SCALING AND ATTENUATION RELATIONS FOR STRONG GROUND MOTION IN EASTERN NORTH AMERICA

Robert B. Herrmann (I)
Otto W. Nuttli (II)
Presenting Author: Otto W. Nuttli

SUMMARY

For eastern North America, a region with a sparse strong motion data base, the following procedure is developed: 1) use microseismic data to obtain attenuation relations in the frequency band 1 to 10 Hz. This will provide distance scaling of response spectra and peak ground motion for distances greater than 50 km. 2) use models of rupture process of plate interior earthquakes to define the relation between seismic moment, M_o, and spectral corner frequency, f_c. 3) use theoretical and empirical considerations to estimate strong motion scaling from the M_o-f_c information. The procedure is also applied to western U. S. earthquakes as a test.

INTRODUCTION

Earthquake activity in eastern North America is an example of a high risk, low probability phenomenon. High risk is associated with both the past occurrence of very large magnitude earthquakes and the low anelastic attenuation of earthquake waves in the frequency range associated with structural damage. Low probability results from the relatively long recurrence times of large earthquakes.

ATTENUATION OF GROUND MOTION

There is only a limited amount of observational strong-motion data for eastern North American earthquakes (Ref. 1,2,3) Several approaches can be taken to overcome the deficiency of data. One is to assume that source scaling relations are the same for California and eastern North America earthquakes but that the attenuation curves for the two regions are different (Ref. 4). A second approach, used in the past for critical facility siting, uses intensity attenuation relations to predict site intensity which is then correlated to strong ground motion. A third, semi-theoretical approach, uses relations between m_b and far-field peak ground motion.

The third, semi-theoretical approach (Ref. 5,6,7) leads to the following forms for peak horizontal acceleration, velocity and displacement as a function of epicentral distance, R, earthquake focal depth, h, and body wave magnitude, m_b for mid-plate earthquake scaling (Ref. 8).

$$\log a_h = A + 0.50\, m_b - 0.83 \log (R^2 + h^2)^{1/2} - E\, R \qquad (1)$$

$$\log v_h = B + 1.00\, m_b - 0.83 \log (R^2 + h^2)^{1/2} - D\, R \qquad (2)$$

(I) Professor of Geophysics, Saint Louis University, St. Louis, Missouri, USA
(II) Professor of Geophysics, Saint Louis University, St. Louis, Missouri, USA

$$\log d_h = C + 1.50\ m_b - 0.83 \log (R^2 + h^2)^{1/2} - F\ R \tag{3}$$

In these relations, the peak ground motion is modeled as an attenuated higher mode surface wave as a function of epicentral distance (Ref. 9):

$$a(R) = A_o e^{-0.83R} \exp(-\gamma R) \tag{4}$$

The 0.83 coefficient in (1 - 4) arises from the geometrical spreading while the E, D and F coefficients describe the effect of anelastic attenuation at different frequencies. The coefficient of anelastic attenuation, γ, is related to surface-wave Q, group velocity U and frequency dependence n, by

$$\gamma(f) = \pi f^{1-n}/UQ_o \tag{5}$$

Q_o is the value of Q at 1-Hz. For the central and eastern United States, $Q_o = 1000$, $n = 0.4$ and $U = 3.5$ km/s (Ref. 9,10). In developing relations for acceleration, velocity and displacement, frequencies of 5, 1-2, and 0.5 Hz were assumed, respectively. Due to the filtering effect of anelastic attenuation the frequency content should necessarily be dependent upon distance, but because Q_o is so large for eastern North America, these assumptions are acceptable.

To determine the coefficients A, B and C, the sparse central and eastern North America strong motion data sets were used (Ref. 1,2,3). Since all other parameters in (1 - 3) are defined, the sparse data were used only to set the level of the curves. The proposed relations for the mean ground motion of the two horizontal components of strong motion records are as follow:

$$\log a_h = 0.57 + 0.50\ m_b - 0.83 \log (R^2 + h^2)^{1/2} - 0.00069\ R \tag{6}$$

$$\log v_h = -3.60 + 1.00\ m_b - 0.83 \log (R^2 + h^2)^{1/2} - 0.00033\ R \tag{7}$$

$$\log d_h = -6.81 + 1.50\ m_b - 0.83 \log (R^2 + h^2)^{1/2} - 0.00017\ R \tag{8}$$

These relations are strictly defined only for the magnitude range of the data ($4 \leq m_b \leq 5$).

Ground Motion Predictions

Equations (6 - 8) represent best judgment relations for eastern North American earthquakes. To present plausible estimates focal depth, h, must be defined. Nuttli (Ref. 8) investigated the scaling of mid-plate earthquakes and estimated the dimensions of these events. Since no eastern North American earthquakes are known to have ruptured the surface of the earth, there must be a minimum focal depth as a function of magnitude. This focal depth is the source width. For a vertical fault,

$$\log h_{min}(\text{km}) = -1.73 + 0.456\ m_b \tag{9}$$

Using (6 - 9), Table 1 presents estimated mean peak horizontal ground motions for an $m_b = 6.5$ earthquake. An m_b=6.5 earthquake represents the largest earthquake which eastern North America is likely to experience in a period of about one century, given the experience since 1600 (Ref. 7). Thus the level of ground motion proposed for eastern North America represents a realistic choice for aseismic design decisions, except for critical structures.

Table 1. Peak Ground Motion for $m_b = 6.5$

R (km)	ACC (cm/s/s)	VEL (cm/s)	DIS (cm)
1.	622.98	74.96	82.22
2.	619.39	74.59	81.85
3.	614.15	74.02	81.25
4.	607.38	73.27	80.45
5.	599.25	72.35	79.47
6.	589.94	71.28	78.33
7.	579.62	70.09	77.05
8.	568.51	68.80	75.67
9.	556.78	67.44	74.19
10.	544.60	66.02	72.66
20.	423.74	51.80	57.21
30.	332.95	41.04	45.50
40.	270.59	33.63	37.42
50.	226.64	28.40	31.72
60.	194.36	24.56	27.53
70.	169.74	21.63	24.33
80.	150.37	19.32	21.81
90.	134.73	17.45	19.78
100.	121.84	15.91	18.10
200.	59.00	8.37	9.88
300.	36.01	5.55	6.80
400.	24.21	4.05	5.15
500.	17.16	3.12	4.12
600.	12.59	2.49	3.40
700.	9.45	2.03	2.88
800.	7.22	1.68	2.48
900.	5.58	1.42	2.16

Response Spectra

Using (6-9) response spectra are estimated for an $m_b = 6.5$ earthquake. At distances of 20 and 50 km, the response spectra are estimated by assuming the Newmark and Hall (Ref. 11) relations, namely that peak spectral acceleration, velocity and displacement equal 2.12, 1.65 and 1.39 times the peak acceleration, velocity and displacement, respectively for 5% damping, that the asymptotic high frequency spectral acceleration equals the peak ground acceleration and the the asymptotic low frequency spectral displacement equals the peak ground displacement. At distances beyond 50 km, the response spectra are generated by attenuating the 50 km spectral values at discrete frequencies according to (4), assuming $Q_o = 1000$ and $n = 0.4$ for $U = 3.5$ km/s. The distance of 50 km was used since the effect of focal depth on the level of the peak ground motions is no longer significant beyond this distance for this size of an earthquake. At greater distances, geometrical and anelastic attenuation control ground motion levels.

Table 2 presents the response spectra for such an earthquake at distances of 20 to 500 km.

Table 2. Pseudo Velocity Response Spectra (cm/s) for $m_b = 6.5$

Period	Distance (km)						A	B
(sec)	20	50	100	200	300	500	50	205
0.08	9.5	5	2.3	.85	.41	.12	1.3	.13
0.10	12	6.5	3.1	1.2	.60	.19	1.8	.18
0.20	23	12.5	6.2	2.8	1.6	.64	4.0	.40
0.40	47	24	12.5	6.0	3.7	1.8	6	2
0.60	70	36	19	9.5	6.0	3.1	8	2
0.80	85	45	24	12	8	4	11	3
1.00	85	45	24	12.5	8	4.5	14	3.5
2.00	85	45	24.5	13	8.7	5.1	15	5
4.00	85	45	24.5	13.5	9.2	5.6	45	5
6.00	85	45	24.5	13.5	9.4	5.8	38	7
8.00	60	36	20	11	7.6	4.7	-	2.8
10.00	50	30	17	9.2	6.4	4	-	2.6

Also given in Table 2 are 5% damped response spectra for two California earthquakes. The 'A' entry is the spectrum of the east component of motion of the Feb. 9, 1971 San Fernando earthquake, of M_L=6.6, recorded at a distance of 52 km at 5260 Century Blvd., Los Angeles. The high frequency part of its spectrum is a factor of 4 times lower than the proposed spectrum for eastern North America at the same distance. This cannot be completely explained by differences in anelastic attenuation and suggests that, for large earthquakes with the same high frequency source spectrum values, the M_L values of the western earthquakes may be numerically larger than the m_b values of the eastern earthquakes. The same phenomenon can be seen for the 'B' entry, corresponding to spectral values of the April 8, 1968 Borrego Mountain earthquake, M_L=6.4, recorded at a distance of 205 km at Terminal Island, Long Beach. The high frequency part of its spectrum is about a factor of 6 to 7 lower than the preposed spectrum for eastern North American earthquakes of m_b=6.5 at distances of 200 km.

ACKNOWLEDGMENTS

This research was supported in part by the U. S. National Science Foundation under Grant CEE-8204222.

REFERENCES

1) Herrmann, R. B. (1977). Analysis of strong motion data from the New Madrid Seismic Zone: 1975-1976, Department of Earth and Atmospheric Sciences, Saint Louis University, St. Louis, Missouri.

2) Weichert, D. H., P. W. Pomeroy, P. S. Munro and P. N. Mork (1982). "Strong Motion records from Miramachi, New Brunswick, 1982 Aftershocks," Earth Physics Branch Open File Report 82-31, Ottawa, Canada, 12 pp.

3) Chang, F. K. (1983). "analysis of strong-motion data from the New Hampshire

earthquake of 18 January 1982," Geotechnical Laboratory, U. S. Army Corps of Engineers, Vicksburg, Mississippi, 14pp.

4) Nuttli, O. W. (1981). "Similarities and differences between western and eastern United States earthquakes, and their consequences for earthquake engineering," Proceedings of the Conference on Earthquakes and Earthquake Engineering: the Eastern United States, J. E. Beavers, Editor, Vol. 1., Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, pp 25-27.

5) Herrmann, R. B. and M. J. Goertz (1981). A numerical study of peak ground motion scaling, Bull. Seism. Soc. Am. 71, 1963-1979.

6) Herrmann, R. B. and O. W. Nuttli (1980). Strong motion investigations in he Central United States, Proceedings of the Seventh World Congress on Earthquake Engineering, Geoscience Aspects, Part II, Istanbul, Turkey, 533-536.

7) Nuttli, O. W. and R. B. Herrmann (1978). "State-of-the-Art for Assessing Earthquake Hazards in the United States; Credible Earthquakes for the Central United States," Misc. paper S-73-1, Report 12, U. S. Army Corps of Engineers, Vicksburg, Mississippi, 100pp.

8) Nuttli, O. W. (1983). Average seismic source-parameter relations for mid-plate earthquakes, Bull. Seism. Soc. Am. 73, 519-535.

9) Dwyer, J. J., Herrmann, R. B. and O. W. Nuttli (1983). Spatial attenuation of the Lg wave in the Central United States, Bull. Seism. Soc. Am. 73, 781-796.

10) Singh, S. and R. B. Herrmann (1983). Regionalization of crustal coda Q in the continental United States, J. Geophys. Res. 88, 527-538.

11) Newmark, N. M. and W. J. Hall (1982). "Design Response Spectra," Earthquake Spectra and Design, Earthquake Engineering Research Institute, Berkeley, California.