ON THE ATTENUATION OF PEAK VELOCITY

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SUMMARY

A set of curves giving peak horizontal particle velocity as a function of distance for various magnitude earthquakes has been constructed by combining the definition of Richter local magnitude (M_L) and a correlation between peak velocity (V) and the computed Wood-Anderson seismograph response (WA) from a set of strong-motion data (V = .77WA, with V in cm/s and WA in m). The attenuation function given by Richter in his definition of M_L needs modification at distances close to the fault surface, for existing data show that at these distances there is less than the expected factor of ten increase in amplitudes for each unit increase in magnitude. Existing data have been used to constrain the curves at close distances. The modified attenuation curves are, by definition, consistent with the local magnitude for moderate distances from the fault (several tens of kilometers) and are consistent with the sparse data at close distances to the fault. The problem of accounting for the saturation in peak motions at a given distance as the size of the earthquake increases is transferred to the estimate of M_L given some measure of the physical size of the earthquake rupture, such as seismic moment. Observations suggest that M_L saturates as the moment increases.

INTRODUCTION

Although considered to be an important parameter in earthquake engineering, horizontal particle velocity has received little attention. Boore and others (1978, 1980) found regression curves for the decrease of peak velocity with distance for limited distance and magnitude ranges. Espinosa (1979) derived an attenuation law for peak velocity by using an empirical power law fit to data from the 1971 San Fernando, California earthquake and assuming that on a log plot curves for other magnitude earthquakes would be similar in shape but offset by a factor of 10 for each increase of one unit in magnitude. His curves are a reasonable fit to the data at distances of several tens of kilometers from the fault. In this paper I obtain a provisional set of curves by combining three things: (1) a remarkable correlation between peak velocity and the maximum amplitude that would have been recorded by an ideal Wood-Anderson seismograph if subjected to the ground acceleration from which the peak velocity was obtained, (2) the definition of Richter local magnitude, M_L (which is defined in terms of the response of a Wood-Anderson seismograph), and (3) the correlation of peak velocity with local magnitude for recordings at a nominal distance of 10 km from the fault.

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CORRELATION BETWEEN PEAK VELOCITY AND WOOD-ANDERSON RESPONSE

Kanamori and Jennings (1978) used a digital computer to simulate the expected output of a Wood-Anderson seismograph to various strong-motion accelerograms. I have plotted the peak horizontal ground velocity from these accelerograms against the maximum Wood-Anderson amplitude computed by Kanamori and Jennings in Figs. 1, 2, and 3; the first figure contains data from the 1971 San Fernando, California earthquake, the second figure includes data from a number of major California earthquakes, and Fig. 3 is a plot of data from a number of other earthquakes, either smaller than those in Figs. 1 and 2 or not occurring in California. The data came from earthquakes with Richter magnitudes ranging from 4 to 7.2; the median magnitude was about 6 1/4. The correlation of peak velocity (V) and Wood-Anderson seismograph response (WA) is excellent. A reasonable fit to the data in all three figures is given by

$$V = 0.77\ WA \qquad \text{Eq. 1}$$

where V is the peak horizontal ground velocity in cm/s and WA is the amplitude, in meters, of an ideal Wood-Anderson seismograph (the large values for WA are due to the magnification of 2800 used in the Wood-Anderson seismograph).

CONSTRUCTION OF VELOCITY ATTENUATION RELATION

Substituting the correlation between WA and V given by Eq. 1 into Richter's (1958) definition of magnitude

$$M_L = \log 10^3 WA - \log A_o(\Delta) \qquad \text{Eq. 2}$$

where $A_o(\Delta)$ is the function of distance Δ tabulated in Table 22-1 of Richter, 1958, gives an attenuation relation between peak horizontal ground velocity V and distance

$$V = 0.77\ A_o(\Delta) 10^{M_L - 3} \qquad \text{Eq. 3}$$

This function, plotted as the solid line in Fig. 5a, predicts a factor of 10 increase in velocity for every unit increase in magnitude, regardless of distance. Fig. 4, which shows peak velocity and M_L for several earthquakes recorded at about 10 km, indicates that although there is an increase of V with M_L from about 15 cm/s for $M_L = 5.5$ to 200 cm/s for $M_L = 7.5$, the difference is less than is required by Eq. 3.

I have used the correlation in Fig. 4 as a constraint on the velocity attenuation function at a distance of 10 km. The dashed lines in Fig. 5a show a modification of the attenuation relations that agrees with the data in Fig. 4 at close distances and with Eq. 3 at greater distances. The dashed curve was drawn by eye between the constraint at 10 km and the curves given by Eq. 3; the distance at which the dashed curve merges with the solid curve was assumed to increase with magnitude. In Fig. 5b the modified attenuation relation (dashed line in Fig. 5a) and a recent relation published by Espinosa (1979) are compared. As

Espinosa requires a factor of 10 increase in velocity at all distances for each unit increase in magnitude, it is not surprising that the largest discrepancies in the two sets of curves occur at close distances. At greater distances the curves are at most a factor of 2 apart, comparable to the scatter in the data (Boore and others, 1978, 1980).

DISCUSSION

If Eq. 1 were based only on the San Fernando earthquake data, then distance would be a hidden variable because the smaller values of V and WA in Fig. 1 were obtained from distant recordings whereas the larger values were obtained from stations closer to the earthquake. If such were the case, it would be inappropriate to apply Eq. 1 to, for example, a close recording of a small earthquake; whereas the peak velocity might be the same, the dominant frequency would probably be relatively greater and therefore the amplitude on a Wood-Anderson seismograph would be smaller than predicted from Fig. 1. Although Eq. 1 may not apply to all magnitudes, the agreement of the data in Figs. 2 and 3 with Eq. 1 suggests that Eq. 1 is applicable over the magnitude range of engineering interest.

Richter's attenuation function $A_o(\Delta)$ deserves attention. Developed primarily from moderate-size earthquakes in southern California, its validity in other geographic areas or for great earthquakes has not been demonstrated convincingly. Figs. 4 and 5a show that $A_o(\Delta)$ may be magnitude dependent at close distances.

I have been purposely vague in defining the distance used in Eq. 3 and Figs. 5a and 5b. Richter (1958) used epicentral distance in developing $A_o(\Delta)$. For stations close to the fault Kanamori and Jennings (1978) calculated the Δ to be used in the function $A_o(\Delta)$ as the horizontal distance between the site and the inferred center of the faulting. Espinosa (1979) used epicentral distance. At close distances to large earthquakes, it is not clear what distance measure is appropriate. The research discussed in this paper has not addressed the problem of attenuation laws at close distance from large earthquakes or at any distance from a great event.

Although the attenuation curves in Fig. 5 are consistent with a well-defined measure of earthquake magnitude, they should be used with caution. Peak motions at a given distance may approach a limiting value as the physical size of the earthquake (as measured, for example, by seismic moment, M_o) increases. If the curves in Fig. 5 were to be used in a risk analysis, this situation would give rise to the local magnitude, M_L, approaching a limiting value as the seismic moment increased. In a sense, the uncertain element in the risk analysis would shift from the attenuation function used given the magnitude, to the determination of the appropriate magnitude. If the response at a site is to be determined from spatially extended faults, one size estimate may be needed for the attenuation of a peak velocity, and another for fault size from magnitude-area or magnitude-fault length relations.

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Table 1. Peak Velocity-Magnitude Data from California Earthquakes

Event	M_L	Station/Distance[2] (km)	Peak Velocity (cm/sec)
Imperial Valley, 1979	6.5	(interpolated)/10	45[1]
Imperial Valley, 1940	6.4	El Centro/6	37
San Fernando, 1971	6.4	Pacoima Dam/3	110
Long Beach, 1933	6.3	Public Utilities Bldg./~15	30
Oroville, 1975	5.7	Oroville Dam/8	5.0
Parkfield, 1966	5.5	Cholame-Shandon #2/7	78
Lytle Creek, 1970	5.4	Wrightwood/15	9.6
Oroville, 1975	4.7	CDMG #5/12	7.7
Oroville, 1975	4.0	CDMG #5/11	2.1
Bear Valley, 1973	3.9	PNM/13	1.2
Oroville, 1975	3.6	CDMG #5/12	1.0

[1]Approximate, based on interpolation of several recordings within a few kilometers of 10 km.

[2]Closest distance to fault, from Hanks and Johnson (1976), Boore and others (1978), and Hanks (written commun., 1979).

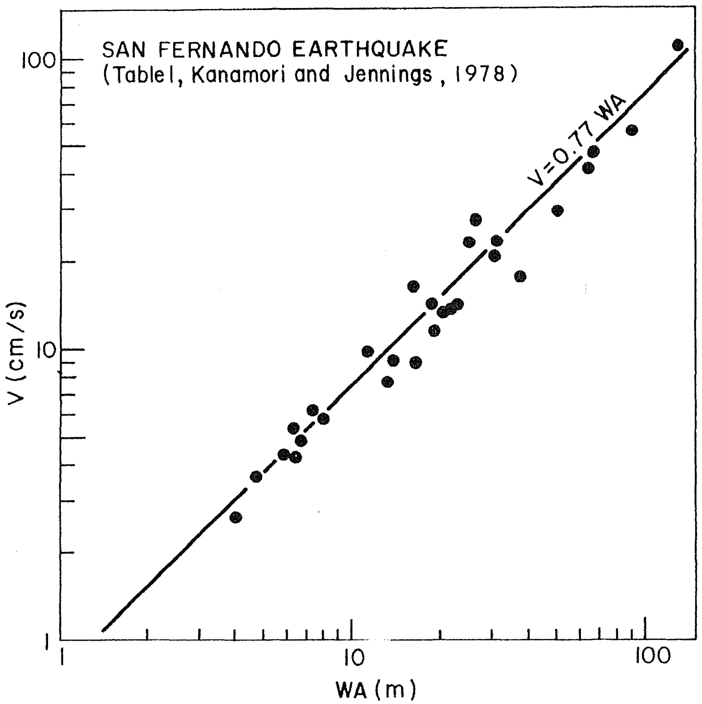

Fig. 1. Peak horizontal velocity (V) versus maximum amplitude of a Wood-Anderson seismograph. The Wood-Anderson amplitude is defined as one-half of the total range of amplitudes in the seismogram. The WA data are from the 1971 San Fernando earthquake, Table 1 in Kanamori and Jennings (1978), and the V data are from Volume II of the Calif. Inst. of Tech. Earthquake Eng. Res. Lab. series "Strong motion earthquake accelerograms".

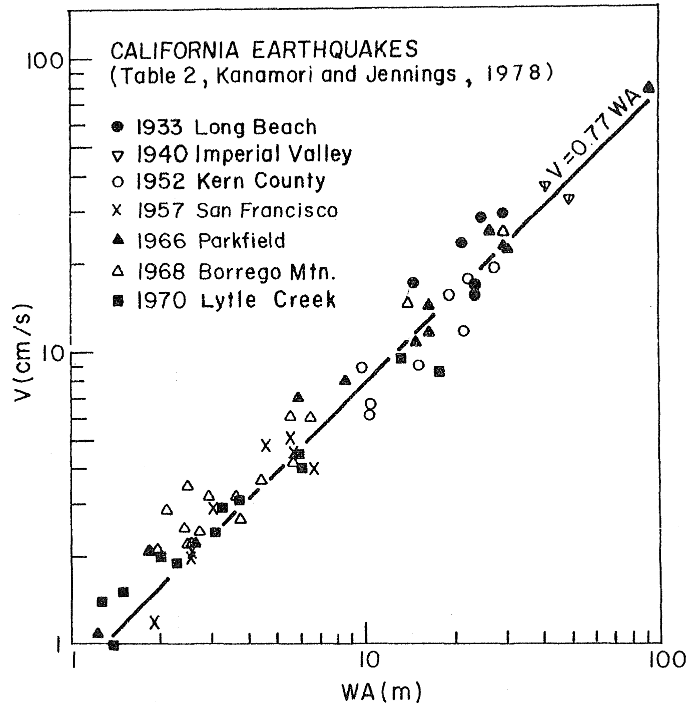

Fig. 2. Same as Fig. 1, but WA data from Table 2 in Kanamori and Jennings (1978).

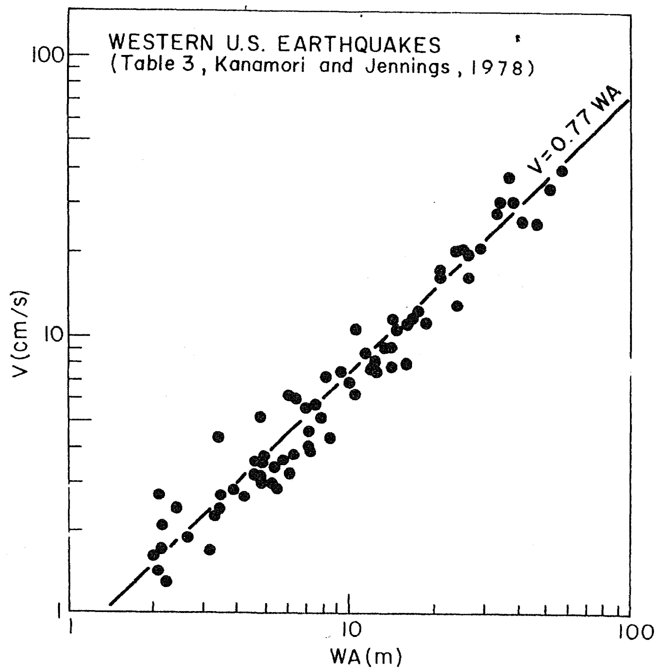

Fig. 3. Same as Fig. 1, but WA data From Table 3 in Kanamori and Jennings (1978).

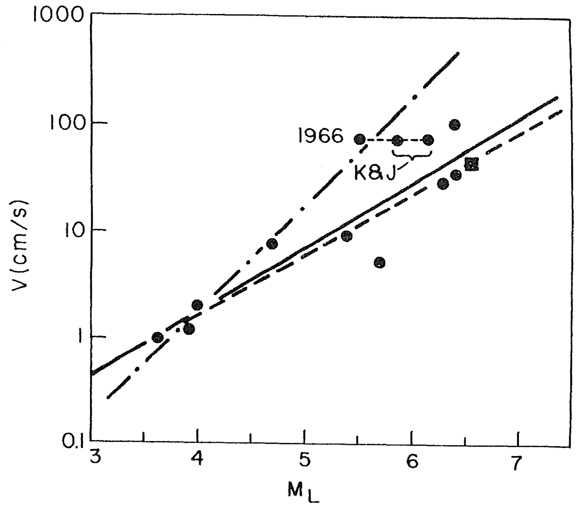

Fig. 4. Peak horizontal velocity versus Richter local magnitude for recordings at a nominal distance of 10 km. The data used are listed in Table 1. The dash-dot line shows the predicted slope of the correlation if the strict definition of magnitude (i.e. Eq. 3) is applied to the peak velocity data at close distances. The solid line is a regression line through all the data (excluding the Kanamori and Jennings M_L values for the Parkfield earthquake). Regression fits using Kanamori and Jennings' (1978) M_L values for the 1966 Parkfield earthquake (points labeled 'K&J') coincide with the solid line. Not using any data from the Parkfield earthquake gives the dashed line. The square data point, from the 1979 Imperial Valley earthquake, was added after the regression curves had been derived.

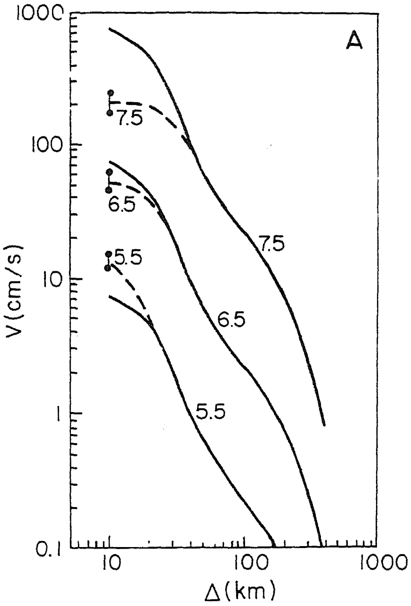

Fig. 5a. Peak horizontal ground velocity attenuation curves derived from Eq. 3. See text for explanation.

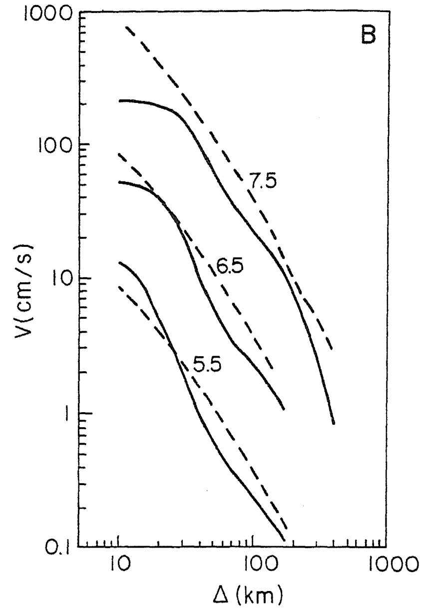

Fig. 5b. Comparison of dashed curves in Fig. 5a with curves adapted from Fig. 4 of Espinosa (1979). Although not written explicitly in his paper, Espinosa's curves are given by $\log V = -3.93 + M_L - 0.28 \log\Delta - 0.36(\log\Delta)^2$. V is in cm/sec, Δ in km.