Final Project Summary — PEER Lifelines Program

Project Title—**ID Number**	*Rapid Ground Motion Estimates*—**701**		
Start/End Dates	5/1/00 – 4/30/01	Budget/ Funding Source	$65,000/ PG&E/CEC
Project Leader (boldface) and Other Team Members	**Dreger (UCB),** Kaverina (UCB), Gee (UCB), Lombard (UCB), Neuhauser (UCB)		

1. Project goals and objectives

The objective of this project was to develop an automated system for the analysis of earthquake finite source parameters such as fault length, orientation and slip distribution quickly after the occurrence of an event and to use this information to determine rapid estimates of near-fault strong ground shaking. The ground motion estimates that take fault finiteness and rupture directivity into account are then used to augment ShakeMaps in sparse monitoring situations or in cases where data telemetry failures preclude the recovery of near-realtime strong motion data. This system was developed to improve ShakeMap capability for magnitude greater than 6 events throughout California.

2. Benefits of the results of this project to develop technologies and protocols to mitigate the vulnerability of electric systems and other lifelines to damage directly and indirectly caused by earthquakes. Also, benefits to develop assessment techniques to evaluate damage to electric systems caused by earthquakes and to assess fiscal impacts due to the loss of electric service to the community.

The results of this project benefit the rapid assessment of earthquake effects on electrical systems and other lifelines by providing the capability to map the distribution of near-fault strong ground shaking. Because of the distributed nature of lifeline systems it is necessary to have a method that can operate under sparse monitoring conditions as well as in densely instrumented urban regions. With the strong motion ShakeMaps users can assess the impact of the earthquake on lifelines systems facilitating inspection and repair. This system was recently tested by the December 22, 2003 San Simeon, California earthquake (Mw6.5), which occurred in a sparsely instrumented region yet killed two people and caused substantial damage. Section 4 describes how this method contributed to the rapid assessment of this earthquake.

3. Brief description of the accomplishments of the project

In this project we successfully updated our finite-source inversion software, integrated this software into the realtime earthquake monitoring system at the Berkeley Seismological Laboratory, defined a protocol for communicating results to USGS colleagues and for updating published ShakeMaps. This involved working closely with scientists at the Menlo Park and Golden offices of the USGS as well as at PG&E to ensure that data formats for the exchange of information was suitable for ShakeMap, the general audience, as well as for the needs of PG&E.

In addition a web-based analyst interface was developed to streamline the review and updating of the results.

4. Describe any instances where you are aware that your results have been used in industry

This system was operational at the time of the December 22, 2003 Mw6.5 San Simeon, California earthquake, which occurred in a region with few nearby strong motion stations. The initial ShakeMap was based entirely on estimates of strong ground shaking using the epicenter and an attenuation relationship since there were no available near-source, near-realtime strong motion stations to provide actual ground motions. As a result this initial map failed to predict the elevated shaking to the southeast in the community of Paso Robles where unreinforced masonry buildings collapsed and two people died (See Figure 1a).

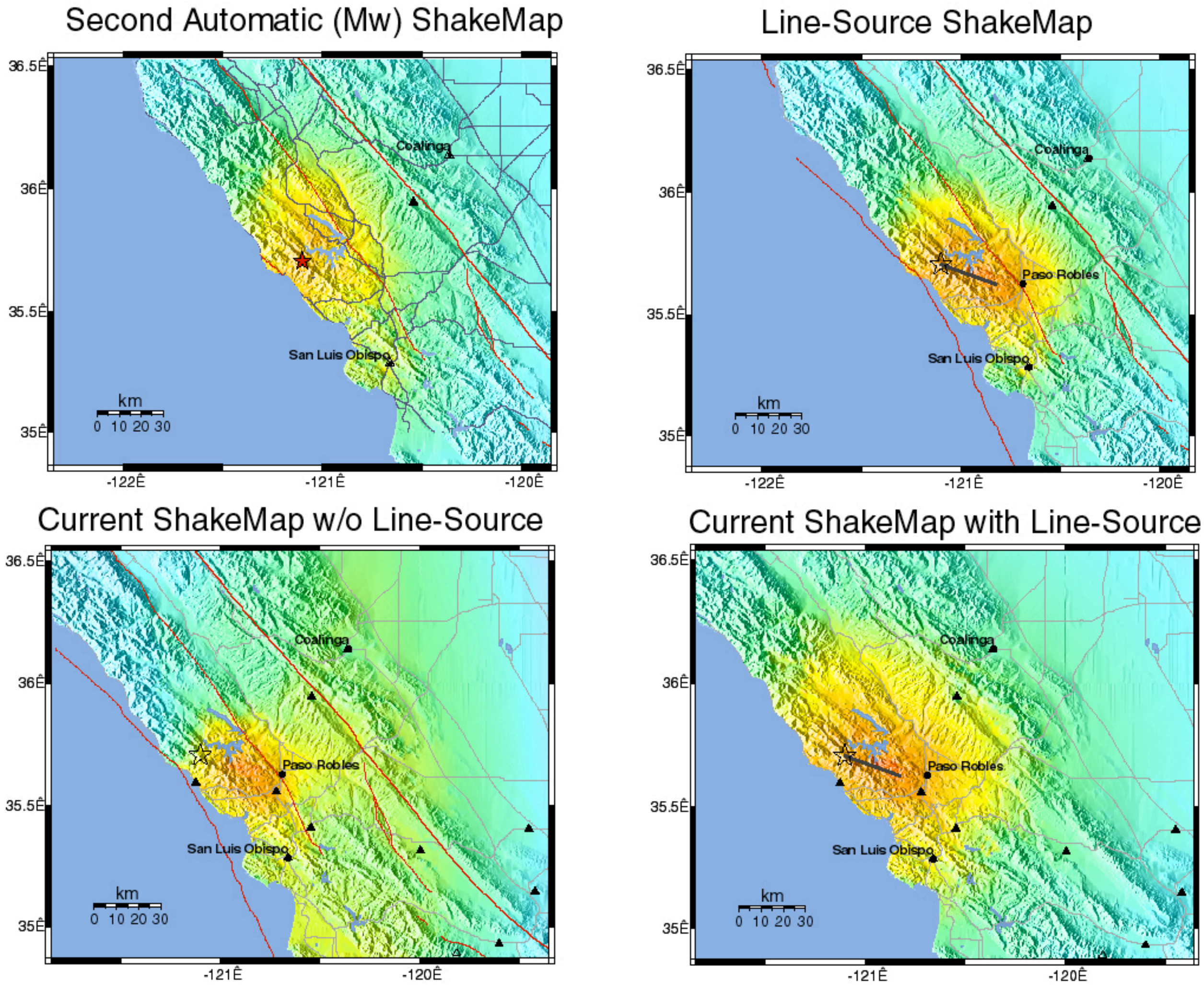
Using the method that we developed we were able to determine the rupture extent of the earthquake, and that the rupture was to the southeast causing elevated ground motions in that direction (Figure 2). Information from a line source inversion with results essentially the same as shown in Figure 2 was used to update the ShakeMap (Figure 1 upper right). The favorable comparison of this corrected map (without near-fault stations) with one that incorporated near-fault stations (Figure 1 lower left) shows that the addition of finite-source information greatly improved the accuracy of the estimated ground motions southeast of the epicenter, and at a time when the near-fault data was not yet available.

The line-source ShakeMap was published several hours after the earthquake and was used to improve loss estimates by the California Office of Emergency Services (see The CISN San Simeon Report., 2004).

For more detailed information regarding the application of the developed method to the San Simeon earthquake see:

Hardebeck, J. L., et al. (2004). Preliminary report on the 22 December 2003, M6.5 San Simeon, California earthquake, Seism. Res. Lett., 75, 155-172.

CISN San Simeon Report (2004). Performance of the CISN during the 2003 San Simeon earthquake, http://www.cisn.org/docs/CISN_SanSimeon.pdf



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	***<.17***	***.17-1.4***	***1.4-3.9***	***3.9-9.2***	***9.2-18***	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	***16-31***	***31-60***	***60-116***	***>116***
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 1. Various intensity ShakeMaps. The epicenter is shown as a star, strong motion stations as triangles and the rupture extent as a thick black line. Upper left: automatic point-source ShakeMap. Because there are no nearby stations constraining the actual ground motion levels the estimated intensity is relatively low in Paso Robles inconsistent with the damage distribution and reported intensity (e.g. Hardebeck et al., 2004). Upper right: Intensity ShakeMap using the rupture extent determined by finite-source inversion to compute distances. The estimated intensity is greater near the fault and extends southeast to Paso Robles. Lower left: ShakeMap updated by adding non-telemetered near-fault data (e.g. the Templeton station is near Paso Robles). Lower right: The preferred and final ShakeMap that incorporates both the near-fault data and the finite-source information.

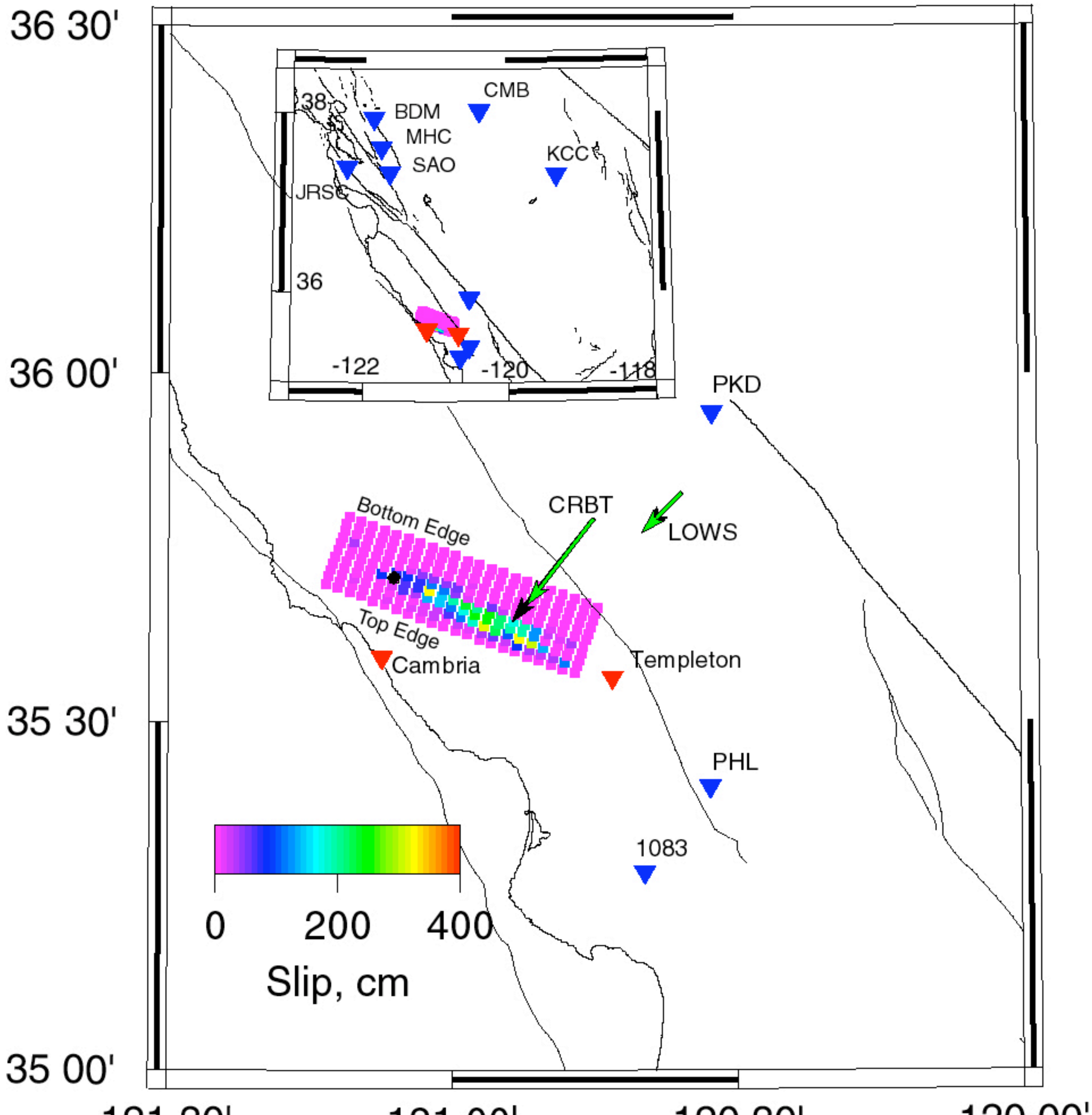


Figure 2. Map showing the locations of seismic stations (inverted triangles), observed (black arrows) and predicted (Green arrows) GPS deformation, and the slip distribution obtained by simultaneously inverting the seismic and geodetic data. The black circle shows the epicenter. Note that the slip extends about 25 km to the SE toward Templeton and nearby Paso Robles.

5. Methodology employed.

The method is described in the following publications that are available online.

Dreger, D. S. and A. Kaverina (2000). Seismic remote sensing for the earthquake source process and near-source strong shaking: a case study of the October 16, 1999 Hector Mine earthquake, *Geophys. Res. Lett.,* 27, 1941-1944.
http://www.seismo.berkeley.edu/~dreger/1999GL011245.pdf

Kaverina, A., D. Dreger, and E. Price (2002). The combined inversion of seismic and geodetic data for the source process of the 16 October, 1999, Mw7.1 Hector Mine, California, earthquake, *Bull. Seism. Soc. Am*. 92, 1266-1280.
http://www.seismo.berkeley.edu/~dreger/kaverina-etal-bssa2002.pdf

6. Other related work conducted within and/or outside PEER

Funding for some aspects of the realtime implementation of this system came from the California Office of Emergency Services. Funding for the initial conceptual work and the development of the regional distance finite-source methodology came from the USGS National Earthquake Hazards Mitigation Program.

7. Recommendations for the future work

We are presently working on updating the method by incorporating near-realtime GPS data. The GPS data will be used independently to determine earthquake source parameters and to provide additional constraints in combination with seismic waveform data. This effort is being funded by the USGS National Earthquake Hazards Mitigation Program.

Future work should include an investigation of methods for the simulation of high frequency strong ground motions from finite-source models, the development of a method for the utilization of GPS derived finite-source models for near-fault strong ground motion simulation, as well as refinements to the analyst interface. Additionally, various moment tensor improvements may be made to extract finite-source and directivity information more quickly, albeit at lower resolution. Dr. Spudich's isochron directivity method should be incorporated to improve strong ground motion estimates from the derived finite-source models.

8. Author(s), Title, and Date for the final report for this project

Dreger, D. S., A. Kaverina, P. Lombard, L. Gee and D. Neuhauser, Development of Procedures for Rapid Estimation of Ground Motions, February 2002.