The Physics of Space-Time Interactions: Analysis based on Recreating Great Earthquakes in the Computer

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The San Francisco earthquake and fire of April 18, 1906 killed more than 3,000 persons, and destroyed much of the city leaving 225,000 out of 400,000 inhabitants homeless. The 1906 earthquake occurred on a 470 km segment of the San Andreas fault that runs from the San Juan Bautista north to Cape Mendocino and is estimated to have had a moment magnitude $m \approx 7.9$. Observations of surface displacements across the fault were in the range $2.0 - 5.0$ m. As we approach the hundredth anniversary of the great San Francisco earthquake, a timely question is the extent of the hazard posed by another such event, and how this hazard may be estimated.

We present an analysis of this problem based upon a numerical simulation, *Virtual California*, that include many of the physical processes known to be important in earthquake dynamics. Virtual California is a "backslip model", meaning that the long term rate of slip on each fault segment in the model is matched to the observed rate. The faults in the model interact by means of quasistatic elasticity, and frictional dynamics are based on laboratory friction experiments. Constraints for the input parameters for these models originate from field data, and typically include realistic fault system topologies, realistic long term slip rates, and realistic frictional parameters. Outputs from the simulations include synthetic earthquake sequences and space-time patterns, together with associated surface deformation and strain patterns that are similar to those seen in nature. Our simulations can be used to compute, or "measure", empirical statistical distributions (probability density functions: PDFs) that characterize the activity. Examples include PDFs for recurrence intervals on selected faults. These PDFs can be used to construct probabilistic seismic forecasts for selected faults or groups of faults. The major difference between the simulation-based method and current statistical approaches lies in the way in which inter-event times and probabilities for joint failure of multiple segments are computed. In our simulation-based approach, these times and probabilities come from the modeling of fault interactions and laboratory-based friction laws.

Space-time patterns of activity can be defined based upon Karhunen-Loeve expansions (Principal Component Analysis) that lead to deeper understanding of fundamental patterns of correlated activity in the fault system. An example of this type of result is our discovery that the two most significant modes of activity represent coordinated events on 1) the Northern San Andreas-Haward-Calaveras system; and on the Big-Bend region of the San Andreas together with the Garlock fault. We also find that the creeping section tends to decouple activity in northern and southern California.

We are presently introducing dipping faults into the model, and moving to much large system sizes. All of our codes are based on an open-source paradigm, and are now written in a full, object-oriented C++ approach.

[1] J.B. Rundle, PB Rundle, A Donnellan, D Turcotte, R Shcherbakov, P Li, BD Malamud, LB Grant, GC Fox, D McLeod, G Yakovlev, J Parker, W Klein, KF Tiampo, A simulation-based approach to forecasting the next great San Francisco earthquake, *Proc. Nat. Acad. Sci.*, 102: 15363-15367 (2005) ; published online before print October 11 2005, 10.1073/pnas.0507528102
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