THE USE OF EXPERT OPINION IN THE ESTIMATION OF EASTERN UNITED STATES EARTHQUAKE HAZARD

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ABSTRACT

This paper summarizes the development and results of a survey of ten expert seismologists and geologists conducted as part of a seismic hazard analysis of the northeastern United States. The survey, conducted by a written questionnaire, proved very useful in providing the most up-to-date information on Eastern seismotectonics within a limited budget and time frame. The questionnaire was composed of five sections: source zone configuration, maximum earthquakes, earthquake occurrence, attenuation, and overall level of confidence. It was found that a great deal of scatter prevailed among the responses of the experts. This posed a challenging problem with regard to dealing with uncertainty and forming a consensus of opinion.

INTRODUCTION

Probability techniques have been used extensively in recent years to assess the risks to life and property associated with the occurrence of earthquakes (Epstein and Lomnitz 1966, Cornell 1968, Donovan 1973, Lomnitz 1974, Kiremidjian and Shah 1975, Algermissen and Perkins 1976). A major shortcoming of these procedures is their complete reliance on the historical record of earthquakes. This record is often plagued by incompleteness and inaccuracies, and is generally too short to serve as an adequate statistical sample for analysis.

Recently, models based on Bayesian probability methods have been introduced in seismic hazard analyses as a way to increase the usable information and reduce the large amount of uncertainty encountered at several steps in the methodology (Cornell 1972, Mortgat 1976, Campbell 1977, Hasselman et al. 1977). One can take full advantage of the capabilities of these models only if consistent and rational ways are developed to extract subjective seismic input from qualified experts and introduce it into the analysis.

This paper summarizes the development and results of a survey to elicit expert opinion on seismicity and intensity attenuation in the northeastern region of the United States. Because it is difficult, or perhaps impossible, to precisely quantify such factors given the sparse historical record, expert judgement was considered crucial. The responses of ten expert seismologists and geologists were used to estimate the seismic hazard at several sites within the region from a probabilistic point of view. The combined opinions were used in a quasi-Bayesian analysis of seismic hazard. The analysis used subjectively-modified historical data as a <u>posterior</u> Bayesian estimate of the earthquake occurrence and attenuation characteristics of the region.

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ENCODING TECHNIQUES

The available techniques for subjective opinion encoding can be grouped into three categories as a function of the effort and level of sophistication they require.

- A session between the expert whose judgment is being encoded and an analyst who conducts the interview
- A computer-aided interrogation where an interactive computer terminal with graphic display asks qualified questions as a function of the expert's answers. Advantage is taken of the computational capability and the vast memory storage of the computer to provide quick cross-checking between several modes of interrogations, immediate inconsistency resolution through additional questioning and direct input from light pen.
- A written questionnaire where the expert is expected to answer in terms of probabilistic values and/or graphs. Questions are presented in such a manner that they provide sufficient cross-checking. After the answers have been interpreted, a follow-up questionnaire or interview may be needed to resolve inconsistencies.

In view of the level of effort required by each of the methods and the scope of the study, the questionnaire method was used to elicit the opinion of the ten Eastern U.S. seismic experts.

QUESTIONNAIRE

The questionnaire was divided into the following five sections:

- Source Zone Configuration
- Maximum Earthquakes
- Earthquake Occurrence
- Attenuation
- Overall Level of Confidence

In the Source Zone Configuration section we were concerned with the specification of various areas or regions that appear to be unique in their potential to generate earthquakes. In particular, we were seeking in this section the definition of regions within which the experts felt future earthquake activity would be homogeneous. As a point of reference, we provided maps giving two possible seismic zonations of the Eastern United States. We asked the experts to carefully review these figures and to indicate where they thought they might be inadequate by modifying, deleting and adding zones. The experts were asked to indicate their "degree-of-belief" in each source zone and source zone alternative by estimating the chances of the seismicity within these zones being part of the background seismicity of the entire region. We also asked them to identify any localized tectonic structures that might be important to the seimsic hazard of nearby sites and to indicate their "degree-of-belief" in their activity.

In the Maximum Earthquake section, we addressed the question of determining the size of the largest event that, in the experts opinions, could be expected to occur in each of the source zones for a given time period in the future. Since extrapolation of results from short time periods to very long ones is controversial due to possible long-term variations in seismicity and other parameters, we explicitly considered two distinct time periods. The first one was chosen to be 150 years since it was generally on the order of our time period of interest and approximately equivalent to the length of recorded history in the East. The second time period was chosen to be 1,000 years since such a period covers most non-catastrophic perturbations in seismic activity and leaves out the uncertainties associated with the extremely long-term geological variations which were outside the scope of the questionnaire. They were also asked to consider the largest event that they might expect to occur within the current tectonic framework in each source zone without specifying any time period.

The Earthquake Occurrence section considered the occurrence of earthquakes within the next 150 years for each source zone. The experts were asked to subjectively assess the future seismicity in the East based on the available data and their judgment as to the validity, quality and completeness of these data to represent the true seismcity in the East. To aid in their decision-making, we presented in an accompanying seismicity booklet earthquake occurrence data for the source zones presented in the zonation maps. These data were not "corrected" for completeness, but rather represented the latest generally available information on locations and sizes of recorded or felt events.

An attractive approach to supplement the limited strong motion data in the East is to infer, based on theoretical or experimental considerations, the difference in peak acceleration and velocity ground motion between the Eastern United States and the Western United States and to modify correspondingly the Western attenuation relations and intensity-groun motion correlations in order to make them applicable in the East. For this purpose, the section on Attenuation provided general information concerning the validity of existing attenuation relationships and ground-motion correlation for use in the Eastern United States. Attenuation data were not specifically provided for this task; rather, we asked the experts to rely on their inherent knowledge of Eastern U.S. attenuation.

In order to obtain a measure of the overall confidence the experts had in their answers, in the final section they were asked to rate on a scale of 1 to 10 (10 being the highest) the confidence they had in their responses to the different sections of the questionnaire and the various source zones. In this way a consensus or partial consensus could be reached among the experts through weighted average procedures based on self-assigned levels of confidence.

The responses to each question could be made in one of several ways, all of which could be converted to a usable format for analysis. Several formats were provided, and a typical answer sheet is shown in Figure 1. These formats were:

- A best estimate only (fixed quantity)

- A range of values defined by lower and upper bounds and associated with a uniform distribution
- A range of values defined by lower and upper bounds and associated with a non-uniform distribution
- A written discussion

The experts were advised not to spend more than three days on the questionnaire and to concentrate on the areas with which they were most familiar.

RESPONSE

It is impossible to summarize the responses within the space of this paper. However, the following qualitative remarks are of interest.

- The questionnaire proved extremely useful in the sense that is provided in a relatively usable format the most up-to-date state of knowledge regarding the seismicity of the Eastern United States. However, the answers to the section on attenuation emphasized the lack of consensus and understanding regarding strong motion propagation in the East.
- Experts were given the choiceof answering in terms of magnitude or intensity. This introduced some difficulty when consensus was to be obtained since those units are not closely correlated.
- Consensus was often made difficult by the large scatter encountered in many answers. Figure 2 shows a typical density function describing the size of the largest event to be expected in a given region. In this plot, all the experts have been equally weighted.
- The weights obtained from self-ranking proved to be less useful than expected. The experts tended to rate themselves high for the questions they answered, and not answer the ones for which they rated themselves low.
- All experts provided their answers in terms of either a best estimate only or best estimate together with a range of uncertainty. Only one expert sketched probability density functions.

USE OF SUBJECTIVE INPUT

In order to keep the systematic differences among experts separate (one expert being consistently high or low in his estimates for example), there was no attempt to reach a consensus among them at the level of their input; each expert's opinion was treated individually in a hazard analysis. This led to a set of ten hazard curves for each site. Synthesis was then obtained at the level of the output using a weighting average procedure.

All the uncertainties the experts associated with their input were considered and integrated in the analysis. They consisted of the uncertainties related to zonation, earthquake recurrence, upper magnitude cutoff and ground motion attenuation.

- When a seismic source was modeled by several zonations, the seismicity was distributed among them as a function of the probability assigned to the respective zones. Heuristically, some experts assigned credibility to reflect their overall confidence in zonation. For example, for two zones (0.9, 0.9) seems to reflect better confidence than (0.1, 0.1). In order to model this heuristic assessment of credibility, an additional "background" was defined to be the union of the sources considered by all experts. Part of the source seismicity determined from the credibility was allowed to occur in the background.
- Most experts opted for an earthquake recurrence relationship of the linear type and gave a range of values for the b parameter. This range was treated as the 2 sigma uncertainty.
- The uncertainty about the upper magnitude cutoff was in most cases represented by a triangular distribution over the range provided by the experts. Finally a lognormal distribution was associated with the attenuation relationship to model the randomness inherent in ground motion attenuation.

RESULTS

The hazard at the site was computed for 10 periods between zero and two seconds using different spectral amplitude attenuation relationships. This allowed the development of a uniform hazard spectrum for a fixed return period.

In a uniform hazard spectrum, each spectral amplitude has the same probability of being exceeded in a given period of time. This comes about since each period is considered individually and the contribution to the loading of all potential earthquakes is computed as a cumulative distribution function of the loading. The procedure is repeated for the periods within the frequency range of interest and the spectrum is built point by point. For design purposes, it is important to realize that different earthquakes contribute to different parts of the spectrum and that a uniform hazard spectrum is not event specific but rather a probabilistic envelope of all the events capable of affecting the site.

A typical set of spectra of each of the experts is shown in Figure 3. The synthesis spectrum (Fig. 4) was obtained as a weighted average of the experts. The weight for each expert was obtained based on the contribution of each sources to the hazard at the site and the level of confidence the expert had for those sources (questionnaire section IV). A striking point about the results in general is that in spite of a broad variation in the expert's input the range of variations remains relatively simple. This can be explained by the fact that many of the input variations counterbalanced each other as they are filtered through the analysis.

CONCLUSIONS

The use of a written questionnaire proved to be very useful in the sense that within a reasonable time and budget frame it provided the most up-to-date state of knowledge regarding the seismicity and seismotectonics of the Eastern United States. It also emphasized the diversity of opinions regarding this region. Extensive sensitivity analysis are being done to determine the importance of the individual parameters and where the future effort should be concentrated. The use of a follow-up questionnaire to resolve some of the controversies is being considered.

ACKNOWLEDGEMENTS

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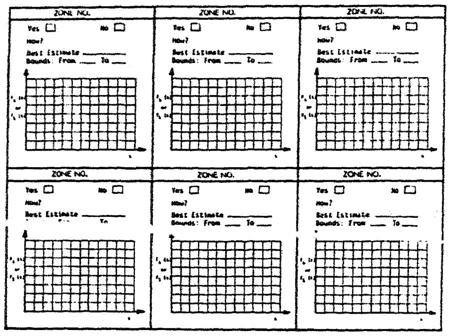

FIGURE 1

TYPICAL ANSWER SHEET

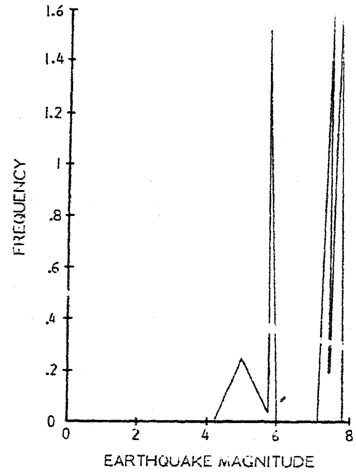

FIGURE 2

DISTRIBUTION OF UPPER
MAGNITUDE CUTOFF FOR A REGION

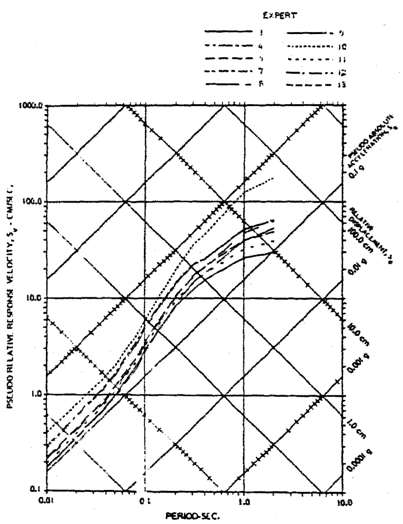

FIGURE 3

UNIFORM HAZARD SPECTRA FOR
1000 YEAR RETURN PERIOD,
ALL EXPERTS, TYPICAL SITE

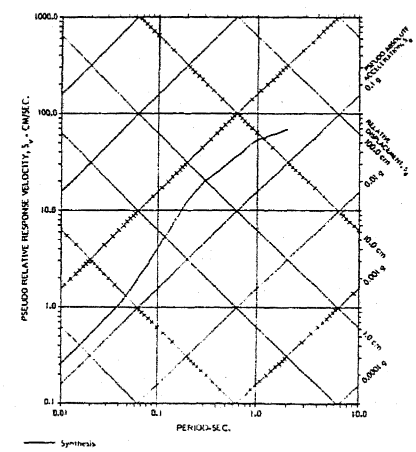

FIGURE 4

UNIFORM SPECTRA FOR 1000 YEAR RETURN PERIOD,
SYNTHESIS, TYPICAL SITE