1998 SCEC Progress Report: **Integrated Approach to Time Histories Prediction**

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We have continued to develop and validate algorithms for broadband ground motion simulations of scenario earthquakes, that include studies of source models and site effects.

Physical constraints on source models. A meaningful statement of the problem of predicting ground motions from a future earthquake should include two global parameters: seismic moment and total radiated energy. That is a common practice in the stochastic approach (Hanks and McGuire, 1981; Boore, 1983), but not yet fully implemented in the kinematic simulations of extended ruptures! Recent advances in compiling estimates of energy and apparent stress for thousands of earthquakes worldwide (Choy and Boatwright, 1995) provide ranges of these parameters for different types of earthquakes in various tectonic settings thus making it practical to use the additional energy parameter. Energy and moment effectively constrain the whole frequency range of radiation from models that are calibrated to reflect the observed earthquake scaling laws (e.g., for the ω-squared model).

We found that using two global characteristics of a seismic source -- moment and energy -- as constraints on model parameters we are able to address the problem of reducing uncertainty of forward ground motion simulations. For kinematic models moment and energy determine the acceptable combinations of the slip heterogeneity (e.g., location of asperities relative to hypocenter), fault discretization (number of subevents), rise time distribution and hypocenter location. For dynamic calculations, energy could serve for choosing a governing friction law (Shaw, 1998).

Modified stochastic approach. High-frequency radiation from seismic sources is one of the major causes of damage in the epicentral areas of large earthquakes. Deterministic high-frequency ground motion waveform modeling has proven to be an impossible undertaking due to two main reasons: i) our inability to describe the subsurface geologic medium on the scale of one to hundreds of meters, and ii) insufficient computational facilities even at the present stage of the high-performance computing, to simulate high frequency ground motions from large earthquakes. Thus for all practical purposes it is adequate to view the high-frequency seismic radiation as a stochastic process. Consequently the development of methods of ground motion prediction based on this approach represents a very important scientific and practical problem. The stochastic ground motion prediction approach proved to be a simple and reliable tool since its inception in early 80's (Hanks and McGuire, 1981; Boore, 1983).

We have developed further modifications of the standard stochastic approach. The first one is to accomodate the observed statistical properties of the ground motion amplitudes in the near-field of large earthquakes. The second modification is to implement a multiple event model in the stochastic scheme to account for source complexity and spatial extent of the ruptures. Both of these modifications are especially important for near-source applications as the predictions at distant sites (at distances exceeding the dimensions of the rupture area itself) are well served by the standard technique.

To validate this approach we participated in the simultaneous simulation project for the special session on the Kobe earthquake held during the 2nd Conference on Effects of Surface Geology (Yokohama, Japan, December 1-3, 1998). SCEC ground motion group was represented by Dr. Rob Graves (Woodward Clyde Federal Services) and Dr. Alexei Tumarkin (UCSB). Both results were chosen by organizers among the more successful realizations. Figure 1 shows one of the sites in the Osaka basin for which we calculated 10 stochastic realizations. We intentionally used a very crude source and site response models trying to reproduce a real forward prediction experiment (Tumarkin, 1999). Nevertheless, the predictions are reasonably close to observations in amplitude, duration and frequency content for the first 25 seconds. At the same time any 1D propagation algorithm is not capable to simulate the prolonged shaking at very long periods characteristic for this site located in a deep part of the Osaka basin. That feature can be successfully modeled using a 3D propagation method (Graves, 1999).

Site response studies. There is an increased awareness both in the seismological and the engineering communities that we should study earthquake ground motions as a three-dimensional wave field. A common practice of using ground motion components separately might produce misleading results in many important cases. A standard approach to estimating relative site response (Borcherdt, 1970) is to calculate a 1D transfer function between a rock and a soil sites as an average spectral ratio of individual components. We introduce a 3D transfer function between all three components of motions at two sites as a 3x3 matrix transformation. This matrix accounts for complex propagation effects such as conversions of different types of seismic waves, differences in incidence angles, etc. It can be determined from observations of at least three earthquakes at both sites. This suggests a possible explanation of some causes of an apparent event-to-event variability of standard 1D relative site response estimates as each single earthquake observation is capable of imposing only three constraints on nine a priori unknown components of the transfer matrix. When there are more than 3 observations, the transfer matrix is obtained as a maximum likelihood solution of an overdetermined system of equations.

After combining two horizontal components into one complex time series we arrived at an efficient way of studying site amplification and polarization properties of ground motion (Tumarkin & Archuleta 1997). Our approach is different from the Takizawa's directional distribution of energy method (Takizawa 1982; Kawase & Aki 1990). By further developing the idea of spectral maximization introduced in Shoja-Taheri & Bolt (1977), for each frequency we calculate the maximum amplitude and the corresponding azimuth of particle motion in the horizontal plane, as well as the eccentricity of this motion. This allows us to perform a detailed analysis of frequencies at which the ground motion is the largest and most polarized. It also allows us to observe how these frequencies vary from site to site, in particular depicting specific azimuths and frequencies at which critical facilities are especially vulnerable to seismic excitations. For example, applying this method for the Kobe earthquake we were able to show that near-fault ground motions are almost linearly polarized in the fault-normal direction for periods longer that 0.5-1 s, while there is no predominant direction of motion even at the longest periods for stations located within the Osaka basin (Figure 2).

The work on this project resulted in the following publications:

Archuleta R.J., P.-C.Liu and A.G.Tumarkin. Source inversion and ground motion prediction with empirical Green's functions. In "Proceedings of the NEHRP Conference and Workshop on Research on the Northridge, California Earthquake of January 17, 1994. Vol. II", CUREe, Richmond CA, 421-428, 1998.

Bonilla L.F., J.H. Steidl, G.T. Lindley, A.G. Tumarkin, and R.J. Archuleta. Comparison of S-wave, coda, and H/V site response methods using Northridge aftershock data. In "Proceedings of the NEHRP Conference and Workshop on Research on the Northridge, California Earthquake of January 17, 1994. Vol. II", CUREe, Richmond CA, 216-223, 1998.

Steidl, J.H., R.J. Archuleta, A.G. Tumarkin, L.F. Bonilla, and J.-C. Gariel. Observations and modeling of ground motion and pore pressure at the Garner Valley, California, test site. In "The Effects of Surface Geology on Seismic Motion. Vol. I", ed. K.Irikura, K.Kudo, H.Okada, T.Sasatani, Balkema, Rotterdam, 225-232, 1998.

Tumarkin, A.G. Site response analysis in 3D. In "The Effects of Surface Geology on Seismic Motion. Vol. II", ed. K.Irikura, K.Kudo, H.Okada, T.Sasatani, Balkema, Rotterdam, 365-370, 1998.

In press:

Tumarkin, A.G. Stochastic simulations based on statistics of strong ground motions. In "The Effects of Surface Geology on Seismic Motion. Vol. III", ed. K.Irikura, K.Kudo, H.Okada, T.Sasatani, Balkema, Rotterdam, 1999.

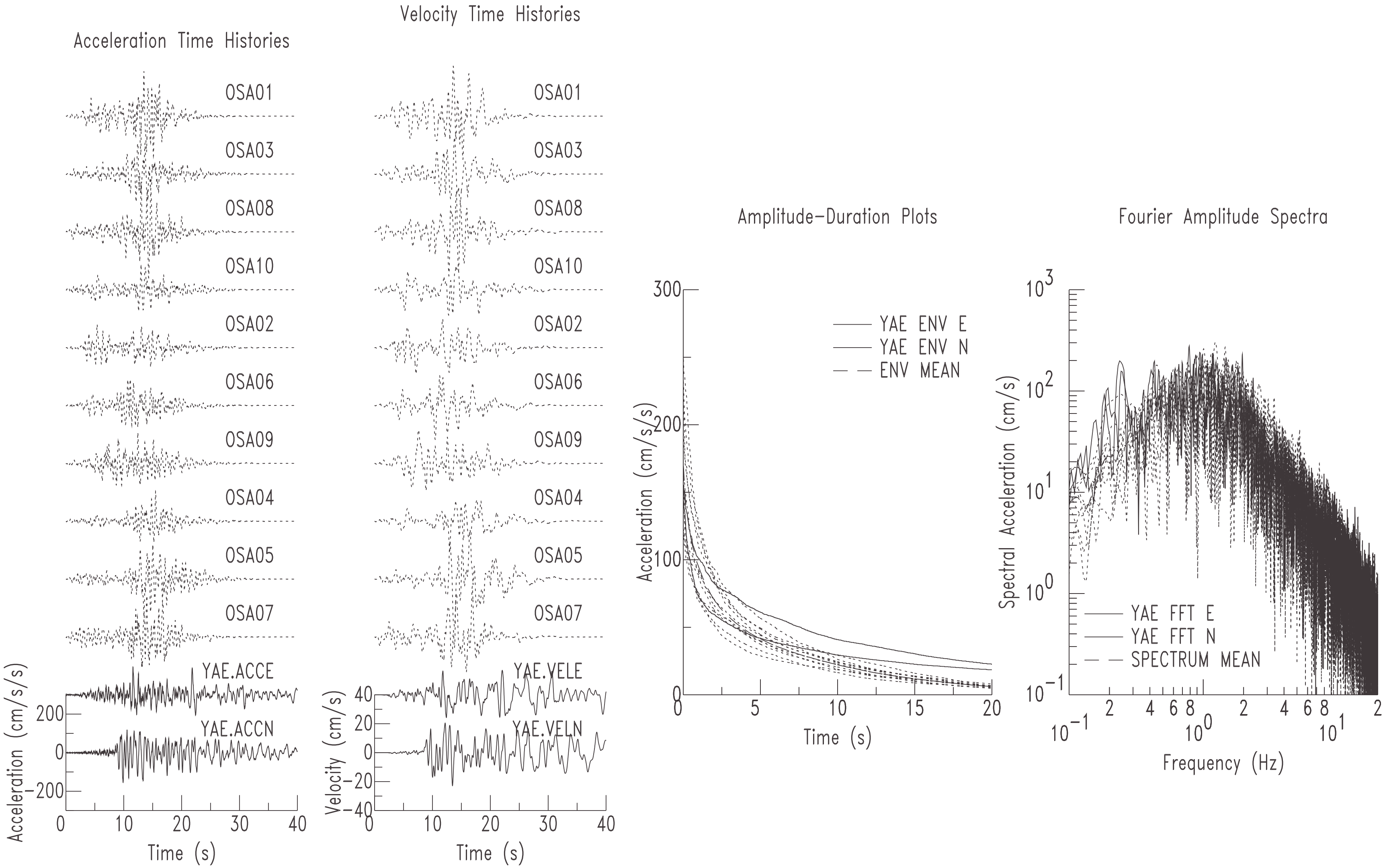

Figure 1. Ground Motion Prediction of Kobe Earthquake at Yae Site: Observed Horizontal Motions – Solid; Stochastic Realizations – Dotted

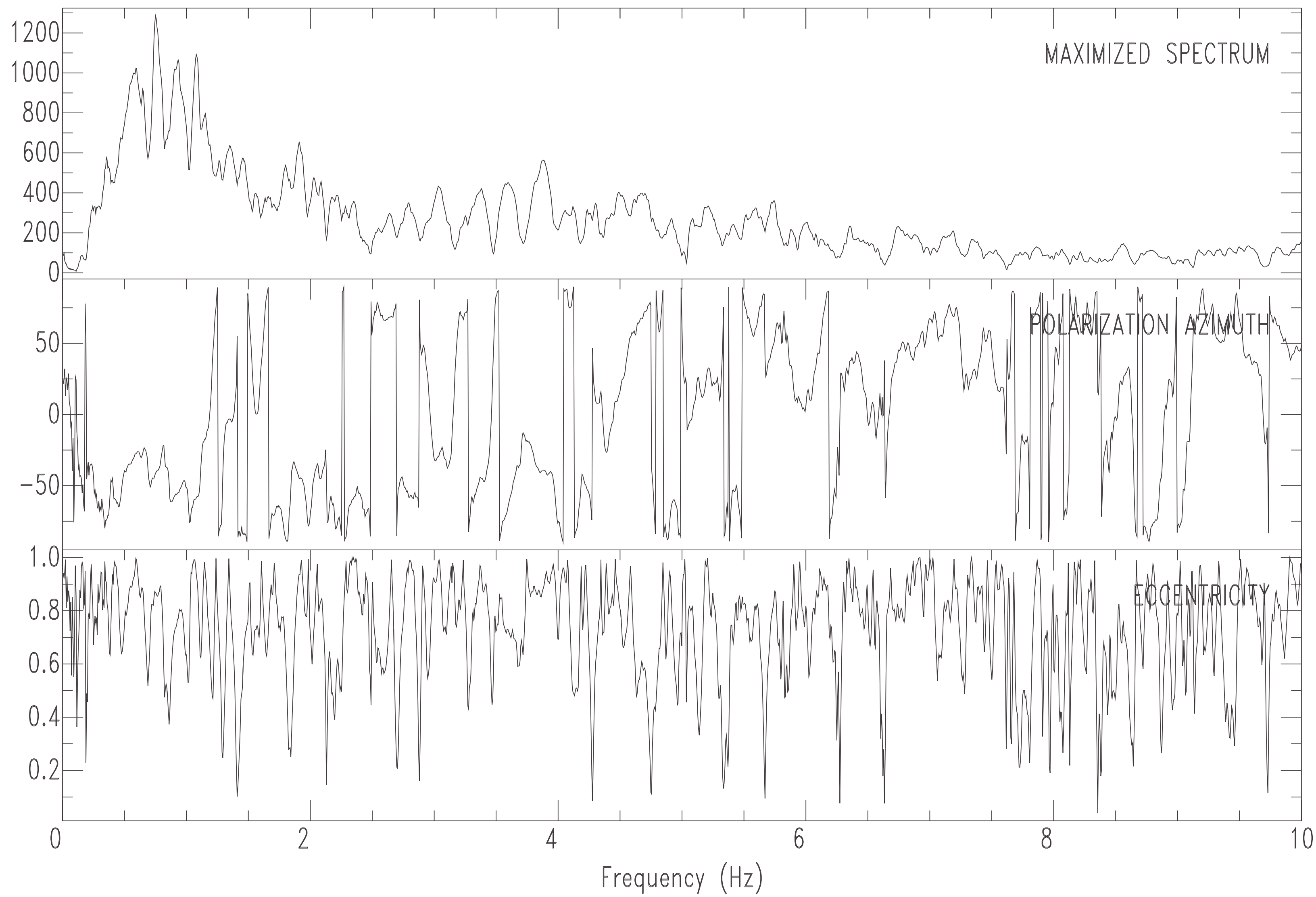

Figure 2. Horizontal Polarization as a Function of Frequency at Kobe JMA Site