GROUND MOTION ESTIMATION IN REGIONS WITH FEW DATA

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SUMMARY

Seismic ground motion can be derived in regions with few strong motion data by estimating intensity levels for given earthquakes, and applying ground-motion-to-intensity correlations from regions with abundant data. Using this method in northeastern North America, we find that peak acceleration estimates are reasonable and compatible with data for $m_b \cong 4.7$. Estimates also appear reasonable for larger magnitudes, by comparison to semi-theoretical equations and California results. In contrast to previous studies, recent California data suggest that the peak velocity-to-MM intensity correlation is distance-dependent.

INTRODUCTION

The estimation of seismic ground motion (quantified by peak ground motion parameters and response spectra) in regions with few data has always been problematic. The usual method is to estimate peak motion parameters (peak acceleration a_g and peak velocity v_g), either by theoretical methods or by using intensity data from the region, and mathematically combining these with peak-motion-to-intensity functions derived from data obtained in more seismic areas. Response spectra are then computed either by scaling a spectral shape to a_g or by amplifying a_g and v_g in various frequency ranges.

The purpose of the present study is to examine these procedures for northeastern North America. Recent strong motion data in this region allow a direct comparison of estimates with observations; also, recent data obtained in California allow a revision of previous peak-motion-to-intensity functions for earthquakes not previously well-documented.

PEAK GROUND MOTION

Two methods of estimating a_g and v_g are available. The first involves theoretical or semi-theoretical methods which attempt to model the physics of seismic wave propagation in the region (e.g., Ref. 1,2).

We pursue here the second method which relies on observations of Modified Mercalli (MM) intensity in the region of concern to calibrate a mathematical model indicating qualitative levels of ground motion. Independently, functions allowing estimation of a_g and v_g from MM intensity are derived from data obtained in California. These two functions are combined mathematically so that a_g and v_g can be estimated for the region of concern, in a way that is consistent with the observations of MM intensity (e.g., Ref. 3,4).

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Table 1 gives a summary of the earthquakes which generated the 82 strong motion records used in our analysis. These events and records were characterized by their moment magnitudes and soil conditions (Ref. 5). The surface distances to the fault projection were converted to an effective hypocentral distance R using an assumed 10 km depth of energy release. Three of the fifteen events (involving 32 of the 82 records used) occurred since our previous analysis in 1977 (Ref. 3).

There are several mathematical forms available to estimate a_g and v_g given site MM intensity I_s:

$$\ln (a_g, v_g) = b_1 + b_2 I_s + b_5 V + b_6 S \quad (1)$$
$$\ln (a_g, v_g) = b_1 + b_2 I_s + b_3 \ln R + b_5 V + b_6 S \quad (2)$$
$$\ln (a_g, v_g) = b_1 + b_2 I_s + b_4 M + b_5 V + b_6 S \quad (3)$$

where M is moment magnitude, V is a binary variable indicating component direction (zero for horizontal, unity for vertical), S is a binary variable indicating site conditions (zero for rock, unity for soil), and b_1 through b_6 are coefficients fit by least-squares regression analysis. Equation 1 assumes that the peak-motion-to-I_s relationship is independent of M and R; equations 2 and 3 accommodate any dependence on these variables which might be exhibited by the data.

The results of the regression analyses are shown in Table 2. The mathematical forms which provide the best fit (in terms of residual standard deviation) are, for both a_g and v_g, the equations which include a ln R term. This result for a_g is consistent with previous analyses (Ref. 3) and has been noted for some time (Ref. 6). It implies that the acceleration associated with any particular value of I_s depends on whether that I_s is observed near the earthquake source (in which case a_g will be relatively high) or is observed at farther distances during a larger event (in which case a_g will be relatively low). The similar result for v_g has <u>not</u> been observed before; our previous analysis (Ref. 3) found no such dependence of the v_g-I_s relationship on ln R.

Figures 1 and 2 illustrate the distance dependence of a_g (normalized by I_s) and v_g (normalized by I_s and S). The dependence is greater for a_g but is still statistically significant for v_g; for the latter variable it is caused primarily by recent strong motion records obtained in California since in 1977.

Several regression analysis results additional to those in Table 2 were obtained. The soil term was not significant in forms involving a_g. Forms involving <u>both</u> an M and a ln R term yielded a very small coefficient for I_s, meaning that M and R governed the estimation of a_g and v_g. These forms were judged to be inappropriate for combination with I_s.

In order to estimate ground motion in northeastern North America, we use MM intensity data from the 1944 Cornwall-Massena earthquake ($m_b \cong$ 5.8). The following equation was derived by regression analysis using the intensity data and the assumption (involving epicentral intensity

I_e) that $I_s = I_e = 2\ m_b - 3.5$ (Ref. 7) near the epicenter:

$$I_s = -0.17 + 2\ m_b - 1.29 \ln R - 0.00085R \qquad (4)$$

where R is hypocentral distance assuming a focal depth of 10 km. The constraint on I_s is assumed to apply at an epicentral distance of 10 km (or R = 14.14 km). Equation 4 was compared to data from other northeastern U.S. earthquakes and was found adequate. Figure 3 shows a comparison between intensity data from the Cornwall-Massena earthquake and equation 4.

Substituting equation 4 into the I_s term of the regressions of Table 2 lead to several predictive equations as shown in Table 3. To make magnitude terms equivalent, the moment magnitude of the Table 2 regressions was converted to m_b using $M = M_L = 1.03\ m_b + 0.3$ (Ref 1). Each of the equations in Table 3 corresponds to an assumption about the independence or dependence of a_g and v_g on I_s, R, and m_b. All of the forms examined here (P1 through P6) have theoretical limitations summarized in Ref. 8. We proceed under the assumption that these observational, intensity-based methods, in comparison to semi-theoretical models, may provide insights and advantages which exceed the limitations. P1 through P6 apply for $R \geq$ assumed focal depth.

Several recent earthquakes in northeastern North America have provided data which can be compared to the predictive equations. Figure 4 shows observations of a_g for three New Brunswick earthquakes (Ref. 9), and one New Hampshire earthquake (Ref. 10), all with $m_b \cong 4.7$, compared to predictive equations P1, P2, and P3. Using a focal depth of 3km for these shallow events, all three equations are in reasonable agreement with the data, given the scatter of points, although P1 is probably more accurate than the other two. Also shown for comparison are estimates from Ref.2 and 12, which are in reasonable agreement with the data. A comparison of equations P4, P5 and P6 with v_g data indicate that these equations over-estimate the observations. Whether the estimates are high for $m_b = 4.7$, or the data are anomolously low, is not clear at this point.

Figure 5 shows predicted values of a_g for a hypothetical event of $m_b = 5.8$ with a focal depth of 10 km. For this magnitude, predictive equation P2 lies below P1 and P3; the theoretical equations (Ref. 2 and 12) lie between P1 and P2, implying that the intensity-based predictions bound the theoretical curves. Figure 6 shows a similar plot for v_g at soil sites; this plot illustrates the same behavior. For comparison purposes, a curve is shown in Figures 5 and 6 for California (Ref. 5) which was generated assuming M = 6.2. The predictive equations generally agree with the California estimates at close distances (where agreement is reasonable), but exhibit the slower attenuation of a_g and v_g with distance for eastern North America.

A further comparison is shown on Figure 6. Measurements on structures indicate that initial damage from ground motion (cracking of plaster) occurs at about 2.5 to 5 cm/sec peak velocity (Ref. 11). This corresponds to MM intensity V; Figure 3 shows that this occurs, for m_b =

5.8, at about 150 km. The box shown in Figure 6 indicates that all three predictive equations match this criterion of initial damage at 150 km; the California curve is significantly below it, as it should be.

CONCLUSIONS

Intensity-based methods of estimating strong ground motion in regions with few data have merit and give reasonable bounds on peak motion parameters. By extension, the same methods should work for response spectra. Recent California data suggest that the v_g-to-I_s correlation is distance dependent; this contrasts previous results. The ultimate verification of any method of estimating ground motion (theoretical or intensity-based) must await the collection of abundant strong motion data in the region of concern.

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TABLE 1
CALIFORNIA EARTHQUAKE DATA

Date	Event	Date	Event
05/18/40	Imperial Valley, CA	12/23/72	Managua, Nicaragua
07/21/52	Kern County, CA	02/21/73	Point Mugu, CA
03/22/57	Daly City, CA	11/28/74	Hollister, CA
06/28/66	Parkfield, CA	08/01/75	Oroville, CA
04/09/68	Borrego Mt., CA	08/13/78	Santa Barbara, CA
09/12/70	Lytle Creek, CA	08/06/79	Coyote Lake, CA
02/09/71	San Fernando, CA	10/15/79	Imperial Valley, CA
07/30/72	Sitka, AK		

TABLE 2
RESULTS OF REGRESSION ANALYSIS ON
PEAK GROUND MOTION PARAMETERS

$$\ln y = b_1 + b_2 I_s + b_3 \ln R + b_4 M + b_5 S + b_6 V$$

No.	y*	b_1	b_2	b_3	b_4	b_5	b_6	$\sigma_{\ln y}$
R1	a_g	-6.01	0.627	x	x	x	-0.527	0.93
R2	a_g	-0.430	0.232	0.968	x	x	-0.530	0.58
R3	a_g	-4.51	0.633	x	-0.243	x	-0.528	0.92
R4	v_g	-1.39	0.629	x	x	-0.439	-0.844	0.82
R5	v_g	2.12	0.383	-0.612	x	-0.483	-0.846	0.69
R6	v_g	-2.48	0.625	x	0.177	-0.436	-0.844	0.82

* a_g is in units of g, v_g is in units of cm/sec.

TABLE 3
PREDICTIVE EQUATIONS FOR
PEAK GROUND MOTION PARAMETERS

$$\ln y = c_1 + c_2 m_b + c_3 \ln R + c_4 R + c_5 S + c_6 V$$

No.	y*	c_1	c_2	c_3	c_4	c_5	c_6
P1	a_g	-6.12	1.25	-0.809	-0.0005	x	-0.527
P2	a_g	-0.469	0.464	-1.27	-0.0002	x	-0.530
P3	a_g	-4.69	1.02	-0.817	-0.0005	x	-0.528
P4	v_g	-1.50	1.25	-0.811	-0.0005	-0.439	-0.844
P5	v_g	2.05	0.766	-1.11	-0.0003	-0.483	-0.846
P6	v_g	-2.41	1.43	-0.806	-0.0005	-0.436	-0.844

* a_g is in units of g, v_g is in units of cm/sec.

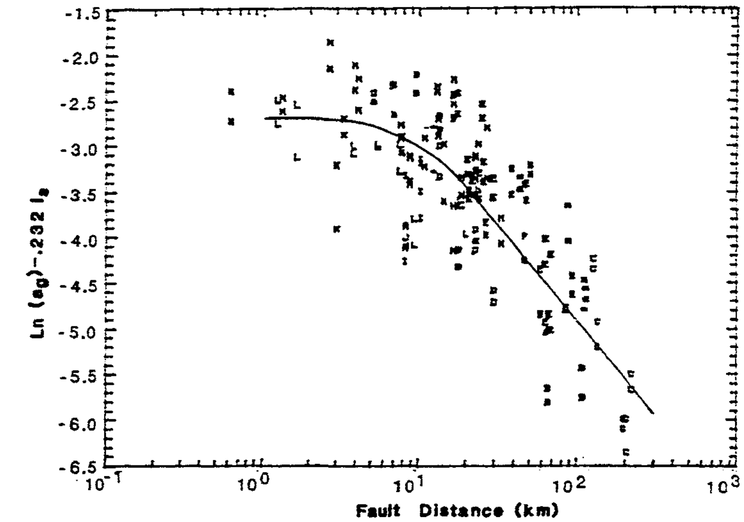

Figure 1: Normalized Peak Acceleration vs. Distance

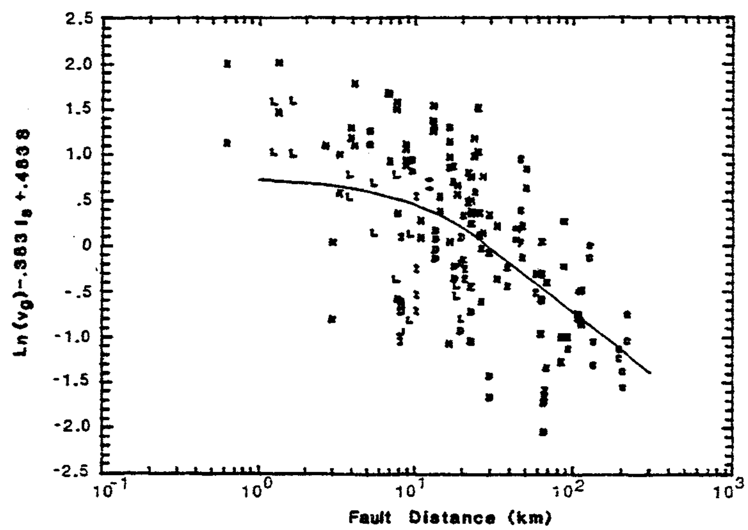

Figure 2: Normalized Peak Velocity vs. Distance

EVENT IDENTIFICATION

- Imperial Valley
- Kern County
- Daly City
- Parkfield
- Borrego Mt
- Lytle Creek
- San Fernando
- Sitka
- Managua
- Point Mugu
- Hollister
- Oroville
- Santa Barbara
- Coyote Lake
- Imperial Valley

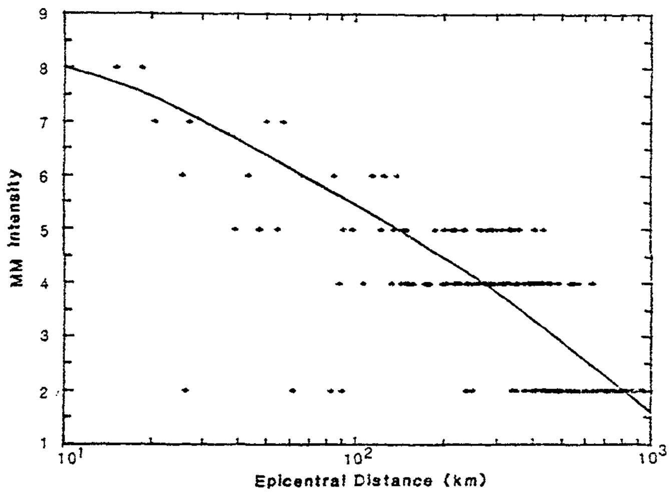

Figure 3: MM Intensities vs. Distance for 1944 Cornwall-Massena Earthquake

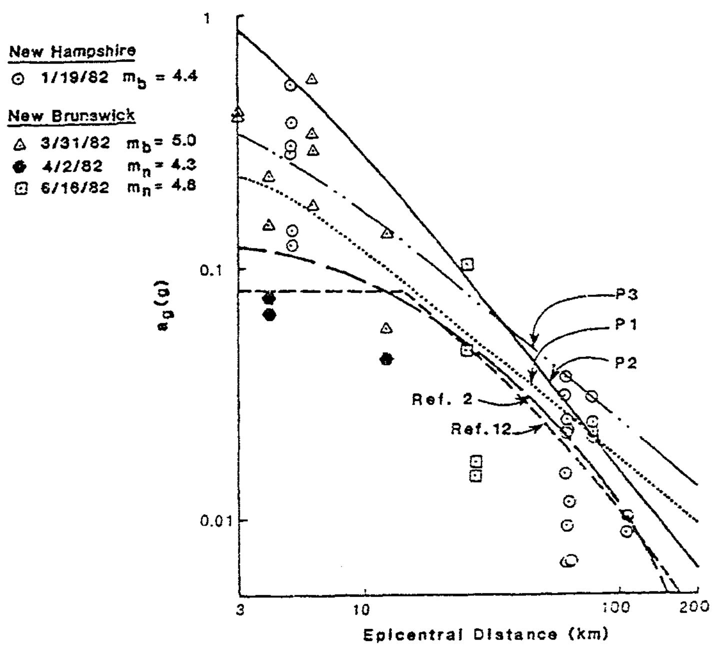

Figure 4: a_g vs. Distance - Data from Northeast and Predictions for m_b = 4.7

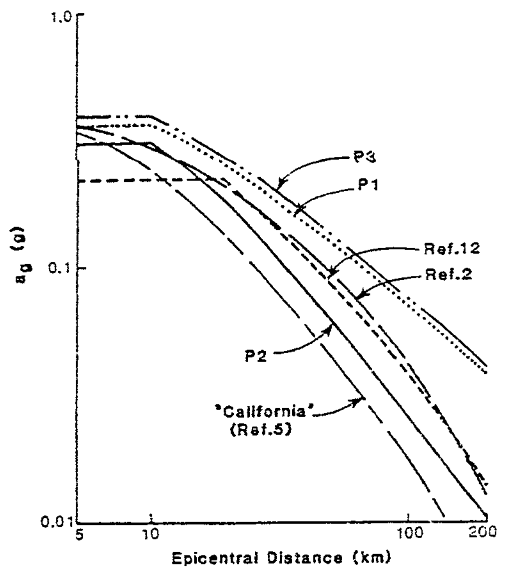

Figure 5: a_g vs. Distance for $m_b = 5.8$

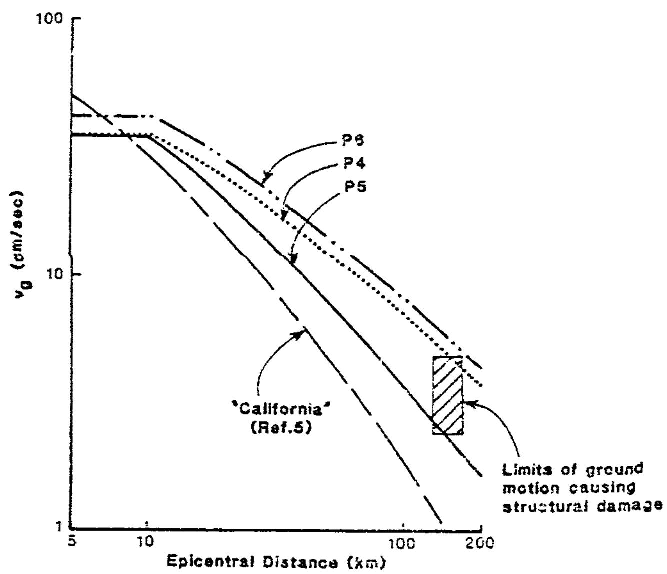

Figure 6: v_g vs. Distance for $m_b = 5.8$