The effect of structural complexity and fault roughness on fault segment size and multi-segment rupture probability

Southern California Earthquake Center Research Summary 2009

Ramón Arrowsmith
&
Olaf Zielke
School of Earth and Space Exploration (SESE)
Arizona State University
Tempe, AZ 85287-1404, U.S.A.
ramon.arrowsmith@asu.edu

Assessing the potential size and recurrence statistics of future earthquakes along an active fault is required for seismic hazard analysis, formulation of building codes, and emergency response planning. It also addresses the basic scientific question of how faults behave seismically. The first step in this assessment is an analysis of seismic and paleoseismic records to determine size and frequency of past earthquakes along a fault. However, for most tectonically active faults, these records are only partially helpful: spanning not even a single seismic cycle, instrumental seismic catalogs contain little information about recurrence probability of the largest earthquakes. Paleoseismic records from only a few sites along a fault on the other hand lack completeness (recording only ground-rupturing earthquakes at the respective locations) and are difficult to extrapolate to whole fault behavior. Additional means to assess potential size and probability of future (large) earthquakes are necessary.

Empirical relationships, derived from historic earthquakes, revealed that earthquake size is proportional to rupture area. Therefore, the size of the largest earthquakes that may occur along a fault is constrained by its spatial dimension (fault length and width). Geologic data show that faults evolve over time, growing laterally and becoming straighter as more and more slip is accumulated along them. Maximum earthquake size and seismic behavior should therefore change at geologic time scales as fault geometry and structural maturity evolve.

Based on numerical earthquake simulations (using FIMozFric--a quasi-static simulator implementing non-planar fault surfaces and depth-dependent coseismic stress drop developed by Olaf Zielke in his Ph.D.), we show how fault geometric constraints and structural maturity (fault roughness) effect earthquake frequency-size relation and maximum earthquake size, fault segmentation, and along-fault slip accumulation patterns. Bimodality in magnitude frequency distribution [small to moderate size earthquakes are following Gutenberg-Richter (GR) relation while large earthquakes are more frequent then anticipated from GR, following the characteristic earthquake model (CEM)] is controlled by fault maturity. As faults accumulate more and more slip (become smoother) the characteristic magnitude of large earthquakes increases and an increasing portion of seismic moment is released via large earthquake rupture. Small to moderate magnitude earthquake behavior is largely independent of fault maturity. Slip at a point is generally variable, however simulation results suggest that variability is not random but systematic. Based on our simulation results we suggest that the previously presented earthquake recurrence models (variable slip model, uniform slip model, characteristic earthquake model) may all be valid--each referring to faults in different evolutionary stages and/or fault system configurations. Our results further suggest that predictability of earthquakes evolves with geometric maturation--major earthquakes along isolated faults may exhibit inherent periodicity. These findings may help to improve assessments of potential size and recurrence statistics of future earthquakes.

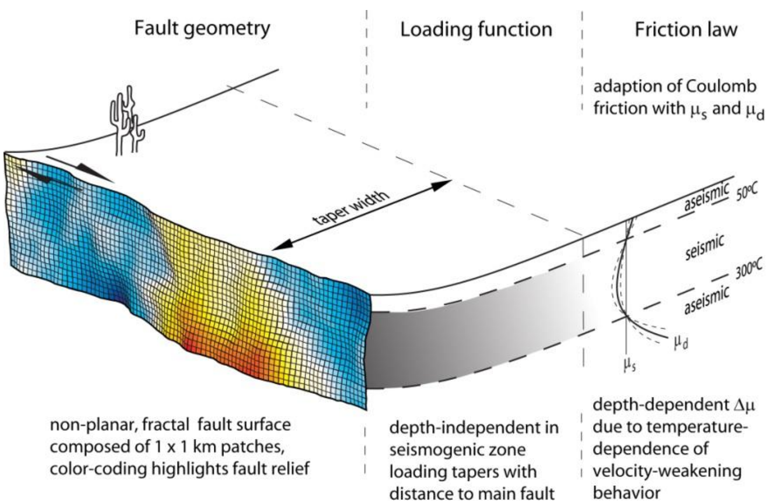

Figure 1. Overview of simulator formulation, consisting of three main components: fault geometry, loading function and friction law.

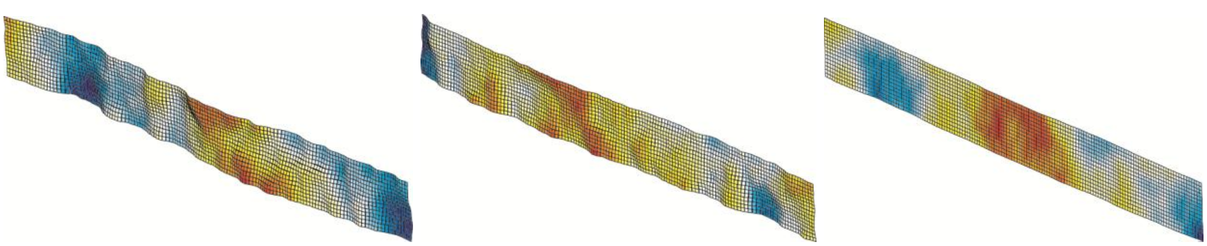

Figure 2. Example faults with different fault geometric roughness (indicated by color-coding), a proxy for fault maturity. As a fault accumulates more and more slip, structural barriers that may serve as arrest points for rupture propagation are subsequently degraded (grinded down). Consequently, ruptures may grow larger: maximum earthquake size along a fault increases over geologic time scales as the fault matures while the frequency-size distribution of small to moderate size earthquakes is relatively insensitive to structural changes.

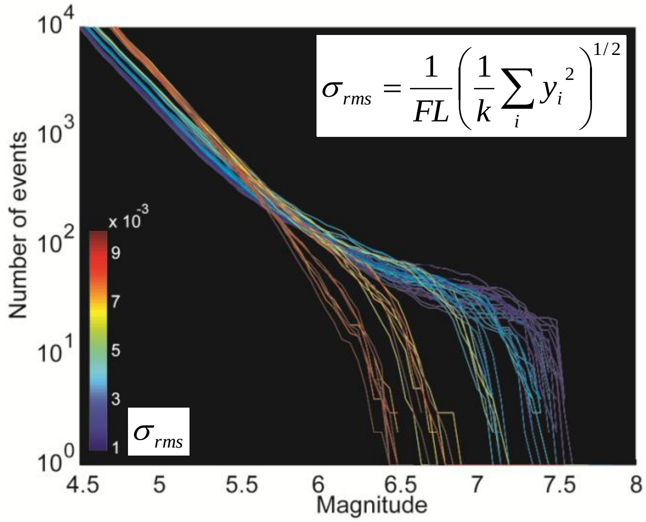

Figure 3. Cumulative magnitude frequency relationship for earthquake simulations along faults with different roughness values (σ_{rms}, normalized by fault length FL). Seismic behavior is becoming increasingly characteristic i.e., bimodal as the fault matures (indicated by decreasing roughness, in cold colors)

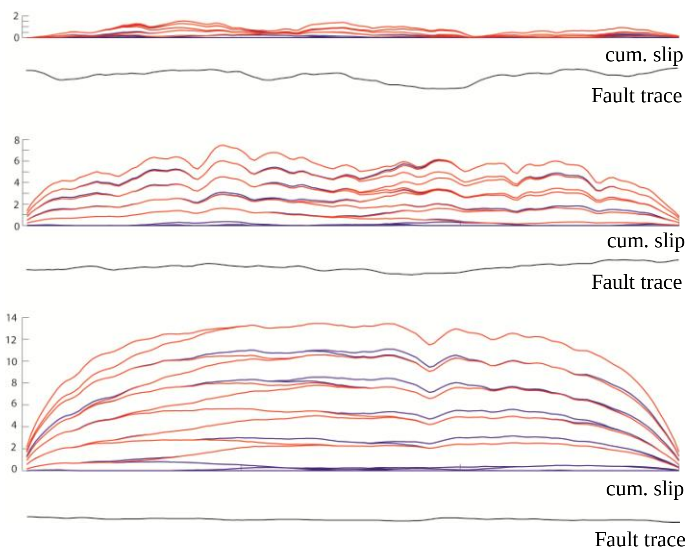

Figure 4. Cumulative surface slip of 10 full rupture earthquakes (in red) and additional partial rupture earthquakes (in blue) during the same time interval for three faults with different fault roughness. Fault trace of each fault is indicated. Slip accumulation becomes increasingly uniform (less segmented) for smoother (more mature) faults. As the fault matures, fault segments coalesce, forming new segments and therefore increasing maximum potential earthquake size.

Results of this study have been presented at AGU 2009, will be presented at EGU 2010 and are a manuscript is in preparation for the Journal of Geophysical Research. We also responded to a request from Doug Burbank to help with developing an instructional box on earthquake frequency magnitude relations for the next edition of the Tectonic Geomorphology textbook.

Zielke, O., How Fault Geometric Complexity and Frictional Properties Affect Seismic Fault Behavior and Accumulation of Slip Along Strike-Slip Faults, Ph.D. dissertation, Arizona State University, December 2009.

O. Zielke; R. Arrowsmith (2009) How fault geometric constraints and structural complexity effect earthquake frequency-size relations and maximum earthquake size, Eos Trans. AGU, Fall Meet. Suppl., Abstract T11F-08.

Zielke, O., Arrowsmith, J R., Fault geometric complexity and how it may cause temporal slip-rate variation within an interacting fault system, European Geophysical Union abstract EGU2010-8073, 2010.