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Lithological and Rheological Constraints on Fault Rupture Scenarios for Ground Motion Hazard Prediction

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Lithological and Rheological Constraints on Fault Rupture Scenarios for Ground Motion Hazard Prediction

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Abstract

This paper tests an approach to predict the range of ground motion hazard at specific sites generated by earthquakes on specific faults. The approach is based upon structural, lithological and rheological descriptions of the fault zones, development of fault rupture scenarios, and computation of synthetic seismograms using empirical Green's functions. Faults are placed within a regional geomechanical model. The approach is based upon three hypothesis: (1) An exact solution of the representation relation that utilizes empirical Green's functions enables very accurate computation of ground motions generated by a given rupture; (2) a general description of the rupture is sufficient; and (3) the structural, lithological and rheological characteristics of a fault can be used to constrain, in advance, possible future rupture histories. Ground motion hazard here refers to three-component, full wave train descriptions of displacement, velocity, and acceleration over the frequency band 0.01 to 25 Hz. Corollaries to these hypotheses are that the range of possible fault rupture histories is narrow enough to functionally constrain the range of strong ground motion predictions, and that a discreet set of rupture histories is sufficient to span the infinite combinations possible from a given range of rupture parameters.

Hypotheses 1 and 2 are supported by previous studies. Hutchings and Wu (1990) developed an exact solution to the representation relation (Aki and Richards, 1980) that utilizes recordings of small earthquakes ($M \le 2.5$) that have effectively impulsive point sources to obtain empirical Green's functions. Jarpe and Kasameyer (1993) constrained the rupture history of the 1989 Loma Prieta earthquake using rupture parameters from independent studies and applied the computational approach of Hutchings and Wu to compute synthetic seismograms at 27 of the strong motion sites that recorded the earthquake. Jarpe and Kasameyer used the rupture model characterization based upon rupture geometry, rupture velocity, hypocenter, and moment described by Hutchings (1991). Jarpe and Kasameyer obtained very good fits to the observed time histories and spectra. They also computed engineering parameters and found that the errors between computed and observed response spectra were less than or equal to those from other methods for periods in the range 0.05 to 0.4 sec. At periods between 0.5 and 2.0 sec, the errors were significantly less than those from methods based on regression of recorded strong motion data. Hutchings (1994) carried out a more extensive investigation of rupture models and found that near exact synthesis of small earthquake seismograms can be achieved when the same small set of parameters is independently constrained. Hutchings also obtained good fits to waveforms recorded from the $M = 6.4$, 1971 San Fernando earthquake using similar simple rupture models.

Foxall *et al.* (1993) have begun to test hypothesis 3 using a three-dimensional tomographic P-velocity model of the Loma Prieta segment of the San Andreas fault zone. The model was obtained by earthquake arrival time inversion and "calibrated" in terms of subsurface lithology using laboratory Vp versus depth data for specific rock types found on either side of the fault and

seismic refraction profiles. They found that a large-scale anomalous high-velocity body coincides with the rupture zone of the Loma Prieta earthquake, and propose a model in which large-scale variations in fault frictional stability and strength are controlled in part by along-strike lithological heterogeneity. They propose that the active fault plane within the high-velocity body is relatively strong and fails only unstably, and that the body acts as a barrier that arrests both stable sliding and dynamic rupture. This concentrates stress on the fault plane within the body, which evolves to become the asperity that fails in earthquakes like that in 1989. The geometry, location of nucleation and directions of rupture inferred for this asperity match the general features of the rupture derived by kinematic inversions of strong motion data.

In the study reported here, we extend the work of Foxall *et al.* to include elastic and frictional properties derived from a lithological model; rupture parameters, such as hypocenter location and rupture velocity, are estimated from the model and fault geometry; and ranges of other parameters, such as slip amplitude or stress drop, are estimated for given moments. The asperity is loaded to failure by driving the fault within a regional geomechanical model, outlined below. In this way we constrain a limited set of possible rupture histories that are used to generate a suite of synthetic strong motion time histories that constitute the range of predicted ground motion hazard expected from an earthquake on this segment of the fault. Hutchings (1991) predicted ground motion hazard to four sites that recorded the Loma Prieta earthquake using an ad hoc estimate of the range of fault rupture scenarios. Here, we extend his prediction to 27 sites using the set of rupture scenarios constrained by the rupture zone model. We test hypothesis 3 that possible future rupture scenarios can be constrained in advance given fault zone models like that for Loma Prieta by determining whether the suite of predicted ground motion hazards at the 27 sites captures the observed ground motions, and how small the estimated standard errors are.

The work described here is carried out within the framework of the *Northern California Dynamic Earth Model* (NCDEM, CONCERT, 1993), which is a working model that is being developed to describe the contemporary dynamic relations of a block segment of the lithosphere in northern California. The model is based upon rock material properties, including rheological parameters, porosity, permeability and density, derived from geology, seismic velocities and other geophysical and hydrological data, and kinematic and dynamic data, such as stress, strain, fault displacement rates, and pore pressures, derived from geology, plate tectonics, geodetics, geomechanical modeling, seismology and hydrogeology. NCDEM is being developed ultimately to provide computer-based intermediate-term prediction of future earthquake locations, sizes, and times of occurrence, and secondary fault rupture triggered by large earthquakes. It will also enable development of fault rupture scenarios and computation synthetic ground motions following the approach discussed in this paper. The extremely large scope of this development requires massively parallel computing to implement, and is being carried out as a cooperative effort of the institutions that makeup CONCERT.

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