Earthquake recurrence models for faults: the crucial role of intermediate magnitude earthquakes in seismic hazard assessment.

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Abstract: *Seismic hazard results (levels and scenarios) obtained for a site located close to a potentially active fault segment of the Durance fault system, southeast France, depend strongly on the assumed seismicity rates of intermediate magnitude events. We consider here three time-independent recurrence models: Gutenberg-Richter, Young-Coppersmith and Maximum Earthquake for the probability density function on magnitude and different slip rate estimates and historical seismicity to estimate the earthquake occurrence rates. We only consider M≥5 events in hazard calculations. The model producing the highest rate of intermediate magnitude events leads systematically to higher hazard levels and lower magnitude scenarios. The integration of the aleatory variability of ground motion prediction equations in the hazard calculation leads naturally to this result. Additional geological criteria indicative of the earthquake frequency-size potential of faults is necessary in order to reduce uncertainty in the modeling of intermediate magnitude events, potentially important contributors to seismic hazard estimates close to faults.*

1. Introduction

In many regions of the world fault characterization is difficult: paleoseismologial studies are scarce and it is often difficult to establish clear relationships between faults and seismicity. Yet potentially active faults have been mapped and have been recognized in high risk regions and they need to be considered in seismic hazard assessments.

To described fault activity in seismic hazard studies we appeal to recurrence models that describe the relative likelihood of different magnitude earthquakes on the fault and the rate of occurrence of earthquakes. Three probability density function on magnitude f(m) are currently used in the literature (Figure 1). (a) The truncated exponential model (GR) based on the results of Gutenberg and Richter (1944), with a lower and upper magnitude cut-off. (b) The maximum magnitude model (CE) based on seismological data compiled by Schwartz and Coppersmith (1984) and Wesnousky (1994), which suggests that some individual faults and fault segments tend to repeatedly generate earthquakes of comparable magnitudes. It consists of a truncated normal distribution for f(m) centered on the maximum magnitude. (c) The characteristic earthquake model (YC) for f(m) which was proposed by Youngs and Coppersmith (1985) to adjust the truncated exponential model to allow for the increased likelihood of characteristic events. The characteristic earthquake is uniformly distributed in the magnitude range of $mu-\Delta mc$ to mu (in this study we centred this interval on the maximum magnitude of the CE model) whereas lower magnitude earthquakes follow an exponential distribution..

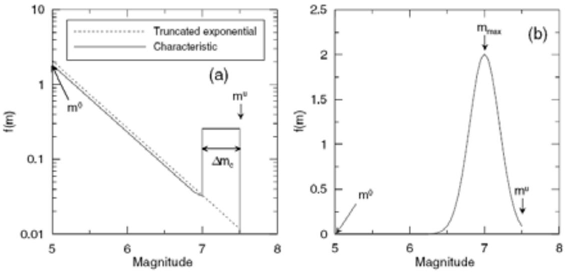

Figure 1 *Probability density functions for magnitude: (a) truncated exponential and characteristic, (b) maximum magnitude (from Stewart et al., 2001).*

Two philosophies are generally used to model the rate of earthquake occurrence: time-independent and time-dependent models. The time independent or Poisson model is the recurrence model commonly used in probabilistic seismic hazard analysis. The implication of this model is that the likelihood of occurrence of an earthquake in any time interval is independent of when the previous event occurred. However, the physics of the process of stress accumulation followed by release in characteristic earthquake ruptures on faults has led a number of investigators to consider time-dependent recurrence models for these sources. In the simplest form, time-dependent recurrence models are cast as a renewal model in which the likelihood of the next characteristic event occurring in a specified time interval is dependent only on the elapsed time since the previous characteristic event (e.g., Cornell and Winterstein, 1988). Here we assume time-independent models only.

The development of such models must be constrained in such a way that the moment release from earthquakes balances moment build up. For a given fault, moment build up is proportional to slip rate, which is the long-term, time-averaged relative velocity of block movements on opposite sides of the fault. Slip rates can be derived from the amount of slip that has occurred over a geologically defined interval, from the measurement of strains across a fault or from the seismic catalogue of the region through some simplified assumptions.

We calculate hazard at a site close to a single fault segment using two different approaches for the estimate of seismicity rates: one based on deformation data and a second one based on the historical seismicity catalogue. We then discuss the impact of each approach and each recurrence model on the seismic hazard and point out the need for additional data and numerical models to help reduce uncertainties in the modelling of intermediate magnitude events, potentially important contributors to seismic hazard estimates close to faults.

2. Model parameters and slip rate estimates

The Durance fault system is a potentially active structure of the south-eastern France tectonic province. Although the segmentation of this fault system is reasonably well characterized, the details of the surface projection of this fault are still debated (Aochi et al., 2005). Here we consider a 10x10 km^2 vertical fault segment and compute hazard for a site located 10km away .

Slip rates estimates (Scotti et al, 2005) along the Durance fault system vary between 0.07 mm/yr (GPS) and 0.2 mm/yr (geological markers). To compute hazard estimates we first compute for each slip rate the equivalent moment rate assuming the maximum magnitude is imposed by the fault geometry. This moment rate is then divided among the different magnitude bins following the three recurrence models. The resulting return periods for $M \geq 5$ events range between 475 and 26000 years.

Historical seismicity records, on the other hand, show evidence for an event of M5 along the Durance fault system almost every century, two of which are located along the southern faults segment modeled here. An additional hypothesis assumes therefore, that the fault segment maybe better characterized by a maximum magnitude recurrence model of M5 events. In this case, based on the historical seismicity and assuming the event can occur anywhere along 60 km long fault, we estimate the return period of $M=5$ for the fault modeled segment events between 400 and 800 years.

There is also paleoseismological evidence for the occurrence of an important seismic event between 9ky and 27ky along this fault segment which provides thus rough estimates of the recurrence periods that can be associated to $M>6$ events along this fault segment.

3. Results, discussion and questions

The resulting seismic hazard estimates and seismic scenarios (only $M \geq 5$ events are modeled) depend strongly on the assumed seismicity rates of the intermediate magnitude events. Assuming the maximum magnitude is imposed by the fault geometry, then the GR recurrence model leads to the higher hazard values and the lower magnitude seismic scenario (Figure 2) compared to CE and YC models. It is the intermediate magnitude range that contributes the most to the hazard due to the tail distributions of the ground motion prediction equations (epsilon > 1) integrated in these calculations. It is for this same reason that hazard computed following the Mmax=5 hypothesis may produce even greater hazard levels depending on the assumed return period and the annual probability of exceedance of interest.

The choice of an appropriate recurrence model for predicting seismic events along a given fault system is very often a difficult task. In this paper we have seen that the scarce data available for the Durance fault system, for example, does not allow to privilege one model or another: GR , CE and YC recurrence models do equally well/bad depending on the data that one prefers to fit. We have also seen that intermediate magnitude events dominate the hazard if the GR model is used or if we assume a maximum magnitude M5 that reflects the historical seismicity rates. Thus, if the search for strong paleoseismic events remains a priority, it is also important to pursue research that will help decision makers in choosing among existing recurrence models given their drastically different predictions for the moderate magnitude events.

In a recent publication Zoeller et al. (2005) suggest, on the basis of numerical modeling, that spatial heterogeneities significantly influence rupture propagation and thus the frequency-size statistics and other aspects of earthquake behavior. According to the authors, immature faults maybe characterized by strongly heterogeneous, non-planar fault zones having a broad spatial distribution of heterogeneities. Progressive slip tends to regularize the disorder and localize it long approximately planar fault-zones, thereby narrowing the range of sizes of the heterogeneities. Is the Durance fault system a mature or an immature fault? Which are the measurable field parameters that, can be injected in numerical models, to help define the maturity of a fault? Does the tectonic strain rate play a role? Answers to these questions may help choosing the appropriate recurrence models and reduce uncertainties in seismic hazard assessments.

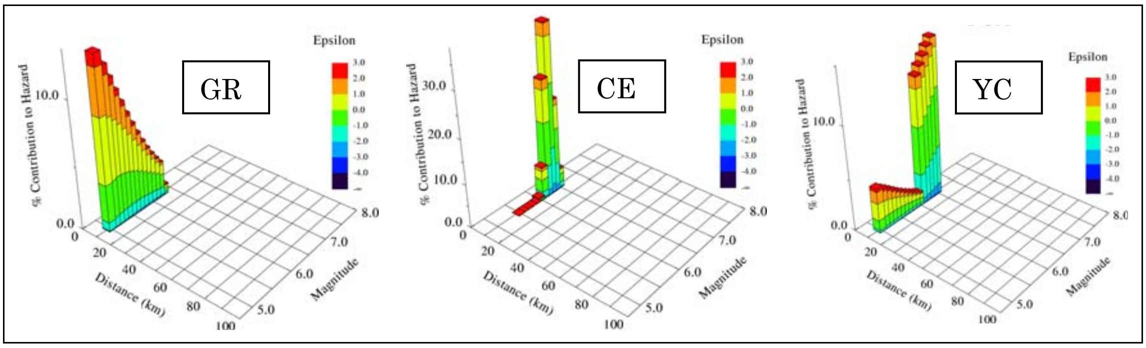

Figure 2 *Magnitude, distance and epsilon contributions to a given seismic hazard level at a site located 10km away from a 10x10km2 segment of the Durance fault system. The dominant seismic scenario depends strongly on the recurrence model used and the assumed slip rates (the moment rate budget is exactly the same for the three recurrence models).*

4. Acknowledgement

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5. References

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