A NEW ATTENUATION MODEL FOR NORTH-EAST INDIA

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ABSTRACT

The characterization of seismic hazard through specification of peak ground acceleration, with a standard spectral shape assumed to be available, is slowly becoming obsolete. This has created a need to develop spectral attenuation models for various seismic regions in India also. A new attenuation model based on pseudo-spectral velocity scaling has been proposed in this study by using 261 accelerograms recorded on stiff soil/rock sites at North-East India. An illustrative numerical study shows that the estimated PSV spectra by this model compare well with the actual PSV spectra for a few recorded accelerograms and that the parametric variations shown by this model are consistent with the known trends.

INTRODUCTION

Development of an attenuation model is an important input to the seismic hazard analysis specific to an area of interest. Such a model helps in estimating the ground motion at a given site due to an event of given magnitude at a given source for a given level of confidence. Since each seismically active region has unique geological characteristics, it is desirable to use the previously recorded strong motion data in the region for developing the attenuation model. Most attenuation models are based on the scaling for peak ground acceleration (PGA). PGA is however associated with the zero time-period response and thus cannot provide any information about the response of non-stiff oscillators. Therefore, a spectral attenuation model based on pseudo-spectral velocity (PSV) scaling is developed in this paper for North-East India, by using a total of 261 accelerograms recorded on stiff soil/rock sites for six different earthquake events. For North-East India, no spectral attenuation relationship is available till date, even though there have been a large number of past studies on developing PSV scaling models for other seismically active regions (e.g., see McGuire (1978), Cornell et al. (1979), Trifunac (1980), Joyner and Fumal (1984), Crouse et al.

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(1988), Trifunac and Lee (1989), Atkinson (1990), Dahle et al. (1990), Niazi and Bozorgnia (1992), Boore et al. (1993), Sabetta and Pugliese (1996), and Spudich et al. (1999)).

DATABASE AND MODEL SELECTION

To develop spectral attenuation model for the North-East India, strong motion accelerogram data recorded at several stations in that region has been used. There are a total of 261 accelerograms recorded on stiff soil/rock sites for six earthquake events: September 10, 1986, May 18, 1987, February 6, 1988, August 6, 1988, January 10, 1990, and May 6, 1995. Further details of this database are given in Das (2002). At a station, the data for two horizontal components has been combined by applying square-root-of-sum-of-squares (SRSS) combination on the PSV spectra for the two components. As the ground motion at a site has strong azimuthal dependence, the SRSS combination helps to normalize for that dependence. The so-obtained PSV spectra should be divided by 1.41 to get the normalized spectra for each horizontal component separately. Thus total of 174 PSV spectra (including SRSS-combined spectra for horizontal component) have been used for finding the attenuation model. The damping ratio considered for these computations is 5 percent. The maximum value of time-period for which the spectra have been computed is 1.0 s, as the data is contaminated by base-line distortions and low-frequency noise signals, and may not therefore give reliable spectra values for the longer time-periods.

Prior to performing the regression analysis on the PSV data, it is required to select a functional form of attenuation model which comprises the parameters governing the attenuation of ground shaking. The model should be such that it makes use of all information available for the recorded data. On the other hand, its level of sophistication should be consistent with the amount of information available to a user. In this study, we consider the variations of the models proposed by Trifunac (1980), Trifunac and Lee (1989), and Lee (1995) as those take care of both horizontal and vertical motions simultaneously. Following models have been considered:

$$\log[PSV(T)] = c_1(T) + c_2(T)M + c_3(T)M^2 + c_4(T)\Delta + c_5(T)\log(\Delta) + c_6(T)v \tag{1}$$

$$\log[PSV(T)] = c_1(T) + c_2(T)M + c_3(T)M^2 + c_4(T)\log(\Delta) + c_5(T)v \tag{2}$$

$$\log[PSV(T)] = c_1(T) + c_2(T)M + c_3(T)M^2 + c_4(T)\log(R) + c_5(T)\log(h) + c_6(T)v \tag{3}$$

$$\log[PSV(T)] = c_1(T) + c_2(T)M + c_3(T)\log(\Delta) + c_4(T)v \tag{4}$$

where, M is the earthquake magnitude, R is the epicentral distance, h is the focal depth, $\Delta\,(=\sqrt{R^2+h^2})$ is the hypocentral distance, T is the time-period of single-degree-of-freedom (SDOF) oscillator, and $v = 0$ and 1 for horizontal and vertical motions, respectively. The coefficients, $c_1(T)$, $c_2(T)$, … are the (period-dependent) regression coefficients. In these models, the terms involving M^2 take care of saturation at higher magnitudes; the terms involving Δ take care of attenuation due to absorption; and those involving $\log \Delta$ take care of attenuation due to geometrical spreading. Focal depth has been considered here as a parameter (either explicitly or implicitly by considering hypocentral distance as a parameter), since the average focal depth of events varies significantly between 10 and 100 km in North-East India. On regression analysis, the regression coefficients indicate that the data considered in this study is not good enough to properly account for the absorption phenomenon. Also, for distances up to 300 km, the effect of anelastic spreading is not that significant as compared to geometrical spreading (Dahle et al. (1990)). The available data also appears to be too limited to account for saturation and absorption, particularly at long periods. In view of the above, even though all four attenuation models are theoretically possible, the model in Eq. (4) is seen to give reasonable values of regression coefficients in case of the available data, and hence, is suitable for describing the spectral attenuation in the North-East India region. This however does not differentiate between two cases of identical distances and different focal depths, and therefore, an extra term involving focal depth is introduced (Crouse et al. (1988)). The proposed model therefore becomes

$$\log[PSV(T)] = c_1(T) + c_2(T)M + c_3(T)h + c_4(T)\log\left(\sqrt{R^2 + h^2}\right) + c_5(T)v \tag{5}$$

without any loss in reasonableness of regression coefficients.

REGRESSION ANALYSIS

The regression analysis is performed in two stages to get the values of regression coefficients. In the first stage, $c_4(T)$ and $c_5(T)$ are estimated by performing linear regression analysis on the following model,

$$\log[PSV(T)] = \sum_{i=1}^{n} a_i e_j + c_4(T)\log\left(\sqrt{R^2 + h^2}\right) + c_5(T)v \tag{6}$$

where, $e_j = 1$ for the jth earthquake event and zero otherwise, and $n = 6$ (total number of events). Through this step, the coefficients, $c_4(T)$ and $c_5(T)$, are decoupled from the other three coefficients. In the second stage, the remaining coefficients are determined by performing the linear regression analysis for the equation,

$$\log[PSV(T)] - c_4'(T)\log\left(\sqrt{R^2 + h^2}\right) - c_5'(T)v = c_1(T) + c_2(T)M + c_3(T)h \tag{7}$$

where, c_4' (T) and c_5' (T) are obtained from the first stage of regression analysis.

Table 1 gives the estimated (smoothed) coefficients, c_1' (T), c_2' (T), c_3' (T), c_4' (T) and c_5' (T) at 20 time-periods. It may be observed that the value of c_3' (T), which reflects the possible effects of focal depth for fixed hypocentral distance, is positive and significant at higher frequencies, and that this becomes insignificant at longer periods. This is expected since the deeper earthquakes are supposed to produce more high-frequency body-wave motion than shallower earthquakes of the same magnitude and hypocentral distance due to less anelastic attenuation and greater stress drop (McGarr (1984)). By using the estimated regression coefficients, the estimated value of log[$PSV(T)$] becomes

$$\log[PSV'(T)] = c_1'(T) + c_2'(T)M + c_3'(T)h + c_4'(T)\log\left(\sqrt{R^2 + h^2}\right) + c_5'(T)v \tag{8}$$

With $PSV(T)$ representing actual values of PSV spectra for an accelerogram, the residuals $\varepsilon(T)$ are calculated as

$$\varepsilon(T) = \log[PSV(T)] - \log[PSV'(T)] \tag{9}$$

for all 174 PSV spectra.

Table 1. Estimated (Smoothed) Regression Coefficients

Period T	c_1' (T)	c_2' (T)	c_3' (T)	c_4' (T)	c_5' (T)
0.040	-0.5402	0.3140	0.0039	-0.9001	-0.4251
0.048	-0.4277	0.3097	0.0038	-0.8873	-0.4164
0.055	-0.3065	0.3042	0.0039	-0.8854	-0.4107
0.065	-0.1401	0.2974	0.0039	-0.8854	-0.4055
0.080	0.0614	0.2913	0.0040	-0.8845	-0.4057
0.095	02108	0.2878	0.0040	-0.8854	-0.4157
0.110	0.3427	0.2852	0.0042	-0.9009	-0.4334
0.130	0.4989	0.2849	0.0044	-0.9326	-0.4607
0.150	0.6054	0.2912	0.0046	-0.9684	-0.4896
0.180	0.6374	0.3101	0.0047	-1.0019	-0.5288
0.220	0.5375	0.3301	0.0046	-0.9870	-0.5578
0.260	0.4110	0.3421	0.0046	-0.9472	-0.5716
0.300	0.2716	0.3498	0.0045	-0.8965	-0.5741
0.360	0.0446	0.3608	0.0044	-0.8207	-0.5639
0.420	-0.1583	0.3738	0.0043	-0.7682	-0.5479
0.500	-0.2913	0.3912	0.0040	-0.7505	-0.5364
0.600	-0.3369	0.4145	0.0032	-0.7672	-0.5375
0.700	-0.4101	0.4418	0.0024	-0.7797	-0.5397
0.850	-0.6807	0.4854	0.0011	-0.7384	-05378
1.000	-1.1532	0.5225	-0.0002	-0.5955	-0.5285

Table 2. Smoothed Residual Spectra, $\varepsilon(p,T)$, for Different Values of Probability Level p

Period	*Probability Level p*								
T (s)	*0.1*	*0.2*	*0.3*	*0.4*	*0.5*	*0.6*	*0.7*	*0.8*	*0.9*
0.040	-0.2964	-0.2098	-0.1391	-0.0541	-0.0054	0.0555	0.1115	0.1687	0.2645
0.048	-0.3057	-0.2118	-0.1232	-0.0503	0.0131	0.0743	0.1229	0.1775	0.2823
0.055	-0.3093	-0.2114	-0.1164	-0.0455	0.0213	0.0847	0.1328	0.1910	0.2979
0.065	-0.3138	-0.2101	-0.1090	-0.0387	0.0296	0.0957	0.1451	0.2088	0.3165
0.080	-0.3201	-0.2069	-0.1014	-0.0307	0.0356	0.1028	0.1570	0.2258	0.3315
0.095	-0.3227	-0.2026	-0.0992	-0.0280	0.0349	0.0997	0.1609	0.2324	0.3349
0.110	-0.3207	-0.1998	-0.1019	-0.0307	0.0303	0.0923	0.1599	0.2354	0.3364
0.130	-0.3170	-0.1983	-0.1076	-0.0371	0.0231	0.0824	0.1565	0.2381	0.3398
0.150	-0.3141	-0.1992	-0.1144	-0.0450	0.0162	0.0745	0.1518	0.2392	0.3443
0.180	-0.3120	-0.2019	-0.1234	-0.0565	0.0073	0.0660	0.1444	0.2380	0.3500
0.220	-0.3112	-0.2038	-0.1288	-0.0655	0.0001	0.0576	0.1372	0.2342	0.3537
0.260	-0.3121	-0.2053	-0.1313	-0.0714	-0.0048	0.0499	0.1305	0.2289	0.3562
0.300	-0.3150	-0.2076	-0.1333	-0.0756	-0.0082	0.0435	0.1229	0.2205	0.3565
0.360	-0.3214	-0.2142	-0.1375	-0.0784	-0.0119	0.0367	0.1108	0.2026	0.3465
0.420	-0.3273	-0.2240	-0.1431	-0.0775	-0.0148	0.0333	0.1022	0.1866	0.3252

0.500	-0.3297	-0.2290	-0.1456	-0.0748	-0.0144	0.0350	0.1005	0.1818	0.3069
0.600	-0.3259	-0.2190	-0.1397	-0.0722	-0.0088	0.0433	0.1059	0.1904	0.3051
0.700	-0.3222	-0.2064	-0.1328	-0.0699	-0.0049	0.0518	0.1114	0.2028	0.3089
0.850	-0.3232	-0.1911	-0.1267	-0.0680	-0.0096	0.0603	0.1139	0.2271	0.3217

For the actual probability p that the residual spectrum, $\varepsilon(p,T)$ (see Eq. (9)), will not be exceeded, Table 2 gives the smoothed values of residual spectra (smoothing carried out along the time-period axis) corresponding to p = 0.1 (10%) to 0.9 (90%) for 5% damping PSV data. The PSV spectra for desired level of confidence may thus be estimated as

$$\log[PSV'(p,T)] = c_1'(T) + c_2'(T)M + c_3'(T)h + c_4'(T)\log\left(\sqrt{R^2 + h^2}\right) + c_5'(T)v + \varepsilon(p,T) \quad (10)$$

Illustrative Examples

Figure 1 shows comparison between the horizontal PSV spectrum computed from the recorded accelerogram at Hatikhali station (R = 53.51 km), for a small and shallow event (May 18, 1987) with M = 5.7, h = 50 km, with the PSV spectra estimated by using Eq. (2.10). Figure 2 shows the comparison for a large and deep event (August 6, 1988) with M = 7.2, h = 91 km in case of vertical PSV spectrum recorded at Gunjung station with R = 153.91 km. In each figure, the pair of top (p = 0.9) and bottom (p = 0.1) estimated PSV curves (see the solid lines) outlines the 80%

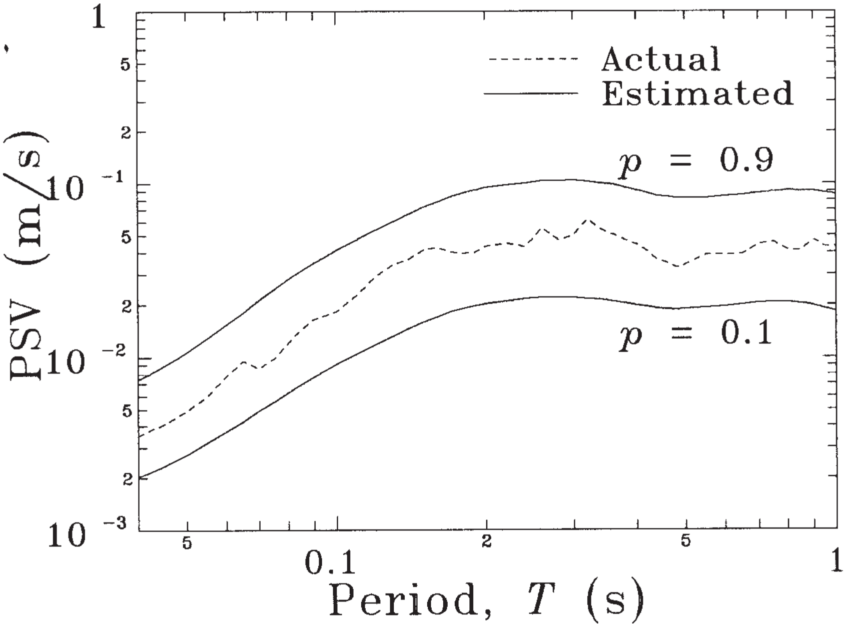

Fig. 1: Comparison of Actual and Estimated PSV Spectra for Hatikhali Record

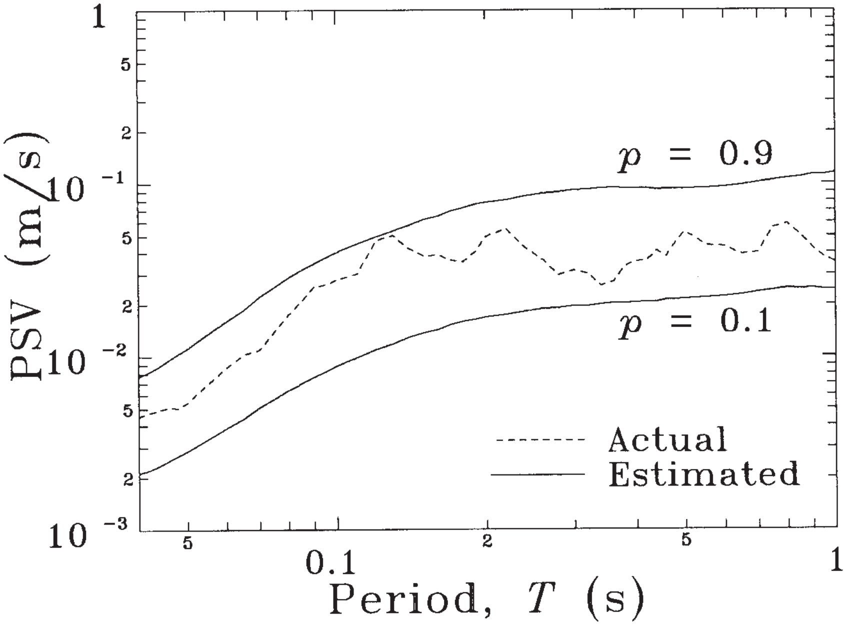

Fig. 2: Comparison of Actual and Estimated PSV Spectra for Gunjung Record

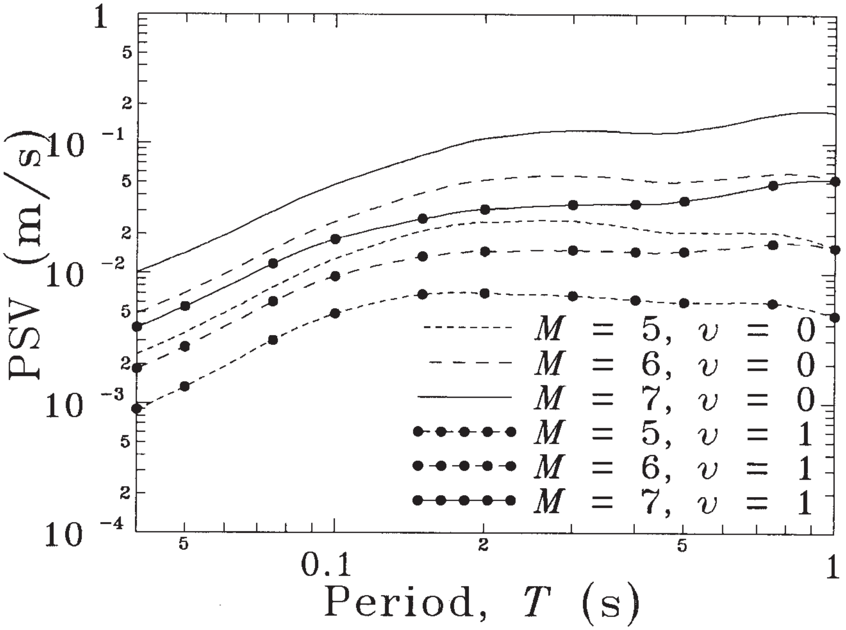

Fig. 3: Comparison of Estimated PSV Spectra for Different Values of Magnitude

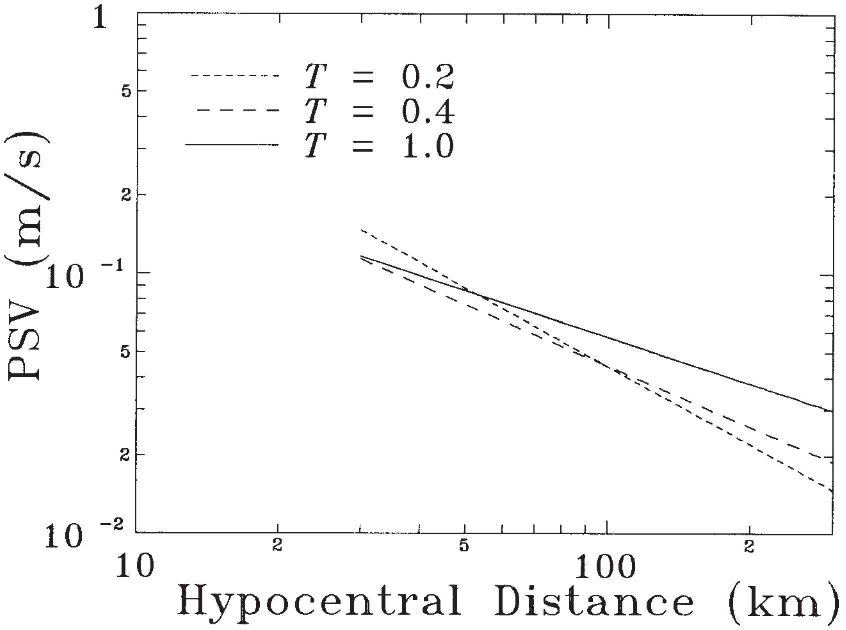

Fig. 4: Variations of PSV Values with Hypocentral Distance at Different Values of *T* in Case of υ = 0

confidence interval of the predicted amplitudes, while the dashed line corresponds to the actual spectrum. It is clear from these figures that the proposed model works well both for shallower and deeper, and smaller and larger events. It also works for near-source and distant sites. However, the 80% confidence band is wide enough to reflect a considerable amount of scattering in the scaling parameter.

Figure 3 shows plots for 50% probability PSV spectra for parametric variation in magnitude with R = 100 km, h = 50 km. The curves without symbols correspond to horizontal motions (v = 0), while those with symbols correspond to vertical motions (v = 1). Figure 4 shows how PSV spectrum at T = 0.2, 0.4 and 1.0 s attenuates with hypocentral distance for M = 6.0, h = 20 km in case of horizontal ground motions. These comparisons, including more as available in Das (2002), are consistent with the known effects of various parameters considered in the present study.

CONCLUSION

A spectral attenuation model has been proposed by using a total of 261 accelerograms recorded at different stations on stiff soil/rock sites in North-East India. The proposed model nicely captures the frequency-dependent variations in PSV for selected recorded motions and properly accounts for known effects of earthquake magnitude, epicentral distance and focal depth on the PSV spectral shape for both horizontal and vertical motions. This can be used in place of available PGA-based attenuation models for more realistic estimation of PSV curves in a seismic hazard analysis of North-East India.

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