I -617

ATTENUATION OF GROUND MOTION RESPONSE SPECTRA OF SHALLOW TO DEEP EVENTS

University of Tokyo Member Gilbert L. Molas
University of Tokyo Member Fumio Yamazaki

INTRODUCTION: The attenuation of peak ground motion for shallow to deep events have been studied by the authors and it was found that the effect of source depth and that of the local site are significant [1]. However, peak ground motions do not contain adequate information on the frequency dependence of the attenuation relations. This paper reports on the regression analysis of the ordinates of absolute acceleration and relative velocity response of single-degree-of-freedom oscillators with 5 percent damping.

DATA: Acceleration time histories from August 1, 1988 to December 31, 1993 recorded at 76 JMA stations using the new JMA-87 type seismometers are used in this study. This includes the acceleration time histories of recent earthquakes like the January 15, 1993 Kushiro-Oki, the February 7, 1993 Noto Peninsula, and the July 12, 1993 Hokkaido Nansei-Oki earthquakes. Due to the resolution (± 0.03 cm/s^2) of the recording instrument, only records whose peak ground acceleration (PGA) are greater than or equal to 1.0 cm/s^2 for both horizontal components are used. Events whose focal depth are reported by the JMA as zero and those greater than 200 km are omitted from the analysis. A total of 2,166 records are used in the analysis.

ATTENUATION MODEL: The attenuation model considered in this paper is of the form:

$$\log y(T) = b_0(T) + b_1(T)M + b_2(T)R + b_3(T)\log R + b_4(T)h + \sum_{i=1}^{N} c_i(T)S_i \qquad (1)$$

where $y(T)$ is the response spectra ordinate under consideration (larger of the two horizontal components), M is the JMA magnitude, R is the slant distance in km, h is the depth in km, $S_i = 1$ for station i, 0 otherwise and $b_i(T)$'s and $c_i(T)$'s are the coefficients to be determined, however, $b_3(T)$ is constrained to 1.0. The inclusion of the depth term and station coefficients are justified by the behaviour of residuals and by the significant improvement of the regression fitting [1].

METHOD OF ANALYSIS: Fukushima and Tanaka [2] proposed that a two-stage regression procedure similar to Joyner and Boore [3] be used to eliminate systematic errors in one-stage regression due to the correlation of magnitude and distance. However, the use of station coefficients in the two-stage regression procedure results in singular matrices in the solution of the regression coefficients. An iterative partial regression procedure is used to solve this problem [1]. In summary, the depth term and station coefficients are first estimated by one-stage regression of Eq. (1). The distance dependence is then determined from the model

$$\log y(T) = \sum_{j=1}^{K} a_j(T)A_j + b_2(T)R + \log R + \underline{b_4(T)h} + \sum_{i=1}^{N} \underline{c_i(T)S_i} \qquad (2)$$

where A_j=1 for event j, 0 otherwise; and $b_4(T)$ and $c_i(T)$'s are constrained to the values determined in the previous step. The third step is to determine the magnitude dependence by weighted least squares [4] by the equation

$$a_j(T) = b_0(T) + b_1(T)M_j \qquad (3)$$

in which $a_j(T)$ is determined from the previous step. The first step is then

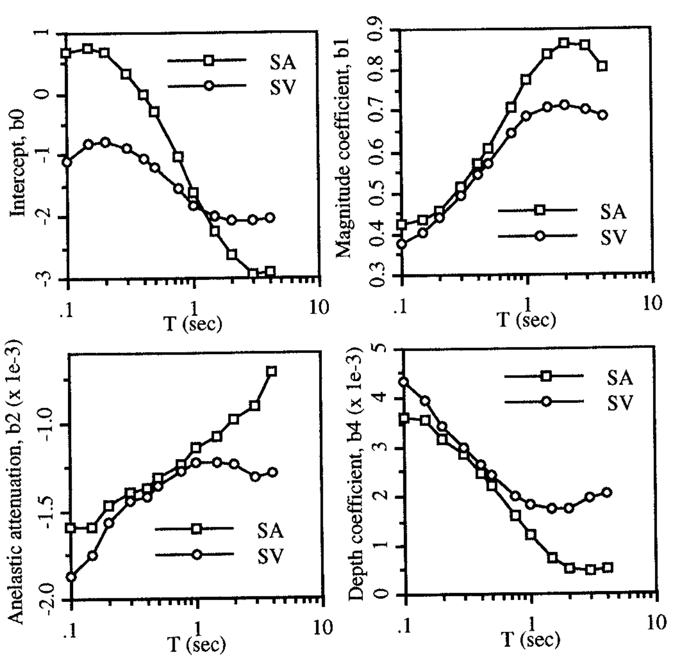


Figure 1. Regression coefficients for $S_A(T)$ and $S_V(T)$

repeated except that $b_1(T)$ and $b_2(T)$ are constrained to the values determined from the previous iteration's steps 2 and 3. The cycle is then repeated until the coefficients stabilize.

RESULTS: Figure 1 shows the frequency dependence of the regression coefficients. The magnitude term increases as structure period increases for both $S_A(T)$ and $S_V(T)$. The anelastic attenuation coefficient decreases as the structure period increases. This is consistent with observations that high frequency seismic waves attenuate faster than low frequency waves. Figure 1 also shows that the effect of depth diminishes as the structure period increases. It can also be seen that the coefficients for $S_V(T)$ stabilize somewhat for structure periods 1 to 4 s.

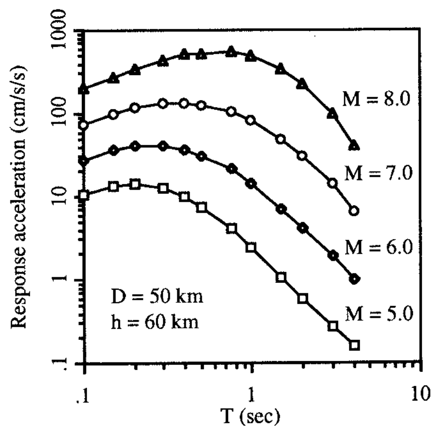


Figure 2. Predicted absolute acceleration response spectra (c_i = 0.0)

A comparison of spectral shapes show that it is dependent on the magnitude (Figure 2) but not on distance, nor depth (not shown). The spectra of station coefficients have a distinct characteristic for each station and cannot be categorized by the soil type of the recording stations. However, the spectrum of station coefficients for $S_A(T)$ and $S_V(T)$ are similar (Figure 3). This suggests that it may be possible to use other ground motion parameters to estimate the frequency dependent amplification at a given site.

By combining the spectrum of station coefficients and the mean predicted response spectra, a site-specific response spectrum can be predicted at a site given the magnitude, distance and depth of an event. Figure 4 shows the predicted response spectra for the JMA Hachinohe and Tokyo stations. It can be seen that the resulting predictive equations can differentiate between two sites in terms of amplitude and spectral shape. This is significant in seismic hazard and risk studies where site-specific response spectra are needed. However, to use the attenuation equations for other sites, we must first find a reliable method to estimate the station coefficients.

CONCLUSIONS: Regression analyses of absolute acceleration and relative velocity response spectra are performed. The effect of source depth and local site are considered in the analysis. It was found that the effect of source depth diminishes as the structure period increases and that the frequency dependence of the site effect cannot be adequately characterized by soil types. The results can be used to predict site-specific response spectra at the JMA stations used in this study.

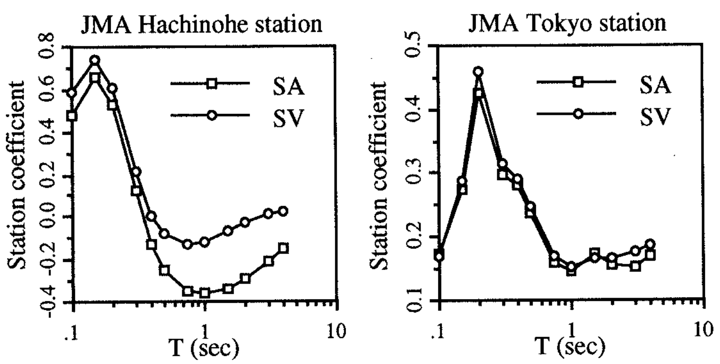
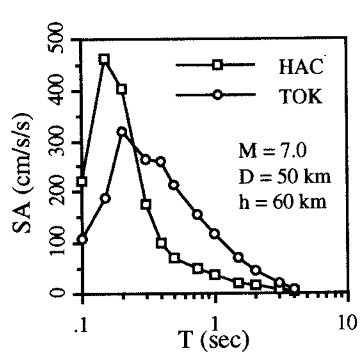


Figure 3. Spectrum of station coefficients for two JMA stations.



Figuire 4. Site-specific predicted response spectrum

References:

[1] G.L. Molas and F. Yamazaki (1994). Effect of focal depth to the attenuation characteristics of earthquake ground motion, *Proc. 9th Japan Eq. Eng. Sym.*, E31-36.

[2] Y. Fukushima and T. Tanaka (1991). A new attenuation relationship for peak horizontal acceleration of strong earthquake ground motion in Japan. *Bull. Seis. Soc. Am.* **80:4**, 757-783.

[3] W.B. Joyner and D.M. Boore (1981). Peak horizontal acceleration and velocity from strong motion records including records from the 1979 Imperial Valley, California earthquake. *Bull. Seis. Soc. Am.* **71**, 2011-2038.

[4] W.B. Joyner and D.M. Boore (1993). Methods for regression analysis of strong-motion data. *Bull. Seis. Soc. Am.* **83:2**, 469-487.