Seismic Hazard Characterization of the Eastern United States

D. L. Bernreuter, J. B. Savy, R. W. Mensing
Lawrence Livermore National Laboratory, Livermore, CA USA

INTRODUCTION

The methodology or our study evolved from two earlier studies that the Lawrence Livermore National Laboratory (LLNL) performed for the NRC. One study, (Bernreuter and Minichino 1983), was part of the NRC's Systematic Evaluation Program (SEP) and is simply referred hereafter to as the SEP study. The other study was part of the Seismic Safety Margins Research Program (SSMRP).

By the time our methodology was firmed up and the calculations performed (i.e. by 1985), the Electric Power Research Institute (EPRI) had embarked on a parallel study.

We performed a comparative study, (Bernreuter, Savy, and Mensing, 1987) to help in understanding the reasons for differences in results between the LLNL and the EPRI studies. The three main differences were found to be: (1) the minimum magnitude value of the earthquakes contributing to the hazard in the EUS, (2) the ground motion attenuation models, and (3) the fact that LLNL accounted for local site characteristics and EPRI did not. Several years passed between the 1985 study and the application of the methodology to all the sites in the EUS. In recognition of the fact that during that time a considerable amount of research in seismotectonics and in the field of strong ground motion prediction, in particular with the development of the so called random vibration or stochastic approach, NRC decided to follow our recommendations and have a final round of feedback with all our experts prior to finalizing the input to the analysis.

In addition, we critically reviewed our methodology which lead to minor improvements and we also provided an extensive account of documentation on the ways the experts interpreted our questionnaires and how they developed their answers. Some of the improvements were necessitated by the recognition of the fact that the results of our study will be used, together with results from other studies such as the EPRI study or the USGS study, to evaluate the relative hazard between the different plant sites in the EUS.

METHODOLOGY

The methodology used in this study is developed around three basic elements:

1. The estimation of the seismic hazard, (the hazard model) is analytically defined by the now classical Cornell model (Bernreuter et al., 1985; Bernreuter, Savy, and Mensing, 1987; Bernreuter et al., 1988; Cornell, 1968; McGuire, 1976)

   The various elements, seismicity and ground motion attenuation are expressed separately and integrated to provide an estimate of the probability of exceedance of the peak ground acceleration (PGA) and of the 5% damping spectral velocity at five frequencies.

2. It is recognized that every element of the hazard modeling is subject to uncertainties. The random (or physical) uncertainties in the prediction of the ground motion are analytically accounted for in the hazard model. Other uncertainties, random and model uncertainties, are propagated in the analysis by means of a Monte Carlo simulation technique.

The result of this experiment is a large set of artificial estimates of the seismic hazard from which the 50th (median), 15th and 85th percentile hazard curves are calculated to represent the central tendency (median) and total uncertainty (random and modeling) in the seismic hazard.

3. This study was intended to represent the opinion of the scientific community with respect to seismic hazard estimation. To this effect, two panels of experts were formed. The seismicity panel, composed of 11 experts (S-experts) in the field of seismicity of the E.U.S., and the ground motion panel, composed of five experts (G-experts), represent a cross section of the various schools of thoughts and opinions currently present in the scientific community. The opinion of each of these experts was elicited via questionnaires to develop the input necessary to the hazard model.

The method developed by the Electric Power Research Institute (EPRI, 1986) has many common elements to ours. The basic hazard model is the same, the input is obtained through the elicitation of expert's opinion and all types of possible uncertainties are recognized including the variability in the expert opinions. The overall uncertainty is propagated by the means of the enumeration method where all the possible combinations of parameters are considered, in contrast to using a Monte Carlo method which selects alternatives at random from known probability distributions.

GROUND MOTION MODELING

Consistent with the philosophy of our methodology, the ground motion model input was developed by elicitation of the G-experts opinion, with two rounds of feed back. The intent was not to obtain what some would be tempted to call "The Model", but rather to sample the experts to ensure that all the models that the experts deemed rational and possible be considered. Each expert was free to select as many models as he wished and assign whatever weight he wanted to each one of them. The total weight of the models for a given expert was unity, and the weight of each expert was the normalized self weight given by the expert himself (the self weights were roughly 1/5 for each of the five G-experts).

The final set of attenuation models selected by experts includes a range of available models including the empirical, intensity based models (Veneziano and Heidari, 1986), Trifunac model (Trifunac, 1986), the empirical model of Nuttli (Bernreuter and Minichino, 1983), and the theoretical models of the Atkinson type (Atkinson, 1984) also called random vibration models (RV models).

Some general comments can be made about these models:

1. The dispersion between the models is large, approximately a factor of 10, in the range of distances of 50km to 200km.
2. The dispersion is much less within 50km.
3. The RV models are much lower than the other models. As much as a factor of 10 for distances greater than 100km, at both magnitudes 5 and 7.
4. Trifunac's model, for rock, is higher than the rest of the models by a factor of approximately two, up to 200km for magnitude 7. However, the difference is much smaller for the deep soil case.

The ground motion attenuation models of the response spectral velocity, in addition of being of the three types, empirical, semi-empirical and theoretical, could be either based on original spectral shapes (the RV models, and Trifunac's model), or Newmark-Hall type models constructed with PGA and velocity models of the types described for PGA: Fig. 1 shows the best estimate spectral models for the five G-experts for the rock case. Model 1 of Fig.1, is a "pure" RV model, and model 3 is a Newmark-Hall model (Newmark and Hall, 1978) constructed with RV models of PGA and velocity. Model 2 is the Trifunac model, and models 4 and 5 are Newmark-Hall models based on semi-empirical relationships of PGA and velocity attenuation models.

In toto, the contribution from RV models was approximately 53%, (including 44% of "pure" RV models and 9% of Newmark-Hall-RV models), 27% of Newmark-Hall-semi-empirical models, and 20% for the Lee and Trifunac model (Lee and Trifunac, 1985). In other words, the pure RV models accounted for 44%, Newmark-Hall models 36% and Lee and Trifunac, 20%. Fig. 1, shows the difference in behavior between the various spectral models. These median models are defined at five periods (0.04, 0.1, 0.2, 0.4, and 1.0 second).

Thus, when comparing previous results to the present study, the present estimates show a drastic change in the estimated spectral shape, with relatively much higher levels at low period and much lower levels at higher periods.

SITE CORRECTION

The ground motion attenuation models selected by the G-experts where derived either for rock site conditions or deep soil. The Trifunac model was derived for rock, deep soil or some other category which the author calls intermediate. In each trial, the Monte-Carlo simulation process selects at random one of the ground motion models, at a rate proportional to the weights assigned by the experts. Thus, each time the ground motion model selected did not match the soil site conditions, a correction was applied, see (Bernreuter and Minichino, 1983; Bernreuter et al., 1988) for details. The opinions of the experts were elicited to define what type of corrections and how the corrections should be applied. In the end, two types were selected.

USE OF THE RESULTS OF THE SEISMIC HAZARD ANALYSIS

The results of a seismic hazard analysis can be used in a variety of ways either in a relative or absolute sense.

Hazard curves used in Probabilistic risk assessment (PRA) studies rely on the estimates as true estimates of the hazard (absolute sense). So does any investigation of a single site without comparing it to other sites. For this reason it is important to incorporate the entire specification of the hazard, including its uncertainty, rather than a point estimate or even a mean or median value. To this effect, most PRA now use a family of curves to represent the uncertainty in the seismic hazard estimates. Comparison between plant sites, regions or groups of sites rely mostly on the relative level of hazard between the sites.

For example, the results of our study show clearly that the seismic hazard in the north central region of the EUS is lower than that of the north east.

Another use of the results is in comparing the spectral shapes of the uniform hazard spectra (UHS) at different sites.

The spectral level is sensitive to both the rate of occurrence and earthquake magnitude. The longer period part of the Constant Percentile Uniform Hazard Spectra (CPUHS) is very strongly influenced by magnitude. Thus, sites which are influenced by very large earthquakes, e.g., around the New Madrid region, will have more longer period energy than sites in New England where the local activity from smaller earthquakes is important. There is some influence of attenuation on the short period end of the spectrum, but it is relatively small.

Another important use of the hazard estimates consists in sorting the various sites according to criteria based on the probability of exceedance of some pre-chosen ground motion value. As an example, Fig. 2 shows an ordering of the 69 sites in the EUS according to the median value of the hazard at 0.2g. Fig. 2 shows that, depending on the type of criteria one would choose, several kind of groupings could be obtained. The first two sites in the ordering, could be considered as forming a group by themselves, then the next five sites could form a second group, etc.....

On the other hand, if the sites were ordered according to the arithmetic mean of the hazard (shown by the symbol "A" on Fig. 2), the order would be quite different. The same would be true of the 85th percentile (represented by the "*" symbol in Fig. 2).

Furthermore, using the hazard at 0.6g instead of 0.2g would also lead to different results. Thus, it is quite obvious that ordering the sites on the basis of seismic hazard alone could be misleading at best and always tainted with some arbitrariness.

Risk based criteria could help in ordering the sites but could also be misleading if one is not careful in selecting the criteria for ordering. One alternative would be to order the sites on the basis of probability of core-melt, or even on the total consequences of release, but clearly this would require enormous efforts to include all sites.

More simply however, generic plant fragility functions could be developed from the 20 or more existing PRA's, and the probability of core-melt could be estimated for all sites. Simpler methods yet can be thought off which in some manner consider some aspect of risk.

In a follow-up project, our charter was to develop grouping techniques and identification of outliers purely on the bases of the seismic hazard at the 69 plant sites. Without specifically involving risk, we considered the probability of exceedance of the SSE values and multiples of the SSE, 0.3g and 0.5g. In addition we defined a new hazard parameter equal to a linear combination of the hazard at the five periods available. This new measure of the hazard places the emphasis on different periods at will, emphasizing the periods which are more important for a given plant. For example the 0.4 sec. to 0.1 sec. period window is in general more important than the rest of the spectrum. In other cases one might want to emphasize the low period range, smaller than 0.1 sec.

This methodology was reported in Bernreuter (Bernreuter, Mensing, and Savy, 1988).

CONCLUSION

The detailed conclusions reached in the course of this study are given in (Bernreuter et al., 1989). The following is a summary of the most important ones:

(1) There is substantial uncertainty in the estimated hazard. The typical range in the value of the probability of exceedance between the 15th and 85th percentile curves for the PGA is on the order of 40 times, for low PGA; it is more than 100 at high PGA values. This translates into an approximate factor of 4 in ground motion for the 15th-85th range of values in the PGA given a fixed return period, and similarly an approximate factor of 4 in the ground motion for the range of values in the PSRV for a given return period.

(2) The 50th percentile CPHC appears to be a stable estimator of the seismic hazard at the site. That is, it is the least sensitive to changes in the parameters, when compared to other estimators considered in this study.

(3) The process of estimating the seismic hazard in the EUS is reasonably stable. Comparison with our previous results indicated that there has not been a major shift in results over the past few years, although there have been some significant perturbations in the form of recent occurrences of EUS earthquakes and the completion of several major studies of the seismotectonics of the EUS, including a significant change in the spectral shape by raising the spectral values in the high frequency range and lowering it in the low frequency range.

(4) It is difficult to rank the uncertainties, because zonation and the parameters of the recurrence models are hard to separate. Nevertheless, our results indicate that the uncertainty in zonation, and ground motion models are more significant than the uncertainty associated with the seismicity parameters. The largest contribution to modeling uncertainty comes from the uncertainty of the ground motion. The correction for local site effects is a significant contribution to the overall uncertainty introduced by the ground motion models.

(5) Although the soil site correction is not region dependent, we found that other complex interactions, with zonation seismicity and ground motion models, made the site correction actually region dependent in our methodology.

ACKNOWLEDGMENTS

The NRC project manager was Gus Giese-Koch.

REFERENCES

Atkinson, G.N. (1984), Attenuation of Strong Ground Motion in Canada from a Random Vibration Approach, BSSA, Vol. 74, pp. 2629-2653.

Bernreuter D.L. and C. Minichino (1983), Seismic Hazard Analysis, Overview and Executive Summary, NUREG/CR-1582, Vol. 1 (UCRL-53030, Vol. 1).

Bernreuter, D.L., J.B. Savy, R.W. Mensing, J.C. Chen, B.C. Davis (April 1985), Seismic Hazard Characterization of the Eastern United States, Vol. 1 and Vol. 2, LLNL UCID-20421, Vol. 1 and Vol. 2.

Bernreuter, D.L., J.B. Savy, and R.W. Mensing (1987), Seismic Hazard of the Eastern United States: Comparative Evaluation of the LLNL and EPRI Studies, USNRC Report NUREG/CR-4885.

Bernreuter, D.L., R.W. Mensing, and J.B. Savy, "Methodology on Plant Grouping for Decision Making", NUREG report to be published for NRC.

Bernreuter, D.L., J.B. Savy, R.W. Mensing and J.C. Chen (1989), "Seismic Hazard Characterization of 69 Plant Sites East of the Rocky Mountains", UCID-21517 and NUREG/CR5250.

Cornell, C.A. (1968), Engineering Seismic Risk Analysis, BSSA,Vol. 58, pp. 1583-1606.

Electric Power Research Institute (1986), Seismic Hazard Methodology for the Central and Eastern United States, EPRI-NP-4726, Volumes 1 through 10.

Lee, V.W. and M.D. Trifunac (1985), Attenuation of Modified Mercalli Intensity for Small Epicentral Distances in California, University of Southern California Report CE85-01.

McGuire, R.K. (1976), Fortran Computer program for Seismic Risk Analysis, U.S. Geological Survey, Open-file Report 76-67, 90 pages.

Newmark, N.M. and W.J. Hall (May 1978), Development of Criteria for Seismic Review of Selected Nuclear Power Plants, Nuclear Regulatory Commission Report NUREG/CR-0098, 49 p.

Trifunac, M.D. (1986), A Note of the Range of Peak Amplitudes of Recorded Accelerations, Velocities and Displacements with Respect to the Modified Mercalli Intensity, Earthquake Notes 47, pp. 9-24.

Veneziano, D. and M. Heidari (1986), "Statistical Analysis of Attenuation in the Eastern U.S.", Section 4 of Methods of Ground Motion Estimation for the Eastern U.S., EPRI RP 2556-16.

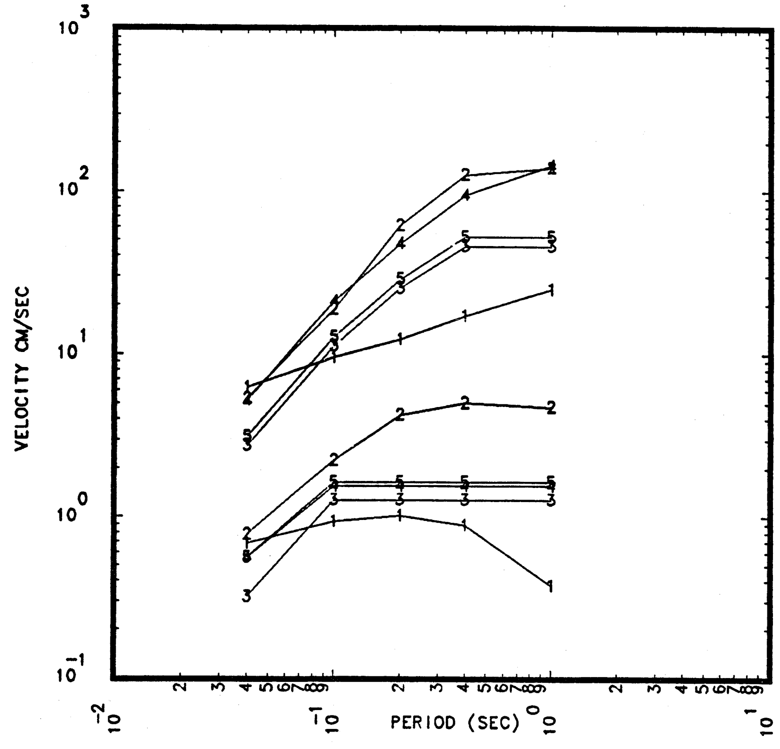

Figure 1 Best estimate 5 percent damped relative velocity spectra models plotted for magnitudes of 5 and 7 at a distance of 25 km. Rock base case.

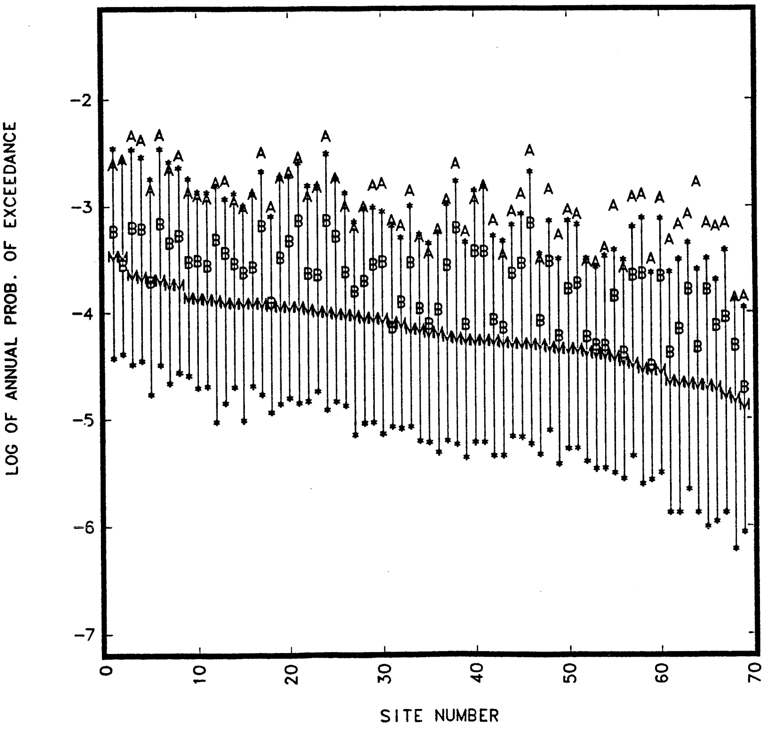

Figure 2 The 69 sites have been ordered by median probability of exceeding 0.2g. The symbols A, B, M and *, respectively represent the arithmetic mean, the best estimate, the median and the 85-15th percentile hazards. Note that if the site had been ordered according to other than the median hazard, a different order would have been obtained.