A Study of the Potential Use of an Energy Based Motion Parameter for Probabilistic Determination of Scenario Earthquakes

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Investigations Undertaken

The amplitude and duration of ground motion are important considerations for engineering analysis. However, the duration of shaking is not modeled routinely in probabilistic seismic hazard assessments. We are examining the potential use of a parameter based on the square root of the elastic input-energy spectrum. This is attractive because it has many similarities to the familiar pseudo-relative velocity (PSV) spectrum, yet it depends upon the duration of shaking as well as the amplitude of motion. The energy-based prediction model may have application in the identification of scenario events for dynamic analysis, assuming that the energy spectrum can be predicted as a function of magnitude and distance and that statistical variability is comparable to that associated with peak motion measures or response spectra ordinates.

This study involves development of regression models for predicting the elastic input-energy spectrum using strong motion data from western U.S. earthquakes. The emphasis of the study is on comparison of those results with PSV response spectra derived from the same data set, using identical processing procedures. Results indicate that similar regression models can be used for PSV spectra and equivalent velocity spectra derived from the absolute and relative input-energy spectra. The energy-based models exhibit a stronger dependence upon earthquake magnitude, compared to the PSV models: that is, the ratio of the equivalent velocity spectral amplitudes to the PSV amplitudes is a function increasing with magnitude. Also, this ratio increases with distance for oscillator frequencies less than approximately 7 Hz. Work in progress will assess the effect these differences have on probabilistic seismic hazard estimates with regard to the definition of events (magnitude and distance) contributing significantly to hazard for specified return periods.

Results

Data Collection:

Strong motion recordings from western North America have been collected for 22 earthquakes listed in Table 1. The sources include the collection compiled on CD-ROM by the NOAA National Geophysical Data Center, and data available via the Internet from the California Division of Mines and Geology, the U.S. Geological Survey Strong Motion Instrumentation Program, and the Department of Civil Engineering, University of Southern California. In most cases, processed data (acceleration recordings) were available. In cases where only unprocessed data were available, the data were interpolated to equal sample intervals, bandpass filtered and corrected for instrument response. The distance metric, as well as the site classification scheme, are as defined by Boore et al., (1993). Figure 1 indicates the distribution of data, in terms of moment magnitude and distance.

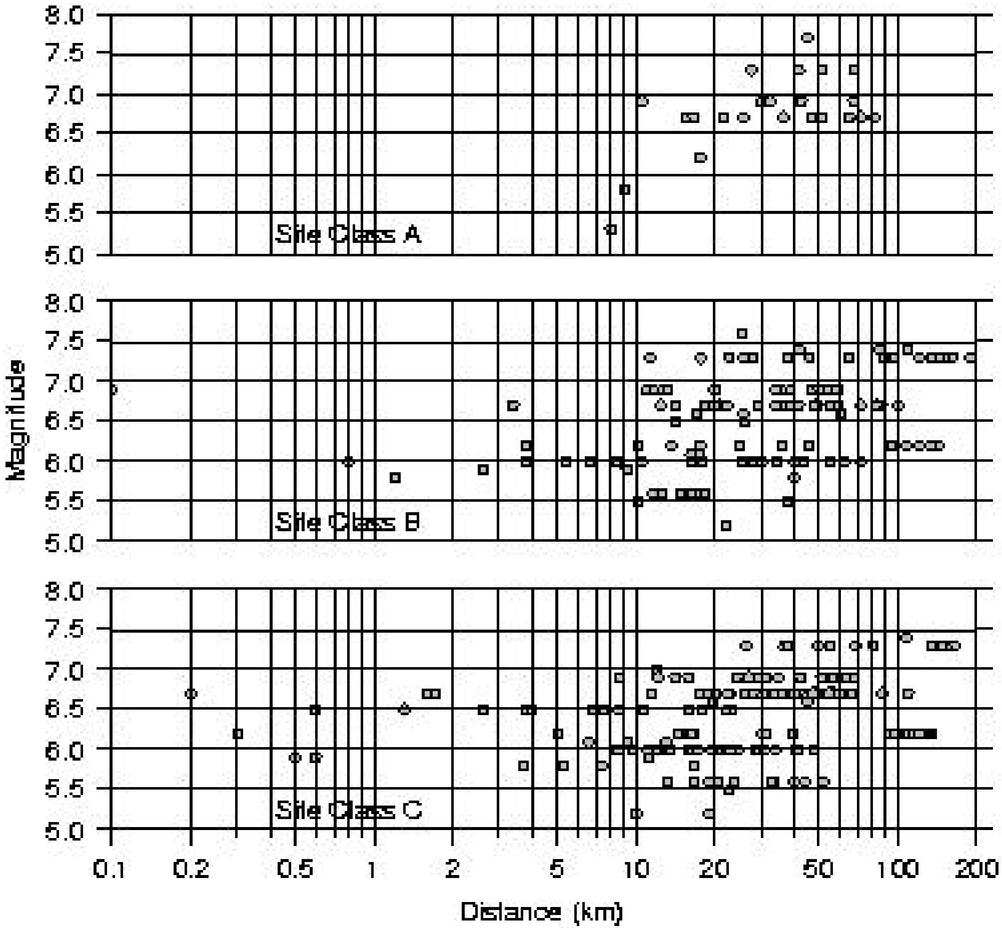

Figure 1: Distribution of data for regression analysis.

Motion Parameters:

The parameters of interest in this study are the elastic pseudo-relative velocity response, PSV, as well as the relative and absolute input energies for an elastic oscillator (E_r, and E_a, respectively). From Uang and Bertero (1990),

$$E_r = -\int m\ddot{x}_g\dot{x}dt, \quad E_a = \int m(\ddot{x}+\ddot{x}_g)\dot{x}_g\, dt .$$

Here x is the relative displacement of the oscillator mass with respect to the ground, and x_g is the ground displacement. We define Vea and Ver as $(2Ea/m)^{1/2}$ and $(2Er/m)^{1/2}$, respectively. The maximum values of the equivalent velocities Vea and Ver during the episode of recorded motion are used for analysis. Vea and Ver are asymptotic to the maximum ground velocity for high and low oscillator frequencies, respectively. Therefore, for direct comparison with PSV, it is convenient to define EV=min(Vea,Ver). Like PSV, EV approaches zero at high and low oscillator frequency.

Regression Analysis:

The following regression model (Boore et al., 1993) is very successful in modeling the PSV, Vea, Ver and EV data sets:

$$\text{Log } Y = a + b(M-6) + c(M-6)^2 + d \log (R^2 + h^2)^{1/2} + e\, G_1 + f\, G_2.$$

Here, Y is the response variable (geometric mean of the two horizontal components for PSV, Vea, Ver or EV), M is moment magnitude, R is the horizontal distance to the nearest surface projection of the fault rupture, and G_1 and G_2 are indicator variables for site classifications B and C (e.g., G_1=1 for class B sites, 0 otherwise). The unknowns a,b,c,d,h,e,f and estimates of random error are determined using the two-step regression procedure of Joyner and Boore (1993, 1994).

The variance of the regression systematically decreases with increasing oscillator frequency over the range of frequency 0.5 to 5 Hz (Figure 2). Also, the variance associated with the energy-based parameter is slightly smaller than that of PSV, for frequencies in the range 0.5 to 7 Hz. Response differences due to site class are largest at the lowest frequencies and decrease systematically with increasing oscillator frequency. EV appears essentially independent of site class at frequencies greater than approximately 4 Hz (Figure 2). Figures 3 and 4 show the PSV and EV regression residuals for the geometric mean of the two horizontal components (log base 10 units) plotted as a function of distance for the 1 Hz oscillator and 5% critical damping. The data for 1 Hz, as well as for other frequencies in the range 0.5 to 10 Hz, appear well-fitted by the regression model, throughout the range 0 to 200 km. Most data at distances in excess of 110 km are from the Landers and Big Bear earthquakes recorded at sites in the Los Angeles area.

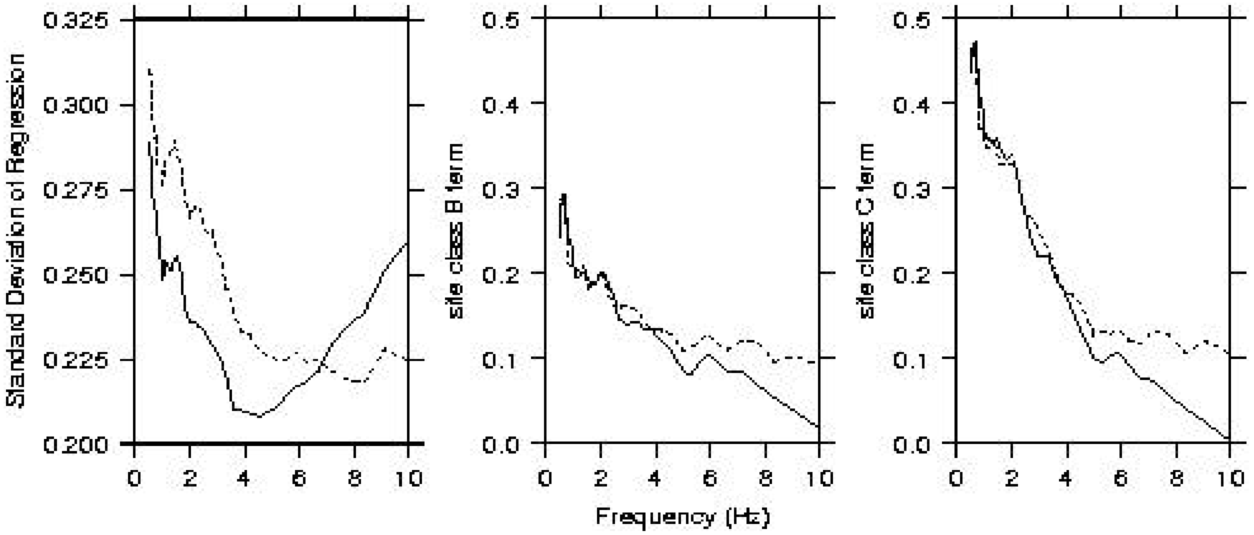

Figure 2: Plot of regressions results (log base 10 units) vs frequency for PSV (dashed lines) and EV (solid lines). Left: standard deviation of regression. Middle: site term for Site Class B. Right: site term for Site Class C.

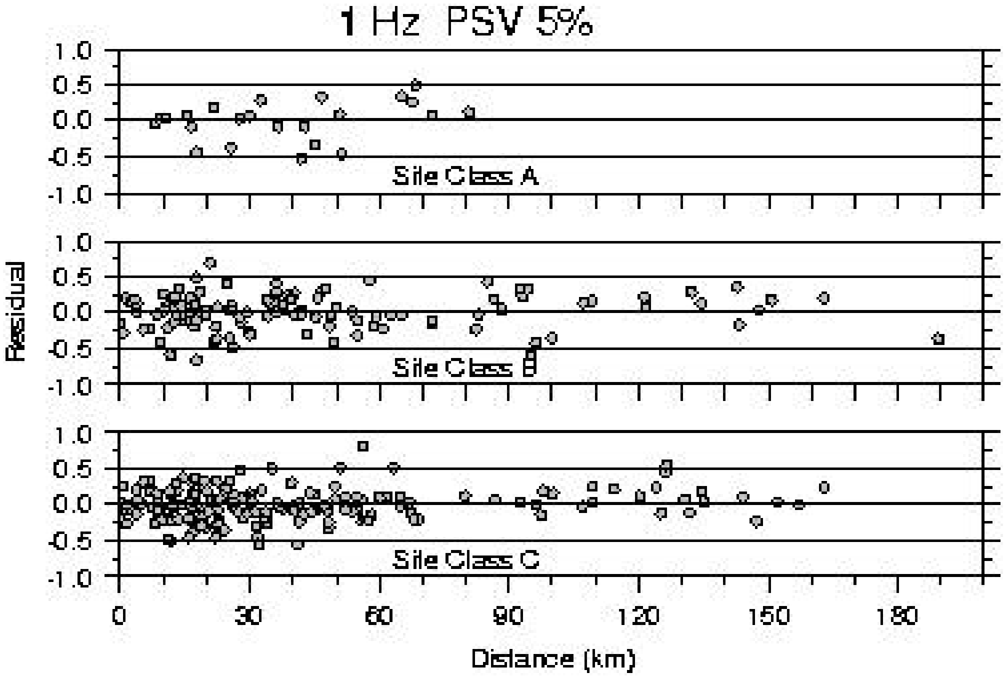

Figure 3: Residuals (log base 10) from regression model for PSV, 1 Hz oscillator, 5% critical damping.

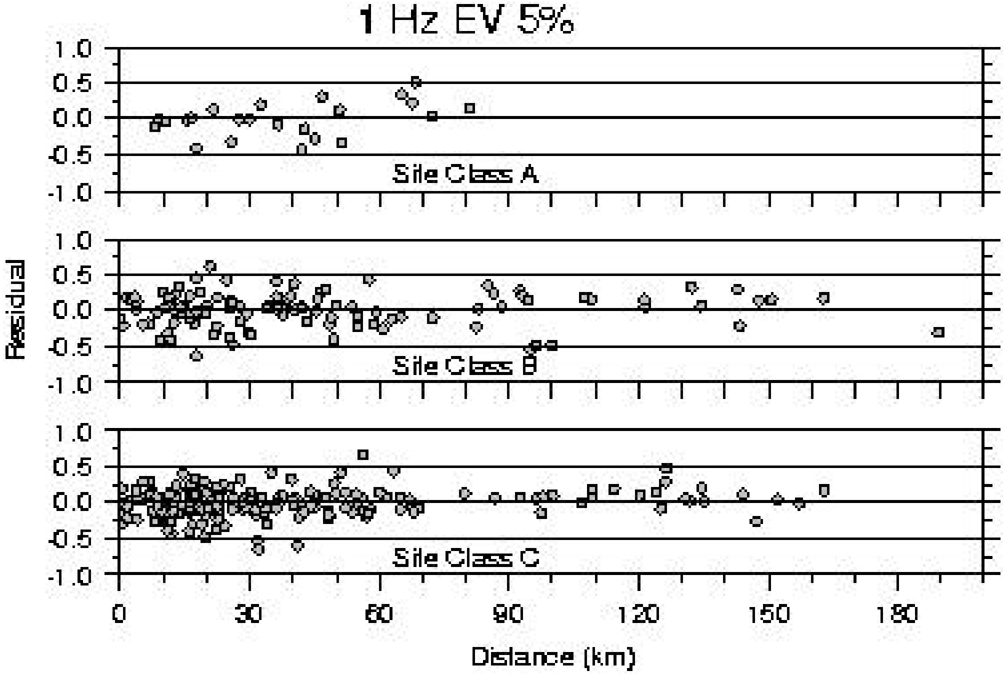

Figure 4: Residuals (log base 10) from regression model for EV, 1 Hz oscillator, 5% critical damping.

Comparison of EV versus PSV:

The regression modeling indicates that, compared to PSV, the amplitudes of the energy-based parameters decay less rapidly with increasing distance, and increase more rapidly with increasing earthquake magnitude. This behavior, which can be attributed to duration of shaking, depends on oscillator frequency and is less pronounced for the low-frequency oscillators. Figure 5 illustrates this for site class B, by plotting the ratio EV (predicted) over PSV (predicted) as a function of distance for a range of magnitudes. In the frequency range 1 to 4 Hz, the ratio EV/PSV is an increasing function of distance and magnitude. High-frequency magnitude dependence is similar to that for lower oscillator frequencies. However, beyond about 30 km, the ratio at high frequency decreases with distance. The reason for this is unclear at present, but may be related to the effects of anelastic absorption of the highest frequency ground motions at the larger distances.

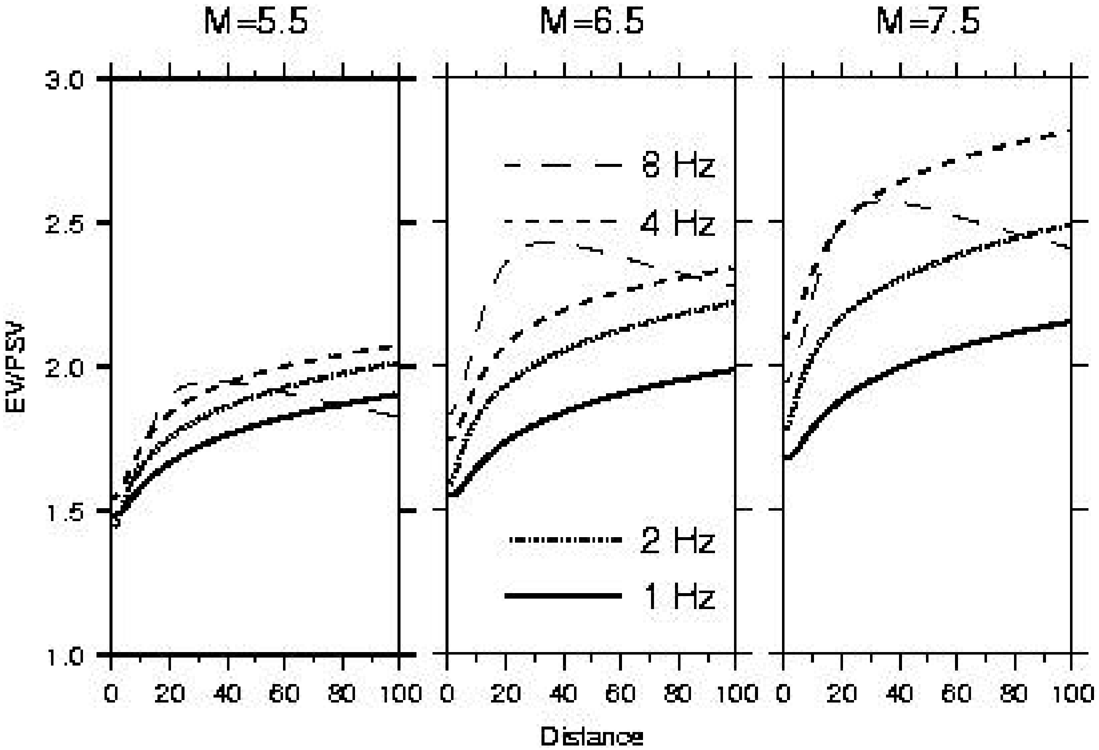

Figure 5: The ratio EV/PSV as a function of distance, for three values of earthquake magnitude. Site classification B.

References Cite*d:*

Boore, D.M., W.B. Joyner and T.E. Fumal (1993), Estimation of response spectra and peak acceleration from western North American earthquakes: an interim report, U.S. Geological Survey Open-File Report 93-509.

Joyner, W.B. and D.M. Boore (1993), Methods for regression analysis of strong-motion data, Bull. Seism. Soc. Am., 83, 469-487.

Joyner, W.B. and D.M. Boore (1994), Errata, Bull. Seism. Soc. Am., 84, 955-956.

Uang, C.-M. and V.V. Bertero (1990), Evaluation of seismic energy in structures, Earthquake Eng. and Struct. Dyn., 19, 77-90.

Table 1
Earthquakes Used For Analysis

Date	Earthquake	Moment Mag.	No. of Sites
1940 May 19	Imperial Valley, CA	7.0	1
1952 July 21	Kern County, CA	7.4	4
1957 Mar. 22	Daly City, CA	5.3	1
1966 June 28	Parkfield, CA	6.1	5
1968 April 9	Borrego Mountain, CA	6.6	1
1971 Feb. 9	San Fernando, CA	6.6	4
1972 July 30	Sitka, AK	7.7	1
1972 Dec. 23	Managua, Nicaragua	6.2	1
1974 Nov. 28	Hollister, CA	5.2	3
1979 Feb. 28	St. Elias, AK	7.6	1
1979 Aug. 6	Coyote Lake, CA	5.8	5
1979 Oct. 15	Imperial Valley, CA	6.5	17
1980 Jan. 24	Livermore, CA	5.9	2
1980 Jan. 27	Livermore, CA	5.2	3
1981 April 26	Westmoreland, CA	5.6	5
1984 April 24	Morgan Hill, CA	6.2	10
1987 Oct. 1	Whittier Narrows, CA	6.0	48
1989 Oct. 18	Loma Prieta, CA	6.9	37
1991 June 28	Sierra Madre, CA	5.6	18
1992 June 28	Landers, CA	7.3	36
1992 June 28	Big Bear, CA	6.4	27
1994 Jan. 17	Northridge, CA	6.7	77

Related Publications and Reports

Chapman, M.C., K. Zhang and J.A. Snoke (1997), The potential use of an energy-based motion parameter for probabilistic seismic hazard analysis, Abst, Program and Abstracts, 69th Annual Meeting of the ES-SSA, Oct. 5-8, 1997, Ottawa, Canada (to appear in Seismological Research Letters, 1998).