SECTION NEWS

S E I S M O L O G Y

Section President, *Paul G. Silver;* **Section Secretary**, *John Ebel*

Earthquake Rupture Dynamics: Comparing the Numerical Simulation Methods

PAGE 321

Thirty years ago, scientists first developed computer programs that could tackle the complicated problem of simulating earthquakes as dynamic rupture processes, and predicting the ensuing fault movement.

At first, only a few people were able to formulate the appropriate numerical solutions, but these researchers were working with methods that could rarely simulate the full three-dimensional world in which real earthquakes occur. Now, three decades later, our computational infrastructure has vastly improved, along with our knowledge about how to construct computer software that numerically simulates the sudden faulting that occurs during earthquakes. Whereas in the past a lack of computational power provided formidable obstacles, in the present computer capacity is less of a concern, but the science is still hampered by a lack of key field observations, along with critical ideas about the predominant physical processes that control earthquakes.

One of the challenges with the increasing amount of sophisticated and complex computer software currently in use is making sure that it is yielding consistent solutions. For simple kinematic cases of earthquake simulation, such as rupture spreading outward at an assumed constant rupture speed, there is an analytical solution with which to check the computer simulations. However, as soon as one considers more complex scenarios, whereby the earthquake's rupture speed and other behavior are not pre-determined, but instead result from the physics (dynamic, spontaneous rupture solutions), there are no analytical solutions for comparison. Accordingly, a strategy to validate these hugely complex rupture-dynamics simulation codes is to compare the results of software written by independent authors. That is, given the same initial information, such as the fault geometry, the material surrounding the faults, the initial stress conditions on the faults, and the friction formulation (Figure 1), each numerical method should be able to produce the same resulting fault behavior, such as the time-dependent slip rates on the fault, and velocities (seismograms) at each point on the Earth's surface (Figure 2).

To address this benchmarking challenge, scientists from the U.S. Geological Survey and the Southern California Earthquake Center (SCEC) are conducting a computer-program comparison exercise. For the first round of tests, performed in the fall of 2003, the users of nine different computer programs were provided with specific details of the parameters needed to computationally simulate the instantaneous nucleation, then gradual propagation of an earthquake on a vertical strike-slip fault. The results, presented at a SCEC workshop held at the University of Southern California in November 2003, showed promise, but consensus was not achieved among all of the methods examined. Only two of the methods produced nearly the same synthetic seismograms and fault rupture velocity distributions. At the workshop, it was realized that user interpretation of the nucleation parameters had led to some of the discrepancies among the simulations, and that this was a problem that could be easily corrected.

In 2004, the USGS and SCEC researchers are continuing their efforts, with the goal of achieving inter-code agreement on the problem first tackled in 2003. This effort will be expanded to examine other simple earthquake scenarios consisting of fault geometries and rheologies that can be addressed by all of the codes; and rupture dynamics and the resulting seismograms recorded in laboratory experiments will be numerically simulated. When inter-code agreement is achieved for these simpler cases, the codes, or types of codes, that are best suited for each particular, more complex view of fault geometry and fault rheology will then be investigated.

This benchmarking exercise provides a means of assessing the precision and, with comparisons to field observations, ultimately the accuracy of the computer programs for a situation for which analytical solutions do not exist. It is hoped that this exercise will inspire confidence in future users of the products, such as building engineers and public policy-makers,

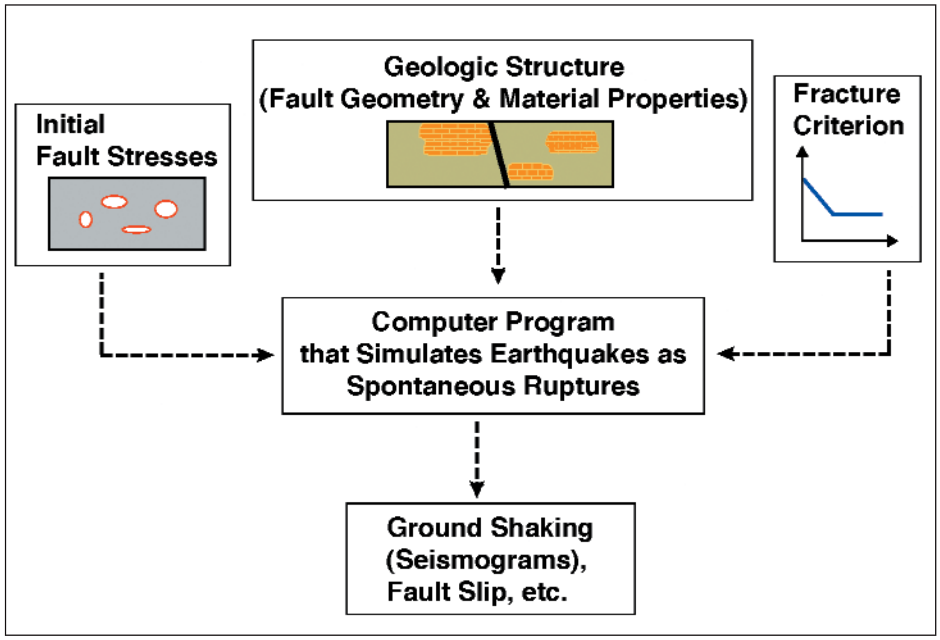

Fig. 1. Flow chart showing how spontaneous rupture computer programs work. The parameters needed to construct a spontaneous rupture earthquake simulation include the initial shear and normal stresses on the fault(s), the fault geometry and the P- and S-wave velocities and densities of the rocks surrounding the fault(s), and the criterion used to determine when each point on the fault(s) can fail. The output from these simulations include a host of options, including seismograms, fault slip, earthquake rupture velocities, among others.

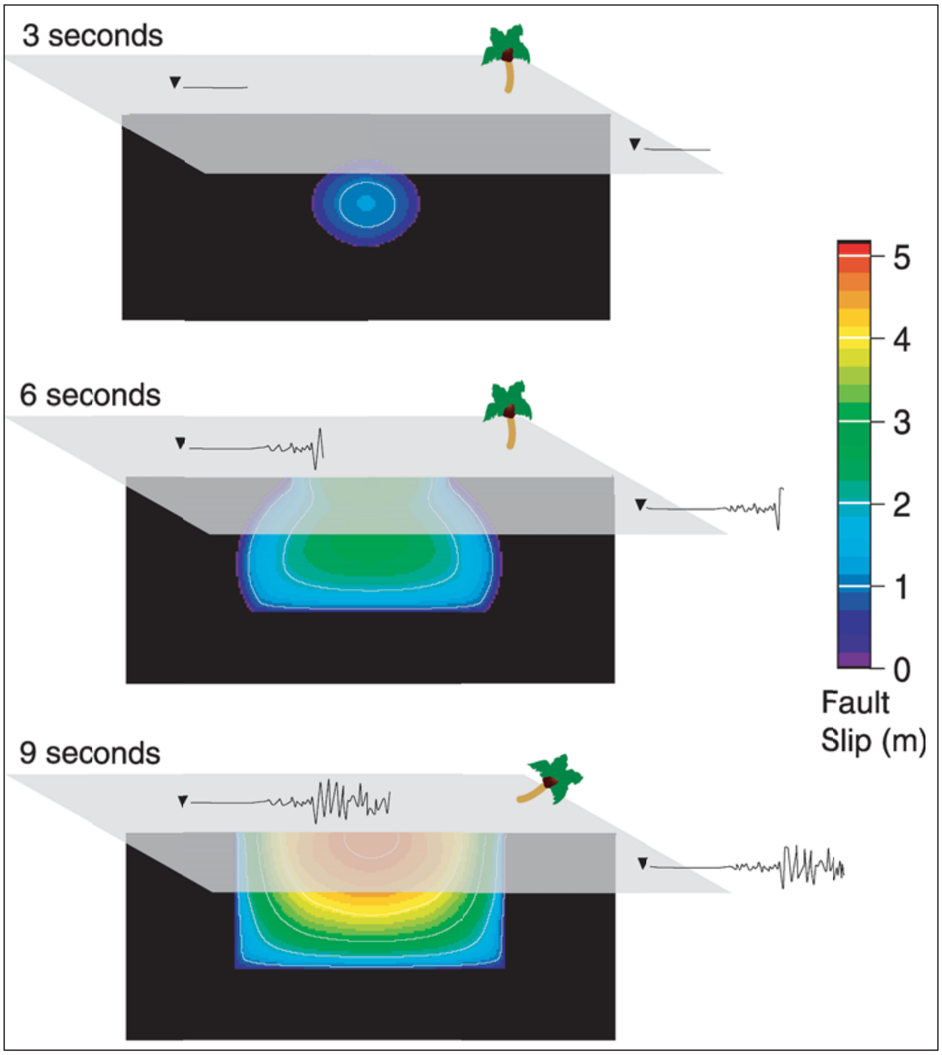

Fig. 2. A spontaneous rupture model of a simulated earthquake that nucleates at zero seconds in the middle of a vertical strike-slip fault. The black regions indicate where no slip has occurred on the fault. The simulated earthquake propagates where the stress conditions and friction are sufficient. The simulated earthquake stops where and when there is not enough energy to continue, such as at the ends and bottom of the rectangular fault. Synthetic seismograms are shown at stations (the triangles) on the Earth's surface.

so that they will consider the use of dynamic rupture simulations when estimating future earthquake hazard.

Acknowledgments

The 2003 workshop was funded by the Southern California Earthquake Center (which in turn is funded by grants from the U.S. Geological Survey and the U.S. National Science Foundation). This is SCEC contribution number 776. We appreciate helpful reviews from Art McGarr, Brad Aagaard, and John Geissman.

—RUTH A. HARRIS, U.S. Geological Survey, Menlo Park, Calif.; and RALPH J. ARCHULETA, University of California, Santa Barbara