A review of earthquake occurrence models for seismic hazard analysis

Thalia Anagnos

Department of Civil Engineering, San Jose State University, San Jose, CA 95192, USA

Anne S. Kiremidjian

Department of Civil Engineering, Stanford University, Stanford, CA 94305, USA

A large number of probabilistic earthquake occurrence models are currently available for seismic hazard assessment. This paper reviews the basic assumptions of the various models, summarizes their stochastic representations and discusses the parameters needed for applications. While the Poisson model is one of the most commonly used in practice it is limited in its representation of the physical earthquake driving mechanism and in its characterization of distinct seismicity patterns. From comparisons of the various models, it is observed that while the Poisson model may apply to regions characterized by moderate frequent earthquakes, other stochastic representations such as the Markov and semi-Markov models describe the sequences of events more adequately at regions with large infrequent earthquakes. Regions that have unique seismicity patterns such as clustering foreshock-mainshock-aftershock sequences are better represented by other stochastic models. It is found, however, that some of these models are difficult to implement and rather restrictive primarily because they require a considerable amount of additional data for model parameter estimation.

INTRODUCTION

Reliable estimation of the seismic hazard in a region requires the prediction of the size, location and magnitude of future earthquake events. An incomplete understanding of the earthquake phenomenon, however, has led to the development of primarily long-term hazard assessment tools relying on statistical averages of earthquake occurrences without considerations of specific patterns. As knowledge of the geophysical mechanisms that drive earthquake events has increased, so have the corresponding mathematical representations. Over the past two decades, numerous probabilistic models have been developed to depict various aspects of seismic occurrence patterns. The trend has been to introduce models that are specific to a particular region or fault. Some models reflect an apparent memoryless property, while others describe energy release sequences that are time and size dependent. Yet other models account for clustering, cyclicity, aftershock sequences and other patterns in the occurrence data.

At present, the number of probabilistic earthquake occurrence models is so overwhelming that a need exists to examine them and to assess their usefulness and applicability in various regions. The purpose of this paper is to review existing stochastic earthquake occurrence models and discuss their application to seismic hazard analysis. The underlying geophysical and modelling assumptions, the critical parameters and data needed for their determination, and the limitations of the various models are summarized and whenever possible critiqued for their applicability in regional earthquake hazard analyses. There is no simple answer to the question which is the best model. Ultimately a great deal of engineering judgement is involved in decisions about which models provide the best assessment of seismic hazard for a particular region. Table 1 provides a summary of the earthquake occurence models found in the literature and gives a brief comment about unique characteristics of each. While an effort is made to include most available models, the list is not intended to be comprehensive.

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STOCHASTIC MODEL FORMULATIONS

The objective in seismic hazard modelling is to obtain long term predictions of the occurrences of seismic events. Most often the prediction is expressed in the form of probabilities of exceedence of a specified earthquake magnitude over a period of time t or as the expected number of such events. Thus, if $N(t)$ represents the number of events in time $(0, t)$ and M defines the size of the events, then that probability is expressed as $P\{N(t)>0$ and $M \geqslant m$, $(0, t)\}$ and the expected number of events are $E[N(t)>0$ and $M \geqslant m$, $(0, t)]$. More recently, attention has also focused on the time dependence of earthquakes and representation of that time dependence. For example, information on seismic gaps, characteristic events, time of occurrence and magnitude of the last seismic event can play an important role in hazard computations. Thus, the probabilities of occurrence of at least one event of size M or greater in time $(t_1, t_1 + t)$ given that the last event was of