ON THE SYSTEMATICS IN DEFINING SEISMIC ZONES

B. RAST [I] and R. SAEGESSER[II]

SUMMARY

Uncertainty in site hazard estimation is still sizeable. Despite considerable progress in earthquake engineering, the overall uncertainty from data scatter and estimated individual uncertainties is not really getting smaller. A significant, and often neglected, contribution comes from the seismic source zoning which is the initial condition of any hazard evaluation. Liberal interpretation of seismotectonic mapping together with different subsequent hazard analysis methods can lead already to deviations of approximatly one intensity for the design earthquake of a given site, particularly in areas with moderate activity. The paper demonstrates effects of uncertainty from seismic source mapping and offers some guideline for a more systematic approach.

1. NATURE OF UNCERTAINTY IN SEISMIC HAZARD ANALYSIS

Despite tremendous efforts made in the past ten years in estimating earthquake design loads, the impression prevails that only marginal overall progress was achieved with respect to consistency and accurracy of results except maybe in the circumpacific areas where strong tectonic activity allowed to gather more specific data than elsewhere. Often new procedures are introduced but existing ones not dropped. Hence probabilistic methods compete with deterministic ones in seismic hazard evaluation, pga with rms and epa terms for ground acceleration etc. And the term 'seismotectonic map' opens up all the possibilities to depict anything from hot springs to so-called seismic regions.

To all those steps in the analysis, uncertainty is an integral part. By nature three different types of uncertainty are involved, which might be described as

(1) data uncertainty,
(2) model uncertainty,
(3) methodological uncertainty.

Data uncertainty (1) is e.g. the type found in incompleteness or inhomogeneity of earthquake data. Model uncertainty (2) is found in the deviation between a supposed and simplified law and the observed events like for attenuation, Poissonian distribution in the time occurrence etc. Since both data and model uncertainty can be expressed through either statistically or empirically determined values, they are commonly introduced in hazard analyses however with varying degree of conservatism.

I : Senior Earthquake Engineer, Basler & Hofmann Consultants, Zurich
II: Earthquake Specialist & Consultant, Zurich (formerly Basler & Hofmann)

The third kind is rather a 'man made' uncertainty type which can best be understood as the scatter resulting when different experts would do the same job. Deviations are then to be found in the definition of 'maximum conceivable earthquakes' or 'upper bounds', in the correlations from magnitude or intensity to ground acceleration and particularly in the free lance definition of seismic source maps, the basis for any hazard analysis.

The field of seismic source mapping - a typical interface problem between geophysics and earthquake engineering - is until today hardly established. Various maps can be drawn showing different kinds of information which all deserve the name 'seismotectonic map'. One of them marking today's seismic potential is usually called a 'seismic zoning map'. Such a general description might be widely agreed on, however, no true definitions for any of the individual maps on seismotectonic regionalization exist. Furthermore the variation on the final results due to different seismic source mapping can be significant but impossible to express in common statistical terms. This might account for the fact that this contribution to the total uncertainty is virtually absent in all analyses.

2. EXAMPLES ON EFFECTS OF VARIATIONS IN SEISMIC SOURCE ZONING

Example 1: Hazard mapping in Central Europe (Fig. 1 and 2)

The first example illustrates the mentioned 'man made' uncertainty obtained from independent analyses for a selected region carried out by different researchers (Fig. 1). Although the same seismic and neotectonic information was available, the same aim was followed (probabilistic hazard mapping) and the studies were carried out parallel in time and with mutual exchange of information, two different source maps were defined (Ahorner and Rosenhauer, 1978 and Sägesser and Mayer-Rosa, 1978). This is obviously due to different weighing of individual seismic and geotectonic information for the definition of seismotectonic sources.

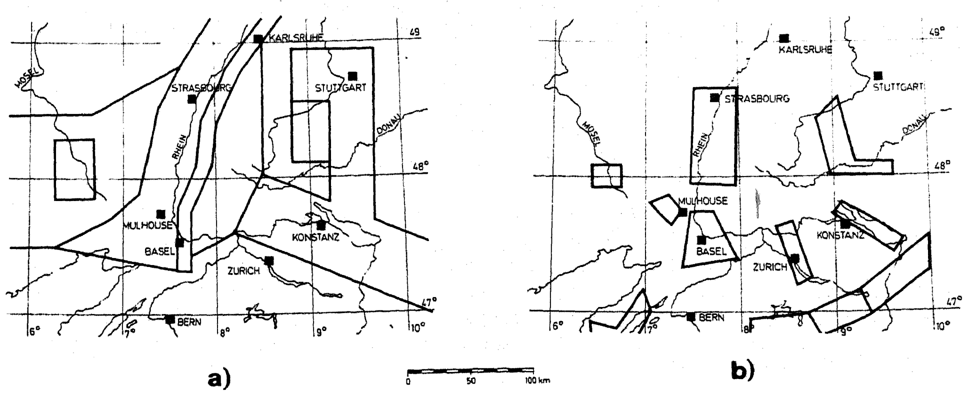

Fig. 1: Seismotectonic source maps for the area of northern Switzerland/ southwest Germany defined in two independent probabilistic hazard analyses

The regional parameters (maximum conceivable earthquakes, attenuation etc.) were determined by different procedures, too. It is hardly possible to indicate the degree of conservatism attached to the resulting hazard maps. But the numerical comparison, e.g. for a W-E profile along latitude 47° 45'N (Fig. 2), allows a rough indication of this kind of uncertainty. In general the agreement is good, but differences of up to 0.7 intensity units are observed, of which half the amount is accounted for by different upper bounds on magnitude and the remaining half by different seismic zoning.

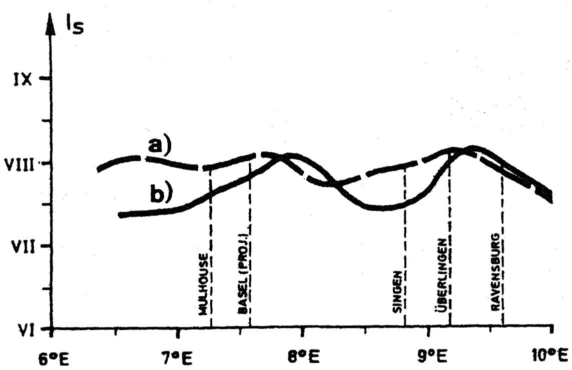

Fig. 2: Results from hazard analyses with source maps of figure 1 a) and b) along a W-E profile defined by latitude 47° 45'N, I_S = site intensity (MSK). The chosen probability level is p = 0.0002 p.a.

<u>Example 2: Site hazard analysis in southern Anatolia (Fig. 3)</u>

Fig. 3 illustrates different ways of seismotectonic zoning for the area north of the bay of Mersin (southern Turkey) which is part of the area investigated for the first Turkish nuclear power plant site (Harsch and Küpfer, 1980; Ergin and Büyükasikoglu, 1980). Special attention is given to the tectonic lineaments called 'Ecemis Fault' because of their limited distance to the site and because of the requirements given by the regulations for nuclear installations. In a first version (Fig. 3a), those parts of the faults which are considered active are separated from the inactive parts by integration in a seismic source, which represents the area of a tectonic basin structure (Eregli-Ulukisla basin). The two possibilities in zoning, which are based on the conservative proposition of an extensive reactivation of the approx. 35 my old Eçemis fault, can be represented either by an area source (Fig. 3b) or by a line source (Fig. 3c). For comparative purposes two sites are considered in this example: Site 1 = Akkuyu NPP site, site 2 = Mersin.

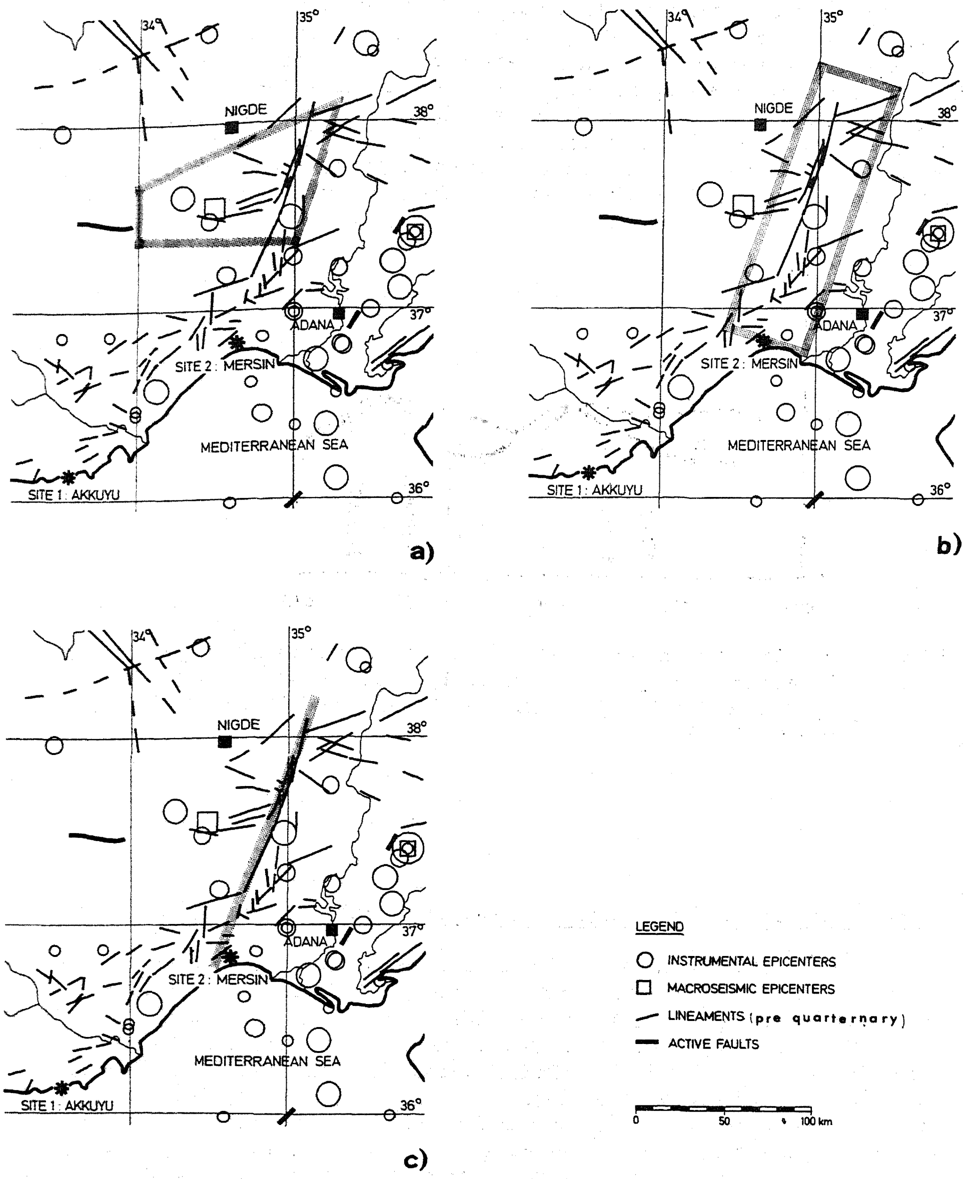

Fig. 3: Three different possibilities of source definitions for a selected area in southern Turkey. Seismic characteristics of the area:
rate (annual number of events with M≧4.0): $\nu = 0.85$
total length of fault: L ≅ 160 km
average focal depth: h ≅ 70 km

The comparison of the resulting site intensities obtained by deterministic hazard analysis based on the attenuation correlation method proposed by Gürpinar et al (1979) shows significant differences for the site 2 ($\Delta I = 2.0$), but only small ones for the site 1 ($\Delta I = 0.3$). Through systematic procedures and problem-oriented zoning concepts the range open for judgements can be limited. The concept applied for a single site analysis can hardly be identical with one for mapping purposes (multi site analysis). The principal criterion is the distance from the site considered to the source area, i.e. the zoning concept should include a reasonable graduation on area subdivisions depending on the distance to the site. Also the degree of conservatism on the rare event potential will effect the shape of zones significantly.

Example 3: Methodological uncertainty in an analysis for eastern U.S. sites (Fig. 4)

The following example (taken from McGuire, 1977) confirms in its own way the influence of different source mapping and analysis procedures on seismic hazard. In Fig. 4 it is demonstrated that the results from a deterministic hazard analysis are very sensitive to the choice of source boundaries ($\Delta I_s = 2.0$). In contrary, probabilistic procedures provide much smaller

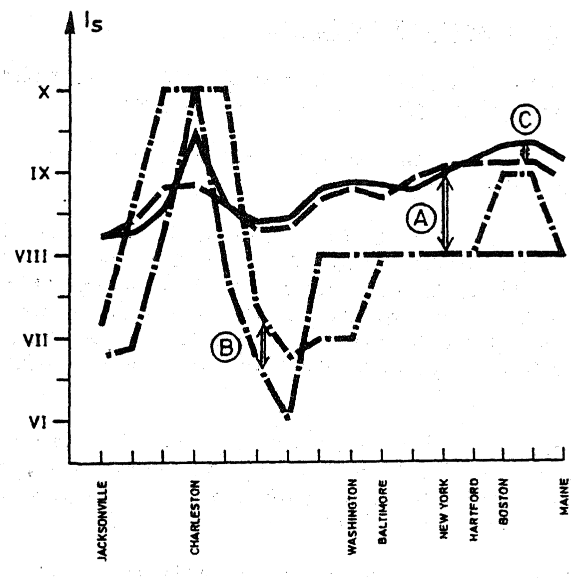

Fig. 4: Comparison of site intensities (I_s) from probabilistic hazard analysis (assumption: 10^{-4} p.a.) with those from deterministic analysis, for two source hypotheses. Large differences (A) are due to the type of analysis. The sensitivity on the results from different source maps is generally larger in the deterministic (B) than in the probabilistic (C) analysis.

differences (ΔI_s = 0.6). Nevertheless, considerable sensitivities can result in probabilistic analyses too, e.g. for sites innermost of active areas. Another conclusion from Fig. 4 is the inconsistency and the large difference (up to ΔI_s = 2.2) observed between the two kinds of hazard analyses (probabilistic/deterministic). Since there is no physical reason for such differences, provided a comparable potential in the energy release is assumed, a zoning concept as consistent as possible in that respect should be followed.

3. WEAKNESS OF SEISMIC SOURCE ZONING

Seismotectonic regions are often found to be defined as areas with equal and uniform tectonic motion of any direction. In consequence a picture of plates and subplates results, indicating that all the differential motion and consequently most of the seismic potential will be concentrated along the boundaries of those regions. Rather an opposite model results from the descriptive confinement of the active areas themselves, which is persued maybe more from the analytical view point. Both evaluations might be equally desirable and useful but hardly will yield the same seismic hazard estimates when applied to standard numerical analyses.

The problem can't be solved in an objective way. Therefore it is even more important that the procedure - the 'rules of the game' - be transparent.

4. SYSTEMATICS ON PROCEDURE

With best possible consistency achieved in data collection, seismic source zoning should then follow certain pinciples e.g. as follows:

1. Source boundaries should be defined with regard to the subsequently applied seismic hazard methodology.

2. Sources (or regions) should be defined as areas with seismic characteristics as homogeneous as possible (e.g., frequency law, focal information, seismic potential). Particularly all features which show specific tectonic mobility associated with higher seismic activity, or which indicate otherwise extra high seismic potential must be tied to their location, provided epicentral stability is statistically sufficient or geologic/tectonic arguments exist.

3. Between sources (regions) of different seismic potential, the boundary should be located close around the "hard core" of the more active one, thus line sources are possible where evidence is given and 'floating potential' within large seismotectonic regions is avoided.

4. In areas of statistically sufficient number of reliable events, boundaries should be mainly based on seismic data as expression of tectonic activity and backed up by tectonic arguments.

5. In cases of insufficient number of events or large uncertainties attached to them, the existence of a boundary has to be proofed by arguments based on the most dominant tectonic or seismic features.

Evidently, the application of any principles requires first a reliable basis to be prepared by a careful evaluation of all available and relevant information. For the consideration, e.g. of a fault's capability this evaluation includes the investigation of:

- geotectonic evolution with its accompanying phenomena (age dating), confirming or disproving the activity or capability of the fault considered,
- epicenter distribution of instrumental and historical locations with corresponding accuracy on coordinates, indicating the seismic activity to be related to the fault or that to be considered as background activity,
- focal depth distribution, indicating the reasonability of a correlation with surface tectonics,
- focal mechanisms of selected events, for comparison with fault displacement observations or with the supposed overall stress regime,
- microearthquake activity, by installation of a dense instrument network, in the case of short site-to-source distance.

5. CONCLUSIONS

In any site hazard analysis and site ground motion estimation several inaccuracies and uncertainties are contained of which many are readily recognized today. Still most dominant is the uncertainty in the bad correlation from intensity/magnitude to response spectra scaling factors (Sägesser and Baumgartner, 1978). Other significant uncertainties are to be found in maximum potential assumptions of a tectonic structure or in attenuation relations.

Of the same order of magnitude but hardly ever mentioned is the uncertainty in the method and technique of mapping seismic sources. Due to its methodological nature, no statistical error terms can be attached to that step in the hazard analysis. The effects only can be demonstrated in form of sensitivity analyses. Most important are transparent procedures. The paper offers a certain systematics to follow.

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