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New developments in probabilistic seismic hazard analysis: Common problems and their resolution

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ABSTRACT

The purpose of this short paper is to highlight and discuss several frequent problems which one faces in Probabilistic Seismic Hazard Analysis (PSHA). The potential difficulties are:

- how to take into account the incompleteness of seismic event catalogues,
- how to handle the uncertainties within the seismic event catalogues,
- how to take into account the inadequacies inherent in the selected model of seismicity,
- how to delineate seismogenic source zones.

The lecture attempts to address the above problems, to provide tools for their solution and to present a coherent methodology for efficient assessment of PSHA.

Key words: probabilistic seismic hazard analysis, common problems.

INTRODUCTION

This short paper highlights and discusses several frequent problems which one faces in Probabilistic Seismic Hazard Analysis (PSHA). The potential difficulties are:

(i) How to take into account the **incompleteness** of seismic event catalogues, or more specifically, how to incorporate into the calculations, (i) very strong, prehistoric events (paleo-earthquakes obtained through trenching of faults etc.), (ii) large historic events and (iii) recent, complete sets of observations, each with its own time-dependent level of completeness.

(ii) How to handle the **uncertainties** within the seismic event catalogues, that is, uncertainties in the determination of earthquake locations, their magnitudes and origin times. This problem is especially relevant in the case of large, pre-historic and historic events.

(iii) How to take into account the **inadequacies inherent in the selected model of seismicity**. The common idealization of the earthquake generation process regards earthquake occurrence as a simple Poisson process with magnitudes following the classic Gutenberg-Richter relation. Often, however, this simple model of earthquake occurrence is inadequate. Many studies of seismic activity suggest that the seismic process is subject to spatial and temporal trends, cycles, short-term oscillations and pure random fluctuations. In most currently used procedures, spatial and temporal variations of seismicity are ignored.

(iv) Delineation of seismogenic source zones. Currently, a frequently used procedure for PSHA is the one developed by Cornell (1968), which requires the **delineation of seismogenic source zones**. Unfortunately, tectonic provinces or specific active faults have often not been identified and mapped, and the causes of the seismicity are not well understood. The problem of the specification of zoning is crucial, because a different delineation of the seismogenic zone can lead to significantly different assessments of hazard.

I will address the above problems, provide tools for their solution and present a coherent methodology for efficient assessment of PSHA.

METHOD AND RESULTS

The proposed procedure accepts combinations of the following three types of data: (a) the largest paleo-earthquakes, (b) the largest, historic events and (c) data sets that are complete from different thresholds of magnitude and upwards (Figure 1). Furthermore, the procedure incorporates the uncertainty surrounding the origin time of paleo-earthquakes, the errors in the calculation of earthquake magnitude and the coordinates of the location. It does not require the specification of seismic source zones.

The maximum regional magnitude $m_{\max}$ is of supreme importance in the proposed PSHA and shall be discussed in detail.

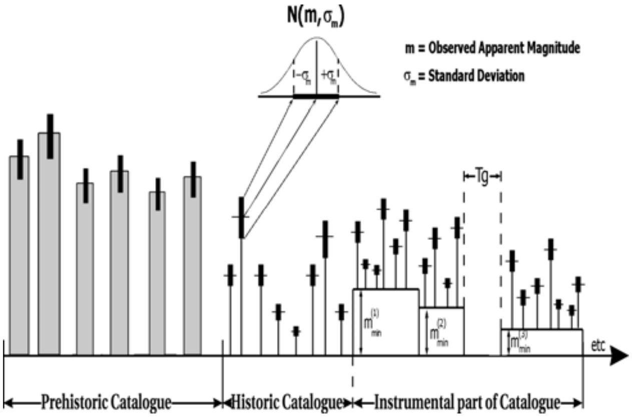

Figure 1. **Data which can be used to obtain the seismic hazard parameters for the area in the vicinity of the selected site. The approach permits the combination of the largest earthquake (prehistoric/paleo- and historic) data and complete (instrumental) data having variable threshold magnitudes. It accepts the "gaps" (T_g) created when records are missing or the seismic networks were out of operation. The procedure is able to account for the uncertainties of the occurrence time of prehistoric earthquakes. Uncertainty in earthquake magnitude is also taken into account by making the assumption that the observed magnitude is true magnitude subjected to a random error that follows a Gaussian distribution with a zero mean and a known standard deviation. (Kijko and Sellevoll, 1992).**

The seismic hazard is expressed in terms ground motion vibration *a*, which can be the peak ground acceleration (PGA) or acceleration response spectra (ARS). The aim is to calculate the conditional probability that a single earthquake of random magnitude *m* at a random distance *r*, will cause the ground motion vibration to be equal to or greater than an acceleration of engineering interest $a_{\min}$. For this purpose assume that for a specific range of interest, the attenuation curve of the *a* has the form:

$$\ln(a) = c_1 + c_2\, m + \phi(r) + \varepsilon \qquad (1)$$

where c_1 and c_2 are empirical constants, *m* is the earthquake magnitude, and ϕ *(r)* is a function of earthquake distance *r*. The term ε is a random error which has been observed to have a normal (Gaussian) distribution. Usually ϕ *(r)* is of the form $c_3 \cdot r + c_4 \cdot \ln(r)$, where c_3, and c_4 are empirical constants and ln(·) denotes the natural logarithm. It can be shown that the acceptance of equation (1) as a model for attenuation of *a*, together with the Gutenberg-Richter distribution of earthquake magnitude, is equivalent to the assumption that the logarithm of *a* is distributed according to the same type of distribution as earthquake magnitude, i.e. negative exponential – the form of the familiar Gutenberg-Richter distribution (Kijko and Graham, 1999). The two distributions differ only in the value of their parameters. If the parameter of the Gutenberg-Richter frequency-magnitude relation is denoted by *b*, the parameter of the distribution of ln(*a*) is equal to b/c_2. Therefore, for a given $a_{\min}$, all the required characteristics of seismic hazard (annual probability of exceedance, mean return period of specified value of *a* for the given site can be described by just three parameters: (1) the mean site-characteristic, seismic activity rate, (2) parameter b/c_2 and (3) the maximum possible value of *a*, $a_{\max}$. The procedure for assessment of these parameters is given by Kijko and Graham (1999).

As an example of the application of the technique, the results of the *a* hazard maps for South and Sub-Saharan Africa are presented. The maps show the contoured median values of acceleration (*a*) with a 10% probability of exceedance in 50 years. The seismic hazard represented in Figures 2 and 3 show a 10% probability of exceeding the calculated PGA and spectral accelerations of 1Hz respectively, at least once in 50 years. Figure 4 shows similar results for Sub-Saharan Africa.

This methodology has been further extended to include an extensive seismic risk assessment which can project the expected damage and expected monetary losses of a critical structure within an area for a certain period of time.

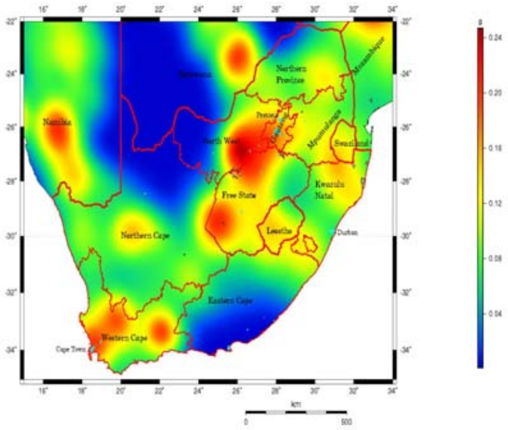

Figure 2. **Map of the expected PGA with a 10% probability of being exceeded at least once in a 50 year period for South Africa**

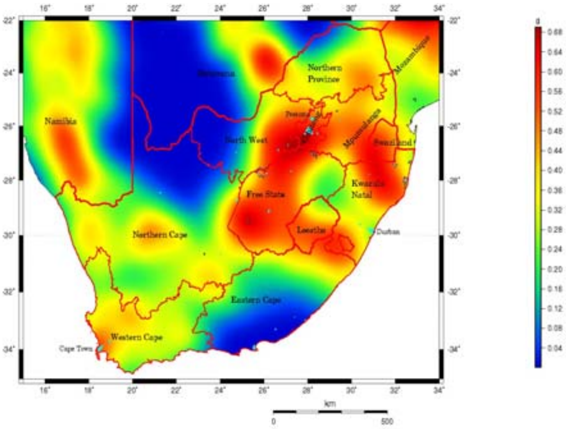

Figure 3. **Map of the 1 Hz acceleration response spectra with 10% probability of being exceeded at least once in a 50 year period for South Africa**

CONCLUSIONS

The procedure presented in this short paper largely addresses the incompleteness and uncertainties of seismic event catalogues (problems (i) and (ii) above), takes into account the inadequacies inherent in the selected model of seismicity (problem (iii)), and does not require the delineation of seismogenic source zones (problem (iv)).

The respective computer codes (written in FORTRAN 77 for PC) used for calculation of above hazard maps can be provided free of charge by the author.

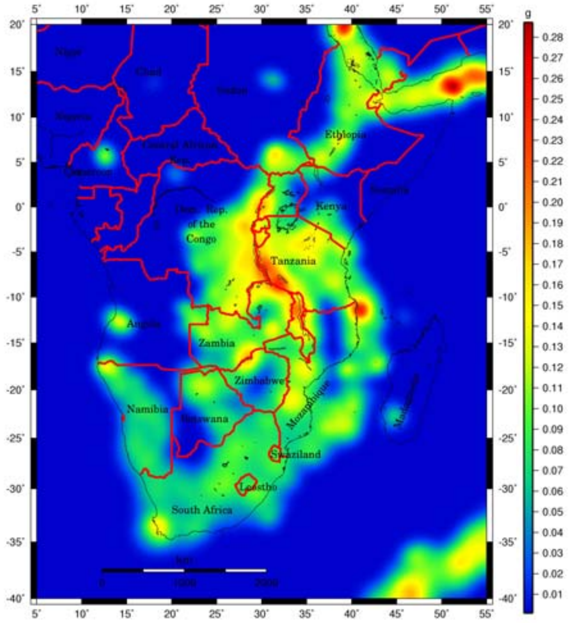

Figure 4. **Map of the expected PGA with a 10% probability of being exceeded at least once in a 50 year period for Sub-Saharan Africa**

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