Attachment A

Project Summary

CSMIP 2005 Data Interpretation Project

Project Title: Investigation of the rupture process of the 2004 Parkfield earthquake utilizing near-fault seismic records and implications for ShakeMap

Data Interpretation Topic (check one or more than one):

___XX___ a) Ground Motion

________ b) Structural Design and Analysis

________ c) Loss Estimation

___XX___ d) Emergency Response

Principle Investigator(s): Signature________________________________

Name___Douglas S. Dreger____________________

Title____Associate Professor of Seismology_______

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2) Statement of Qualifications

The PI Douglas Dreger is qualified to perform the proposed strong ground motion modeling work. He is an expert in the areas of seismic wave propagation and earthquake source studies. He has published 55 peer-reviewed papers on the topics of seismic wave propagation, earthquake source studies and realtime applications for ground motion reporting (see below). Of particular relevance to the proposed research are numerous studies of kinematic rupture models of recent earthquakes (e.g. publications 45, 41, 39, 36, 35, 33, etc.], near-realtime application of finite-source modeling for improved ground motion estimation for ShakeMap (e.g. publications 53, 53, 47, 35, 29), and modeling of seismic ground motion with three-dimensional velocity models (e.g. 55, 54, 35, 24, 10).

Dreger has developed preliminary models for the 2004 Mw6.0 Parkfield earthquake and has used this information to investigate near-realtime applications for ground motion reporting (53, 52). This model, and those of other researchers, show the Parkfield earthquake rupturing principally 25 km to the northwest of the epicenter, with minor levels of slip extending 5-10 km to the southeast. The preliminary models do not explain the large peak motions (acceleration and velocity) observed at sites near the ruptured fault and southeast of the epicenter. The new kinematic models obtained as part of the proposed study will incorporate the near-fault strong ground motion records. The proposed analysis will also investigate the contributions to the observed ground motions from source and from 3D wave propagation for fault zone sites. Finally, the results of this study will be used to improve the automatic finite-source modeling and near-realtime ground motion simulation program implemented at the Berkeley Seismological Laboratory (e.g. 53, 29).

Douglas S. Dreger Curriculum Vitae

Education:
Ph.D. Geophysics, California Institute of Technology, 1992
M.S. Geophysics, California Institute of Technology, 1989
B.S. Geophysics, University of California, Riverside, 1987

Career Experience:
Associate Director of the Berkeley Seismological Laboratory, 2002-
Associate Professor of Seismology, University of California, Berkeley, 2002-
Assistant Professor of Seismology, University of California, Berkeley, 1996 - 2002
Assistant Research Seismologist, University of California, Berkeley, 1993-1996
Postdoctoral Researcher, University of California, Berkeley, 1992-1993
Seismological Consultant, Woodward-Clyde Consultants, Pasadena, 1990-1993
Staff Geophysicist, Aragon Geotechnical Consultants, Riverside, CA 1985-1987

Synergistic activities:

- Associate Editor, JGR, (2002-)

Collaborators and other affiliations:

- Doctoral Advisor: Donald Helmberger (Caltech)
- Post-doctoral Advisor: Barbara Romanowicz (UCB)
- Recent Collaborators (48 mos.): Michael Antolik (Harvard), Eiichi Fukuyama (NIED), Mizuho Ishida (NIED), Malcolm Johnston (USGS), Shawn Larsen (LLNL), Alan Lindh (USGS), Tom Parson (USGS), David Oglesby (UCR), Steve Day (SDSU), Kim Olsen (UCSB), Jacobo Bielak (CMU), Robert Graves (URS), Arben Pitarka (URS), Anil Chopra (UCB), Kevin Mayeda (LLNL), William Walter (LLNL), Luca Malagnini (INGV), Annastassia Kiratzi (AU).
- Students advised: Ahyi Kim (Ph.D. student), David Dolenc (Ph.D. Candidate), Dennise Templeton (Ph.D. Candidate), Gilead Wurmann (MS 2003), Laurie Baise (MS 2000), Wu Cheng Chi (Ph.D, 2003), Christiane Stidham (Ph.D. 1999), Peggy Johnson (Ph.D. 1998), Janine Weber-Band (Ph.D. 1998), Michael Antolik (Ph.D. 1997), Brian Savage (BS 1998), Joseph Franck (BS 1997)
- Postdoctoral Researchers advised: Anastasia Kaverina (1997-2000), Michael Antolik (1997-98), Michael Pasyanos (1997-98), Geoff Clitheroe (1999-2000), Peggy Hellweg (2000-2004)

Publications

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3) Scope of Work

Objectives of Proposed Research

The 2004 Mw6 Parkfield earthquake, while only a moderate sized event in rural central California is arguably the best recorded ever due to the foresight of the scientists who elected to densely instrument the region in order to 'catch' the next in the sequence. The coverage afforded by regional distance seismic networks, local continuous GPS instruments, and the extensive strong motion network located near the fault offer the best possibility to date for recovering the detailed kinematic rupture process of a large earthquake, with the data needed to really assess the resolution of the key kinematic parameters and the distribution of fault slip. By obtaining such a high resolution source model it will be possible to assess methods presently used for simulating near-fault strong ground motion from kinematic models to augment near-realtime strong ground motion ShakeMaps (e.g. Dreger and Kaverina, 2000; Dreger et al., 2005). The proposed research will develop a high resolution source model by performing a suite of kinematic inversions using the combined near-fault and regional seismic waveform, and near-fault GPS data set. The results of the study will be used to improve upon the currently implemented automated finite-source analysis procedures operated by Berkeley (e.g. Dreger and Kaverina, 2000; Dreger et al., 2005).

A number of the near-fault sites are in the fault zone itself, and these sites show the largest ground motions in terms of both peak acceleration and velocity. Proximity of these sites to coseismic slip is probably the primary factor, however the effects of site amplification and 3D focusing due to fault zone velocity structure also need consideration, as studies of microseismicity clearly image fault zone guided waves in the upper few kilometers of the fault (Korneev et al., 2003). Additionally, Stidham et al. (1999) showed that velocity contrasts across vertical strike-slip faults, as is the case in Parkfield (e.g. Michael and Eberhart-Phillips, 1991), affects the strong motion wavefield significantly. Thus, once the kinematic models are obtained they will be used to assess the effect of 3D fault velocity structure on the wavefield using finite-differences. Inverting for slip using a 3D velocity model is beyond the scope of the proposed study, but should be investigated once models and corresponding sensitivity analyses have been completed using more standard approaches. The 3D finite-difference modeling that we will perform in this study will illuminate the effects of lateral velocity contrast and low-velocity fault gouge. This analysis will also contribute to a Caltrans funded effort to understand near-fault motions for fault crossing bridges (Chopra and Dreger, 2005), and can also be used as a basis for future 3D source inversions. Most importantly the proposed research will model the large near-fault motions and place them into context with respect to both source and wave propagation effects.

A preliminary kinematic source model for the Parkfield earthquake has been determined by inverting strong motion and weak motion records from stations located in the 3-200 km distance range, and near-fault static deformation from the continuous GPS network operating in Parkfield (Langbein et al., 2005; Dreger et al., 2005). This preliminary model as well as the models of others, as reported in Langbein et al. (2005), show that the earthquake nucleated at the southern end of the 1934 Parkfield rupture area at Gold Hill, and then ruptured approximately 25 km to the northwest to Middle Mountain. Figure 1 shows the preliminary slip model, and Figure 2 shows the locations of the seismic stations and the fit to the GPS data. The seismic waveform data constrains the slip at depths below 5 km, and the two shallower asperities are controlled by the near-fault GPS data. Incorporating the near-fault strong motion waveform data will provide better constraint of the slip model. In the preliminary model two stations, SMM and SLOR, located south of Parkfield help to constrain the northward rupture directivity. Comparing the waveforms at the Parkfield station (PKD) and SMM (Figure 3) reveals a 30-fold difference in amplitude in which SMM is smaller and also with a relatively broader pulse-like waveform. These are characteristics of directivity toward the northwest. Although SMM is further away the 30-fold difference in amplitude cannot be explained by geometric spreading and attenuation alone.

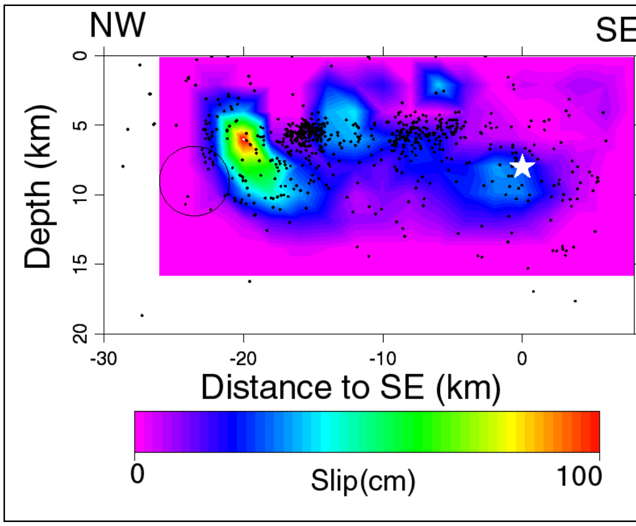

Figure 1. Slip map obtained by inverting local and regional distance seismic waveform and near-fault GPS coseismic offset data (e.g. Dreger et al., 2005). The hypocenter is shown as the white star. Black dots show aftershocks in the first 48 hours, and the large circle shows the hypocenter of the 1966 Parkfield earthquake (location of Middle Mountain). Most slip is to the NW, however there is some extending SE though it is too low to model the large ground motions there.

There is a problem with this model, and those of other researchers as well, in that it fails to explain the large ground motions close to the fault, and south of the epicenter (Figure 4). In Figure 4 simulated ground velocity is shown as light blue contours and compared with the observations shown as the numbers. At many sites there is good correlation between simulated and observed PGV (blue numbers). Yet in some cases there are large differences between sites that are close together indicating that differences in site response is important. Figure 4 also shows significant discrepancy in model predictions and observations (red numbers) in two regions. One for sites close to the fault northwest of the epicenter suggesting that there is unmodeled slip in the preliminary model. The other is for sites southeast of the epicenter, which suggests a component of southward directivity that is not present in the preliminary model. Also in both cases due to the proximity of the sites to the fault zone there could be 3D focusing effects.

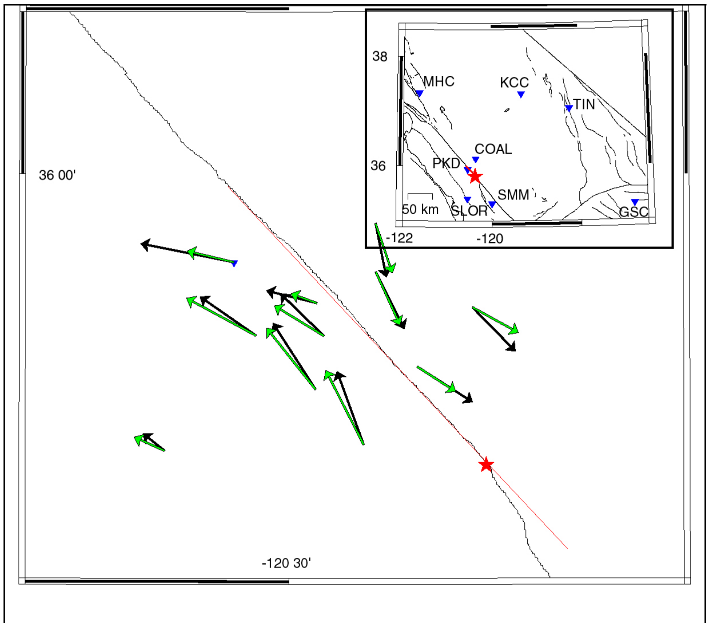

Figure 2. Inset shows the distribution of seismic stations (blue triangles), postion of the fault (assumed to be vertical) and epicenter are shown in red. Observed (black) and simulated GPS deformation vectors are compared. Clearly the preliminary fault model fails to negotiate the jog SE of the epicenter. In the proposed research an improved fault geometry model will be used.

In the proposed study we will incorporate the extensive near-fault strong motion waveform data set obtained by CSMIP and the USGS. This data set will be combined with the distant waveforms and also the near-fault GPS displacements. The GPS displacements can be included either as static vectors or as time series given the continuous nature of the data. We will use the method employed by the PI's group to study other recent earthquakes, which is briefly described below. In addition to obtaining a better model of the kinematic rupture process for the earthquake a thorough sensitivity analysis will be performed in order to assess the resolution of key kinematic parameters such as the minimum rise time, rupture velocity, variations in rise time and rupture velocity during the rupture, and the effect of these parameters on estimates of near-fault ground motions. The high ground velocities at some near-fault sites indicate high slip velocity on the fault not presently imaged by the more distant seismic waveform data. The geometry of the fault plane will also be investigated with the combined data set. Inversions will be performed initially assuming the same velocity structure sites on either side of the fault, but as shown by Michaels and Eberhart-Phillips (1991) there is a marked velocity contrast across the fault, which can possibly affect the source inversions. Therefore we will also perform a suite of inversions using two different 1-D velocity models for either side of the fault to account for this observation. This suite of inversions will also investigate the resolution of key kinematic parameters.

Strong Motion Records and other Data for the Proposed Research

The data that will be employed includes seismic waveforms from CISN participating networks, which include regional broadband stations operated by Berkeley and Caltech, continuous and campaign-mode GPS, possibly deformation from InSAR sources (e.g. Johansson et al., 2004), and near-fault strong motion records from the CSMIP and NSMP programs. These near-fault records have already been obtained from the COSMOS data center.

The preliminary model shown above is based on only the GPS and regional distance seismic waveform records. As illustrated this model fails to explain near-fault strong-ground motions at a number of sites. Some of this may be due to unaccounted for site effects, 3d seismic wave propagation effects and unmodeled fault rupture. It is essential to fold these near-fault records into inversions for the source to 1) better understand the rupture process of the Parkfield earthquake, 2) understand better the source and wave propagation influences on the observed ground motions, and 3) to improve finite-source model based ShakeMap reporting (e.g. Dreger et al., 2005).

Methods of Analysis

The established method of Hartzell and Heaton (1983) that we have used to analyze a number of recent earthquakes (e.g. Dreger and Kaverina, 2000; Kaverina et al., 2002) will be employed. Our code allows for multiple fault planes to account for changes in fault orientation, variable slip direction, and multiple time windows to allow for variations in the rupture velocity and slip rise time. As shown in Figure 2 the single-segment fault model fails to account for the jog south in the San Andreas fault south of the epicenter. In the proposed modeling we will need to test several possible subsurface geometries to account for the jog in order to model the strong ground motion records from sites in that region.

The results of any source inversion relies on the Green's functions being employed. For the preliminary model we used model GIL7 (Dreger and Romanowicz, 1994), which has been found to be suitable for determining the seismic moment tensors of events in the Central Coast Ranges. Green's functions are computed using a frequency-wavenumber intergration method that produces complete, three-component, regional seismograms that include the near-, intermediate- and far-field terms of the solution. With these Green's functions it is possible to simulate static deformation as well as the transient motions due to the rupture. Velocity contrasts have been found across the San Andreas fault in the Parkfield region (e.g Michael and Eberhart-Phillips, 1991). We will perform a second series of inversions that allows for this complexity by utilizing two 1D velocity models (derived from Michaels and Eberhart-Phillips (1991)) for stations on each side of the fault. We will thus document the effect of using two velocity models verses one in recovering kinematic models of the rupture process.

The preliminary model utilized data filtered in the 0.05 to 0.3 Hz passband. This low-frequency passband recovered areas of major slip, but not at sufficient resolution to predict the near-fault motions. Because of the proximity of the near-fault sites it will be possible to add these data to the inversion and consider higher frequencies (1-3 Hz).

Forward 3D finite-difference modeling of the near-fault strong ground motions utilizing the obtained kinematic model (based on 1 or 2 1D velocity models) will be performed to investigate the effects of a first-order velocity discontinuity across the fault as well as the effect of a narrow zone of low-velocity fault gauge. This modeling will be done in the context of better understanding the complex motions recorded at many of the fault zone stations such as FZ1, FZ12, FZ14, etc.

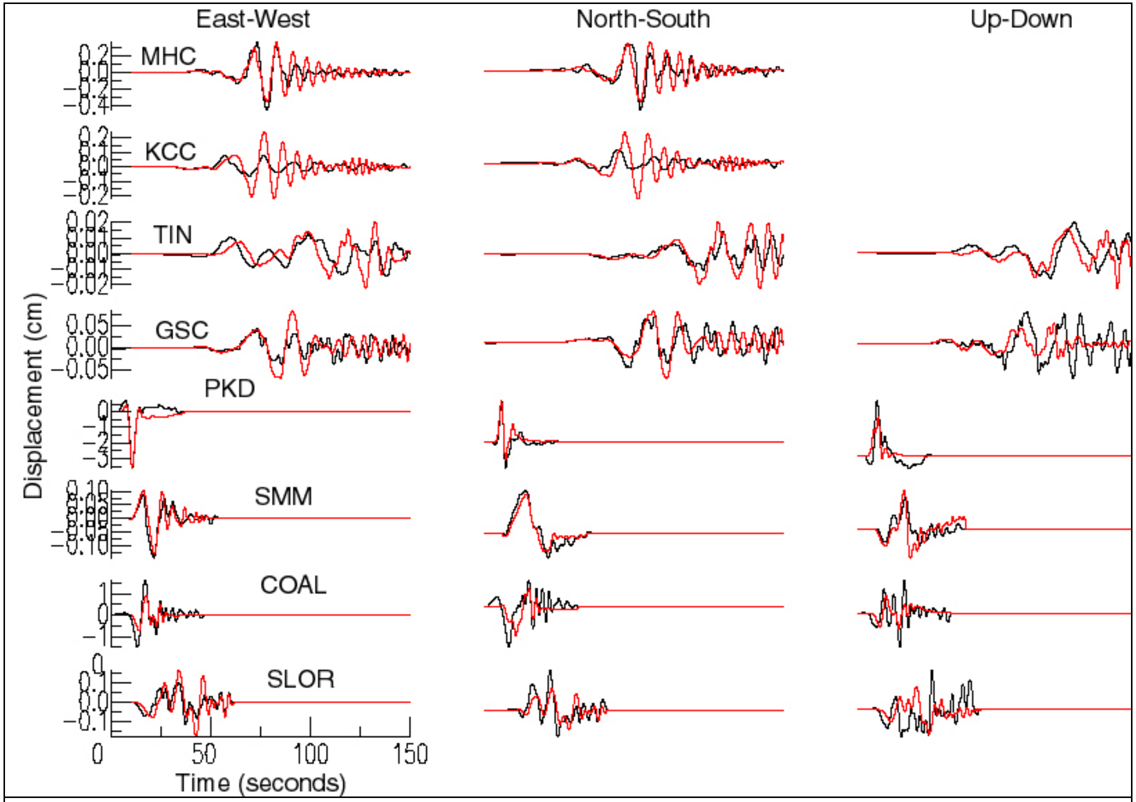

Figure 3. Observed (black) and synthetic (red) displacement waveforms for the model shown in Figure 1. Station PKD is 3 km from the fault, and has the largest amplitude with a short duration pulse-like waveform. Two stations, SMM and SLOR are located southeast of the epicenter and provide constraint on rupture directivity in that direction. It is notable that SMM has amplitudes a factor of 30 lower than at Parkfield, and although the site is further way the difference in amplitude cannot be explained by the greater distance alone.

The finite-difference modeling will be performed with the E3D code developed by Dr. Larsen of the Lawrence Livermore National Laboratory, which we have used in several other studies (e.g. Stidham et al., 1999; and PI publications 55, 54 and 32). With this code we are simulating motions to 20 Hz at sites within 40m of fault zones for our Caltrans funded project investigating bridge response across faults (Chopra and Dreger, 2005). The forward modeling will document the effects of across fault velocity contrast and low-velocity fault gouge on the seismic wavefield and will provide insight into the observed motions for the Parkfield earthquake. In addition, it will provide a means to evaluate the relative importance of considering such structure in inversions for finite-source parameters. Our future work, beyond the scope of the proposed research, will use E3D to generate a suite of 3D Green's function that will be used to invert for kinematic slip parameters if it is deemed to be important from this study.

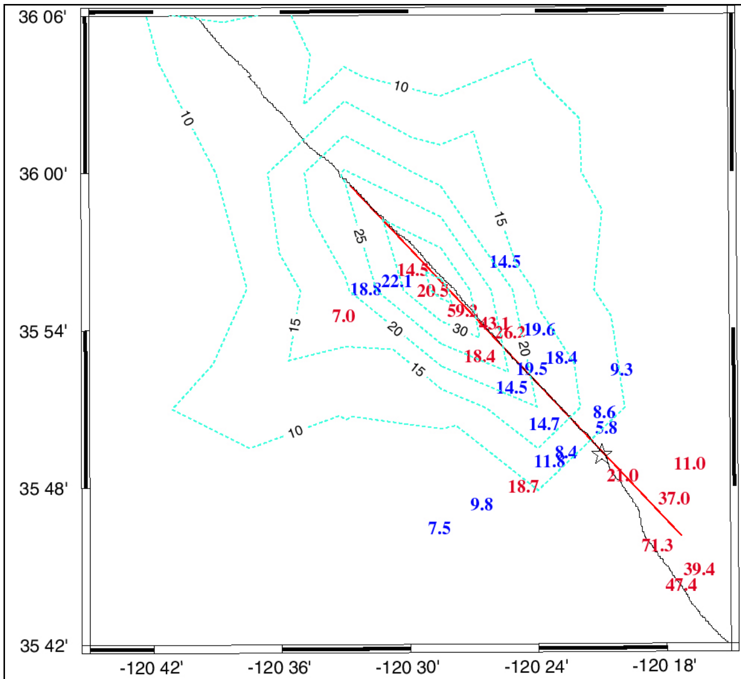

Figure 4. Map showing the location of the modeled fault (red line), the epicenter (star), simulated peak ground velocity PGV (light blue contours, cm/s), and observed PGV (colored numbers, cm/s). Blue observations are for sites with values within 50% of the nearest contour, and red are those sites that deviate by more than 50%. For both the observations and simulations the geometric mean of the two horizontal components is plotted.The observed values were obtained for stations within 20 km of the fault and 50 km of the epicenter from the COSMOS data center.

References

Chopra, A., and D. Dreger (2005). Analysis of bridge structures crossing fault rupture zones, Caltrans funded research effort, PI: Chopra and Dreger.

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Dreger, D., 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.

Hartzell, S. H., and T. H. Heaton (1983) Inversion of strong ground motion and teleseismic waveform data for the fault rupture history of the 1979 Imperial Valley, California, earthquake, Bull. Seism. Soc. Am., 73, 1553-1583.

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Korneev, V. A., R. M. Nadeau, and T. V. McEvilly (2003). Seismological studies at Parkfield IX: Fault zone imaging using guided wave attenuation, Bull. Seism. Soc. Am., 93, 1415-1426.

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Michael, A. J., and D. Eberhart-Phillips (1991). Relationships between fault behavior, subsurface geology, and three-dimensional velocity models, Science, 253, 651-654.
Stidham, C., M. Antolik, D. Dreger, S. Larsen, and B. Romanowicz (1999). Three-Dimensional Structure Influences on the Strong Motion Wavefield of the 1989 Loma Prieta Earthquake, Bull. Seism. Soc. Am., 89, 1184-1202

Work Schedule

As requested the project will have a 13-month performance period. The major phases in the project are: 1) data review and preparation, 2) combined inversion of seismic and geodetic data using 1 1D velocity model, 3) sensitivity analysis of inversion results, 4) combined inversion of seismic and geodetic data using 2 1D velocity models one for each side of the fault, 5) sensitivity of the inversion results, 6) 3D forward modeling of fault zone sites, 7) analysis of near-fault contributions to obtained source model and how automated procedures need to be improved for ShakeMap applications, 8) dissemination of research results and preparation of final report and presentation for the CSMIP data utilization workshop. The following outlines the work schedule.

Phases	Month												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Phase 1	X												
Phase 2	X	X	X										
Phase 3		X	X	X									
Phase 4			X	X	X								
Phase 5				X	X	X							
Phase 6							X	X	X				
Phase 7										X	X		
Phase 8												X	X

The PI who will oversee all aspects of the project and meet reporting requirements. The graduate student will assist the PI in performing the work associated with phases 1-5.

Dissemination of Results

The results of the proposed research will be disseminated to the broader research community through peer-reviewed publication. At least two such publications are anticipated from this work. Additionally, the final results of the conducted research and recommendations will be described in a final project report submitted to CSMIP, and will be presented at the data utilization workshop.

Proposal to the Strong Motion Instrumentation Program

Project Title: "Investigation of the rupture process of the 2004 Parkfield earthquake utilizing near-fault seismic records and implications for ShakeMap"

PI: Douglas S. Dreger

PROPOSED BUDGET: May 1, 2005 - May 31, 2006

					AMOUNT
A)	**Salaries – Senior Personnel**				
	Douglas S. Dreger, PI, Assoc. Prof. (Summer Res.) (1 mo. FTE)				
	(07/05) 8,411 /mo. @ 100% x 1 mo.			8,411	
B)	**Salaries – Other Personnel**				
	Grad. Student Researcher (Step 3) (5.25 mos. FTE)				
	3 months @ 100% (Summer) and 4.5 months @ 50% (Acad. Yr. – 1 semester)				
	(05/05) Summer 2,913 /mo. @ 100% x 3.00 mos.		8,739		
	(08/05) Acad. Yr. 2,913 /mo. @ 50% x 1.25 mo.		1,821		
	(10/05) Acad. Yr. 2,971 /mo. @ 50% x 3.25 mos.		4,828		
				15,388	
	Total Salaries				**$23,799**
C)	**Employee Benefits**				
	Assoc. Prof. (Summer Res.)	8,411 x 13.3%		1,119	
	Grad. Student Res. – 10 mos. (Acad. Yr.)	9,562 x 1.6%		153	
	2 mos. (Summer)	5,826 x 3.0%		175	
	Grad. student health insurance and fee remissions (1 semester):		4,236		
	Non-resident tuition (1 semester):		8,082		
				12,318	
	Total Employee Benefits				**13,765**
E)	**Travel**				
E.1)	**Domestic Travel**				
	PI and Grad. Student to attend 2006 Spring SSA Meeting – San Francisco, CA:				
	Registration & Abstract Fees:		380		
	Meals:	5 days @ $33 /day	165		
	Ground Transportation :		35		
		2 trips @	580	1,160	
	PI to present research results at 2006 CSMIP Data Utilization Workshop (1 day) – unknown location within California:				
	RT Airfare:		200		
	Meals:	1 day @ $33 /day	33		
	Ground Transportation:		100		
				333	
	Total Domestic Travel				**1,493**
G)	**Other Direct Costs**				
G.1)	**Misc. Supplies & Expenses** (photocopying, express mail, long distance phone charges)			500	
G.4)	**Computer Services**				
	Computer Usage – Berkeley Seismological Laboratory				
	Sun Network and Geophysics Computer Lab.	80 hrs. @ $25 /hr.		2,000	
	Total Other Direct Costs				**2,500**
H)	**Total Direct Costs**				**41,557**
I)	**Indirect Costs –** 25.0% x **29,239** (MTDC)				**7,310**
J)	**AMOUNT PROPOSED FOR PROJECT**				**$48,867**

Salaries are based on current levels with projected annual increases as follows: 2% range adjustments effective Oct. 1 and 5% merit increases as applicable effective July 1. Graduate student health insurance and fee & tuition remissions are based on current levels with projected increases of 10% effective each August. Modified total direct costs (MTDC) excludes equipment, graduate student health insurance & fee remissions, and non-resident tuition.

Budget

Attachment B – Contractor Certification

Attachment C – Payee Data Record