ATTENUATION OF RESPONSE SPECTRA IN JAPAN USING NEW JMA RECORDS

by

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ABSTRACT

New attenuation relations for absolute acceleration and relative velocity response spectra for Japan are developed. These relations were derived from acceleration time histories recorded by the new accelerometers of the Japan Meteorological Agency (JMA). The focus of the events used in this study have a depth of up to 200 km making the equations applicable to subduction zone regions, which are common in Japan. The attenuation relations consider the effect of depth and the local site amplification. A numerical technique called the iterative partial regression is used to apply Joyner and Boore's two-stage regression methodology while considering the effect of the recording site.

The resulting attenuation relations show that the attenuation of absolute acceleration and relative velocity response spectra decreases as structural period increases and that the spectral shape is dependent on the magnitude. The effect of source depth on the response spectra is significant. However, this effect diminishes as the structural period increases. The frequency dependent relative amplification of the sites are found to be distinctive from site to site and that stations with the same soil type classification do not show an apparent pattern. However, since the local-site characteristics are explicitly derived, the resulting predictive equations can be considered as site-specific response spectra for the 76 JMA stations examined here.

INTRODUCTION

Many researchers use the peak ground motion (i.e., the peak ground acceleration, peak ground velocity, peak ground displacement) to refer to the intensity of a given ground motion. As reflected by the number of attenuation relations developed for peak ground motion, their use in hazard/risk analysis are still useful. However, peak ground motion do not give a complete characterization of the ground motion, particularly to the frequency contents. The frequency contents of the ground motion is important to the dynamic responses of the ground and the structure, especially special and critical structures like hi-rise buildings and nuclear power plants. The response spectrum is an excellent way of quantifying the frequency contents of the ground motion and can be used with hazard and risk methodologies currently in use. This provides the rationale for several attenuations developed for the response spectrum.

Much of the discussion in this study will refer to the contents of our previous study regarding the attenuation relations of the peak ground acceleration and peak ground velocity (Molas and Yamazaki, 1995). The source of data are the same and the methodologies used are those that were developed in the preceding paper. In order to avoid duplication, we try to refer to our preceding paper as much as possible, but for clarity, a brief background is included in this paper.

One of the major results of the previous study is that the effect of source depth were significant. The effect of the local site to the regression were examined and were also found to be

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significant. Thus, the attenuation model chosen for this study also considers the effect of depth and recording station. We proposed an iterative partial regression procedure to solve a matrix singularity problem that arises when the effect of the recording station is determined with the two-stage regression procedure introduced by Joyner and Boore (1981).

The results showed that effect of recording station in terms of relative amplification factors are quite scattered such that the use of soil type classifications cannot adequately represent the amplification observed at the 76 JMA stations. Thus, the effects of the local site are very important to the prediction of attenuation relations. In addition, it is widely accepted that amplification at a site are frequency dependent. The safety of structures from earthquakes depends not only on the intensity but also on the frequency contents of the ground motion. Although they are widely used indices of ground motion intensity because of their simplicity, peak ground motion values like the PGA and PGV cannot indicate the frequency characteristics of an earthquake ground motion. In this paper, we develop attenuation relationships for the absolute acceleration and relative velocity response spectra for the 76 JMA stations. While the data and techniques are basically the same as our previous study, we can show the frequency dependence of the attenuation characteristics including the effect of depth and local site amplification. The resulting attenuation relations are vaery useful for seismic hazard/risk analysis involving subduction zones, especially in Japan.

DATA

A summary of the characteristics of the data set is given in Table 1. As in our previous study, the data used for regression were obtained from the acceleration time histories of 76 JMA stations. The maximum response of single-degree-of-freedom systems with a damping coefficient five percent of critical is calculated by Newmark's direct integration method from the acceleration time history of each horizontal component. The larger of the two horizontal maximum responses of each structural period is used in the regression analysis. Twelve structural periods from 0.1s to 4.0s are used and regression analysis is performed separately for each structural period. By treating the attenuation of each structural period as independent to the others, a form of the spectral shape is not imposed. The spectral shape for a given magnitude and distance can be determined by attenuating the expected responses of each structural period to the site.

ATTENUATION MODEL

As in the previous study, the initial model is based on the attenuation of body waves in an elastic medium from a point source (e.g., Joyner and Boore, 1981; Abrahamson and Litehiser, 1989; Ohno, et al., 1993) and given as

$$\log y(T) = b_0(T) + b_1(T)M + b_2(T)r + b_3(T)\log r \qquad (1)$$

where $y(T)$ is the maximum amplitude of the response under consideration. In this study, $y(T)$ is taken as the larger maximum amplitude of the two horizontal components, M is the JMA magnitude, r is the slant distance between the source and the recording station, and $b_i(T)$'s are the coefficients to be determined. The definition of the JMA magnitude is different for focal depths greater than 60 km. For deep events the effect of depth on attenuation are taken into consideration so that it is reasonable to use the magnitude scale continuously from shallow to deep events. The $b_2(T)$ term represents anelastic attenuation and the $b_3(T)$ term represents geometric spreading. If we assume spherical spreading, $b_3(T)$ should be -1.0 but we initially unconstrain $b_3(T)$ to allow flexibility in the model. However, as in the previous study, preliminary regressions showed that this results in $b_3(T)$'s that are less than -1.0 which is beyond the physically admissible range. Therefore, the geometric spreading term, $b_3(T)$, is set to -1.0.

As in the previous study, r is defined as the shortest distance from the recording site to the plane of the fault rupture. However, published reports of fault extent and orientation are difficult to find or nonexistent for the events in the data set except for two large earthquakes of magnitude 7.8; namely, the 1993 Kushiro-Oki earthquake and the 1993 Hokkaido-Nansei-Oki earthquake. Most of the records are in the far-field and the third largest event with records close to the fault has a magnitude of 6.6. For the other records, we use the hypocentral distance. Since the effect on the regression of the change in distance definition is small in the far-field and for small events, the use of hypocentral distances is practical and justified.

The effect of source depth and local site was found to be significant to the prediction of PGA and PGV for this data set (Molas and Yamazaki, 1995). By considering the depth and local site effects in the regression model, we can check the frequency dependence of these effects. The regression model is then given by

$$\log y(T) = b_0(T) + b_1(T)M + b_2(T)r + b_3(T)\log r + b_4(T)h + c(T) \quad (2)$$

where h is the depth in kilometers of the point in the fault plane that is closest to the recording site (i.e., the point where r is measured) and $c(T)$ is a coefficient representing the local site effect at the recording site. Although the results are not reported here, preliminary analyses were performed to verify the significance of the depth term and station coefficient to the regression as in our previous study.

Since regression analysis is performed for each structural period independently, we drop the index indicating the frequency dependence of each variable in the equations that follow for clarity. It is thus understood that the regression procedure is performed sepately for each structural period under consideration.

METHOD OF ANALYSIS

Since the maximum response of the single-degree-of-freedom systems are treated separately, we can apply the method of analysis done for the PGA and PGV for each structural period of the response acceleration and response velocity.

In summary, the two-stage regression methodology proposed by Joyner and Boore (1993) are applied. However, the consideration of the depth and station effects in the analysis produced a singular matrix which cannot be inverted. An interative partial regression technique was used to solve the regression. A more detailed description of this technique can be found in Molas and Yamazaki (1995).

RESULTS AND DISCUSSION

Regression coefficients

The results of iterative partial regression for the attenuation of absolute acceleration and relative velocity response spectra are given in Tables 2 and 3. Figure 3 shows the comparison of the structural period dependent regression coefficients for the acceleration and velocity spectra. The regression intercept, b_0, indicates the mean response of the data set after adjusting for the effects of source depth and local site. It has a decreasing trend as the structural period increases, although this trend is more pronounced for the acceleration response spectrum.

The magnitude coefficient, b_1, has an increasing trend as the structural period increases, although in the case of the velocity response, the coefficient is a bit flat for structural periods of 1 to 4s. This implies that as the magnitude increases, the longer-period structures will have a greater increase in response than the short-period ones. This reflects the trend that large events produce stronger long-period ground motion and these propagate farther than shorter-period ground motion.

The anelastic attenuation rate, b_2, decreases as the structural period increases for both the acceleration and velocity response. This is consistent with observations that high-frequency contents of strong ground motion are attenuated faster than low-frequency contents.

The depth effect term, b_4, decreases as the structural period increases. In the case of acceleration response, the depth effect is not significant for structural periods of 1s and above,

Table 1. Summary of data used in this study

No. of records	2,166
No. of recording stations	76
Date recorded	August 1, 1988 to December 31, 1993
Instrument	JMA-87 type accelerometers
Recording Institution	Japan Meteorological Agency (JMA)
Magnitude range	4.0 to 7.8 (JMA Scale)
Minimum intensity (larger of two horizontal components)	PGA ≥ 1.0 gals
Depth range	0.1 km to 200 km
Structural period (s) analyzed	0.1, 0.15, 0.2, 0.3, 0.4, 0.5, 0.75, 1.0, 1.5, 2.0, 3.0, 4.0
Damping coefficient	5 percent of critical

Table 2. Regression coefficients for absolute acceleration response spectrum, $S_A(T)$ (in cm/s^2)

T (sec)	b_0	b_1	b_2	b_3	b_4	σ_r	σ_e	σ
0.10	0.702	0.424	-0.00159	-1.00	0.00362	0.250	0.150	0.292
0.15	0.773	0.434	-0.00158	-1.00	0.00357	0.258	0.149	0.298
0.20	0.691	0.457	-0.00147	-1.00	0.00319	0.262	0.133	0.294
0.30	0.349	0.515	-0.00139	-1.00	0.00287	0.254	0.127	0.284
0.40	-0.004	0.570	-0.00136	-1.00	0.00246	0.244	0.127	0.275
0.50	-0.296	0.608	-0.00131	-1.00	0.00222	0.238	0.119	0.266
0.75	-1.028	0.707	-0.00124	-1.00	0.00161	0.232	0.123	0.263
1.00	-1.593	0.775	-0.00114	-1.00	0.00123	0.223	0.123	0.255
1.50	-2.240	0.838	-0.00107	-1.00	0.00073	0.216	0.120	0.247
2.00	-2.608	0.862	-0.00098	-1.00	0.00053	0.215	0.111	0.242
3.00	-2.929	0.858	-0.00091	-1.00	0.00048	0.214	0.097	0.235
4.00	-2.912	0.807	-0.00071	-1.00	0.00053	0.216	0.090	0.234

σ_r^2 = record to record component of variance (determined in second step)

σ_e^2 = earthquake to earthquake component of variance (determined in third step)

σ^2 = total variance $\cong \sigma_r^2 + \sigma_e^2$

while for the velocity response the depth effect becomes almost constant for periods 1s and above. The frequency dependence of the depth effect may give us a clue as to the physical significance of the depth effect. Figure 2 shows the predicted response absolute acceleration for structural periods 0.10s, 0.50s, 1.0s, and 2.0s for source depths of 30 km, 60 km, 90 km, and 120 km. From this figure, it can be seen how the structural period affects the attenuation rate and the effect of depth. In our previous study, we stated that the depth effect may be caused by the high-Q zones travelled by seismic waves from a deep source resulting in a lower effective attenuation rate and in which case the depth term, b_4, is a kind of adjustment factor. It was also observed that the depth effect is also evident for shallow events. In this case, the scattering of the seismic waves as it nears the surface results in the effective increase in the attenuation rate. Since the term b_4h is larger for deeper events and the sign is opposite that of the anelastic attenuation and geometric spreading terms, it can consider the depth effect for both the shallow and deep events.

If this premise is accepted, then the frequency-dependence of the attenuation rate as shown in Figure 1c can explain the decrease in the depth effect for longer-period structures. Since the attenuation rates for longer-period structures are low, these will be closer to the attenuation rates of the high-Q zones (for deep events) and there is less "adjustment" made in the regression results.

For the case of the response velocity, the frequency dependent attenuation coefficients appear to become stable from structural periods 1.0 s to 4.0 s. In these period range, the coefficients approach those of the log PGV.

Spectral shape

An important aspect of response spectra is the spectral shape since this will largely determine the expected response of a given structure. By taking the regression for several structural periods independently, it is not necessary to pre-determine the shape of response spectra. Figures 3 and 4 compares the spectral shapes for different magnitudes and the effect of changing the slant distance, r, and source depth, h. It can be seen from the figures that the spectral shape of both the response acceleration and velocity depend on the magnitude. The structural period where the peak of the response curves occurs increases as the magnitude increases. This is consistent with the change of the magnitude term with respect to the structural-period (Figure 1b). The effects of distance and source depth on the spectral shape, however, are not apparent.

Depth effect

Figure 5a shows the predicted acceleration response spectra for a given magnitude and slant distance with changes in the source depth. There is a slight shift of the peak to a shorter structural period as the source depth increases, although this may not be significant. The response from deeper events are larger than those from shallower events, however, it must be noted that these response spectra refer to different sites since a deeper source with the same slant distance will have a shorter horizontal distance. If the site is kept constant (i.e., constant horizontal distance) and the source depth changes (Figure 5b), the response from shallow events are larger. The same observations can be made for the velocity response spectra (Figures 5c and 5d), except that the slight shift in response peak is not apparent.

Local site effect

The station coefficients determined from the regression can be regarded as amplification factors relative to the other stations. As in the previous study, the regression was performed such that the mean of the station coefficients is zero. Site amplifications are known to be frequency dependent. Figure 6 shows the spectra of station coefficients for four JMA stations. These stations were chosen because of the large number of records for each station (about 100 records per station). The spectrum of station coefficients for the response acceleration and response velocity for each of these stations are very similar, although the shapes are quite different from station to station. The dominant peak seen in both response spectra may represent

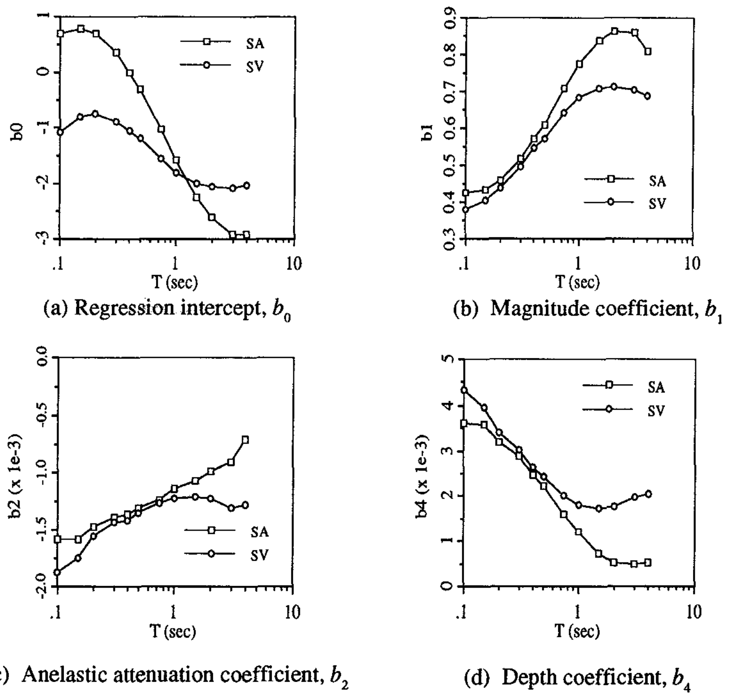


Figure 1. Regression coefficients for the absolute acceleration (SA) and relative velocity (SV) response spectra.

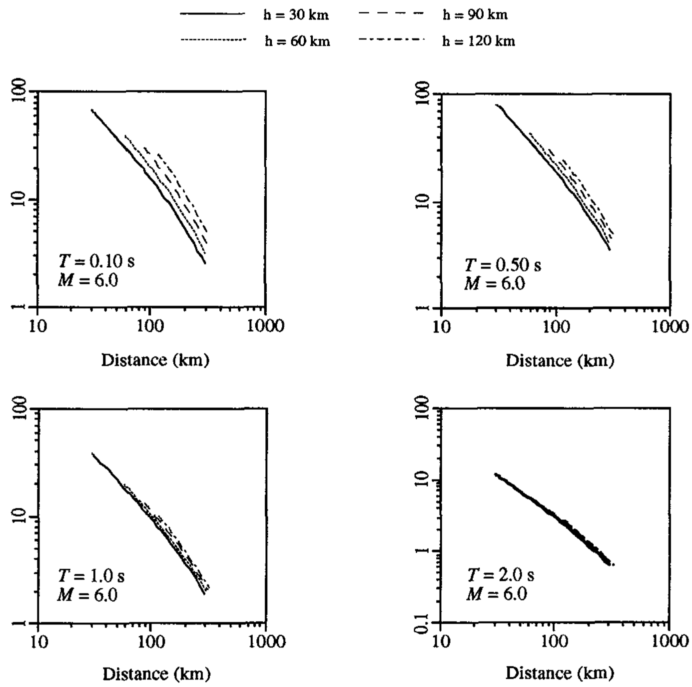


Figure 2. Predicted attenuation curves for the absolute acceleration response of single-degree-of-freedom systems with selected natural periods with damping five percent of critical. The frequency dependence of the attenuation rate and depth effect can be clearly seen.

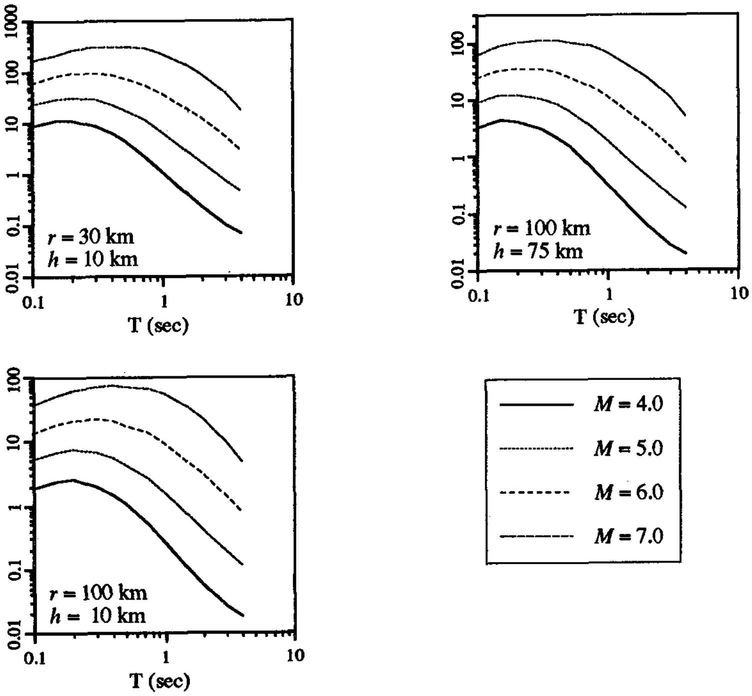


Figure 3. Spectral shapes of absolute acceleration response spectra showing the effects of changes in magnitude, distance, and source depth.

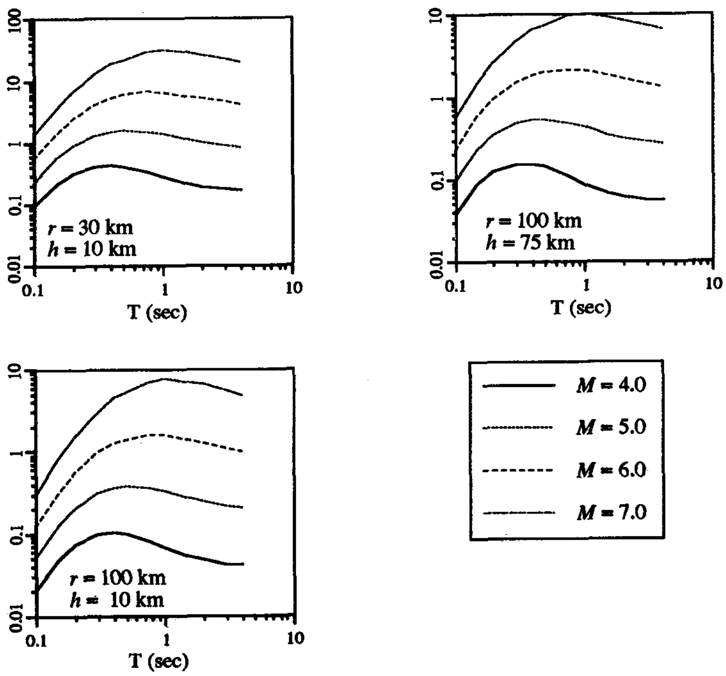


Figure 4. Spectral shapes of relative velocity response spectra showing the effects of changes in magnitude, distance, and source depth.

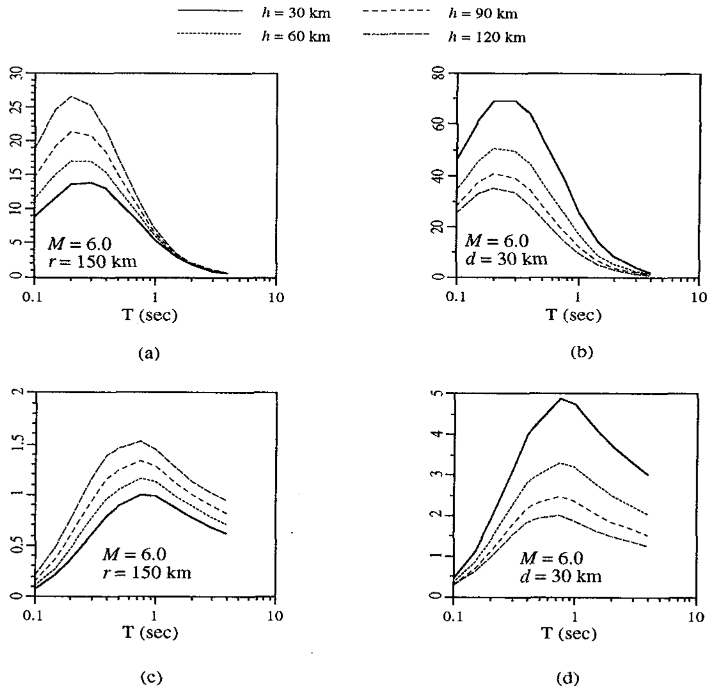


Figure 5. Spectral shapes of the absolute acceleration and relative velocity response spectra with different source depths for a constant slant distance ((a) and (c)) and constant horizontal distance ((b) and (d)).

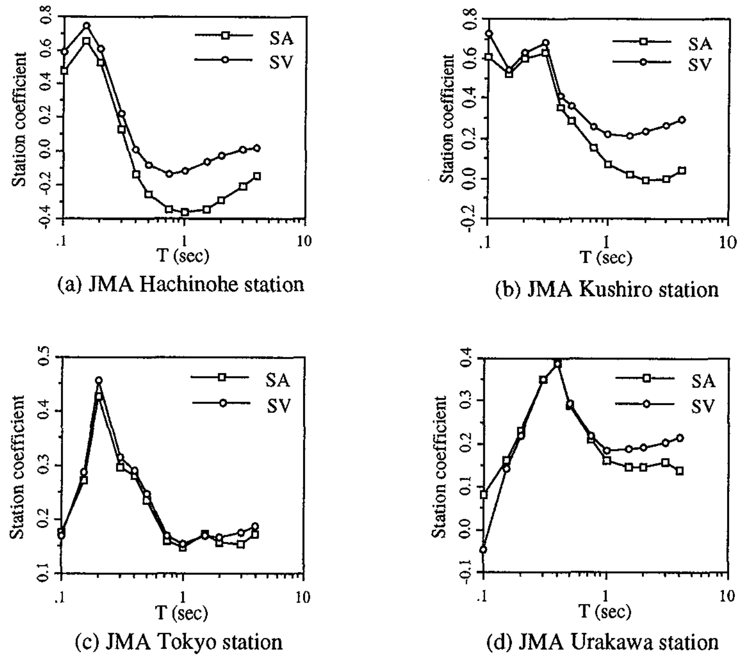


Figure 6. Spectra of station coefficients for four selected JMA stations. The number of records for each of these stations is about 100.

the natural (predominant) period of the recording site, although the peak is obtained from the relative amplification of the site with the others.

Each recording station is classified into four soil types given in the Appendix of Molas and Yamazaki (1995). The definitions of the soil type categories, which are the commonly used classification in Japan, are reprinted in Table 4 for convenience. Although not shown here, plots of the spectrum of station coefficients of stations with the same soil type classification do not have a common characteristic. In the case of the PGA and PGV, the station coefficients with the same soil type have a large scatter and it was concluded that soil type classifications cannot adequately represent the local site effect, at least for the 76 JMA sites used in that study (Molas and Yamazaki, 1995). Figure 7 shows the frequency dependence of the mean of the station coefficient for each soil type. In this figure, stations with unconfirmed soil types classification given in the Appendix of the previous study are excluded. Unfortunately, there are only two stations with soil type 4 used in this figure so that the mean line for soil type 4 may not be reliable. The horizontal lines indicate the mean station coefficients for each soil type for the PGA and PGV.

Except for structural periods less than 0.3s, the mean of the station coefficients for each soil type increase (higher amplification) as the soil becomes softer. The shape of the mean of the station coefficients for each soil type are similar for the response acceleration and response velocity. The peaks of the plots for the mean of the station coefficients coincide with the natural period of the ground for the different soil types. In the case of the velocity response, the mean of the station coefficients approach those for the PGV at structural periods of about 1.0s and above.

Site-specific response spectra

Since the local site effect is considered in the regression analysis, the resulting predictive equations for each site are in effect, site-specific expected response spectra. By combining the expected response spectra of the mean station (with $c_i = 0.0$) and the spectrum of station coefficients, we can predict site-specific response spectra for each of the JMA recording stations. Figure 8 shows sample site-specific response spectra for the four JMA stations given in Figure 6. These spectra are different in terms of the amplitude and shape and the dependence of the spectral shape to the magnitude is implicitly considered. These characteristics are important in the seismic hazard and risk analysis of critical structures. However, an efficient and reliable method to estimate the spectrum of station coefficients of new sites is needed to fully utilize "true" site-specific response spectra prediction.

Comparison with other attenuation relationships

The attenuation relationships derived in this study are basically for the 76 JMA stations whose records were used. The mean of the response acceleration and velocity of the JMA stations are represented by the station coefficient, $c_i = 0.0$. We try to compare the predicted absolute acceleration and relative velocity response spectra with those of Annaka and Nozawa (1988) and Crouse et al. (1988) which were both developed for subduction zone or otherwise includes deep events and those of Kawashima et al. (1984) whose attenuation relations are currently used in the Japanese bridge design code. A summary of the data used by Annaka and Nozawa (1988) and by Kawashima (1984) can be found in Molas and Yamazaki (1995). Annaka and Nozawa's attenuation relations are for rock (shear wave velocity, $V_S \geq 300$ m/s) while Kawashima (1984) and Crouse, et al. (1988) are for soil.

Figure 9(a) shows the predicted response acceleration for a magnitude 7.0 event with a ruptured fault surface where the point in the fault surface which is closest to the site is 30 km deep and which the closest distance is 50 km. Annaka and Nozawa (1988) used the mean of two horizontal components for their regression while Kawashima (1984) used the vectorial sum of the two horizontal components. To compare with the results of this study, which uses the larger of two horizontal components, the predicted values of Annaka and Nozawa (1988) were increased by about 12 to 15% and the results of Kawashima et al. (1984) were reduced by about 6 to 8%, in accordance to the results of Ansary, et al. (1995). The predicted response of the

Table 3. Regression coefficients for relative velocity response spectrum, $S_V(T)$ (in cm/s)

T (sec)	b_0	b_1	b_2	b_3	b_4	σ_r	σ_e	σ
0.10	-1.073	0.381	-0.00187	-1.00	0.00435	0.270	0.185	0.327
0.15	-0.794	0.404	-0.00175	-1.00	0.00396	0.273	0.169	0.321
0.20	-0.764	0.438	-0.00156	-1.00	0.00342	0.271	0.144	0.307
0.30	-0.883	0.495	-0.00144	-1.00	0.00301	0.258	0.131	0.290
0.40	-1.057	0.544	-0.00142	-1.00	0.00266	0.247	0.128	0.279
0.50	-1.182	0.572	-0.00135	-1.00	0.00243	0.242	0.114	0.268
0.75	-1.553	0.643	-0.00127	-1.00	0.00201	0.237	0.113	0.262
1.00	-1.812	0.685	-0.00122	-1.00	0.00182	0.231	0.110	0.256
1.50	-2.002	0.707	-0.00121	-1.00	0.00175	0.228	0.102	0.250
2.00	-2.068	0.711	-0.00123	-1.00	0.00176	0.228	0.101	0.249
3.00	-2.076	0.703	-0.00130	-1.00	0.00196	0.230	0.101	0.251
4.00	-2.018	0.686	-0.00128	-1.00	0.00205	0.230	0.098	0.250

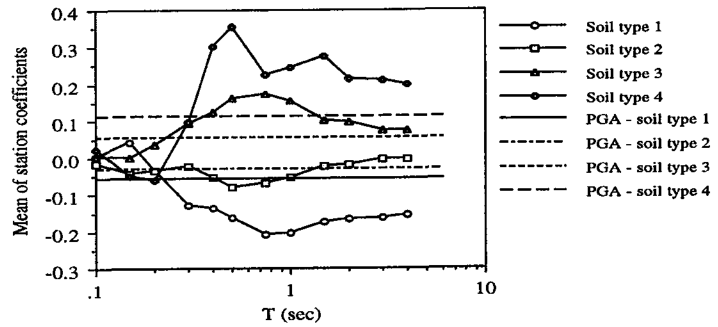
σ_r^2 = record to record component of variance (determined in second step)

σ_e^2 = earthquake to earthquake component of variance (determined in third step)

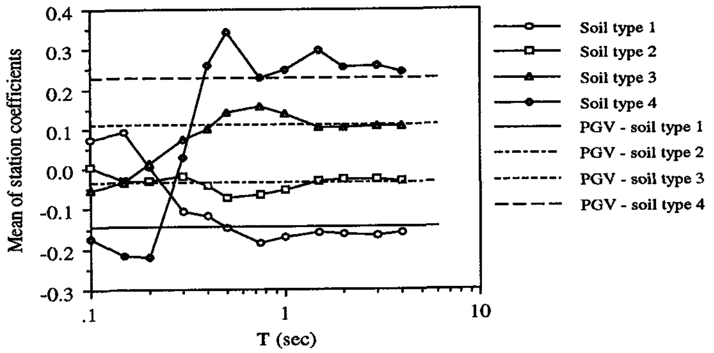
σ^2 = total variance $\cong \sigma_r^2 + \sigma_e^2$

Table 4. Classification of ground conditions for JMA stations

Soil Condition	Geological Definition	Definition by natural period
Type 1 (Rock)	Tertiary or older rock (defined as bed-rock), of diluvium with H < 10 m	T < 0.2s
Type 2 (Hard soil)	Diluvium with H ≥ 10 m, or alluvium with H < 10 m	0.2 ≤ T < 0.4s
Type 3 (Medium soil)	Alluvium with H < 25 m including soft layer with thickness less than 5 m	0.4 ≤ T < 0.6 s
Type 4 (Soft soil)	Other than above, usually soft alluvium or reclaimed land	T ≥ 0.6 s



(a) Response acceleration



(b) Response velocity

Figure 7. Spectra of the mean station coefficient for each soil type classification given in Table 4 of the absolute acceleration (top) and the relative velocity (bottom) response spectra. Horizontal lines show the mean station coefficient for each soil type for the peak ground acceleration (PGA) and peak ground velocity (PGV) from Molas and Yamazaki (1995).

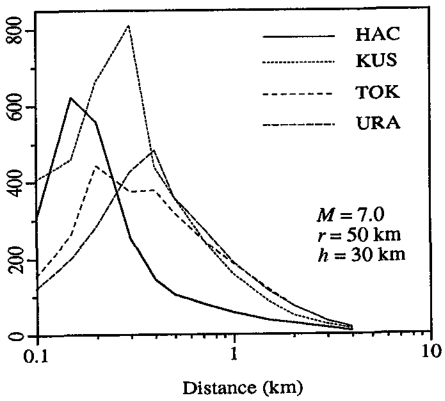
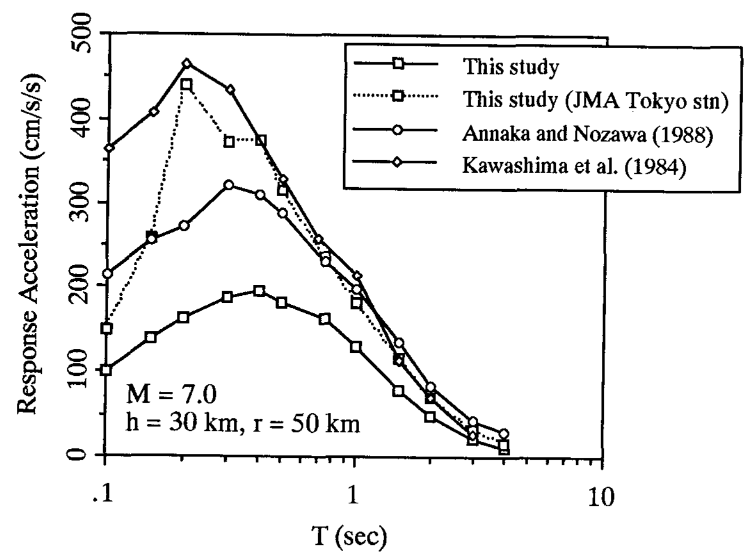


Figure 8. Predicted site-specific absolute acceleration response spectra for the four JMA station shown in Figure 6. By applying the site coefficients for each structural period, the response spectra for each JMA station can be predicted. It can be clearly seen that the response spectra for each station differ in terms of spectral shape and/or intensity.



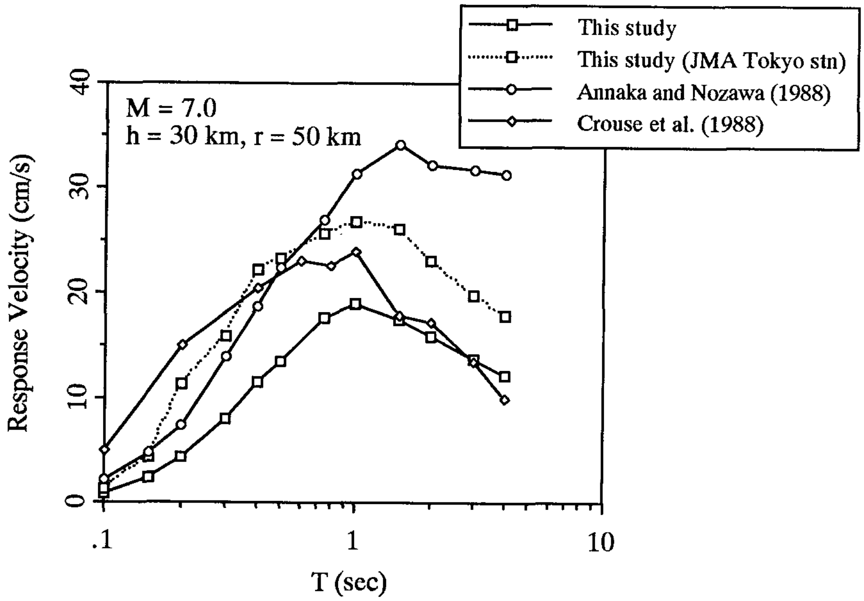


Figure 9. Comparison of predicted absolute acceleration and relative velocity response spectra for source depth of 30 km and closest distance of 50 km for magnitude 7.0.

mean JMA station (i.e., c_i=0.0) is much less than those using Annaka, although the spectral shape is quite similar. This is consistent with the comparison of the PGA and PGV for the same data sets (Molas and Yamazaki, 1995) in which the predicted PGA and PGV for the mean JMA station is also smaller than the ones predicted by Annaka and Nozawa (1988). If we compare Annaka's predicted acceleration response with that of a single recording station (for example, the JMA Tokyo station), it can be seen that the predicted response spectra become comparable, especially for the structural periods 0.5s to 4.0s, although the peak response is much greater for the JMA Tokyo station. This illustrates that response spectra of a specific site may be quite different from the response averaged for a collection of sites.

Kawashima et al's (1984) predicted response acceleration is quite large compared to Annaka and Nozawa (1988) and the results of this study in the short-period range. We used Kawashima's attenuation relation for soil type 2 which is a combination of soil types 2 and 3 given in Table 4. Kawashima's relations do not consider the depth of the source and the attenuation rate for large distances is small compared to those which consider anelastic attenuation and geometric spreading (Annaka and Nozawa, 1988; Fukushima and Tanaka, 1990; Molas and Yamazaki, 1995). Therefore at large distances, Kawashima's relations predict much higher response (Molas and Yamazaki, 1995). Figure 9(b) shows the comparison of the relative velocity response spectra. In this figure the predicted response of Crouse et al (1988) are included as a reference. About half of their data are from Japanese subduction zone events. Crouse et al. used both horizontal components as data points in the regression. Although Ansary et al. (1995) did not calculate conversion factors for the velocity response spectra, we assumed the conversion factors to be the same as for the acceleration response spectra. Crouse et al. used data with different magnitude scales but at a magnitude of 7.0, most magnitude scales are consistent (Ambraseys, 1990). Similar observations as in Figure 9(a) can be made for the response velocity. The predicted response velocity of Crouse in the short-period range are higher than those for the Japanese attenuation relations although the JMA Tokyo station response shows a similar characteristic. The spectral shape Annaka and Nozawa (1988) and that for the mean of the JMA stations are similar, although the intensity of the latter is lower. Comparison with a site-specific response (e.g., for the JMA Tokyo station) shows that the predicted response velocity is comparable with Annaka for structural periods up to about 0.75s but less than Annaka for structural periods greater than 0.75s. The predicted velocity response for the JMA Tokyo station shows similar characteristics compared to Course (1988) in terms of spectral shape and intensity.

CONCLUSION

This paper reports on the results of a regression study for the attenuation of the absolute acceleration and relative velocity response spectra. As in a previous paper that dealt with the peak ground acceleration and peak ground velocity, this study uses ground motion recorded by the new JMA 87-type accelerometers from 76 Japan Meteorological Agency recording stations. The use of these new records is significant because there is no need to correct for suppressed instrument sensitivity in the high frequency range.

Records from earthquakes with depths of up to 200 km are considered. The attenuation rate is found to decrease as the structural period increases which is consistent with observations that high-frequency ground motion attenuate faster than low-frequency ground motion. The spectral shape is found to be dependent on the magnitude but not on the shortest distance to the fault nor the source depth.

The effect of source depth and recording site are explicitly determined. The depth effect was found to be significant but diminishes as the structural period increases. In the case of the absolute acceleration response spectrum, the depth term becomes insignificant at periods of about 1.0s and above, while for the relative velocity response spectrum, the depth term stabilizes at about the same structural period.

The frequency dependence of the station coefficients is found to be specific to a recording station. However, the station coefficients for the acceleration response spectra and velocity response spectra of a given station are similar. The peak of the station coefficient spectrum seems to represent the natural period of each recording site. The mean of the station coefficients for each soil type follows the general trend that larger ground motion are expected as the ground becomes softer.

The attenuation relationships proposed in this study can be used to predict site-specific expected response spectra for the JMA stations used.

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