structure with the design ground motion used as input. Though more recent analytical procedures go a long way towards giving more realistic results, the FRS for early vintage plants are typically very conservatively computed, or in some cases not computed at all.

A large number of NPPs have been built in various regions of the world, including some seismically active ones, in the last two decades. Recorded earthquake data from one or more earthquakes have been obtained at several of the seismically instrumented plants located in seismically active areas. Typically, structures in such plants have strong motion instruments located at various elevations including typical floor levels, basement and sometimes in the adjacent freefield. This data can be used to determine more realistic amplification of the seismic motion that the structure experiences. Such amplification may then be used as a guide to limit computed FRS, or to estimate FRS given the ground level design spectrum. FRS determined this way may be termed as "experience-based seismic demand" for equipment qualification.

SUMMARY OF DATA AND PROCESSING

Under a project sponsored by Electric Power Research Institute (EPRI) to determine seismic demand based on experience, a large amount of recorded earthquake data and other information from thirteen nuclear power plants (NPP) around the world has been collected. Most of the data were obtained by EPRI directly from the utilities owning the plants. Some data were obtained from public sources such as papers presented in various professional journals or conference proceedings. A summary of the data obtained and used in the study is shown in Table 1.

The earthquake data, in general, consists of hardcopy plots of acceleration time histories and acceleration response spectra (5% damping). For two plants, the owners provided digitized acceleration time-histories from which the 5% damped acceleration response spectra were computed. Data provided also include sections and plans of the plants showing the location of the recording instruments. Records were obtained from a total of 28 separate structures and 30 different earthquakes, adding up to almost a thousand spectra. Data from adjacent freefield locations were available for only three plants. Peak ground acceleration (PGA) levels varied between .01g and 0.14g. Magnitudes of earthquakes ranged from 4.2 to 7.4. Most of the structures were embedded with embedment ranging from 30 to 100 ft.

Peak acceleration values and peak spectrum values were determined from the available data. While most peak acceleration values were obtained from acceleration time history plots, for a few cases they were read off from the response spectrum plots as the so called zero period acceleration or ZPA. Peak spectrum value, was obtained as the maximum spectral acceleration on a 5% damped acceleration response spectrum curve irrespective of the period or frequency at which the peak occurs. These values are termed spectral peak accelerations, or SPAs.

A section through a typical BWR MKII Reactor Building is shown in Figure 1. The freefield, basemat and typical floor locations were indicated. Various amplification factors may be defined in terms of ZPAs and SPAs at freefield, basemat or typical floor which could provide the ZPA or the SPA at a typical floor in terms of the ZPA at the freefield surface or the basemat (Jhaveri et al, 1988). Of particular interest here are two ratios as follows:

Building Amplification Factor including embedment effects, BAFe =

$$\frac{\text{ZPA at typical floor}}{\text{ZPA at freefield}} \qquad (1)$$

Total Amplification Factor including embedment effects, TAFe =

$$\frac{\text{SPA at typical floor}}{\text{ZPA at freefield}} \qquad (2)$$

Note that BAFe and TAFe values will be a function of floor location, in other words different floors will have their own BAFe and TAFe values for a given building and earthquake. Similar frequency dependent amplification factors may be defined for the spectra values over the entire frequency range. In particular, BAFe(f) =

$$\frac{\text{Sa(f) at typical floor}}{\text{Sa(f) at freefield}} \qquad (3)$$

DISCUSSION OF RESULTS

Various amplification factors, including those defined above, have been studied to examine the influence on earthquake response of a number of important parameters, such as building type, location in building (height above basemat), site soil properties, earthquake characteristics, peak ground acceleration in the freefield or the basemat, etc. Some of the results obtained thus far (Jhaveri et al, 1988) indicate, with a very few exceptions, much lower amplifications than obtained from typical analytical procedures. Furthermore, the collected data is for low PGA levels compared to typical design PGA levels. Because damping in both soil and structure is strain or stress level dependent, it is felt that the amplification values obtained for collected data are conservative, and that amplification factors at design level earthquakes may be even lower.

In this paper, the results obtained for the operating deck level of BWR MK II Reactor Building (RB) are examined in detail. The operating deck level forms the top of the concrete portion of a BWR MK II RB, above which a steel braced frame structure supporting the roof is located. In the database there are three BWR MK II RBs where records are available at the operating deck level as well as at adjacent freefield surface. The RBs at all three plants are very similar in construction and embedment (55 to 60 feet) and are founded on soil with shear wave velocity in the range of 1600 to 1800 feet per second. The freefield surface instruments are located approximately 400 to 500 feet from the nearest substantial plant structure.

There are 48 sets of BAFe, TAFe, and BAFe(f) ratios available for the horizontal components of recorded data for the operating deck level from the three BWR MK II RBs, each with two components and several earthquakes. The histograms for the BAFe and TAFe ratios are given in Figure 2. The mean and mean+1σ values are 1.0 and 1.3 for BAFe, respectively, and 3.8 and 5.6, respectively for TAFe. These values imply that at the operating deck level, on the average, the ZPA is no greater than the PGA value at the freefield surface and the peak spectral acceleration (SPA) in a 5% damped FRS is no greater than four times the freefield PGA value. These values are clearly much lower than these obtained from typical analysis procedure, especially those using lumped mass stick models or those not accounting properly for radiation damping.

The variation of these BAFe and TAFe values with the corresponding freefield PGA values are shown in Figure 3. There appears to be a quite a wide variation of the values of these ratios, especially TAFe, for any given PGA level, but the general trend is for lower amplification ratios with increasing PGA levels. Thus, these ratios are expected to be lower at the design PGA levels which are typically larger than those found in the database.

The mean and mean$\pm$1σ plots of the frequency dependent ratio BAFe(f) are given in Figure 4. Again, these are based on 48 sets of these ratios at the operating deck level from the three BWR MK II RBs. The values are plotted for a frequency range from 1 to 20 Hz for which the spectral values are considered reliable. These plots show that, on the average, the spectral value in a 5% damped FRS at any frequency, at the BWR MK II RB operating deck level, is no greater than 1.4 times the corresponding spectral value in the freefield spectrum.

Complete results of this EPRI sponsored study will be published in a report sometime in late 1989.

CONCLUSION

In summary, the actual recorded data in NPPs indicate much lower amplification of earthquake motion in NPP structures than those typically obtained from standard conservative analytical procedures used in seismic design. Statisical values based on actual recorded data, such as mean or mean+1σ values, are suggested as guides or limits to computed FRS for the structures, and other parameters, that are similar to those found in the experience database.

REFERENCES

Jhaveri, D. P., R. M. Czarnecki, R. P. Kassawara and A. Singh (1988). Seismic Demand Evaluation Based on Actual Earthquake Records. Presented at the 2nd Symposium on Current Issues Related to Nuclear Power Plant Structures, Equipment and Piping, Orlando Florida.

TABLE 1

RECORDED EARTHQUAKE DATA GATHERED FROM NUCLEAR POWER PLANTS

PLANT		BLDGS	SOIL TYPE	NUMBER OF EQS.	TOTAL SPECTRA
BWR1	MK1	RB	SOIL	4	15
BWR2	MKII	RB,TB	SOIL	19	283
BWR3	MKII	RB,TB	SOIL	18	274
BWR4	MKII	RB	SOIL	14	80
BWR5	MKI	RB	SOIL	1	12
BWR6		RF	ROCK	1	9
BWR7	MKIII	SC	ROCK	1	6
BWR8	MKI	RB	ROCK	1	4
BWR9	MKII	RB	SOIL	2	9
PWR1		IC,AB	SOIL	1	17
PWR2		IC,SC,CC,AB	ROCK	6	196
PWR3		IC,SC,CC,AB,TB	ROCK	4	161
PWR4		IC	SOIL	2	17

NOTES:

RB - Reactor Building
TB - Turbine Building
AB - Auxilliary Building
RF - Refuelling Building
CC - Conc. Containment Bldg
IC - Interior Conc Structure
SC - Steel Containment Shell
SOIL - V_s < 3000 ft/sec.
ROCK - V_s > 3000 ft/sec.

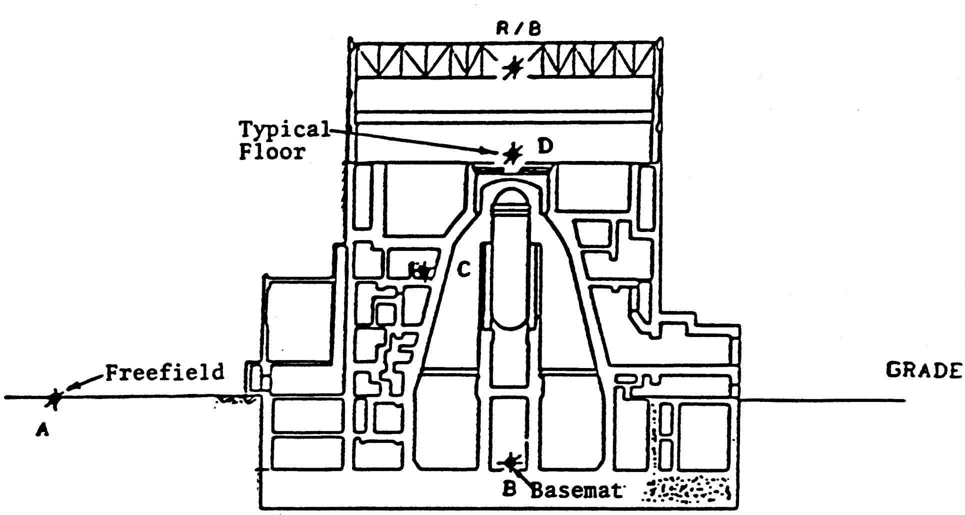

Figure 1. Section of a Typical BWR MK II Reactor Building

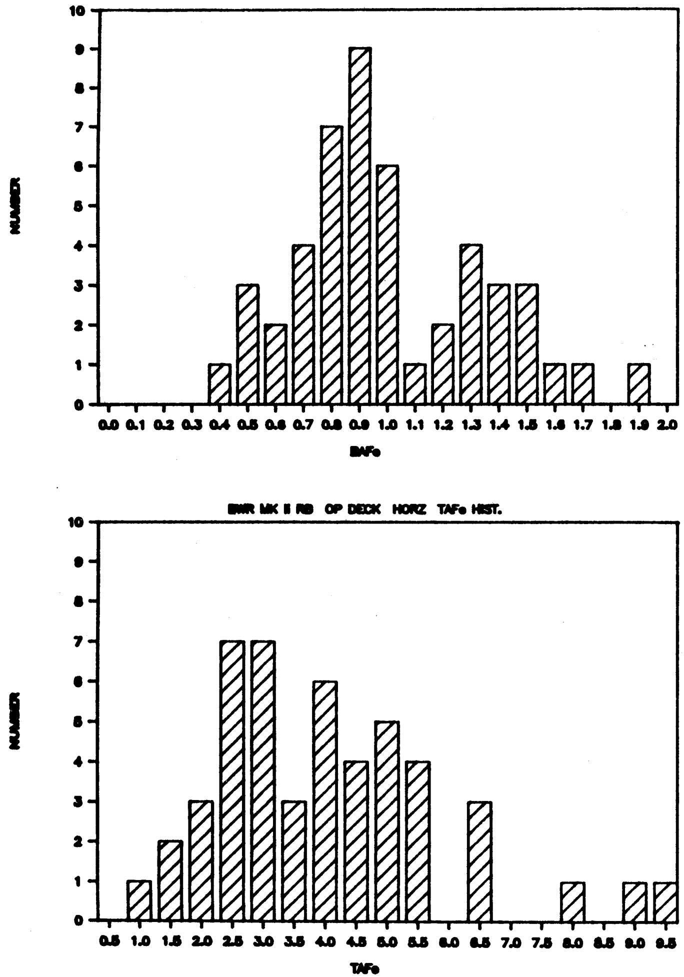

Figure 2. Histograms for BAFe & TAFe Ratios
BWR MK II RB Op. Deck

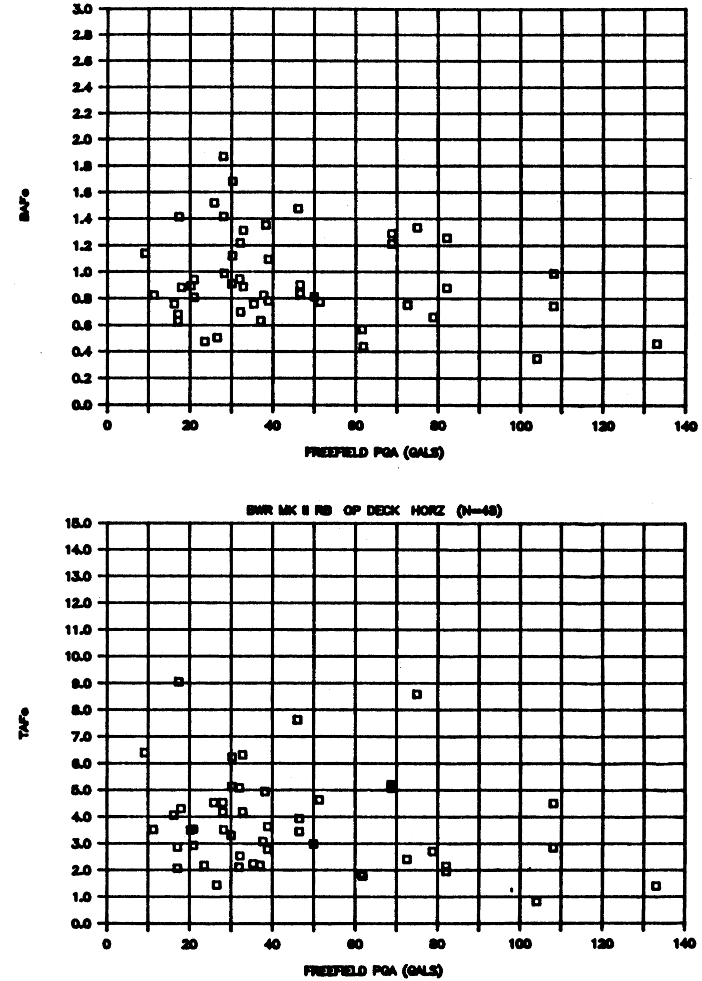

Figure 3. BAFe & TAFe Ratios vs. Freefield PGA
BWR MK II RB Op. Deck

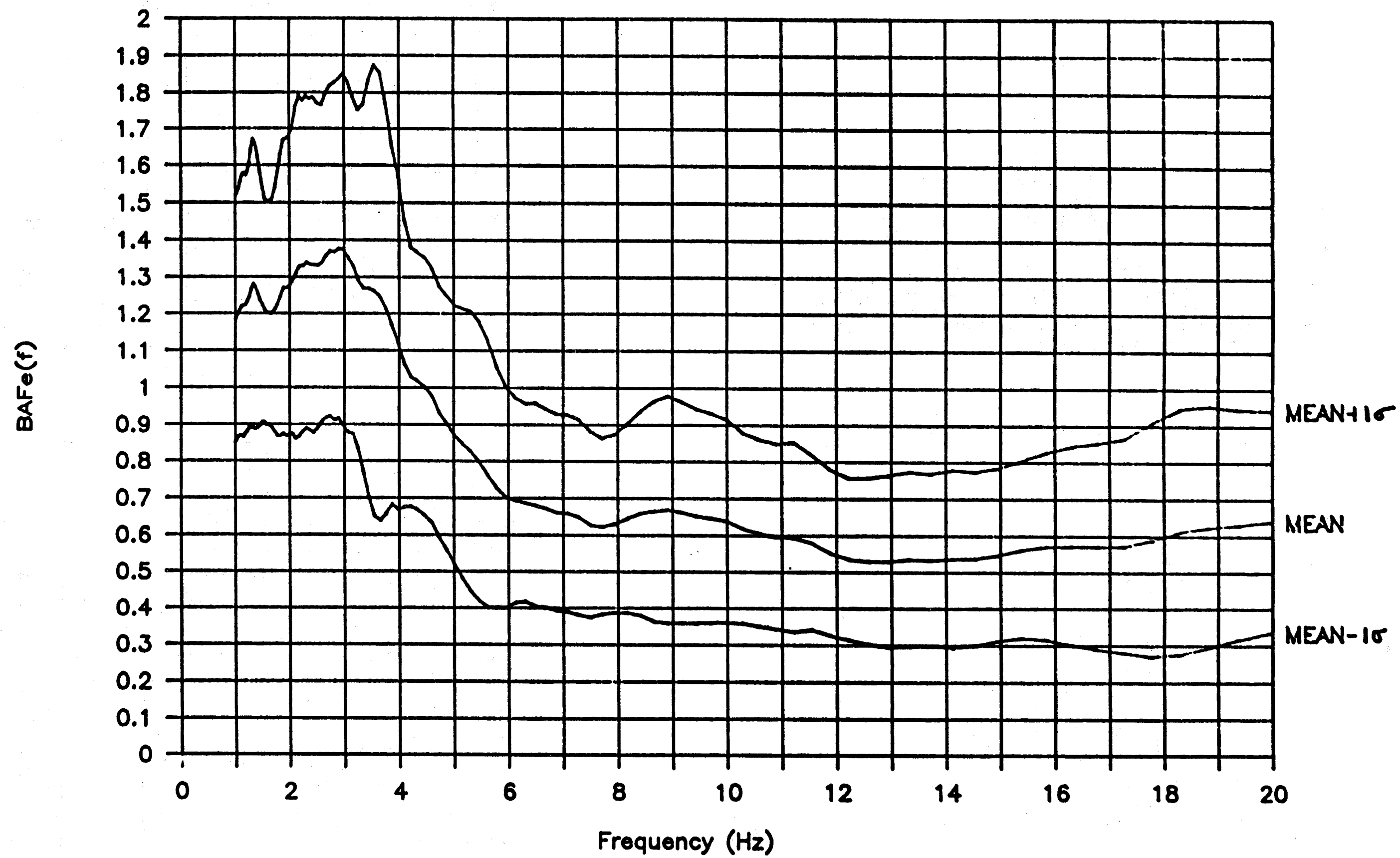

Figure 4. BAFe (f) Ratio for BWR MK II Reactor Building Op. Deck