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ATTENUATION OF STRONG GROUND MOTION IN SPACE AND TIME IN SOUTHWEST WESTERN AUSTRALIA

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SUMMARY

The attenuation of strong ground motion for an earthquake of magnitude $4.5 \le ML < 7$ in Southwest Western Australia (SWWA) has been determined and is given by $\log PHA = [(5\log R+3)/20](ML-6) - 0.77\log R - 0.0045R + 1.2$ where PHA is the peak horizontal acceleration in ms^{-2} at a site of slant distance $5 \le R \le 200$km. Alluvial and hard rock sites respectively amplified and attenuated the mean PHA estimates by up to a factor of 3. For earthquakes of $2 < ML < 6.3$ the equivalent function for peak horizontal velocity (PHV in mms^{-1}) was also derived and is expressed as $\log PHV = 0.60ML - 1.14\log R - 0.0050R - 0.33$. Other relations obtained were $\log T = 0.14ML - 1.68$ and $ML = 2.17\log t + 0.033t + 1$ where T and t (both in s), represent the ground period at PHA and the duration of strong ground motion respectively.

INTRODUCTION

The history of strong motion recording in Western Australia has been described (Ref. 1). It was not until an earthquake of magnitude ML4.5, which was centred near Cadoux (located about 180km northeast of Perth) that the data base was adequate to seriously attempt to define strong motion attenuation in SWWA. The data base for the study comes directly from Ref. 1, in which there are about 200 strong motion events listed. Most of these have been obtained from minor events and consequently only some of them have been digitized (See Table 1). This paper graphically illustrates the PHA attenuation function over various T-windows and endeavours to interpret the results mathematically. It also investigates the attenuation of PHV. It is most apparent that more data are required to further refine these relationships suggested. In addition, the paper attempts to describe how t is related to event magnitude, ML.

PHA, PHV DEPENDENCE ON ML, R and T

PHA and PHV data from the ML4.5 earthquake discussed above are found in Table 1. The PHA attenuation function is plotted in Fig. 1 from these data and compared with the equivalent eastern Australian relation derived in Ref. 2. The curves virtually coincide out to 30 km where McCue's curve remains log linear, as no provision for internal damping was made. The reading corresponding to R = 55 km was used, despite the uncertainty shown, as it gave some control in the middle R range. This result was recorded on the 6/1/88 during a ML4.3 event and hence the result was normalised to ML4.5 by increasing it by 25%. Explanation of this factor is given later. The curve in Figure 1 was fitted

by-eye and can be described by the expression :
$\log PHA = 1.64 - 1.53\log R - 0.0033R$ for $ML = 4.5$, $5 \leq R \leq 200$ and $T > 0$.

Because the PHA in the events in Fig. 1 occurred at typical T of 0.045s, which is generally not of engineering interest, these events were band-pass filtered so that amplitudes in the various bands of interest could be examined. The 3dB points for the T-windows are shown in Table 1 and the roll off used was 18dB per octave. Filtered amplitudes of events 7/3/87 and 6/1/88, corresponding to column $0.1 \leq T \leq 0.5$ were plotted in Fig. 2 as crosses. Once $T < 0.1$ were removed, the PHA's near the epicentre were reduced by a factor of about 2. Also although the PHA's were independent of site geology in the unfiltered data of Fig. 1, a correlation is seen in Fig. 2 and Table 1. The amplitudes at alluvial sites were about twice that on other sites of similar R. The dots associated with the crosses in Fig. 2, are from all remaining events in Table 1. The PHA amplitudes of these events were normalised to ML4.5 using Fig. 3, which relates PHA with ML. In an effort to eliminate the effect of R on this relation only PHA's recorded at $2 < R \leq 20$ from the $0.1 \leq T \leq 0.5$ column in Table 1 were used in this plot. These were then normalised to R=5km using the curve designated by the crosses in Fig. 2. PHA's taken from the epicentral region of 4 overseas events, listed in Table 2, were also plotted in Fig. 3 and it was found that the fit to the extrapolated Western Australian data was reasonable. The standard deviation (SD) in the residuals of the resultant attenuation function shown in Fig. 2 is 0.10, which means that about 2/3 of the observed PHA are within 26% of the values obtained from the by-eye regression.

The 2 other attenuation curves for ML4.5 earthquakes which appear in Fig. 2 have been plotted from the filtered and normalised data shown in the corresponding T-windows in Table 1. It is apparent from these data that compared to the fitted curves, the amplification and attenuation at alluvial and rock sites respectively, increases from about 2 to 3 as the T-windows goes from 0.15 to 0.2. The other 2 curves which appear in Fig. 2 are attempted PHA-R curves for the Meckering (ML6.9, on 14/10/68) and the Cadoux (ML6.2, on 2/6/79) earthquakes. During this Cadoux event, 5 accelerograms were recorded and the raw PHA data from them are listed in the first T-column in Table 1 and have been plotted in Fig. 2. As there was no recording made in the near field, the value shown corresponding to 5km, comes from Fig. 3. The only information available on the Meckering earthquake is discussed briefly in Ref. 5. Theoretical estimates of PHA in Perth during this event have been made and are plotted in Fig. 2. Because the greater of these estimates was made on what is considered to be an alluvial site, the factor or 3, mentioned above, was applied to reduce the result to that expected on an average site. The second result is the minimum value required to overturn bells at the top of a tall church tower. Hence the building response is incorporated in the estimate and is therefore likely to be in excess of the PHA of the ground below. The value at R = 5km is taken from Fig. 3. The fact that the PHA decay exhibited for curves of corresponding T in Fig. 2 compare well, is further support to the attenuation adopted for the top 2 curves which have far less control. The other point is that with this set of curves it is clear that the PHA associated with longer T, is more efficiently transmitted. A general equation relating the parameters ML,R and PHA in SWWA has been derived from interpolation of the 3 main curves in Fig. 2 resulting in the function $\log PHA = [(5\log R+3)/20](ML-6) - 0.77\log R - 0.0045R + 1.2$ which has the limits $4.5 \leq ML < 7$, $0.1 \leq T \leq .5$ and $5 \leq R \leq 200$.

The engineer is also interested in T, the period at which PHA occurs. To define the (ML,T) function over $0.2 \leq ML \leq 6.2$ on both hard and soft rock sites 157 data points from Ref. 1 were plotted as found in Fig. 4 and the resultant function derived by a by-eye fit for hard rock, alluvial and average sites (the latter are defined in this study as having a shallow firm soil over basement rock) are : logT = 0.10ML - 1.70, logT = 0.18ML - 1.65 and logT = 0.14ML - 1.68 respectively. The T values given for the Cadoux and Meckering earthquakes in Fig. 2 have been derived from this relation.

The digital data from events listed in Table 1 was then integrated into ground velocity using a high-pass filter to eliminate unreal drift and the PHV was determined for each event. These were then plotted against ML to determine the PHV-ML relationship as it was for PHA. The PHV's were then plotted against R (Fig. 5) and the function can be described as log V = 0.60ML-1.14logR-.0050R-0.33 No filtering of the velocity data was carried out, as typical ground periods of the velocity plots were in the field of engineering interest. The SD determined for the velocity function was 0.095 which can be interpreted that the observed values were typically within 25% of the expected values.

THE ML-t RELATION

To assess how duration of strong motion (t in seconds, defined as equivalent to human perceptibility which was quantified as 0.005 ms^{-2}) is related to event magnitude, about 150 events listed in Ref. 1. were plotted and are displayed in Fig. 6. The by-eye fit to the data gave rise to the function ML = 2.17logt + 0.033 + 1. The 2 arrows corresponding to ML6.2 in Fig. 6 indicates that the duration was longer than the value shown as the accelerograph turned itself off before the threshold was reached.

DISCUSSION

Unfortunately the data base used in this study still leaves large gaps in our knowledge of how strong ground motion is attenuated in Western Australia. For example we have no recording in the epicentral region of a large event and only scanty knowledge of what happens in the middle-distance range. However, the engineer needs at least the best estimate of what is expected to happen at such places. Hence as long as the user is appropriately warned of the techniques involved and the associated uncertainties then such estimates should and have been made. Furthermore because the data has relatively low scatter and the estimates derived from them are internally consistent, the user can have some confidence in them. The user is encouraged to obtain information on site geology however as it has been shown that this greatly influences ground amplitudes at ground periods of engineering interest.

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Table 1 PHA's (for various T-windows), and PHV's for digitised SWWA events

DATE	LOCATION	ML	R (km)	Peak Horizontal Acceleration (ms^{-2}) T>0	$0.1 \leq T \leq 0.5$	$0.15 \leq T \leq 0.5$	$0.2 \leq T \leq 1.0$	Peak Hoztl Vel. (mms^{-1})
7/3/87	CAA(2)	4.5	8	3.36;3.27	0.93	0.25	0.18	30.0
	CAK(R)		9	1.49	0.49	0.14	0.10	15.7
	CAE		14	0.42	0.21	0.067	0.039	6.2
	CAS(A)		7	1.82	1.43	0.56	0.41	35.0
	CAR(A)		7	1.36	1.26	0.53	0.42	39.7
	CDL(R)		175	[0.0067]	[0.0067]	-	-	-
24/11/78	MEK	3.1	[5]	0.27	0.050/0.34	0.022	0.014	1.4/9.7
29/4/79	MEM	2.1	[5]	0.54	0.047/2.85	0.019	0.013	2.2/60.6
27/11/79	MEK	3.0	5	1.18	0.167/1.32	0.033	0.027	6.9/54.8
8/12/79	MEK	2.6	5	1.27	0.162/2.69	0.039	0.025	6.4/88.3
21/1/80	MEM	2.9	4	0.93	0.093/0.87	0.028	0.023	3.6/32.8
21/2/80	CAK(R)	2.8	2.5	0.70	0.15 /1.68	0.030	0.016	4.6/48.2
15/4/82	CAK(R)	3.9	20	0.34	0.041/0.09	0.0088	0.0080	2.0/4.6
2/8/82	MEK	2.8	3.5	0.49	0.13 /1.45	0.030	0.017	3.8/39.8
6/2/86	CAS(A)	3.4	[7]	0.81	0.29 /1.24	0.051	0.031	6.5/29.7
6/1/88	CAR(A)	4.3	55	0.024-.06	0.03-0.075	-	-	-
2/6/79	MES(A)	6.2	110	0.35	0.18/0.033	0.069/0.013	0.042/.0079	4.7/0.45
	MER(R)		85	0.12	0.059/.011	.025/.0047	0.012/.0023	2.0/0.19
	MEK		95	0.21	0.13/.024	.057/.011	0.053/.0100	2.1/0.20
	MUW(R)		155	[0.13]	[.077/.014]	-	-	-
	MEM		90	0.31	0.083/0.16	.031/.0059	0.030/.0057	2.4/.23

Footnotes: 1. The first 2 letters in location code is derived from the closest town, e.g. CA means Cadoux and ME, Meckering. The third letter is reserved for the farm identification. The letter in brackets gives the geology, e.g. A, Alluvial, R, hard rock and nothing means an average site.
2. The slash has been used to separate the raw and normalised values.
3. Data designated with [ ], are considered less reliable.

Table 2 Overseas earthquake data used in Fig. 3

EARTHQUAKE	YEAR	ML	R(km)	PHA(ms^{-2})	REFERENCES
San Fernando	1971	6.7	5	12.25	REF 3
El Centro	1940	6.5	10/5	3.2/5.9	REF 3
Koyna, India	1967	6.35	5	6.2	REF 3
Edgecombe, NZ	1987	6.3	10/5	3.2/5.9	REF 4

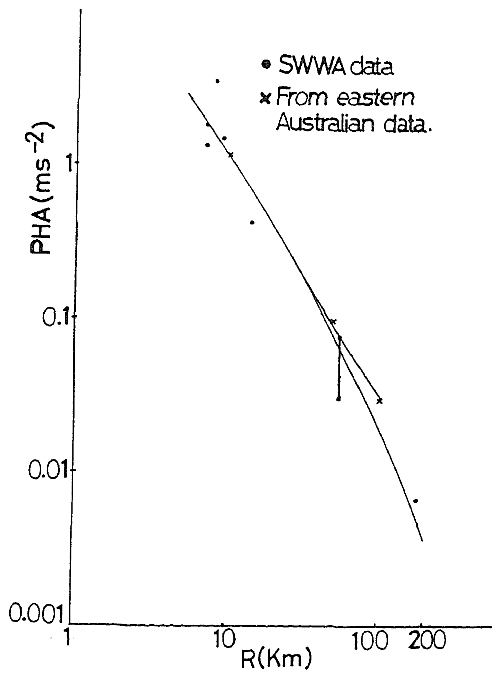

Fig. 1 PHA attenuation for ML4.5 earthquakes in SWWA with equivalent curve for eastern Australia.

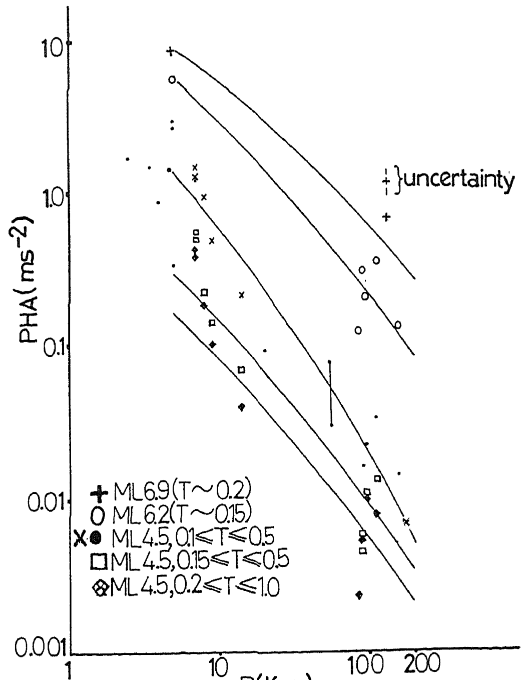

Fig. 2 PHA attenuation for different T-windows during ML4.5 event. Also includes some data for ML6.2 and ML6.9 earthquakes (See text).

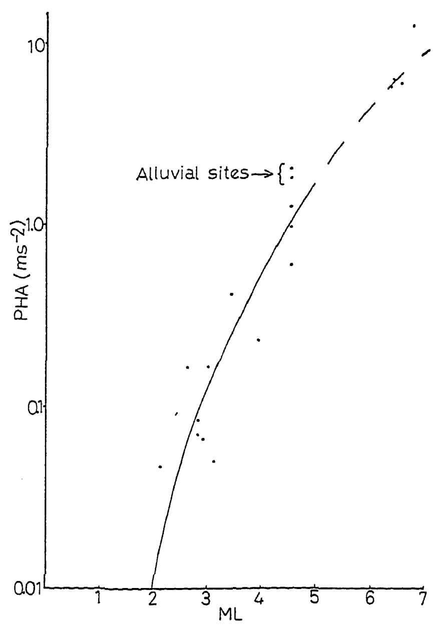

Fig. 3 PHA as a function of ML for 0.1≤T≤0.5 and 2.0<ML≤6.7 at R = 5km.

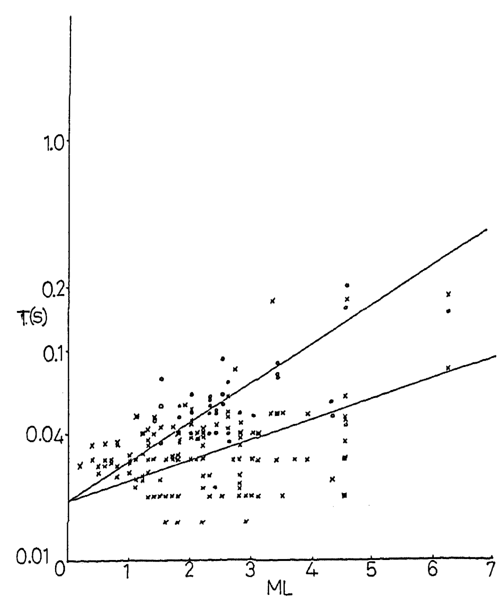

Fig. 4 T at PHA as a function of ML, and site geology ("o" depict alluvial sites and "x" depict the rest).

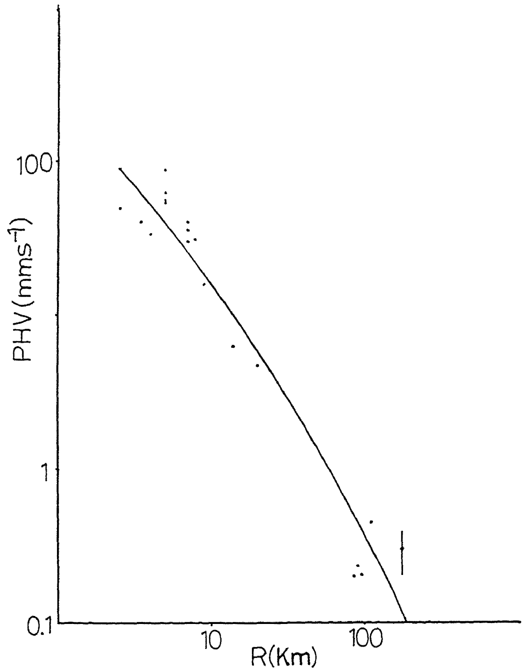

Fig. 5 PHV attenuation for ML4.5 event.

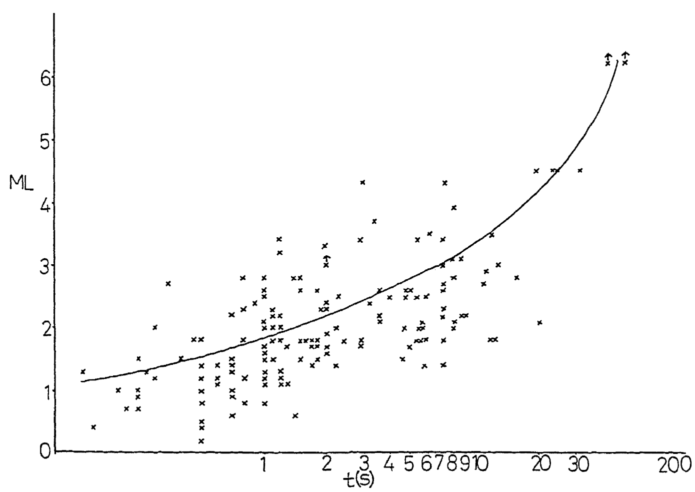

Fig. 6 The ML-t interrelationship.