Annual Report, 2003
SOUTHERN CALIFORNIA EARTHQUAKE CENTER

Title of Projects:
Collaborative Research: Paleoseismic Constraints on Earthquake Simulation Models of Southern California:
Methods for evaluating and testing earthquake potential in and around California

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Our SCEC funded research in 2003 dealt with: 1) continuing efforts to improve and deploy various classes of earthquake potential/earthquake likelihood models in support of the RELM program and 2) a new collaborative effort with paleoseismologists to push forward southern California Earthquake Simulators. Much of the material in this report also appears in our 2004 SCEC proposals to continue these projects.

I. Southern California Earthquake Simulator - Physics Based.

We continue to develop a physics based earthquake simulator that produces spontaneous ruptures on geographically correct and complex system of interacting faults. The current simulator encompasses all 5500 km of the faults in southern California that slip faster than 1/4 mm/y. While the simulator admits several simplifications (2-D geometry, purely elastic media, modified quasi-static assumption), it has been designed specifically to reproduce and incorporate behaviors that geologists measure such as slip rate, slip per event and recurrence interval. We call this a "data first" approach to model building as opposed to "technique first" approaches. The simulator generates quakes from magnitude 8+ down to about magnitude 4, so a 2000 year run produces ~10,000 events spread from Mexico to Parkfield, and from San Clemente Island to Nevada. The best means to grasp the complex patterns of quakes is through animation. These animations represent a portion of this year's progress. Figure 1 shows a few frames of a recent run. We encourage readers to view the movie at:

http://es.ucsc.edu/~ward/simulation6_pga.mov

The simulations provide all details of every rupture. Computed surface offsets along strike however, are especially telling because the purest paleoseismic data are earthquake dates and earthquake slip measured at a point -- the paleoseismic site. Geologists can locate their site on these maps and compare predicted slip per event and its variation directly. Over long periods, the slip for all quakes always sums to the specified slip rate of the fault. The agreement of the predicted long-term seismic offset with measured geologic slip rate is a fundamental feature of this simulator.

II. Paleoseismic Constraints -The SERT

This year we have ramped up the use of paleoseismic data and started work on a new data product call the *Simplified Earthquake Recurrence Table.* The SERT represents a simplified working consensus on recurrence interval versus magnitude for the faults of Southern California for comparison with earthquake simulators. The SERT data constrain earthquake simulators in two ways: 1) through input of measured *slip rates*, and 2) by comparison of computed *recurrence interval* and *slip per event* with actual field measurements. While fault slip rate is a direct constraint, slip per event and recurrence interval are applied indirectly. For these reasons, iterative fault strength adjustments are made to the model to match reasonably well paleoseismic recurrence intervals. The current SERT (see Table 1) has recurrence estimates for 41 of 101 faults. The columns list recurrence interval in years for M6+, M6.5+, M7+ and M7.5+ earthquakes breaking various faults and fault segments. All higher magnitude events are included in the rates of lower magnitude events so the recurrence interval decreases right to left. Large magnitude events that break several fault segments are included in the recurrence statistics of multiple lines. We view the SERT not as a database like the FAD, but rather a *data product*.

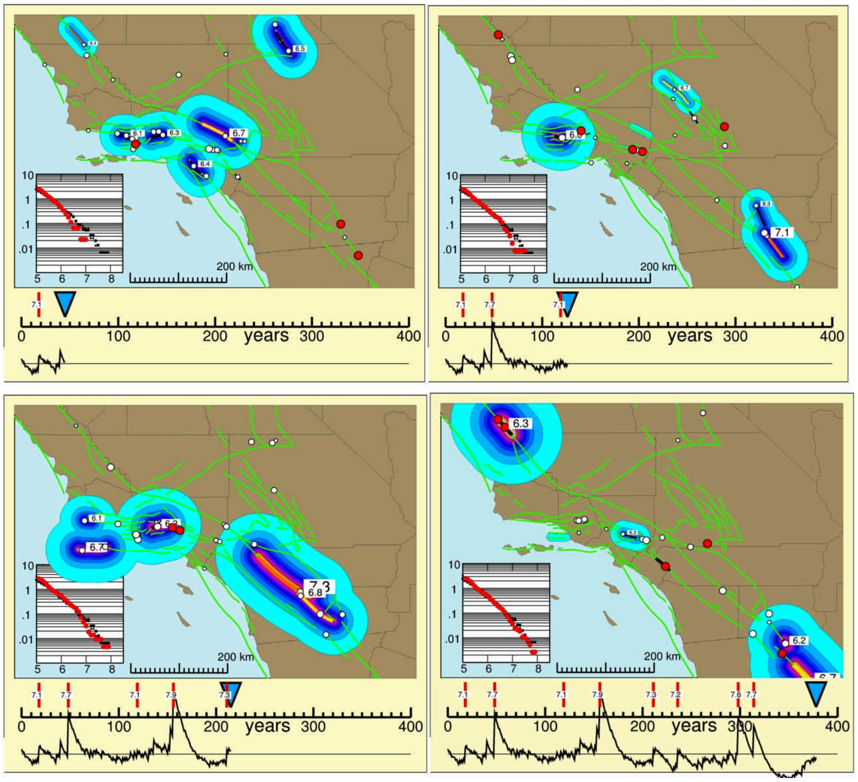

Figure 1. Four frames of animation from a recent run of the earthquake simulator. The animation shows a 400 year earthquake sequence in 1 year steps. The movie plots all earthquakes M>5. For events M>6, PGA is contoured around the rupture and a magnitude number is shown. To the left is a graph of the cumulative number of M5+ quakes (red dots) overlaid on the actual rates (black dots) from 1850-2002. The simulator now involves a wide enough selection of faults such that bulk seismicity is Gutenberg-Richter like, with a b value near 0.9. Along the bottom is a sliding time indicator that deposits red bars at the occurrence of M>7 events. The residual "bar code" pattern gives some feeling for the periodicity or aperiodicity of major quakes. The jagged line along the bottom is the 25 year average rate of M5+ events. See http://es.ucsc.edu /~ward/simulation6_pga.mov

SERT2003.10

Fault	M6+	M6.5+	M7+	M7.5+	Slip Rate
A7 SAF-Creeping					0
A8 SAF-Parkfield	<	25			34
A9 SAF-Cholame	<	<	230		34
A10 SAF-Carrizo	<	<	160	250	34
A11 SAF-Mojave	<	<	105		30
A12 SAF-San Bernar	<	<	144		24
A13 SAF-Coachella	<	<	220		18
A14 Brawley	200	<			5
A15N Imperial-N	<	130			20
A15C Imperial-C	<	<	240		20
A15S Imperial-S	<	130			20
SJ8 San Bernardino	<	<	200		15
SJ9 San Jacinto	<	<			15
SJ10 Anza	<	<	250		15
SJ11 Coyote Cr	<	80			5
SJ12 Borrego	<	80			4
SJ13 Superstion Mt.	<	<	300		5
SJ14 Superstion Hll	<	150			4
SJ15 Elmore Ranch	150				1
EL15 Whittier	<	<	1750		2.5
EL16 Glen Ivy	<	175			5
EL17 Temecula	<	<	500		5
EL18 Julian	<	<	<	2500	3
EL19 Coyote Mt.	<	<	900		3
EL20 Laguna Salada	<	<	2000		3.5
EL21 Earthqk Valley	<	<	3000		2
LA12 Palos Verdes	<	<	1500		3
SB09 San Cayetano	<	450			6
SD02 Rose Cny-off	<	<	2500		1.5
SE02 Garlock E	<	<	<	500	7
SE01 Garlock W	<	<	<	700	6
SE12 Pinto Mtn	<	<	3300		2.5
LA09 Hollywood	<	<	10000		1
LA13 Newport Ing	<	<	2000		1
CI01 Santa Rosa Isl	<	<	8000		1
SE03 Blackwater	<	<	5000		0.6
SE05 Helendale	<	<	3300		0.6
SE08 Bullion-Mesq	<	<	3300		0.6
SE09 Johnson Vly-N	<	<	5000		0.6
SE10 Landers	<	<	6000		0.6
SE11 Emerson-CpMt	<	<	5000		0.6

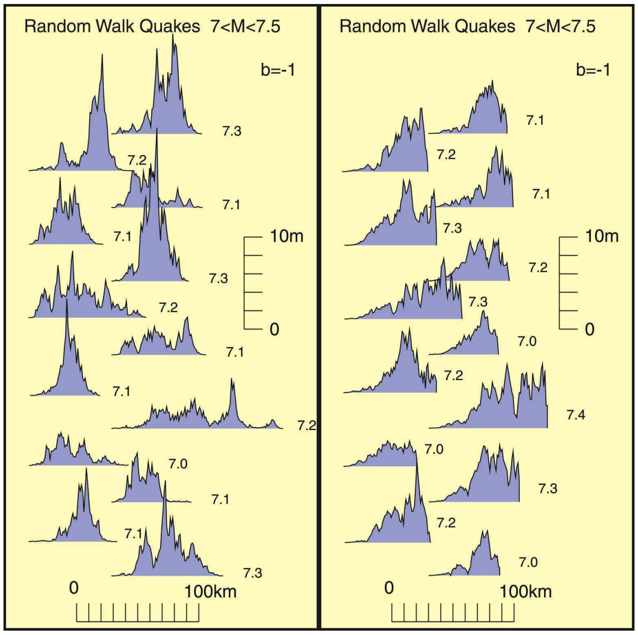

Figure 2. Earthquake ruptures $7<M_w<7.5$ as simulated by a two classes of restricted random walks with b=-1. *(left)* The slip functions here centered but are quite "peaky" with a ratio of peak slip to mean slip of about 4. (*right*) The slip functions here have a smaller peak to mean ratio (about 3) but they are visibly skewed. Which is better? The Earthquake Slip Function Catalog will tell.

While a database strives to collect all objective information from original sources, a data product employs experts to pre-digest the raw data base and arbitrate as needed. A purest may view data products as "contaminated" but often, data products are more useful for many parties who'd rather not trace back original data and make interpretations themselves.

III. Southern California Earthquake Simulator - Statistically Based.

Many SCEC scientists are working to construct physically-based earthquake simulators. Physical simulators intend to employ fundamental laws of physics to generate long sequences of earthquakes on the fault system of southern California. This approach has considerable appeal and physical earthquake simulators continue to become increasingly rigorous in fault geometry, rheological structure and fault friction assumptions. One concern however, is that physical simulators may become so complex and non-linear that much of the model building effort is expended in finding a physical basis for essentially random behavior. If certain aspects of earthquake behaviors are random to the extent that real data can constrain them, then a more practical approach toward modeling these aspects may be to embrace the randomness whatever its physical origin.

To help ease this concern, in 2003 we have made initial steps to: 1) Develop and apply random walk rupture simulations to southern California earthquake issues; and 2) Begin to assemble an earthquake slip function catalog (ESFC) with which to test the simulator and to serve as a SCEC community resource for other applications. The statistical simulator is intended to complement the physical simulator in those applications where it may be better suited. The degree to which any earthquake simulator finds use depends upon its success in reproducing

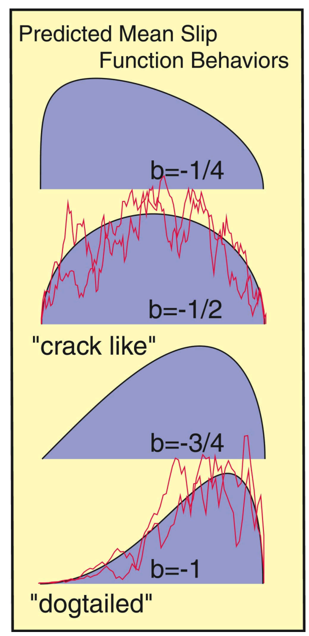

Figure 3. The blue curves are mean slip function behaviors derived from random walk theory for different b-values. The red lines are sample quakes with the given b-value

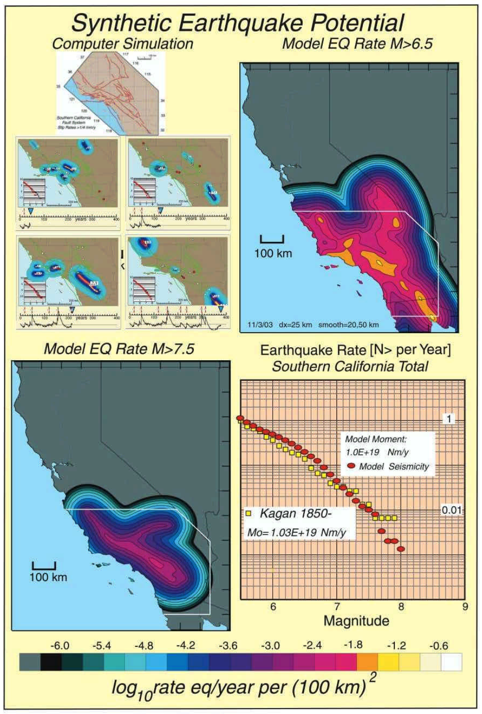

Figure 4. Synthetic earthquake potential models for $M_>$=6.5 (top right) and 7.5 (lower left). These maps were produced from a 1500 year run of the earthquake simulator, much like Figure 1.

known earthquake properties. Accordingly, a collaborative effort between modelers and geologists is called for.

Initial random walk results tell us that: 1) Not only does b-value control the ratio of large to small events, but it also dictates the form of earthquake scaling laws: slip versus length, moment versus length, etc. 2) Moreover, b-value controls the "look and feel" of earthquake slip functions (see Figure 2). Look and feel includes most anything that can be measured in the field: peak slip to mean slip, skewness etc. For instance, b=-1/2 random walks give crack like behavior in the mean (see Figure 3) while b=-1 quakes present a dogtailed/rainbow look. Most of the slip shapes in Figure 3 are seen in the field and are found in the physical simulations too. We believe that random walks can not be far off base in capturing a unified view of earthquake behaviors, even if randomness is just a stand-in for unknown physics. We think that this work forms the motivation/framework to start to catalog earthquake slip functions and build a classification scheme for slip shapes.

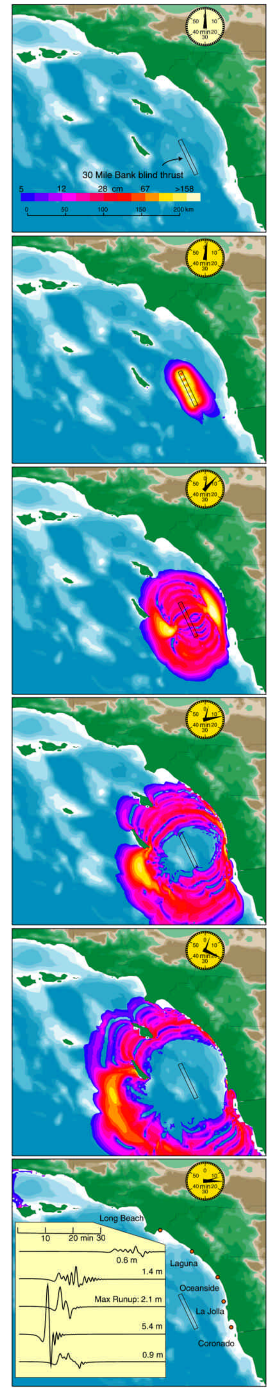

Figure 5. Tsunami waves from a 30 mile bank earthquake.

IV. Earthquake Simulation Hazard Models

In 2004 we continued to consider earthquake potential models for RELM. The new results from the physical earthquake simulator have been included in an updated Synthetic Earthquake Potential map (see Figure 4). A new geodetic model based on the SCEC Crustal Motion Map 3 will be ready by the February RELM meeting.

V. Borderland Tsunami Models

In 2004 we also began work on wave modeling of earthquake and landslide-generated tsunami in the California Borderland (see Figure 5.)