Southern California Earthquake Center

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Annual Project Summary

Highlights of SCEC's activities for the past year are summarized in the following sections.

1. Continuation and Completion of Planned SCEC Activities:

- **LARSE II.** The Southern California Earthquake Center and the U.S. Geological Survey collaborated on the second Los Angeles Region Seismic Experiment (LARSE II). This study involved active and passive seismic components along a 100-km-long corridor extending from Santa Monica Bay northward to the western Mojave Desert, (through the 1994 Northridge earthquake epicentral region). During the active component approximately 1400 seismographs were deployed at 100-m spacing along the main transect. Energy was supplied by 96 shot points spaced approximately 1000 m apart along the line. In addition, several shorter lines (10-20 km in length) were deployed across the main transect in the San Fernando Valley and Santa Monica areas. Primary imaging targets included the Santa Monica, San Gabriel, and San Andreas faults, blind thrust faults (including the Northridge fault), and the subsurface geometry of sedimentary basins in the San Fernando Valley and Santa Monica. Data reduction is complete and preliminary results indicate the data are generally good to excellent given the relatively high level of urbanization along the transect. For example, several of the small shots (5-25 lbs.) in Santa Monica area and the San Fernando Valley were recorded as far north as the Mojave Desert, 60-80 km away. Travel time and amplitude anomalies are evident in first arrivals near the San Andreas fault, and reflections from the middle and lower crust are apparent in raw shot gathers.

- **SCIGN/GPS.** The Southern California Integrated GPS Network (SCIGN) has had a productive year, with many new stations coming on-line. As of mid-year 2000, approximately 225 stations had been installed with 90% operating. We plan to reach our final goal of 250 stations by the end of calendar year 2000.

  Processing continues at both JPL and Scripps, with agreement between solutions continuing to converge.

SCEC researchers have been collecting unprecedented continuous and campaign GPS data sets bearing on post-seismic deformation associated with the 1999 M7.1Hector Mine earthquake. Results indicate considerable post-seismic deformation that follows the expected pattern of right-lateral slip, with the highest velocities occurring 10 to 20 km from the surface rupture, indicating a deep source of deformation.

SCIGN and SCEC have participated in the formation of the C*alifornia Spatial Reference Center*, a new organization that will provide an interface between SCIGN and the Land Surveying profession. This is an important step toward directly involving the State of California and surveying community in the use and operation of dense GPS networks.

- **Phase III Report.** A major SCEC activity over the past year was related to the completion of the so-called "Phase III" report. Given the variety or earthquake locations considered in probabilistic seismic hazard analysis, a fundamental question is how and if site effects can be accounted for. This was the question addressed by the SCEC Phase III working group. In a collection of 14 papers (in press in BSSA), we have addressed the problem from a variety of angles including theoretical modeling and empirical data analysis. In particular, three new customized attenuation relationships have been developed to account for site effects in southern California, and these have been evaluated with respect to the implied seismic hazard. Our tentative conclusions are: 1) Although a detailed geological classification is not warranted, a map based on average 30-meter shear wave velocities is; 2) Sedimentary basin depth is a significant and important factor. For example, sites over the deepest parts of the LA basin have ground motions up to two times greater (on average) than sites near the edge; and 3) The uncertainty of ground motion (i.e., sigma in the attenuation relationship) is not significantly reduced after making all possible site corrections. In other words, the intrinsic variability of response at a site remains high due to the sensitivity of basin effect and scattering with respect to different source locations. See (www.scec.org/research/phase3).

- **"Legacy" Document.** The SCEC community has agreed to proceed with the production of a so-called "legacy" document, wherein SCEC's successes and accomplishments over the past 10 years will be summarized. The document will be mounted on the Web, and a glossy summary version (circular) with graphics will be printed for distribution by the center, NSF, and USGS. A draft of the legacy document also will serve as the SCEC accomplishments section for the SCEC-2 renewal proposal, currently underway.

- **Response to Major 1999 Worldwide Earthquakes.** Four important earthquakes relevant to understanding earthquake phenomena in southern California occurred throughout the world in 1999 (Izmit and Duzce earthquakes in Turkey, Chi Chi earthquake in Taiwan, and Hector Mine earthquake in California). SCEC scientists participated in the scientific response to these events. It is important to recognize: 1) the benefit to SCEC science derived from the study of these earthquakes worldwide, from both the seismological and earthquake engineering points of view, and 2) the benefits that the SCEC multi-disciplinary approach has brought to the local studies of these significant events. Colleagues, worldwide, specifically requested cooperation with SCEC scientists, and were rewarded with rapid response and support from the major SCEC sponsors (NSF and USGS).

  The Turkish Izmit and Duzce Earthquakes. The August 17, 1999, M7.8 earthquake occurred on the North Anatolian fault, a continental transform structure similar, in many respects, to the San Andreas fault. Issues of segmentation, stress transfer and seismic gaps are common to both faults. SCEC was assumed a leadership role, in coordination with the USGS, for the U.S. portion of the seismological scientific response to these events. The effort, which included both geological and seismological components, was coordinated with Turkish colleagues. A seismological deployment focused on aftershocks, fault-zone trapped waves, and geodetic (GPS) measurements targeted at post-seismic deformation. The

November 12, 1999 Duzce earthquake, constituted a stringent, somewhat unexpected test of current theories of stress transfer and event triggering. SCEC scientists are continuing research on this pair of events. SCEC's efforts to date are described in the abstracts of the 1999 Fall AGU meeting, with manuscripts in preparation.

The Taiwan Chi-Chi Earthquake. Several SCEC scientists participated in studies of the September 22, 1999, M7.6 Chi-Chi (Taiwan) earthquake, specifically the strong motions that it generated.

The Hector Mine Earthquake. The October 16, 1999, Hector Mines, CA earthquake (M7.1) was again in SCEC's "backyard". SCEC took the lead in initiating post-earthquake studies in collaboration with the USGS and CDMG. The response involved geological investigations, post-earthquake GPS geodetic measurements, and a uniquely thorough two-dimensional seismic deployment, that was made possible by the presence of a large number of instruments in southern California due to the LARSE II experiment. In addition, INSAR images using the ESA ERS-2 spacecraft radar were analyzed by SCEC scientists at UCSD and JPL within 4-days of the event, and images were made available to field geologists in time for them to study the distribution of small cracks and fractures off the main fault, which might have been missed otherwise. This constitutes a "first" in post-earthquake response, and demonstrates the unique potential of remote sensing techniques in this regard. Hector Mine studies, as well as studies of earthquakes mentioned earlier, were the object of special sessions at the 1999 Fall meeting of the AGU, the 2000 Spring meeting of the SSA.

2. Leadership in Collaborative Earthquake Research

There is a clear trend, worldwide, in earthquake research toward collaborative initiatives. SCEC is perceived as a leader, and in some cases a model, in this respect. In some instances, SCEC has been able to act as a direct catalyst for such efforts. In a few instances, SCEC has provided the basic organizational infrastructure based on our previous experience. Major examples from the last couple of years are listed below:

- **WG 2000.** Following the series of collaborative studies and reports referred to as "SCEC Phases I to III", we are proceeding with Phase IV (RELM – Regional Earthquake Likelihood Models), an update of Phase II (source characterization). This effort will be led by Ned Field, formerly a SCEC researcher at USC and now with the USGS. As such, Phase IV will truly be a USGS/SCEC cooperative endeavor.

  The goals of Phase IV are:
  - To develop and test a range of viable earthquake-potential models for southern California (the probability per unit area, magnitude, and time of all M>5 events);
  - To examine and compare the implications of each model with respect to probabilistic seismic hazard analysis (PSHA). This will not only define existing uncertainties in seismic hazard, but will also identify what research topics should be targeted in order to reduce these uncertainties; and
  - To test these models for consistency with existing geophysical data (e.g., historical seismicity), and to design and document conclusive tests with respect to future observations.

  SCEC's Phase II report (WGCEP, 1995) represented the first large-scale effort to integrate seismic, geodetic, and geologic constraints into a complete seismic-hazard source model using the concept of seismic moment budgeting. However, the model predicted that magnitude 6 to 7 earthquakes will occur about twice as often as they have historically, which led to a widely publicized debate on whether the apparent deficit was real, an artifact of the limiting magnitude implied by fault size, or simply a reflection of uncertainties (Jackson,

1996; Hough, 1996; Schwartz, 1996; Stirling and Wesnousky, 1997; Stein and Hanks, 1998). Similarly, the model developed for the USGS/CDMG statewide hazard maps also exhibits a factor of two discrepancy near magnitude 6.5 (Petersen et al., 1996). Following the work of others, Field et al. (1999) presented an alternative, mutually consistent source model (based on active fault data and in agreement with historical seismicity). They also summarized several factors that produced the discrepancy in previous models.

Although the earthquake-deficit problem raised by WGCEP (1995) is solved in that neither M>8 earthquakes, nor an accelerated earthquake rate, are *required* to satisfy available data, neither phenomenon can be ruled out either. For example, time-dependent recurrence models generally predict a rate acceleration because most faults are deemed overdue. In addition, some models allow a finite probability of M ~8.5 earthquakes (Kagan, 1999). Because these models cannot be excluded, it behooves us to evaluate their implications for seismic hazard. This will define the range of hazard levels implied by our current understanding and identify important issues for future research.

Our approach is different from previous "working group" reports in that we are evaluating several viable models rather than constructing one consensus model. This approach is appropriate for several reasons: 1) it is consistent with SCEC's role of developing and testing the ingredients used for seismic-hazard analysis; 2) we won't force consensus where none exists, so that participants will not be asked to compromise their best judgement; 3) we will avoid the dropout effect that has plagued previous working groups (as type-A personalities took over the "consensus-building" process); 4) a comparison of results will reveal which factors are most significant, thereby establishing a basis for setting future research priorities; 5) our approach will provide the background research needed by those who produce official source models; and 6) we won't confuse the user community with yet another "consensus" hazard map or interfere with those whose mandate it is to generate such maps. We do anticipate, however, that the next official USGS/CDMG hazard model will be developed in conjunction with the RELM working group.

An important part of the effort will involve updating and documenting the geological fault database, the earthquake catalog, and the geodetic strain-rate map. We envision publishing our results as a collection of papers in a peer-reviewed journal such as the *Bulletin of the Seismological Society of America*. Specifically, there will be separate papers on each model, or each class of models, and on the updated data constraints. There will also be a paper comparing the hazard implications of each model, a paper outlining a formalism for testing the models against observed and/or synthetic earthquake catalogs, and an overview paper.

- **WInSAR.** Recently, Interferometric Spaceborne Synthetic Aperture Radar (InSAR) has become one of the most spectacular new methods for studying shallow earthquakes. At the present time, the only assets available to scientists are the ESA ERS-1 and 2 spacecrafts, and the Canadian RadarSat spacecraft. The consequence is that U.S. researchers must purchase data from foreign distributors. This year, a consortium (WInSAR – Western U.S. InSAR) of academic groups, including JPL and the USGS (both SCEC partners) has been organized by SCEC in order to acquire ERS data at an advantageous price from the ESA distributors (SpotImage and EurImage). A WInSAR standing committee, will coordinate data acquisition requests on behalf of the community, and will coordinate purchase of these data. WInSAR is governed by a set of bylaws that have been approved by members and by the SCEC Board of Directors. This is viewed as an experiment designed to place INSAR data in the hands of researchers, cost-effectively. Acquisition and processing of InSAR data by WInSAR members are well underway. Targets include the Landers and Hector Mine epicentral regions, San Andreas fault system, Cascadia, Yellowstone, Long Valley caldera, and portions of the Basin and Range.

- **GEM and ACES.** GEM (General Earthquake Models) refers to the development of models and numerical simulations of earthquake fault systems, combined with theoretical investigations, space-time pattern analysis and applications to both laboratory and observed data. Numerical simulations pose a major challenge, because earthquakes are a multi-scale problem, involving time scales of hundreds to thousands of years and spatial scales of meters to as much as a thousand km. To advance GEM, SCEC has held a series of workshops throughout the past year, and managed seed funding granted by NSF for GEM research. In addition, from January 31 to February 5, 1999, and again from October 15 to 20, 2000, members of the U.S. GEM community attended the APEC Cooperation on Earthquake Simulations (ACES) workshop in Brisbane/Noosa Head, Australia, and Tokyo/Hakone, Japan. SCEC has been the official U.S. coordinating entity for ACES. A number of scientific papers that have developed as a result of the GEM collaboration are in preparation. In particular, the forthcoming AGU monograph on "Physics of Earthquakes" will contain over 15 papers, many of which have resulted from GEM efforts. All of these results and more are summarized on the GEM Web site: http://geodynamics.jpl.nasa.gov/gem.

- **EarthScope and PBO.** The SCEC community has taken an active role in the formulation and promotion of the new EarthScope initiative for MRE (Major Research Equipment) funding by the National Science Foundation (See: www.EarthScope.org). SCEC's Directors (T. Henyey and J.B. Minster) are key members of the EarthScope Working Group (Henyey is Chair), and SCEC has organized and hosted two major national workshops for the Plate Boundary Observatory component, October 2 to 5, 1999 in Snowbird, Utah, and October 29 to November 1, 2000 in Palm Springs, California. SCEC Director for Administration, John McRaney (also Secretary to the EarthScope Working Group), acted as workshop organizer.

- The first workshop resulted in a white paper highlighting the major scientific issues identified by the participants, that will require major equipment acquisition and deployment over the next decade. Particularly noteworthy was the preparation of a letter to NSF and NASA emphasizing the potential role of INSAR in this context. The second workshop dealt with siting of specific geodetic (GPS) and borehole strain clusters. The results of this workshop are currently being summarized. SCEC will continue to play a leadership role in promoting EarthScope in collaboration with the organizers of other EarthScope components, notably, USArray and SAFOD.

- **EQ 2000.** In 1999, SCEC joined forces with the California Division of Mines and Geology (CDMG), the Pacific Earthquake Engineering Center (PEER), the TRINET project, the USGS, and other collaborative seismological efforts in California, to explore the possibility of initiating a broader, most systematic support by the State of California of earthquake hazards research in California. This is still in the formative stages, and SCEC intends to continue its efforts at leading such an initiative.

3. Highlights of the 1999-2000 SCEC Education and Outreach Program

- **The Real Meaning of Seismic Risk Symposia and Workshops.** SCEC conducted the first workshop in a series designed to encourage compelling exchanges among earth scientists, earthquake engineers, building officials, public policymakers, architects, insurers, developers and the media. Held in partnership with Los Angeles County Urban Search and Rescue and the Los Angeles City Emergency Planning Commission, who sponsored the event. About 100 people attended the daylong symposium.

- **1999 and 2000 Summer Internship Programs.** Ten students from California universities and colleges participated in the 1999 program and eight students participated in the 2000 program. This program is under the direction of SCEC Associate Director, Mark Benthien. Colloquia were held near the end of the summer programs, and students were also invited to

make poster presentations at the SCEC annual meetings in September. The colloquia included a day of research presentations by the interns and a three-day field trip to southern California seismological points of interest where SCEC scientists met the group to explain each location. Reports from the interns are available for download on the SCEC Web site.

- **DESC Online Education Modules.** SCEC's DESC Online Advisory Group, led by SCEC Director or Outreach, Jill Andrews conducted five meetings and completed the overall design, story line and accompanying lessons and activities for a Middle School level module. The first group of lessons is now in the hands of the Web authors (John Marquis and Maggi Glasscoe). Estimated time to completion of the Middle School modules is mid- to late 2000. This particular curriculum is highly popular among K12 teachers; beta versions presented in annual meetings (i.e., California Science Teachers Association) and workshops (i.e., AGU annual meeting) are enthusiastically received and endorsed by teachers.

- **SCEC Museum Partnerships.** SCEC has established ongoing partnerships with several museums: California Science Center, Exposition Park, Los Angeles (Earth Science education programs and exhibits, patron programs); San Francisco's Exploratorium (development and filming of "Faultline," a multi-media, interactive exhibit that "aired" on local TV and the Web in October, 1999 to commemorate the 10th anniversary of the 1989 Loma Prieta earthquake); Riverside County Children's Museum (in partnership with UC Riverside to create an educational, family-oriented exhibit on earthquakes in their region); Santa Barbara Museum of Natural History (to plan a new earth sciences exhibit, with features such as a tour of the Mission Ridge fault, which runs through museum grounds; a walking tour of the surrounding area, which includes the fault scarp, an ancient landslide, and a paleo channel; and a CUBE/REDI computer display); and the Denver Museum of Natural History patrons (led a field trip to a series of local faults and the Caltech-USGS seismic network and seismological laboratory displays in Pasadena).

- **EQNET.** This effort is best described by direct examination of the EQNET Web page. See: www.eqnet.org. This Web page has benefited from extensive revisions to improve search capability.

- **SCEC Science Workshops, Liquefaction Report, and Accompanying Workshops.** SCEC produced and printed a new document to help engineers, geologists, and building officials evaluate and take protective measures against liquefaction hazards in southern California. SCEC and CDMG announced the report through a press conference and subsequent workshop held in April 1999. Over 1000 copies were distributed (sold or given to workshop participants). Liquefaction Workshops were held in June and November in partnership with CDMG to aid practitioners, building officials, decision-makers and others in implementing the new guidelines. 190 people attended the first workshop in June. 95 people attended the second workshop in November.

- **LARSE II Activities.** SCEC Outreach personnel assisted with the public awareness, education, permitting and siting processes for LARSE II. In coordination with the USGS, SCEC developed publications, coordinated dissemination and press releases, presentations to local government, civic groups, and the media. This was a successful effort, based on our earlier experiences with LARSE I, and which contributed to a bug-free execution of the experiment. Experiments such as LARSE clearly illustrate the advantages and institutional memory of an on-going center activity in the academic community.