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The need, throughout PSHAs, for techniques which can accommodate and represent uncertainty

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"The need, throughout PSHAs, for techniques which can accommodate and represent uncertainty"

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Every PSHA encounters uncertainties and, given this situation, it is important that the methods used to treat and interpret the available data are, from the outset, designed specifically to facilitate the expert judgements that will have to be used to address those uncertainties. This lecture discusses and illustrates some of the techniques that have been found useful in this regard when estimating probabilistic ground motion hazard levels for facilities in a region which experiences no more than moderate seismicity.

Uncertainty is present as a ubiquitous accompaniment to all the stages of the process by which a PSHA is carried out. This is because:

(i) all mechanistic representations (i.e. models) of the process - or any part of the process - are, inevitably, simplifications with uncertain validity, and

(ii) there is always some degree of uncertainty associated with the input parameter values that are used to make such representations.

Given the fact there are so many potential sources of unavoidable uncertainty that can be encountered in carrying out a seismic hazard assessment, it is self-evident that every effort needs to be made not to introduce additional sources of uncertainty.

The best way of avoiding such problems is to work, wherever possible, with directly relevant local data: each time data or parametric relationships or, even, understanding is imported, potentially, this introduces additional uncertainty. (This explains why IAEA has always insisted that the hazard modelling process should be "data-driven").

The problem, of course (particularly in a moderate seismicity environment like that of the UK where there is, inevitably, only limited information), is that there is often no alternative to importing data or relationships or understanding. On all such occasions, it is essential that decisions are directed towards minimising the uncertainties that will be introduced by the process of importation: the particularisation and selection process should ensure that all imported material merges as directly and coherently as possible with the local data that are available. (Imported material - whether data, or relationships, or understanding - should be regarded only as surrogates which can reliably be used until such time as they can be replaced by local information that would not change the outcome.)

It is of paramount importance in conducting a PSHA that every effort is made to reduce uncertainty: techniques or methods which actually introduce additional uncertainties should be eschewed, whatever their superficial merits.

The role of conservatism in addressing uncertainty

The only proper response to uncertainty is to employ a commensurate degree of conservatism: this said, conservatism should not be presumed to be an adequate substitute for a coherent analysis of uncertainty.

The role of expert judgement in addressing uncertainty

Where a decision has to be made on the basis of uncertain evidence, the only practical recourse is to make use of expert judgement. Recognising this to be the case, the use of expert judgement in the practice of seismic hazard assessment is, nowadays, an accepted feature of such studies (see, for example, IAEA safety guides).

This said, even where formal elicitation procedures are used for making the actual hazard modelling decisions, experience suggests that other judgements, of potentially similarly significance for the PSHA, are sometimes afforded no special attention at all.

The role of sensitivity tests in addressing uncertainty

It is hard to see how expert judgement can properly be exercised without an adequate general understanding of how the decisions that are being made are likely to impact on the hazard results. Thus, sensitivity tests are an important component of the process of making a PSHA as I will discuss in a later lecture.

The lecture will go on to describe in detail procedures that have been found useful for handling and treating data and for hazard model-building in ways that are tailored to meet the particular demands of PSHA with all the attendant uncertainties. In this latter connection, emphasis will be placed on the merits of using a logic-tree formulation making the actual hazard estimate.

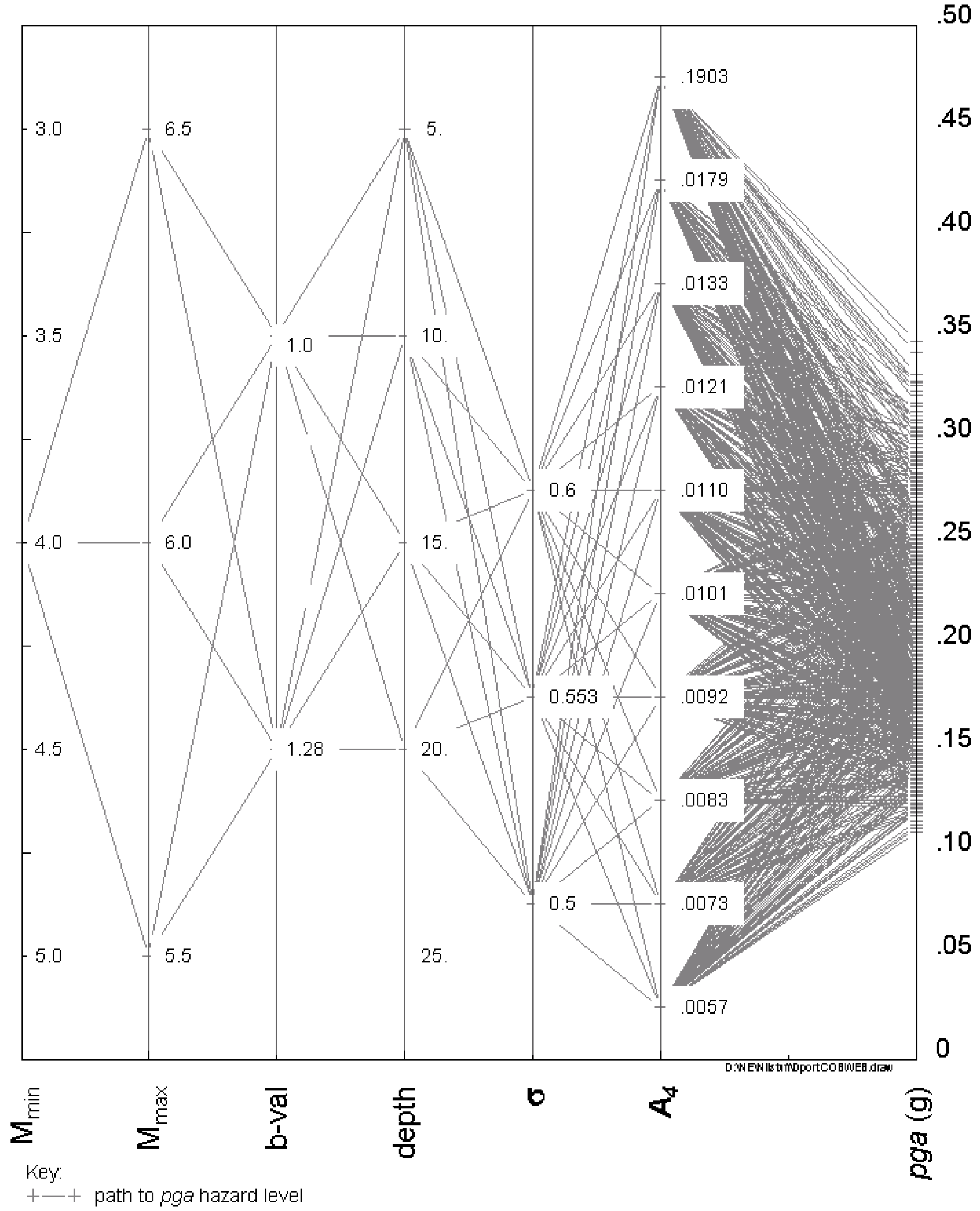
There now follow a few sheets which give an indication of the type of material that will be discussed in the lecture.

Selecting the most appropriate magnitude scale

To maintain internal consistency, and, thereby, avoid introducing unnecessary uncertainty, it is desirable if the same magnitude scale is used throughout the process, i.e.:

> For deriving a correlation with macroseismic intensity patterns so that \`magnitudes\` can be estimated for historical, i.e. pre-instrumental events
>
> As the measure of earthquake size that is employed in ALL attenuation relationships, i.e. instrumental and macroseismic parameters
>
> As a prerequisite which conditions the selection of data for characterizing ground motion spectra
>
> As a measure which will be available for present-day earthquakes whose most significant characteristic is their <u>size</u>.

Example of a 'cobweb' plot showing the spread of hazard results given by all the combinations within a logic-tree formulation



A scheme for categorizing the locational uncertainty of earthquakes

In reviewing the locational reliability of the macrocentres assigned to historical earthquakes, four categories have been found appropriate:

> Grade 1 locations, known to within 5km;
> Grade 2 locations, known to within 10km;
> Grade 3 locations, known to within 20km, and
> Grade 4 locations which have an uncertainty radius of more than 20km.

A scheme for categorizing the quality of focal mechanisms:

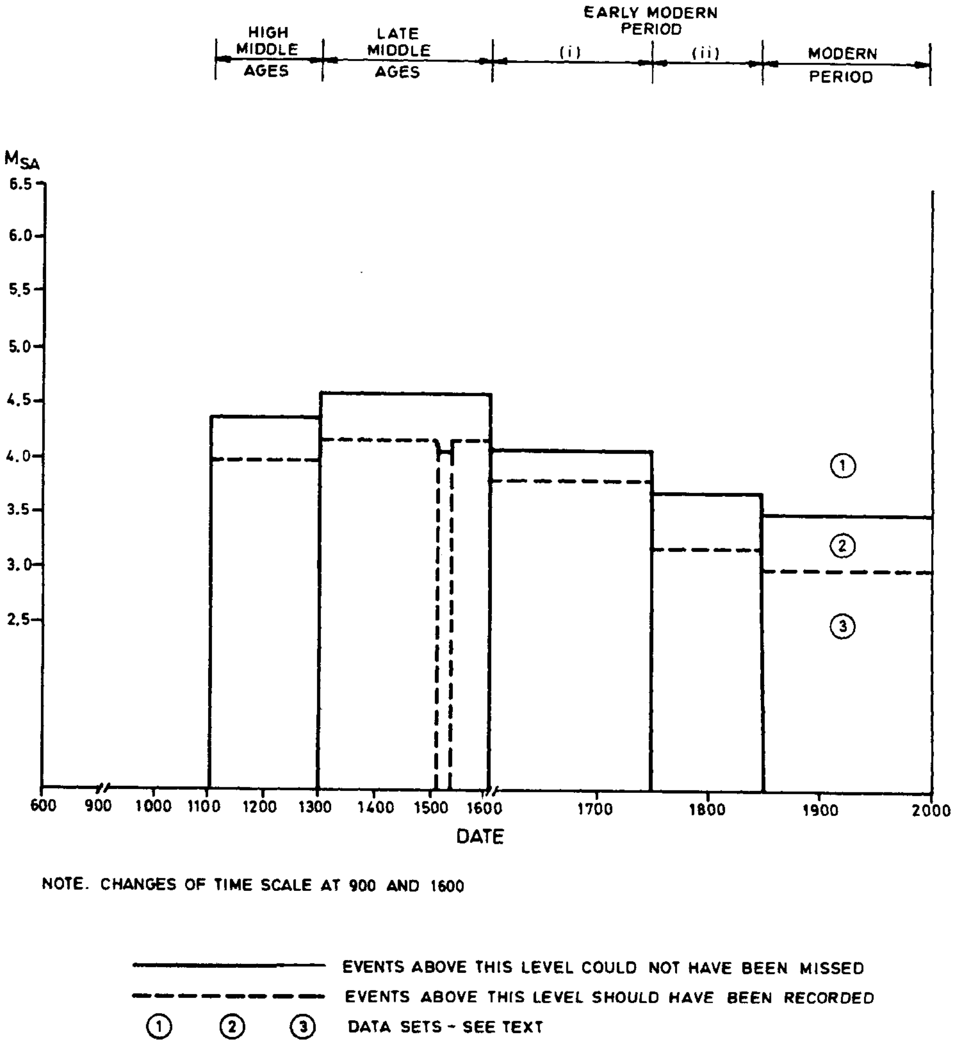
Based on three criteria:

> (i) the most significant criterion concerns the accuracy of depth determination: a well-constrained depth is essential because of the effect of crustal discontinuities on the geometry of raypath take-off angle. For this reason only Grade 1, or exceptionally, Grade 2 depths should be accepted.
>
> (ii) there should be a sufficient distribution of clear first motion readings. Preferably, all four quadrants of polarity should be populated by some unequivocal first motion data although this requirement may be relaxed where the data include closely-spaced first motions of opposite polarity, serving to constrain either or both focal planes.
>
> (iii) consideration must also be given to the number of polarity errors (and amplitude ratio errors, where these are used) which have had had to be accepted in arriving at the preferred solution: a large proportion of discordant data undermines confidence in the robustness of the solution.

All three of these factors are appraised for each event so that its solution can be placed in a four-category classification scheme (Qualities A to D) which determines the use that can properly be made of that solution:

> Events of Quality A have well-defined, unequivocal solutions of high confidence, such that any seismologist would arrive at the same conclusion regardless of method: other earthquakes, with satisfying solutions which lack only some data completeness or the depth control required of an A rating, are accorded Quality B.
>
> Focal mechanism solutions of Qualities A and B are deemed to be of sufficient quality that they can reasonably be used in testing associations with geology.
>
> The remaining events have solutions which are classified as Quality C, or Quality D:
>
> - only marginal confidence is vested in Quality C events as individual solutions although, with suitable caution, they might be considered for composite mechanisms or as contributing to the regional data on P- and T- axis directions, for example.
>
> - the Quality D solutions cannot be relied upon.

Example of a framework for assessing the magnitude completeness thresholds of a historical earthquake dataset



The uncertainties associated with activity rates

The confidence limits which can be placed on apparent mean annual activity rates vary markedly with the number of events that have occurred.

As an illustration of this variability, consider four situations each suggesting a mean annual activity rate of 0.05 for events of magnitude 4 and greater:

- For a zone with 50 magnitude 4 events observed in 1000 years,

  the 95% confidence limits for the average annual activity rate at magnitude 4 are 0.035 and 0.063

- For a zone with 25 magnitude 4 events observed in 500 years,

  the 95% confidence limits for the average annual activity rate at magnitude 4 are 0.029 and 0.070

- For a zone with 10 magnitude 4 events observed in 200 years,

  the 95% confidence limits for the average annual activity rate at magnitude 4 are 0.020 and 0.085

- For a zone with 5 magnitude 4 events observed in 100 years,

  the 95% confidence limits for the average annual activity rate at magnitude 4 are 0.013 and 0.105

Allowing for the uncertainties about activity rates

The effect on hazard results of making allowance for the uncertainty which surrounds typical activity rates can be illustrated by considering the case of an area which has had so few historical earthquakes that there are effectively no events from which to calculate an activity rate, as follows:

> *- take a site in the middle of a large area (say 100km radius) of presumed uniform seismicity where there are no earthquakes above the locally-defined magnitude completeness thresholds, which are:*
>
> *surface wave magnitude 5 since 1000AD, and*
> *surface wave magnitude 4 since 1800;*
>
> *- assume, for simplicity:*
>
> *a single focal depth of 10km,*
> *a single b-value of 1.28,*
> *a single maximum magnitude of* $6.5M_s$
> *that pga attenuation accords with the PML (1982) relation*
>
> *- then, the expected* 10^{-4} *p.a. probability of exceedance pga at the site of interest is 9.6%g*

Some examples of the effects of alternative zonations on hazard results

SITE	**MODEL**	**WEIGHT**	**Individual 10^{-4} p.a. *pga***	**Overall 10^{-4} p.a. *pga***
I	1 2 3	0.4 0.4 0.2	0.212g 0.223g 0.193g	0.213g
II	A B C	0.4 0.4 0.2	0.196g 0.114g 0.217g	0.179g
III	A B C	0.37 0.41 0.22	0.258g 0.234g 0.183g	0.236g
IV	A B	0.57 0.43	0.239g 0.277g	0.257g

(N.B. both of the alternative zonations for Site IV include the same fault source.)

Attenuation relations

It is important to use attenuation relations that are locally valid.

Preferably, they should be derived using local data.

Where this is impossible, every effort should be made to confirm the suitability of:

(a) any imported data, where new relations are being determined, or
(b) any imported relations that are going to be used directly

In the latter case, particular care should be taken to ensure that the ranges of validity (for magnitudes, focal mechanisms, epicentral distances, focal depths, peak accelerations, site types, etc.) of the imported relation are appropriate for the environment that is under scrutiny.

Preferably, the employment of either new relations based on imported data or imported relations should not involve any manipulations, such as magnitude scale conversions.

The distance term which is invoked in the attenuation relation should be consistent with the calculational methodology that is being employed

Whilst it is reasonable to allow for some uncertainty in the sigma value, it is probably sensible to make the central value of the weighted distribution of possible values equal to the figure actually derived from the database that has been used.

Other information presented in one or other of my three lectures appears in the following references:

Mallard, D.J. (1986) The investigation of historical earthquakes and their role in seismic hazard evaluation for the U.K. Paper presented at IAEA Technical Committee Meeting on "Earthquake ground motion and seismic evaluation of NPPs", Moscow, USSR. Reproduced (1989) in: IAEA-TC-472.2, Vol.1. IAEA, Vienna, 201-219.

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