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A SPECTRAL ATTENUATION MODEL FOR JAPAN USING DIGITAL STRONG MOTION RECORDS OF JMA87 TYPE

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SUMMARY

A preliminary spectral attenuation model derived from JMA strong motion data is presented. A consistent record processing procedure and consistently determined focal depths were adopted, and the regression analysis followed a random effects method. The JMA data set does not have enough near-field data to support model parameters that could reliably control the near-field behaviour. Residuals analyses show that the attenuation model can adequately predict recorded spectra for subduction events but tends to over-estimate the response spectra from inter-slab events in subduction zones, when the model does not explicitly account for the nature of the tectonic source.

INTRODUCTION

Recent developments in attenuation modelling indicate that ground motions generated by earthquakes located in different parts of the earth's crust may have different attenuation characteristics [Abrahamson & Silva 1997 and Youngs et al 1997]. For example, ground motions generated by shallow crustal earthquakes have different attenuation rates from those generated by inter-slab and intra-slab (subduction) events, and attenuation functions for subduction events are usually dependent on the depth of the earthquake source. In Japan the tectonic and geological settings are complicated. All of the above-mentioned three tectonic types of earthquake source exist. Importantly the majority of the earthquakes in the data set that we use, the JMA data set, are intra-slab events within the subduction zone.

The JMA data set has some severe disadvantages. First, many events do not have JMA focal depths. In order to account for the effect of source depth effect it is necessary to have a consistent determination of focal depth, hence it is not appropriate to utilise the JMA focal depth. Second, the JMA data set lacks near-field data for all magnitudes. Parameters that control the near-field behaviour of the model cannot, therefore, be determined reliably from the JMA data set alone, and so in this preliminary study we develop a model with a simple form and adopt parameters for near-field behaviour from an existing model. Further study based on a much larger data set is being carried out. Third, most of the earthquakes in the data set are from the subduction zone. Hence it is difficult to fully incorporate tectonic source parameters into the model. We present models that do not explicitly account for tectonic source effects, and also present the results of residuals analyses to demonstrate the importance of the tectonic source.

Zhao [1999] found that the attenuation characteristics for the data from the eastern and the western parts of Japan, divided by the Izu-Itoigawa tectonic line, were significantly different. The model derived for earthquakes of the eastern part of Japan has, however, very similar attenuation characteristics to the model from the complete data set. We present here the models for the complete data set and for the events in the western part of Japan to demonstrate regional differences.

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STRONG MOTION DATA

The modelling we present is based on preliminary results from a continuing project. In early work Zhao [1999] noted a high level of long-period noise in many of the JMA records and developed a method for determining the maximum useable period for each record, as follows. Because the displacement response of a site is determined mainly by low-frequency motions, the wave form of a displacement time history can be used as a good indicator of low-frequency noise. An accelerogram is first interpolated in the frequency domain from 0.02s to 0.005s interval and the displacement time history is calculated using a fast Fourier transform (FFT) method. At least 5s of zeros is prepended to the beginning of the record and 5s of zeros appended to the end. The number of samples in the FFT is made large enough that the duration used in FFT is at least twice that of the selected duration for the processing window. This is done to make sure that the numerical errors generated by FFT are small. An Ormsby filter is used to band-pass filter the records between 0.2 and 24.5 Hz, and then the displacement time-history is plotted. If a record contains significant low frequency noise the displacement amplitude in the pre- and appended 5s portions is large, and in such cases the lower frequency limit for the Ormsby filter is increased until the displacement amplitudes in the pre- and appended parts became sufficiently small. Smoothed Fourier spectral amplitudes are plotted from 0.05 Hz to 25 Hz and also used to assist in determining the lower frequency limit for a record. For an earthquake record containing no low frequency noise, the Fourier spectral amplitude should in theory monotonically decrease with decreasing frequency. This property of the Fourier spectra is also used in determining the low frequency limit for each record.

We compared focal depth determinations from a number of seismological organisations in the world and adopted the most consistent, those determined by ISC, in the present study.

MODEL DEVELOPMENT

In the present study, the random effects model of Abrahamson and Youngs (1992) was used. This method is superior to the ordinary least-squares method and also to the two-step regression method of Joyner and Boore (1993). When there is a strong correlation between magnitude and source distance an ordinary least-squares approach will not give a set of true estimates of the model parameters. On the other hand, for a two-step regression method, when there are a large number of events having only a "single" record, and there are a large number of site correction factors, the model parameters have to be determined by an iterative method as shown by Molas and Yamazaki (1995). The general form of the model used in the present study is

$$\log_{10}[y_{i,j}(T)] = a\,M_i - bx_{i,j} - \log_{10}(x_{i,j} + c\,10^{d\,M_i}) + e\,h + S_k + \xi_{i,j} + \eta_i \qquad (1)$$

where y is either peak ground acceleration (PGA) in cm/s^2 or pseudo-velocity spectrum in cm/s for a spectral period T, M is moment magnitude, x is source distance in km, h is focal depth in km and S is the site factor for a given site k. Random variable $\xi_{i,j}$ is associated with intra-event errors with zero mean and a standard deviation of σ and random variable η_i is associated with inter-event errors with zero mean and a standard deviation of τ. The total standard error is defined by $\sigma_T^2 = \sigma^2 + \tau^2$. Parameters a, b, and e and site factor S_k will be determined by regression analysis for each period. Parameters c and d can only be reliably determined by near-field data and the corresponding values (c=0.06 and d=0.51) from Fukushima & Tanaka [1991] were adopted in the present study. Near field magnitude saturation was not imposed. The number of periods is 17, i.e., with equally spaced periods in log scale between 0.1 and 5s plus 0.0s for PGA. The numbers of records at periods longer than 1.5s decrease significantly with increasing period. The model parameters are given in Table 1. For data generated by events in the western part of Japan, model parameters a, c, d and S_k derived from all data are used.

MAIN RESULTS

The data was truncated at a source distance at which the Fukushima & Tanaka model [1991] predicts a PGA smaller than 2 gal. The resulting distribution of data for PGA is shown in Figure 1(a) for all data up to 400 km. The data from earthquakes in the western part of Japan, Figure 1(b), is significantly less than that from the events in the eastern part of Japan. The model parameters derived from all data are given in Table 1 and the subscripts R, H, M and S for the site factors in Table 1 denote rock, hard soil, medium soil and soft soil classes. The model's predictions for PGA are shown in Figures 1(c) – 1(f). At large magnitudes, the model developed from all data predicts PGAs very similar to those predicted to the model of Fukushima [1991]. At magnitudes 5 and 6, the present model predicts considerably smaller PGAs than the Fukushima model. The difference at the small and moderate magnitudes probably arises because much of our data in this magnitude range are not present in the data set of Fukushima [1991]. The comparison of the normalized data with the model in Figure 1(f) suggests that the present model fits the data well.

Figures 2(a) – (d) show variations of model parameters with spectral period. Events in the western part of Japan, Figure 2(b), have somewhat smaller anelastic attenuation rates than those derived from all data. The difference is reasonably small, and may simply be a consequence of the small amount of data from events in the western part of Japan. Focal depth terms derived from the data in the western part of Japan, Figure 2(c), are smaller than those derived from all data at short periods but larger at long periods. The mean site factor for all data, Figure 2(d), is very similar to that of the hard soil sites, probably because most of the data is from either hard or medium soil sites. Figures 2(e) show the residual factors, defined by the exponential of mean residuals, for each tectonic source type. When the residual factor is close to 1.0, the model's prediction is on average very close to the data, when residual factor is larger than 1.0 the model over-predicts the strong motion data, and when the residual factor is less than 1.0 the model under-predicts the data. Figure 2(e) shows that the model over predicts the interface events by a significantly large amount, but predicts slab events very well. Note that the model does not explicitly include tectonic source type as a parameter, and that slab event data dominates the data set.

Figures 3(a) – 3(d) show mean site correction factors for each ground class and the correction factors for all individual sites. Site correction factor for a site class is defined as the difference between the site factor and the mean site factor of that site class. The site correction factors for rock sites have the largest variations among the 4 site classes, suggesting that the rock site class may include both hard rock and soft rock sites. Figure 3(e) shows the intra-event residual distribution with source distance, and Figure 3(f) the inter-event residual distribution with magnitude. Both Figures are for PGAs for slab events. The residual distributions show no significant bias (for slab events).

Figures 4(a) - (d) show the spectral ratios between the model derived from records generated by the earthquakes in the western part of Japan and the model from all data. The spectral ratios are dependent on distance and focal depth. However, caution must be exercised when interpreting the ratios because (1) there is a relatively small amount of data from all earthquakes in the western part of Japan; and (2) there is only one interface event record from there. Figure 2(e) shows clearly that interface events produce significantly smaller ground motions on average than events from the other types of tectonic sources.

Figures 4(e) and 4(f) show the pseudo-velocity spectra predicted by the model from all data. The predictions are very similar to those presented by Zhao [1999].

CONCLUSIONS

We have presented the preliminary results of a spectral attenuation study based on a JMA strong-motion data set. Many of the records in the data set were found to contain significant low frequency noise and so we developed a new procedure for determining the maximum usable period for each record. We found the JMA focal depths to be inadequate. By adopting depths determined by ISC we were able to significantly improve the predictions made by our model. We were not able to explicitly account for the effect of tectonic source type. By residuals analysis we found that a model derived from JMA data without explicitly accounting for tectonic source type could adequately estimate spectra for intra-slab (subduction) events but records from inter-slab events were significantly over-estimated at all periods. A model derived from just records generated by events located in the western part Japan predicted different spectra than a model derived from all data, but the differences were not large. We expect that the differences could be reduced if the effects of tectonic source type were accounted for.

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TABLE 1 MODEL PARAMETERS DERIVED FROM ALL DATA

Periods	a	b	e	S	S_R	S_H	S_M	S_S	σ	τ	σ_T
0.000	0.578	0.00355	0.00661	-0.069	-0.210	-0.114	0.023	0.237	0.213	0.162	0.268
0.100	0.558	0.00403	0.00745	0.258	0.193	0.212	0.317	0.505	0.216	0.193	0.290
0.126	0.554	0.00409	0.00765	0.355	0.294	0.310	0.412	0.591	0.213	0.198	0.290
0.158	0.551	0.00405	0.00747	0.437	0.394	0.388	0.493	0.661	0.218	0.193	0.291
0.199	0.545	0.00400	0.00681	0.542	0.451	0.505	0.610	0.741	0.220	0.173	0.280
0.251	0.557	0.00385	0.00602	0.498	0.365	0.457	0.594	0.720	0.216	0.155	0.265
0.315	0.598	0.00377	0.00582	0.232	0.035	0.199	0.344	0.510	0.212	0.138	0.253
0.397	0.622	0.00340	0.00553	0.003	-0.199	-0.045	0.122	0.375	0.203	0.149	0.252
0.500	0.639	0.00314	0.00506	-0.193	-0.407	-0.276	-0.026	0.227	0.195	0.140	0.240
0.629	0.653	0.00277	0.00417	-0.373	-0.618	-0.451	-0.182	-0.021	0.202	0.143	0.247
0.792	0.663	0.00238	0.00421	-0.586	-0.826	-0.653	-0.412	-0.258	0.202	0.149	0.251
0.998	0.706	0.00204	0.00366	-1.028	-1.257	-1.095	-0.860	-0.687	0.197	0.136	0.239
1.256	0.727	0.00184	0.00265	-1.317	-1.538	-1.372	-1.178	-0.952	0.187	0.126	0.226
1.581	0.732	0.00158	0.00225	-1.543	-1.761	-1.589	-1.427	-1.167	0.182	0.119	0.217
1.991	0.780	0.00153	0.00183	-2.013	-2.236	-2.047	-1.918	-1.667	0.180	0.115	0.214
2.506	0.801	0.00128	0.00258	-2.319	-2.555	-2.335	-2.224	-2.086	0.156	0.105	0.188
3.155	0.823	0.00095	0.00221	-2.657	-2.842	-2.692	-2.546	-2.468	0.151	0.105	0.184
3.972	0.823	0.00082	0.00178	-2.850	-3.055	-2.870	-2.752	-2.686	0.150	0.104	0.183
5.000	0.823	0.00086	0.00000	-2.955	-3.156	-2.972	-2.886	-2.775	0.125	0.119	0.173

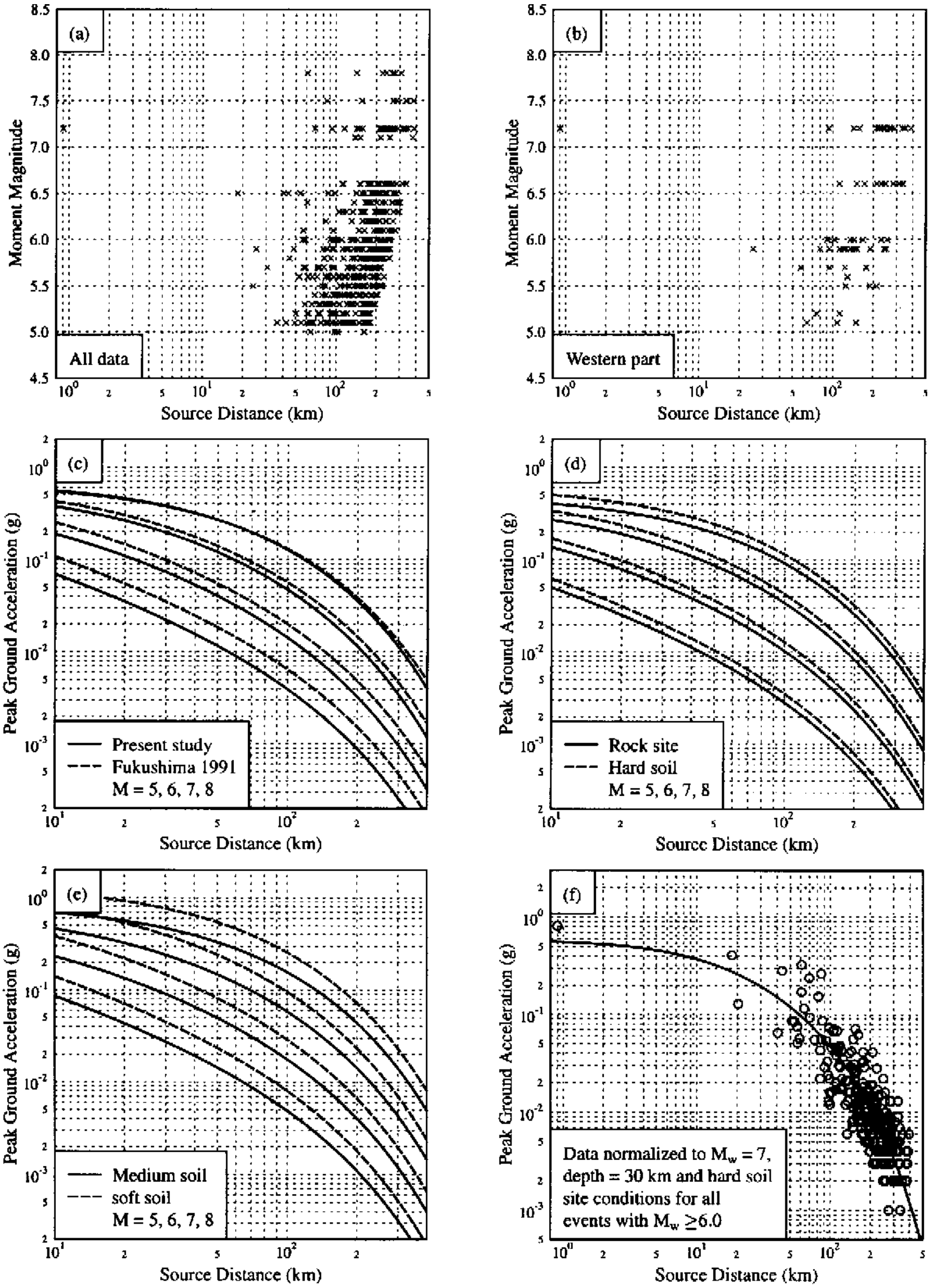

Figure 1 Magnitude-distance distribution of the JMA strong motion data used in this study and PGAs predicted by the model derived from all JMA data, (a) all data for source distance up to 400km and PGAs larger than or equal to 2 gal for both horizontal components; (b) data from earthquakes in the western part of Japan; (c) comparison with Fukushima 1991 model; (d) PGAs predicted for rock and hard soil sites; (e) PGAs predicted for medium and soft soil sites; and (f) comparison with normalized PGAs.

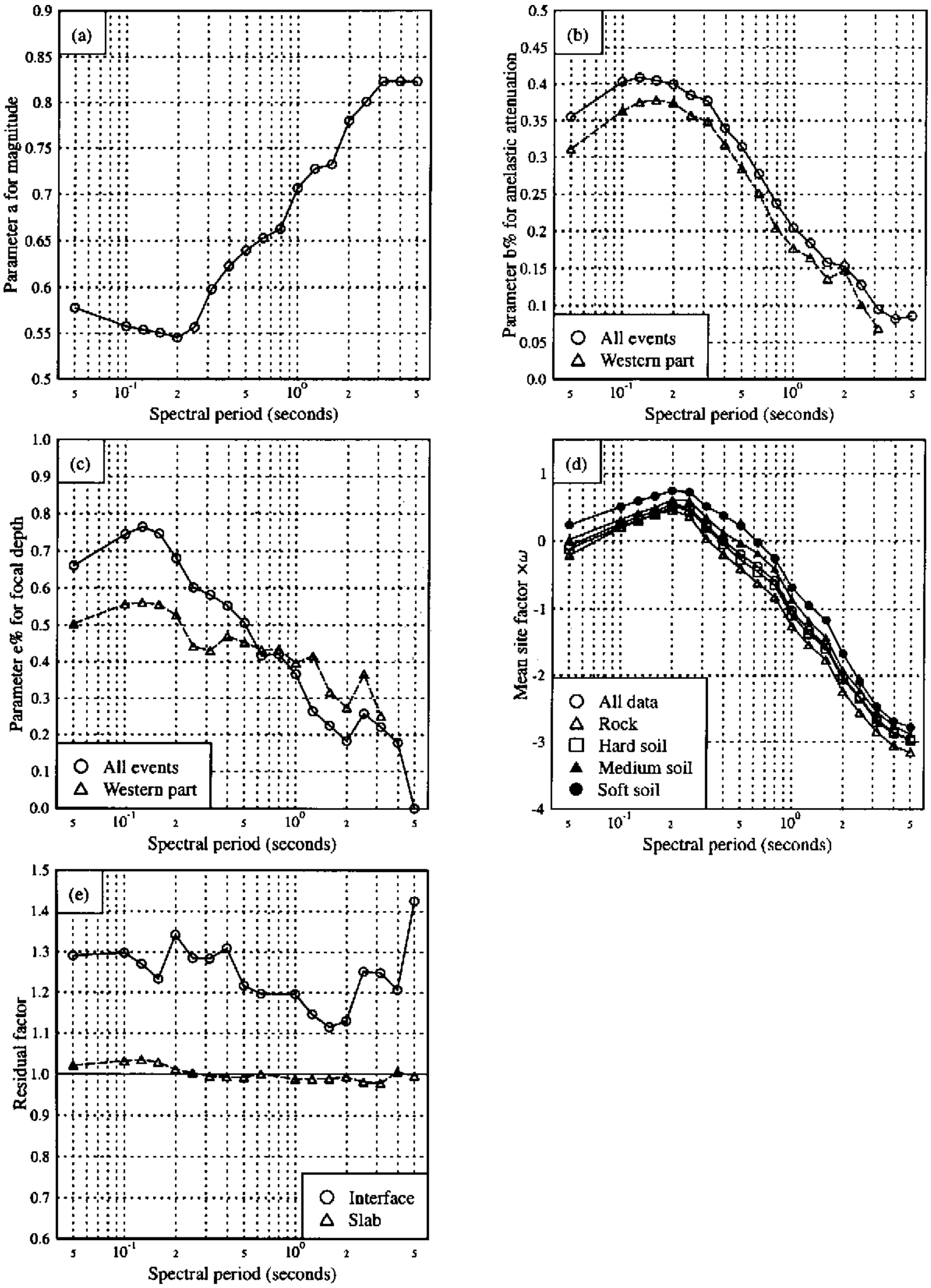

Figure 2 Model parameter variation with periods for all events, and the western part of Japan and residual factors, (a) parameter a for magnitude; (b) parameter b for anelastic attenuation term; (c) depth term; (d) mean site factors; and (e) residual factors for interface and slab events. Parameters for PGA are plotted at 0.05s for plotting convenience

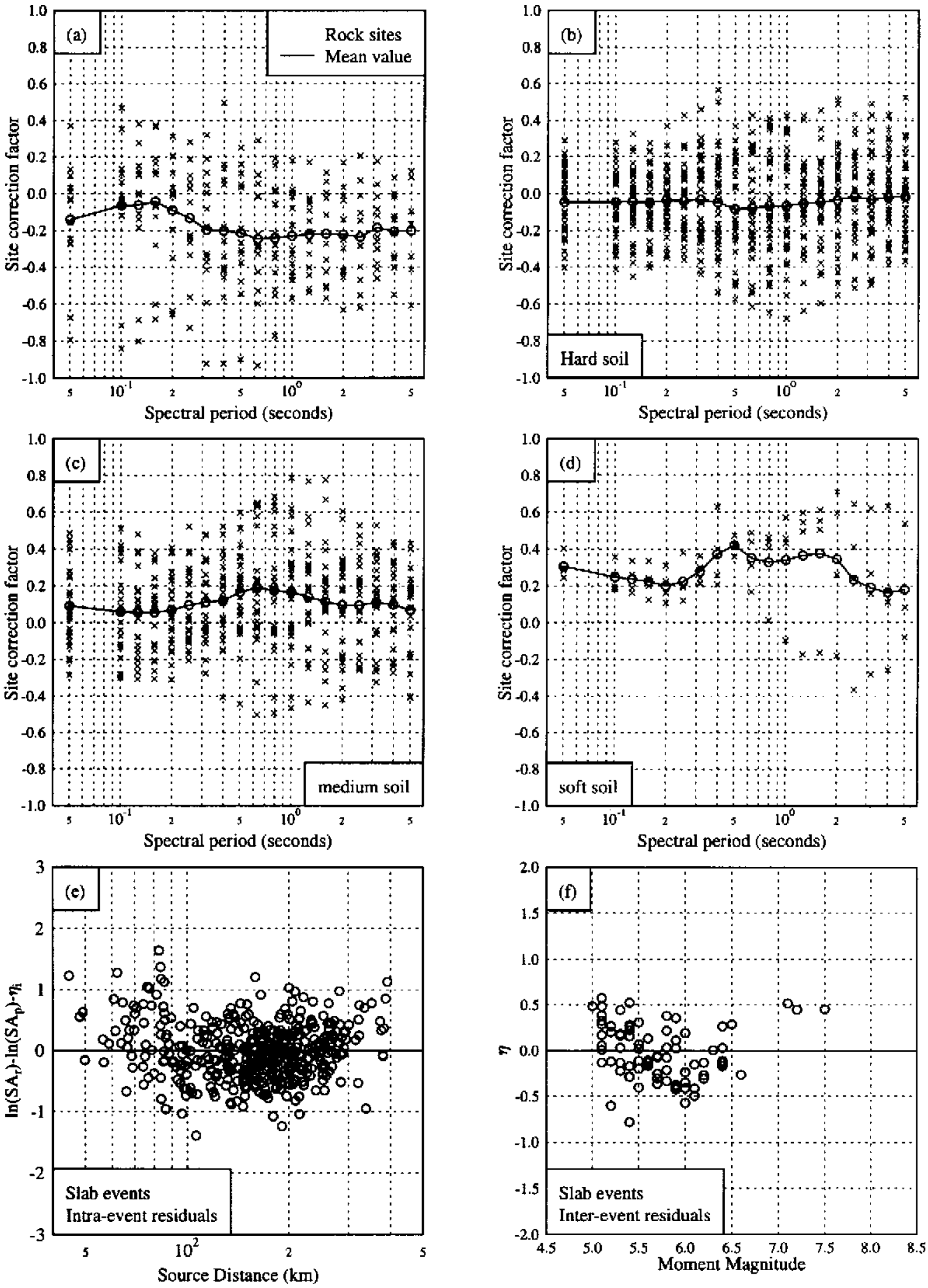

Figure 3 Variation of site correction factors and their mean values with periods and residual distributions, (a) rock sites; (b) hard soil sites; (c) medium soil sites; (d) soft soil sites; (e) intra-event residuals; and (f) inter-event residuals. Parameters for PGA are plotted at 0.05s for plotting convenience.

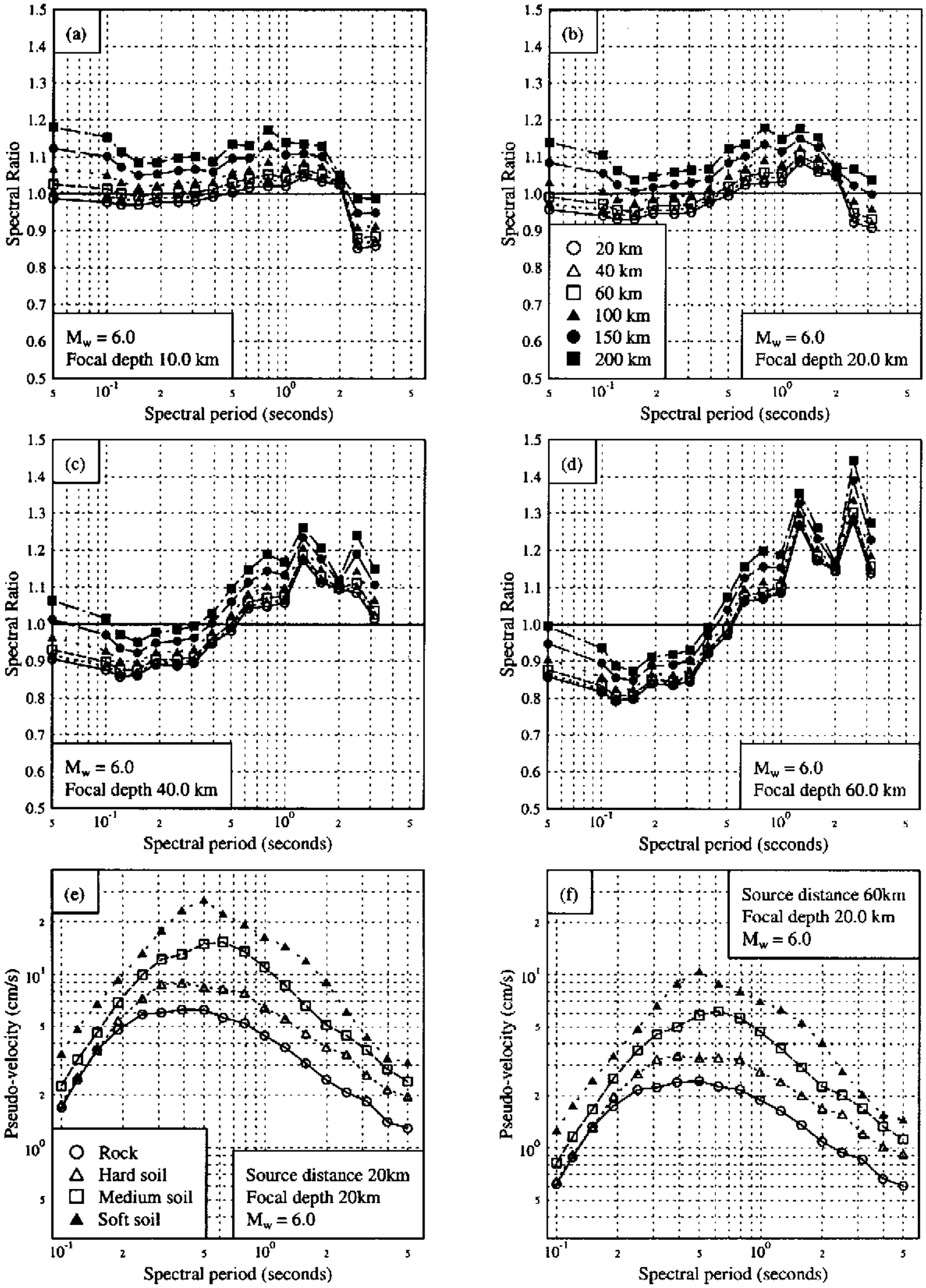

Figure 4 Spectral ratio between the model for the western part of Japan and that for all Japan and the pseudo-velocity spectra prediced by the model for all Japan for M_w = 6 (a) 10km depth; (b) 20km depth; (c) 40km depth; (d) 60km depth; (e) 20km source distance; and (f) 60km source distance. Parameters for PGA are plotted at 0.05s for plotting convenience.