Kinematic Source Study of the November 3, 2002 Mw7.9 Denali Earthquake and Implications for the Simulation of Near-fault Strong Ground Motion and Rapid Post-Earthquake ShakeMaps - ANNUAL PROJECT SUMMARY DECEMBER 1 2004.

Award: 04HQGR0013

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Program Element: I

Key words: source inversion, strong ground motion, amplification

Non-technical Summary:

In this study we combined various geophysical data sets to invert for a model of the rupture process of the November 3, 2002 Denali, Alaska earthquake. The resulting models are used to help constrain investigations of the rupture dynamics and to evaluate the effectiveness of near-realtime reporting of simulated near-fault strong ground motions for large earthquakes. They have also been used to investigate the relationship between ground motions and liquefaction occurrence.

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Investigations Undertaken

During the grant period we have undertaken an investigation of the kinematic source process of the November 3, 2002 Mw7.9 Denali mainshock, compared the kinematic results with spontaneous dynamic rupture models (Oglesby et al., 2004), and correlated simulated near-fault ground motions with the occurrence of liquefaction features (Kayan et al., 2004). In addition, two moderate earthquakes that occurred in Central California during the project period, namely the 2003 Mw6.5 San Simeon and the 2004 Mw6.0 Parkfield events, were investigated to determine kinematic source models. These analyses were used to investigate the use of finite-source models in updating ShakeMaps of the near-fault strong ground motions (Dreger et al., 2004; Hardebeck et al., 2004; Langbein et al., 2004).

Numerical testing of possible 3d fault zone structure, fault complexity and super shear rupture (Ellsworth et al., 2004) as explanations for the unusual strong-motion records at the near-fault pump-station 10 site in the Denali earthquake was carried out using a 3d finite-difference code. This work is ongoing and will be reported in the final project report. In addition, updated GPS data recently became available and these data will be used to update the kinematic model of the Denali mainshock and will be reported on in the final project report.

Results

The results of the Denali source modeling are described in detail in Dreger et al. (2003) and Oglesby et al. (2004). In the following the main findings are described. Our kinematic model is very similar to other models (e.g., Eberhart-Phillips *et al.*, 2003; Hreinsdóttir *et al.*, 2003; Ozakar *et al.*, 2003; Ji and al., 2004) in that: 1) initiation of rupture is principally reverse, 2) there are low levels of slip on the Denali fault from the hypocenter to about 60 km to the east, and 3) there is a large strike-slip asperity between 170 to 216 km on the Denali fault (Figure 1). All of these models and ours indicate that slip is shallow, with the majority shallower than about 10 km. The other seismic models (Eberhart-Phillips *et al.*, 2003; Ozakar *et al.*, 2003; Ji and al., 2004) also agree with ours in the sense that they have a fast average rupture velocity that ranges between 3.3-3.5 km/s. Our preferred rupture velocity is 3.3 km/s, which is consistent with the infrasound observations of Olson et al., 2003. Considering the shallow nature of the slip and that the upper crust shear wave velocity is about 3.5 km/s or less, there is strong evidence that on average the rupture propagated at near shear wave velocity and in places may have exceeded it. Finally, the kinematics of Ji *et al.*'s (2004) model and the model we obtained are consistent in that the transfer of slip from the Susitna Glacier fault to the Denali fault was delayed by 10-12 seconds, even though there is a direct connection between the Susitna Glacier and Denali faults at depth in the kinematic models. Dynamic modeling revealed that due to the favorable orientation of the principal stress direction with the Totschunda fault the rupture may have jumped ahead 15 km from the Denali fault to the Totschunda fault due to dynamic triggering from body waves. Unfortunately, the seismic waveform data is unable to resolve this level of detail.

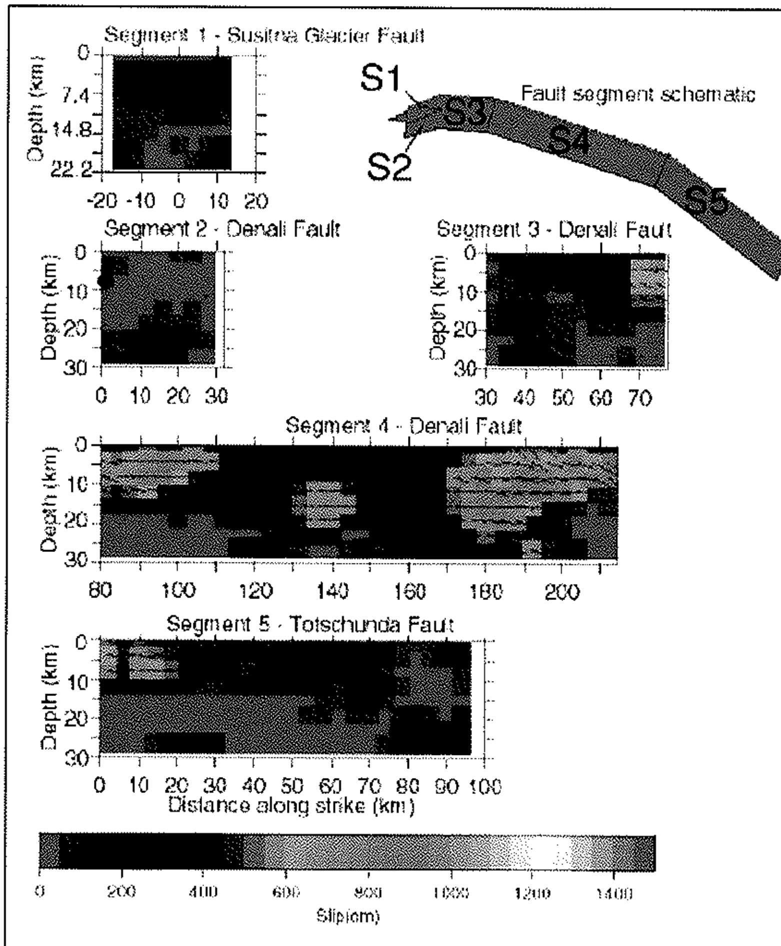

Figure 1. Results of inversion of broadband seismic waveform and geodetic data for the fault slip distribution. The schematic shows how segments 2-5 (S2-S5) form the arcuate shape of the Denali-Totschunda fault system. S1 shows the Susitna Glacier fault, which dips to the north-northwest and intersects with the Denali fault at 8 km depth. S2-S5 are vertically dipping. Both right-lateral and northside-up dip-slip were solved for. The results show dip-slip on S1 and principally strike-slip on S2-S5, though locally oblique slip is recovered. The hypocenter is shown on S1 and S2 as the black circle. For this model a best rupture velocity of 3.3 km./s was found.

Continuing work on the Denali earthquake will incorporate additional geodetic data that has recently become available from the University of Alaska, Fairbanks (Jeff Freymueller, written communication, 2004).

Simulated peak-ground velocity from the model shown in Figure 1 was used to define the region of strong shaking around the fault. This analysis shows a strong eastward directivity effect in which the region exceeding 10 cm/s ground velocity correlates well with areas that experienced significant liquefaction (e.g. Kayen et al., 2004). In the final report we will compare the simulated ShakeMaps for the preferred model (Figure 1), the updated model using the new GPS data, and also simplified models that may be anticipated to be available soon after the occurrence of the earthquake.

2003-2004 was a busy year for moderate earthquakes in California and during the project period we also studied the December 22, 2003 Mw6.5 San Simeon and the September 28, 2004 Mw6.0 Parkfield earthquakes. For the San Simeon event automatic and rapidly reviewed finite-source models (e.g., Dreger and Kaverina, 2000) were used to update the ShakeMap (Hardebeck et al., 2004; Dreger et al., 2004). Inversion of three-component broadband displacement data at regional distance stations revealed that the slip extended about 25 km southeast of the epicenter. This information was used to redefine the site-to-source distance in ShakeMap from site-to-fault rather than site-to-epicenter. This change incorporates source finiteness in the ground motion estimation. Figure 2 compares several versions of ShakeMap. The finite-source version (Figure 2b) was produced 4 hours and 17 minutes after the event, and compares well with maps obtained when near-realtime data were added afterward (Figure 2cd). See Hardebeck et al. (2004) and Dreger et al. (2004) for details.

For the Parkfield earthquake automated finite-source models revealed a northwestward directivity that agreed with the early aftershock zone (Dreger et al., 2004). The ShakeMap was updated for rupture finiteness based on the aftershock distribution.

These two events are the first real tests the system developed several years ago (Dreger and Kaverina, 2000) and implemented on the Berkeley Seismological Laboratory near-realtime processing system shortly thereafter. For the San Simeon earthquake the update to the ShakeMap occurred several hours after the event, but this was largely due to the short staffing during the holiday season. For the Parkfield earthquake the automatic code produced robust line-source results within 30 minutes of the earthquake demonstrating that it is possible to obtain finite-source information that can be used to correct ShakeMaps for both finiteness and directivity in a time frame useful for emergency response purposes. Lessons learned from these two earthquakes as well as the analysis underway for the Denali earthquake will help us to improve the realtime system.

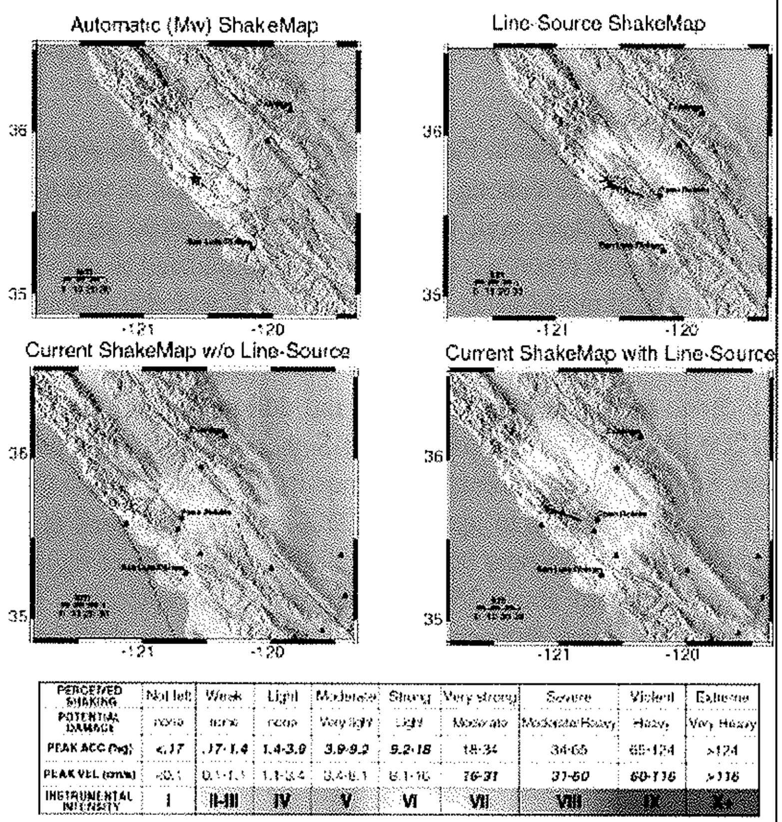

Figure 2. Comparison of Instrumental Intensity ShakeMaps for the 2003 Mw6.5 San Simeon earthquake;

A) Upper left, automatic ShakeMap.

B) Upper right, modified ShakeMap using line-source results to correct for source finiteness.

C) Lower left, ShakeMap using all available, non-realtime ground motion data.

D) Lower right, current ShakeMap that combines the finite-source information and the non-realtime, near-fault data.

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Non-technical Summary:

In this study we combined various geophysical data sets to invert for a model of the rupture process of the November 3, 2002 Denali, Alaska earthquake. The resulting models are used to help constrain investigations of the rupture dynamics and to evaluate the effectiveness of near-realtime reporting of simulated near-fault strong ground motions for large earthquakes. They have also been used to investigate the relationship between ground motion and liquefaction occurrence.

Reports published

Three peer-reviewed papers on the rupture kinematics and dynamics of the Denali earthquake have resulted from this grant:

Dreger, D., D. D. Oglesby, R. A. Harris, N. Ratchkovski and R. Hansen (2003). Kinematic and dynamic rupture models of the November 3, 2002 Mw7.9 Denali, Alaska, earthquake, *Geophys. Res. Lett.,* 31, L04605, doi:10.1029/2003GL018333.

Kayan, R., E. Thompson, D. Minasian, R. E. S. Moss, B. D. Collins, N. Sitar, D. Dreger and G. Carver (2004). Geotechnical Reconnaissance of the 2002 Denali Fault, Alaska, *Earthquake, Earthquake Spectra*, 20, 3, 639-667.

Oglesby, D. D., D. S. Dreger, R. A. Harris, N. Ratchkovski and R. Hansen (2004). Inverse kinematic and forward dynamic models of the 2002 Denali fault earthquake, Alaska, *in press special issue of Bull. Seism. Soc. Am.*.

In addition, two moderate sized, California events, namely the December 22, 2003 San Simeon (Mw6.5) and the September 28, 2004 Parkfield (Mw6.0) occurred and their study was relevant to the strong motion reporting aspect of the funded project. Three peer-reviewed papers have resulted from these studies:

Dreger, D. S., L. Gee, P. Lombard, M. H. Murray, and B. Romanowicz (2004). Rapid Finite-Source Analysis and Near-Fault Strong Ground Motions – Application to the 2003 Mw6.5 San Simeon and 2004 Mw6.0 Parkfield Earthquakes, *Seismo. Res. Lett. Special issue on the Parkfield earthquake.*

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Seismic and geodetic data used in these studies may be obtained by written request to Douglas Dreger.