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Simulation-Based Distributions of Earthquake Recurrence Times on the San Andreas Fault System

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Abstract Earthquakes on a specified fault (or fault segment) with magnitudes greater than a specified value have a statistical distribution of recurrence times. The mean recurrence time can be related to the rate of strain accumulation and the strength of the fault. Very few faults have a recorded history of earthquakes that define a distribution well. For hazard assessment, in general, a statistical distribution of recurrence times is assumed along with parameter values. Assumed distributions include the Weibull (stretched exponential) distribution, the lognormal distribution, and the Brownian passage-time (inverse Gaussian) distribution. The distribution of earthquake waiting times is the conditional probability that an earthquake will occur at a time in the future if it has not occurred for a specified time in the past. The distribution of waiting times is very sensitive to the distribution of recurrence times. An exponential distribution of recurrence times is Poissonian, so there is no memory of the last event. The distribution of recurrence times must be thinner than the exponential if the mean waiting time is to decrease as the time since the last earthquake increases. Neither the lognormal or the Brownian passage time distribution satisfies this requirement. We use the "Virtual California" model for earthquake occurrence on the San Andreas fault system to produce a synthetic distribution of earthquake recurrence times on various faults in the San Andreas system. We find that the synthetic data are well represented by Weibull distributions. We also show that the Weibull distribution follows from both damage mechanics and statistical physics.

Introduction

The purpose of this article is to study the recurrence-time statistics of earthquakes in California. To do this we present the results of a 10^6-yr simulation of earthquake occurrence on a specified set of interacting faults in California. This simulation, "Virtual California," gives the statistical distribution of recurrence times between earthquakes on the faults and fault segments. An essential question is whether these simulation results can be used to quantify probabilistic earthquake-hazard assessments in California.

Clearly, the primary seismogenic fault in California is the San Andreas. Great earthquakes occur on the northern section, that is, 1906, and on the southern section, that is, 1857. The simplest model for the behavior of major faults is based on the hypothesis that a fault, or fault segment, experiences a periodic repetition of "characteristic" earthquakes (Youngs and Coppersmith, 1985). These ideas have been quantified by the slip-predictable and time-predictable models of earthquake occurrence (Shimazaki and Nakata, 1980). It is now well established, however, that earthquakes rarely occur without some aperiodicity. In addition, neither the slip-predictable nor the time-predictable models for earthquake recurrence have been successful. According to available evidence there is considerable variability in both the recurrence times and in the magnitudes of characteristic earthquakes. This variability can be attributed to the interactions between faults and fault segments. One example is the role of "stress shadows" following an earthquake or volcanic inflation (Rundle and Whitcomb, 1984; Harris, 2003). A relevant question is whether the reduced number of $m \approx 6$ earthquakes in northern California since 1906 can be attributed to the stress shadow of that earthquake.

Despite the extreme complexity of seismicity in California, well-known scaling laws are applicable (Turcotte, 1997). One example is the Gutenberg-Richter frequency-magnitude scaling. Another is Omori's law for the temporal decay of aftershocks. The question to be addressed in this article is whether recurrence-time statistics of earthquakes also satisfy a universal scaling law. Ideally, this question would be answered by using actual data. However, observed sequences of earthquakes on faults are so small that is it not possible to establish statistical patterns. For this reason we utilize numerical simulations of earthquake occurrence. With our simulation using Virtual California, we generate thousands of earthquakes on each fault segment considered.